Province of British Columbia
Ministry of Energy, Mines and
Petroleum Resources

MINERAL RESOURCES DIVISION
Geological Survey Branch

GEOLOGICAL FIELDWORK 1988

A summary of Field Activities and Current Research

PAPER 1989 – 1

MINERAL RESOURCES DIVISION
Geological Survey Branch

British Columbia Cataloguing in Publication Data

Main entry under title:
Geological fieldwork. — 1974 –

(Paper, ISSN 0226-9430)
Annual.
Issuing body varies: 1974-1980, Geological Division; 1981-1985, Geological Branch; 1986– , Geogical Survey Branch.
Subseries, 1979– , of: Paper (British Columbia. Ministry of Energy, Mines and Petroleum Resources)
"A summary of field activities of the Geological Division, Mineral Resources Branch."
ISSN 0381-243X = Geological fieldwork

1. Geology — British Columbia — Periodicals. 2. Geology, Economic — British Columbia — Periodicals. 3. Mines and mineral resources — British Columbia — Periodicals. I. British Columbia. Geological Division. II. British Columbia. Geological Branch. III. British Columbia. Geological Survey Branch. IV. British Columbia. Ministry of Energy, Mines and Petroleum Resources. V. Series: Paper (British Columbia. Ministry of Energy Mines and Petroleum Resources)

QE187.G46 557.11'05
Rev. Dec. 1987

VICTORIA
BRITISH COLUMBIA
CANADA

January 1989

FOREWORD

The 1988 edition of *Geological Fieldwork: A Summary of Field Activities and Current Research* is the fourteenth in this publication series. It covers a year during which the Geological Survey Branch again expanded its mapping and research activity to improve the geoscience database in British Columbia.

The Branch budget was increased in 1988 for the second year in a row. The $2 million increase in 1987 was followed by an additional $1.5 million this year, bringing the total base budget of the Geological Survey Branch to $6.7 million. The government's policy of encouragement for mineral exploration and mine development in the province is solidly backed by funding for geoscience research. Provincial base funding in 1988 supported 32 field projects, with an additional 10 projects funded by the Canada/British Columbia Mineral Development Agreement. Highlights of the program are:

- Three new 1:50 000 regicnal mapping projects, in the Atlin and Stikine River areas, were added to the seven continuing projects in the Sicker Group on Vancouver Island, the Sylvester allochthon, the Whitesail Lake and Taseko Lake – Bridge River areas, the Manson Creek – Germansen Landing area, the Babine and Telkwa ranges and the Tutshi and Tagish lakes area of northwestern British Columbia.
- Reconnaissance geochemical surveys were completed over four 1:250 000 map sheets covering northern Vancouver Island and the adjacent Mainland.
- Metallogenic studies included continuing work in the Iskut-Sulphurets gold belt, the Bridge River mining camp and the Rossland volcanic rocks of the West Kootenay District, and assessment of the mineral potential of Alaskan-type ultramafic complexes in northern British Columbia.
- Industrial minerals research included evaluation of the provinces sulphur, fluorite, zeolites and feldspar resources. Regional mapping and analysis of gypsum occurrences led to the discovery of extensive gypsum resources near Canal Flats in the East Kootenay District.

Fieldwork in the province's coalfields decreased in 1988 with the completion of several major projects in the Elk Valley, Peace River and Bowser Basin coalfields but work continued on regional mapping, sampling and coal-quality studies in the Comox and Nanaimo coalfields on Vancouver Island. The new computerized, mineral inventory database, MINFILE, entered its production phase during the year. Support to Universities and individuals was continued through the successful Geoscience Research Grant program and the 1988 results are reported in this volume.

This very active field program is reflected in the number of publications released during the year and in the increased number of contributions to this year's edition of Fieldwork. The volume continues to grow while the time available for its production does not. The efforts of our editorial staff, including Brian Grant and John Newell, who edited the volume and managed the production process; Doreen Fehr, Janet Holland, Debbie Bulinckx and other typists who wore out their fingers at the keyboards; Janet Fontaine who did the page layout; and John Armitage, Martin Taylor and Pierino Chicorelli, the drafting staff, are gratefully acknowledged. Appreciation is also extended to the management and staff of the Queen's Printer, without whose cooperation timely delivery would not be possible.

W.R. Smyth
Chief Geologist
Geological Survey Branch
Mineral Resources Division

GEOLOGICAL SURVEY BRANCH

1988 FIELD PROJECTS

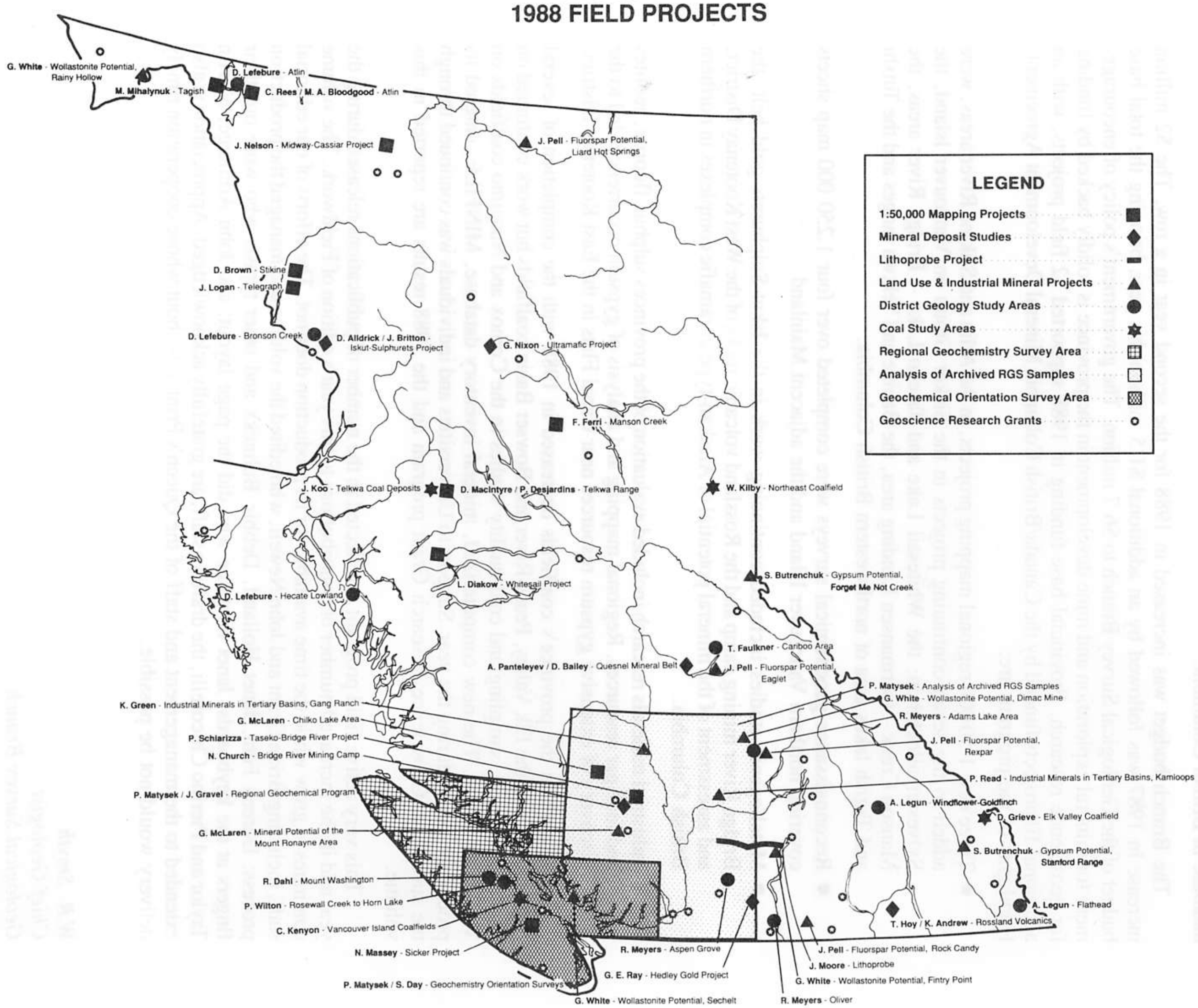


TABLE OF CONTENTS

TABLE OF CONTENTS *(Continued)*

TABLE OF CONTENTS *(Continued)*

TABLE OF CONTENTS *(Continued)*

Regional and District Mapping

GEOLOGY OF THE PRE-TERTIARY ROCKS IN THE ROCK CREEK–GREENWOOD AREA (82E/2)

By James T. Fyles
Consulting Geologist

KEYWORDS: Regional mapping, Boundary District, Knob Hill Group, Brooklyn Formation, listric faults, Tertiary extension, pre-Tertiary thrust faults.

INTRODUCTION

The area covered in this study is the west half of NTS sheet 82E/2 south of latitnde 49°10′ north in the Boundary District of south-central British Columbia. This area contains "windows" of Paleozoic and Mesozoic volcanic and sedimentary rocks between large down-faulted blocks of Tertiary cover. By contrast, the east half of 82E/2, and beyond to the Grand Forks gneiss complex, contains mainly the same Paleozoic and Mesozoic rocks with isolated small blocks of Tertiary cover. The purpose of the study has been to extend geological knowledge gained from recent work in the older, well-mineralized rocks in the east half of the map sheet to the same rocks in the west half. Specifieally the objectives of the research are:

- To determine the stratigraphy and structure of the late Paleozoic Knob Hill Group of cherts and greenstones.
- To assess the significance of the serpentinites and associated diorite in relation to the stratigraphy of the Knob Hill Group.
- To search for equivalents of the late Paleozoic Mount Attwood sedimentary rocks.
- To trace the middle Triassic Brooklyn Formation and overlying volcanic rocks westward from the established sections near Greenwood.
- To determine the nature of the pre-Tertiary surface at as many localities as possible.
- To provide a geological framework for the interpretation of the metallic mineral deposits of the area.

The focus of the research was to review by ground traverses, Geological Survey of Canada Maps 1500A (Little, 1983) and 10-1967 (Monger, 1968). In general these maps were found to be detailed, complete and accurate and new interpretations presented here result from the application of new concepts, the experience of the writer in the east half of the Greenwood sheet and from the opportunity to study specific problems. Figure 1-1-1 shows the geology of the pre-Tertiary rocks in the area. The outlines of the Tertiary rocks are modified from Map 1500A. Table 1-1-1 summarizes lithologies and the stratigraphic relationships and gives an explanation of the map numbers used on Figure 1-1-1.

KNOB HILL GROUP

Most of the pre-Tertiary rocks in the map area belong to the Knob Hill Group, a thick assemblage of mainly greenstone and chert. The rocks are described in two parts, a relatively undeformed segment north of the Kettle River and a much smaller, highly deformed sequence to the south.

The relatively undeformed Knob Hill rocks are found in most of the map area. They are on strike from the type locality a few kilometres east of Greenwood, but separated from it by patches of Tertiary cover. Correlations are based on this proximity and on general lithological similarities. The age is taken to be late Paleozoic from a single fossil locality in the lower part of the succession 8.5 kilometres east of Greenwood (Little, 1983).

Greenstones in the Knob Hill Group are mainly pillow lavas and breccias, and agglomerates derived from them. Good pillow structures are rare but crusts of pillows outlined by curving dark bands or epidote layers, interpillow lenses of chert, epidote or limestone, and vaguely mottled or banded dark and light green masses within the greenstone are taken to be broken remnants of pillow structures. The rocks are aphanitic, commonly calcareous and grade into massive fine-grained diorite crossed by finc, irregular, white-weathering feldspathic veinlets and lenses. Some of the fine-grained diorites are dykes whereas others cover large areas and apparently grade into greenstone as well as into medium and coarse-grained diorite. Coarse-grained diorite, referred to by Little (1983) as amphibolite and by Church (1986) as the old diorite, are striking, dark green rocks with many criss-crossing light-coloured veins of felsic rock. The veins bound blocks which differ slightly in composition and texture. Rarely the blocks have a light and dark layering. Dykes of the old diorite intrude greenstone and chert of the Knob Hill Group but the gradation from coarse to fine-grained diorite, to massive greenstone and pillow lava has been observed or inferred in a number of places, particularly along the north and east sides of the Kettle River north of Rock Creek. A potassium-argon whole-rock date of 258 ± 10 Ma from drill core of old diorite from the Winnipeg mine, 7.5 kilometres east of Greenwood, is reported by Church (1986). Thus the pillow lavas, greenstones, fine-grained diorite and the old diorite are all considered to be parts of the Knob Hill Group.

Many small irregular masses of altered serpentinite or listwanite and schistose antigorite serpentinite occur along the valley of the Kettle River, in lower Bubar Creek and on the hills east of lower Ingram Creek. The listwanite is a yellow-brown-weathering, hard, aphanitic, grey to very light grey rock with veinlets of quartz, iron carbonate and flecks of dark

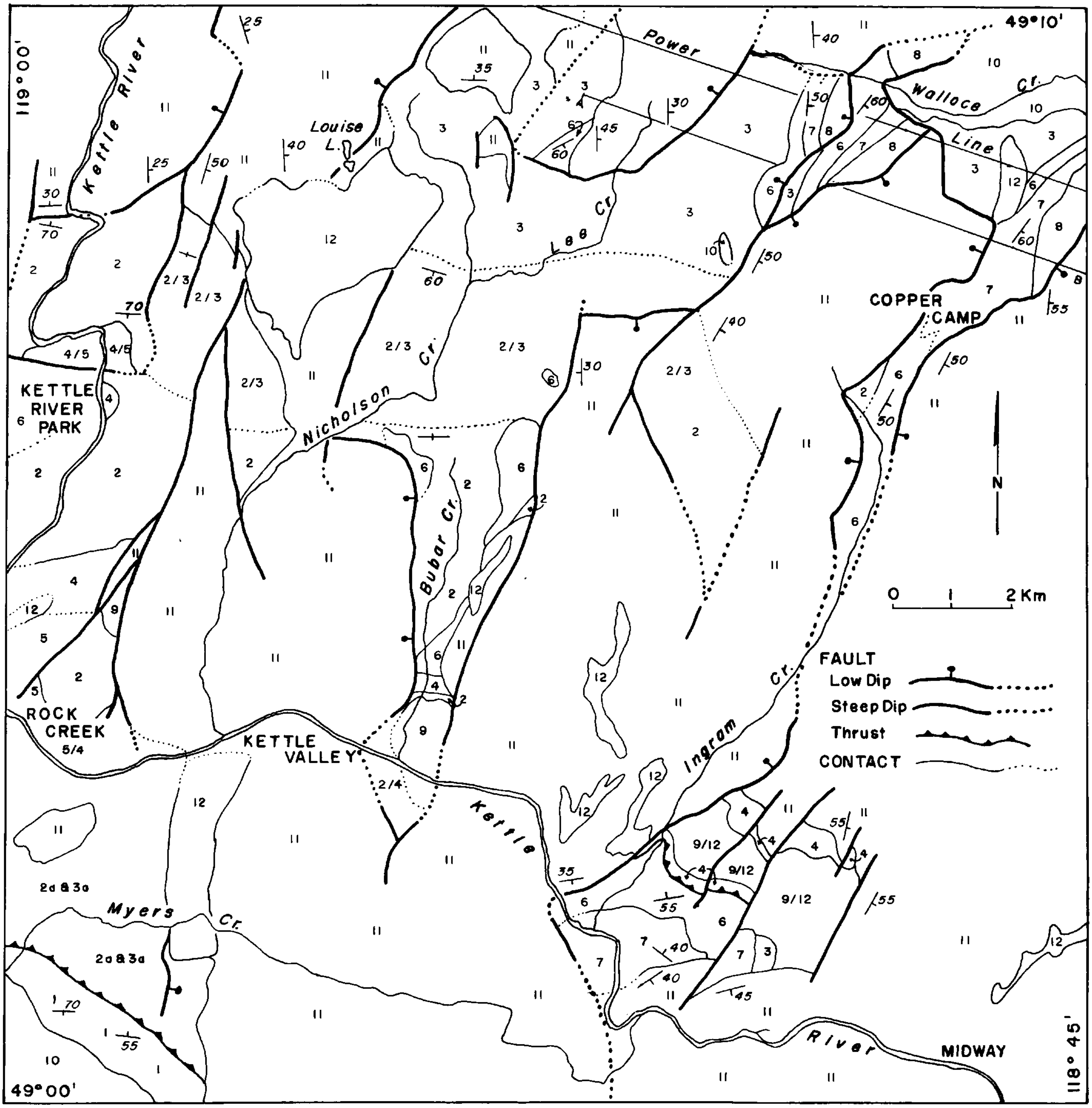


Figure 1-1-1. Geological sketch map of the southwestern part of the Greenwood map sheet. Tertiary geology modified from Little (1983).

minerals and locally of bright green mica (mariposite?). Antigorite serpentinite which is a dark and light green, generally sheared soapstone, is found with the listwanite at only a few places in the map area. The smaller lenses of serpentinite and listwanite are intrusive into the greenstone. Three larger masses, one exposed on both sides of the Kettle River 1.5 to 2 kilometres north of Rock Creek, another in lower Bubar Creek and a third in the hills east of lower Ingram Creek are probably emplaced tectonically and may be parts of a north-dipping tectonic sheet of regional extent. Because of the close association of the serpentinites with the diorite, and particularly the old diorite, both in this map area and to the east, they are included with the Knob Hill Group.

The sedimentary rocks of the Knob Hill Group are mainly grey, buff or white cherts which are highly fractured and only rarely show typical ribbon structure. Grey chert grades into black chert and sooty siliceous argillite. The chert occurs as lenses in greenstone and as thick continuous masses with only minor lenses of greenstone. The small lenses which also include brick-red jasper, have irregular shapes and probably formed between pillows or lava flows. A few lenses of grey to white crystalline limestone, not shown on Figure 1-1-1, are

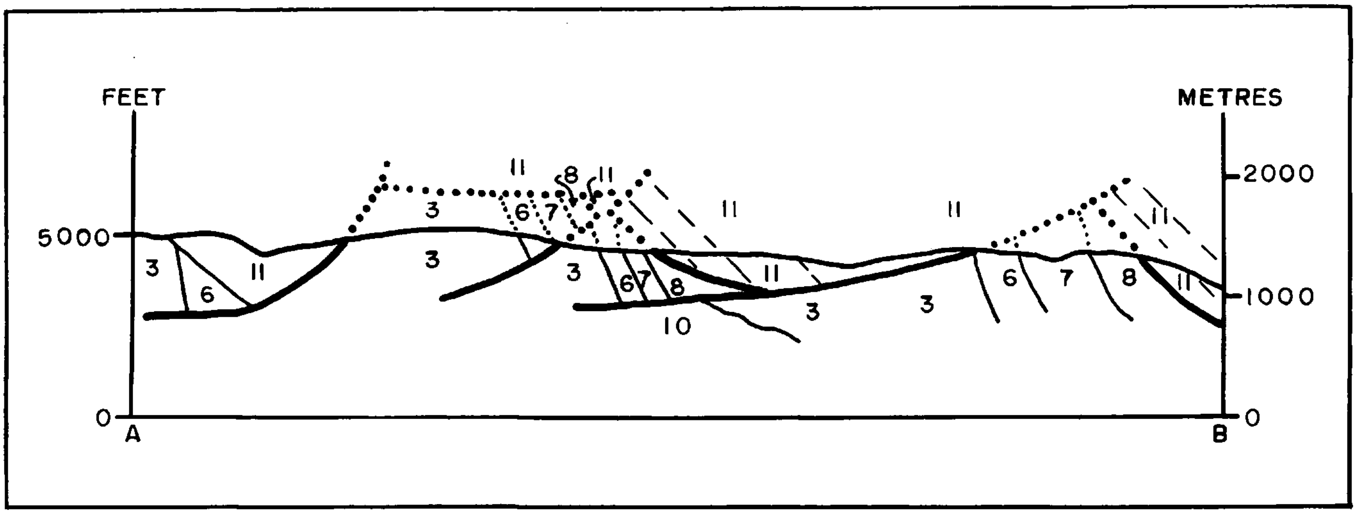


Figure 1-1-2. Diagrammatic cross-section (A-B on Figure 1-1-1) at the heads of Wallace and Lee creeks showing the apparent offset of Units 6, 7, and 8 on west-dipping listric faults.

TABLE 1-1-1
FORMATIONS AND MAP LEGEND

Age	Group/ Formation	Symbol Correlation		Lithology
		Figure 1-1-1	GSC 1500A	
TERTIARY	PENTICTON GP	12	Emi	Dykes, sills and small plutons of alkaline syenite. Pulaskite, diorite and porphyry.
		11	Emv	Flows of andesite, trachite and phonolite, minor pyroclastics.
			Ekrs	Feldspathic and lithic tuffaceous sandstone, conglomerate and siltstone.
UNCONFORMITY				
JURASSIC AND CRETACEOUS	NELSON PLUTONIC ROCKS	10	Jkad	Granodiorite and quartz diorite.
		9	KTi	Quartz feldspar porphyry.
INTRUSIVE CONTACT				
EARLY JURASSIC		8	Jv	Fragmental greenstone.
DISCONFORMITY				
MIDDLE TRIASSIC	BROOKLYN FM	7	TR1	Limestone, siltstone, sandstone, limestone conglomerate and skarn.
		6	TRs	Chert-pebble conglomerate and chert breccia.
UNCONFORMITY				
LATE PALEOZOIC	KNOB HILL GP	5	CPkh 3	Aphanitic to coarse-grained diorite.
		4	Jum	Listwanite and serpentinite.
		3	CPkh 1	Grey to buff chert, dark grey siliceous argillite, minor greenstone and limestone.
		2	CPkh 2	Calcareous greenstone, pillow lava, breccia, minor limestone and chert.
		2a & 3a		Greenstone, chlorite schist, chert, white quartzite, micaceous quartzite and gneiss, limestone and calcareous greenstone, white dolomite.
FAULT CONTACT				
UNKNOWN	MT. ATTWOOD(?) FM	1		Dark grey siltstone and grey sandstone.

associated with either chert or greenstone. The most continuous is a bed 10 to 20 metres thick within grey chert which has been traced for almost 500 metres along strike in one of the valleys forming the head of Nicholson Creek. One lens of limestone about 3 kilometres southwest of Louise Lake is overlain by a greenstone flow in which ripped up limestone blocks clearly show the stratigraphic top to be to the north, but this is the only good top determination found in these rocks.

The thickness and the internal structure and stratigraphy of the Knob Hill Group present problems of interpretation which have not been satisfactorily resolved. Attitudes of primary structures consisting of bedding in siliceous argillites and cherts, greenstone-chert contacts, and beds of limestone, are found at relatively few places but consistently strike between 70 and 100 degrees and dip steeply north or south. Although greenstone-diorite and greenstone-chert contacts are too indefinite to be traced on the ground, inferred contacts are shown on Figure 1-1-1. Chert, with little or no greenstone, outcrops in the northeast part of the map area on the hills at the head of Nicholson and Wallace creeks, whereas greenstone and diorite with only minor chert are found farther to the south and west along the valley of the Kettle River for several kilometres north of Rock Creek. Between, are mixed greenstones and cherts and these mixed rocks contain most of the limestone lenses.

No evidence has been found for tight or isoclinal folding of the Knob Hill rocks. Major repetitions of stratigraphy by faults subparallel to the formations have not been recognized although a possible east-trending fault follows the serpentinite 1 to 2 kilometres north of Rock Creek and may thicken the section. Tertiary faults cross the stratigraphy and extend it in an east-west direction and many of the fractures in the chert belong to a set of north to northeast-trending Tertiary faults. The width of the outcrop of Knob Hill rocks from the Kettle Valley to the north edge of the map area, where they are cut off by large bodies of Nelson plutonic rocks, is about 10 kilometres. These very incomplete data lead to the interpretation that the Knob Hill Group is several kilometres thick in the map area, faces north and that an intrusive feeder system of diorite and greenstone in the south and west spread greenstone flows into a sedimentary chert basin to the northeast.

The deformed part of the Knob Hill Group is exposed in a small area near the head of Myers Creek, 3 to 5 kilometres south of Rock Creek. Lithologies are very similar to those already described and they have been included with rocks mapped as Knob Hill by Little (Little, 1983). They are rusty white chert and quartzite, micaceous quartzite and banded siliceous mylonite as well as greenstone, sheared greenstone (locally with elongate pillow structures) and chlorite schist. Minor amounts of grey and white crystalline limestone grading into calcareous greenstone and limy chlorite schist are also present. A lens of white dolomite within this deformed sequence is quarried 4.5 kilometres southeast of Rock Creek by Mighty White Dolomite Ltd. In this deformed part of the Knob Hill Group lenses of relatively blocky rock, tens to hundreds of metres across, occur between zones of schist and mylonite. The schistosity and deformed zones trend 295 degrees and dip 40 to 60 degrees north but weave around the more competent blocks.

The base of this deformed zone is well defined by a sheared zone trending 305 degrees and dipping 60 degrees northeast along the contact of a belt of dark grey siltstones and sandstones which lie to the southwest. The deformed zone is more than a kilometre wide. The upper contact with relatively undeformed Knob Hill rocks is not well defined, partly because of the poor outcrops south of the Kettle River and partly because the transition appears to be gradational. More study is required to resolve these relationships and to clarify the significance of this zone of intense deformation.

ATTWOOD(?) FORMATION

Dark grey siltstones and grey sandstones in the extreme southwest corner of the map area, not distinguished from Knob Hill Group on Geological Survey of Canada map 1500A, form a distinctive unit closely resembling some parts of the late Paleozoic Attwood Formation which occurs widely in the east half of the Greenwood area. This correlation, however, is very tentative as neither the internal structure and stratigraphy nor the stratigraphic relationships with other rock units have been defined.

The siltstones have a well-developed slaty cleavage and a thin rhythmic bedding which is commonly cut by the cleavage, indicating the rocks are tightly folded. Similar features are seen in the sandstone but the cleavage is less well developed. To the south, where the rocks are intruded by a large body of quartz diorite, they are blocky hornfels and the cleavage and bedding are obscured.

BROOKLYN FORMATION AND OVERLYING VOLCANICS

These formations form a distinctive succession throughout the Greenwood area but have been identified with certainty only in the northeastern part of the study area. The Brooklyn Formation overlies the Knob Hill Group with a pronounced angular unconformity and contains Middle Triassic (Ladinian) microfossils as well as Triassic macrofossils (Little, 1983) at several localities east of the map area. The volcanic rocks which, within the map area, overlie the Brooklyn, elsewhere interfinger with it. The best section of the Brooklyn and overlying volcanics is in the northeastern corner of the map area along the B.C. Hydro powerline, where it dips steeply to the east (Table 1-1-2).

The basal conglomerate and the greenstone form good markers which are very similar to rocks found in comparable sections east of Greenwood (Seraphim, 1956). The intervening rocks change more or less systematically along strike to the south, from the relatively thin, thin-bedded succession of hornfelsic siltstone, sandstone and calcareous conglomerates along the powerline, to essentially massive skarn with lenses of white crystalline limestone to crystalline limestone with pods of skarn in the Copper Camp. Still farther to the south the only Brooklyn rocks exposed are greenish, relatively

TABLE 1-1-2
BROOKLYN FORMATION AND ADJACENT ROCKS EXPOSED ON THE POWERLINE NORTH OF THE COPPER CAMP

Thickness (metres)	Map Unit	Lithology
		Penticton Group above fault
400 +	8	Greenstone, dark green aphanitic to very fine-grained blocky rock with rounded and subrounded fragments up to 10 cm across, rich in epidote or similar to the matrix but more feldspathic.
250	7	Mixed metasedimentary rocks including hornfelsic siltstone and sandstone, calcareous sandstone and quartz-pebble conglomerate, limestone, skarn and minor chert breccia.
125	6	Metasharpstone-conglomerate, grey to greenish grey chert breccia, angular fragments of quartz mainly less than 3 cm across.
		Unconformity
	3	Grey to brownish grey quartzite, dark grey thin-bedded hornfelsic siltstone, grey massive argillite, minor greenstone of the Knob Hill Group.

unmetamorphosed sharpstone conglomerate with a few lenses of green calcareous sandstone. In upper Ingram Creek the base of the sharpstone conglomerate, overlying dark green and purplish volcanic rock taken to be part of the Knob Hill Group, is exposed in trenches.

The same two members of the Brooklyn Formation and the overlying volcanics occur again 2 to 4 kilometres to the west, exposed mainly on the south side of upper Wallace Creek. The section is very similar to that just described. The Brooklyn limestone is lenticular and in the westernmost outcrops consists of several metres of limestone-boulder conglomerate overlain by hornfelsic siltstones and skarn. Lenses of roundstone conglomerate occur in the uppermost part of the section in or just below the overlying volcanic rocks. All the rocks are metamorphosed and grade northward into gneissic amphibolite, fine-grained biotite schist and marble exposed in Wallace Creek.

Five kilometres to the west, on the ridge north of Lee Creek, a small lens of chert-pebble conglomerate and breccia overlain by greenstone or green sandstone dips and faces to the southeast. The upper part of the section is covered by Tertiary rocks, but this section is probably a faulted segment of the sections described in upper Wallace Creek.

Isolated patches of chert-pebble conglomerate and chert breccia also occur to the south. They are brown-weathering greenish grey rocks composed of rounded and subangular fragments of chert, minor greenstone, siltstone and limestone, mostly less than 3 centimetres across, in a matrix of similar material. At places they are poorly cemented and the fragments break out, a characteristic not found elsewhere. The patches have no bedding but, judging from their shape and the basal contacts, which at some places are well exposed, they appear to form channel fillings and erosional remnants unconformably above the Knob Hill rocks.

Sharpstone conglomerate exposed near the entrance to Kettle River Park is correlated with the Brooklyn Formation but the correlation is very uncertain. These rocks are dark grey chert breccia composed of angular and subangular chert fragments, less than a centimetre across, in a grey sandstone matrix. Lenses of conglomerate with rounded cobbles of chert, siltstone and volcanic rocks, and of dark grey slaty siltstone within the chert breccia, dip north at moderate angles. These rocks are in fault contact with diorite to the north and probably unconformably overlie Knob Hill rocks to the south, although this contact has not been traced far to the west. Similar dark grey chert breccia is found along strike east of the Kettle River, to the south near the outcrops of serpentinite about 2.5 kilometres north of Rock Creek, and in lower Bubar Creek where they are along strike from a patch of Brooklyn conglomerate. The distribution and significance of these rocks require further study.

Finally, a thick section of the Brooklyn Formation crops out between Midway and lower Ingram Creek and is well exposed along Highway 3 between 6 and 7.5 kilometres west of Midway. The rocks are thermally metamorphosed and intruded by Tertiary dykes and irregular bodies of pre-Tertiary diorite and quartz feldspar porphyry. The formation exposed has two members, a limestone with an apparent thickness of more than 750 metres, lying beneath a sharpstone conglomerate more than 550 metres thick. The base of the section is covered by the valley of the Kettle River and the top is truncated by a fault lined with serpentinite. The stratigraphic top has not been determined with certainty. The limestone is grey and white, finely crystalline with blocky beds 10 centimetres to 1 metre thick and thin partings of hornfelsic siltstone. The sharpstone is composed mainly of angular and subangular chert fragments generally less than 2 centimetres across and minor amounts of greenstone, jasper and limestone. Interbeds of hornfelsic siltstone and sandstone, and conglomerate with a calcareous matrix occur as lenses within the sharpstone.

Detailed correlations of these rocks with the type section at Phoenix are speculative. If the limestone west of Midway is the Brooklyn limestone, and if the section is right side up, the sharpstone conglomerate above the limestone is the "upper sharpstone" of the Phoenix section and the basal sharpstone conglomerate is not exposed in the valley to the south.

NELSON PLUTONIC ROCKS

Parts of the southern edge of the Wallace Creek granodiorite batholith, and of another large pluton of similar composition to the southwest, outcrop in the map area but have not been studied. Very small fault slivers of quartz diorite occur in the Copper Camp and small granodiorite plutons are exposed near the head of Ingram Creek 5 kilometres to the west, and within the Brooklyn limestone 4.5 kilometres west of Midway. Zones of thermal metamorphism associated with these plutons extend from a few hundred metres to more than 3 kilometres from the exposed plutonic contacts.

Small intrusions, referred to as quartz feldspar porphyry, occur in a belt across the southern part of the map area, continuing to the east for 10 kilometres. These are grey, fine-grained porphyritic and equigranular rocks ranging from diorite to quartz monzonite. They are referred to by Little (1983) under the heading Map Unit KTi and are described in considerable detail. They have also been closely studied by Church (1986) who obtained a uranium-lead zircon age interpreted as an "early Jurassic zircon, probably Sinemurian, with inherited lead of early Proterozoic or Archean age" (The University of British Columbia Geochronology Laboratory report). The rocks are significant because they commonly occur with serpentinite and west of Midway they intrude it and may be the cause of the extensive alteration.

TERTIARY FAULTS

The structure of the area is dominated by Tertiary faults. They commonly form the boundaries of the Tertiary rocks and can be identified in outcrop, located as airphoto linears and inferred from offset contacts. Intense fracturing, particularly of the Knob Hill chert, breccia, fault gouge and slickensided faces are found both along faulted contacts which show on the map, and away from them. Slickensides most commonly trend east and movement indicators show normal faulting. Many faults are intruded and obscured by Tertiary dykes, but faulted dyke margins and offset Tertiary dykes, most common in the eastern part of the area, indicate that faulting continued after intrusion.

Patterns of Tertiary faulting are complex but consistent relationships across the Greenwood area indicate there are three fault sets, one with a low easterly dip, a later set with a low westerly dip and the latest which dips steeply and trends between north and northeast.

The oldest set dips east and southeast and occurs at or near the base of the Tertiary. The Tertiary formations characteristically dip east at angles commonly up to 45 degrees and locally as much as 70 degrees. The faults dip less steeply and down the dip they cut out the basal Tertiary sedimentary section. Three faults of this set with regional extent are shown on Figure 1-1-1.

The second set of faults dips at low to moderate angles to the west and produces the largest offsets. A measure of the apparent offset is given by four faulted segments of Brooklyn Formation in the northeast part of the map area as illustrated in the cross-section in Figure 1-1-2. The segments all dip steeply east, and the one exposed in the Copper Camp is offset 3 kilometres to the west by a low-angle west-dipping fault referred to as the Copper Camp fault. This second segment is also truncated by a west-dipping fault and repeated almost a kilometre farther west. If the Brooklyn section north of Lee Creek is considered to be another faulted segment, it has been offset in the order of 4 kilometres by a fault at the head of Wallace Creek referred to by Little as part of the Wallace Creek fault. The Copper Camp fault has been traced southward along the valley of Ingram Creek, crossing the Kettle River 7 kilometres west of Midway, and throughout its length it appears to have a low dip to the west. Other gently west-dipping faults occur along the west side of Bubar Creek and within Tertiary rocks east of Bubar Creek.

Three west-dipping faults occur along the northern edge of the map area and extend to the north. The one at the head of Wallace Creek is well exposed south of the creek where it dips 45 to 50 degrees west, curving westward across the head of Lee Creek where it dips north. To the west it appears to die out or to be offset by a later fault. The second, near Louise Lake, continues many kilometres to the north and is cut off by a large Tertiary syenite referred to as the Nicholson Creek intrusion (Le Cheminant, 1966) and has not been identified to the south or west. The third, though intruded by Tertiary dykes, is well defined in a canyon on the east side of the valley of the Kettle River and on Highway 33 about 9 kilometres north of Rock Creek. It dips northwest and curves northward, dipping west at low to moderate angles, and is intruded by one or more thick, grey porphyritic syenite dykes. These three faults are linked together on Map 1500A to form the Wallace Creek fault but detailed mapping along the fault trace could not substantiate the presence of a single fault.

These west-dipping structures are listric normal faults which tend to be curved in both plan and cross-section. They continue eastward at least as far as the Granby River fault north of Grand Forks (Preto, 1970). Probably much if not all the tilting of the Tertiary formations took place by extension and rotation on these curved fault surfaces, which in itself led to renewed movement on the bedding planes and was followed by regional block-faulting on a steeply dipping set.

The latest Tertiary faults dominate the structural grain of the map area. They dip steeply and trend between north and northeast, most commonly striking between 25 and 40 degrees. They are very abundant and only the most significant are shown on Figure 1-1-1 and the maps of Little and Monger. The faults are described and analysed in detail by Monger (1968) who included in the analysis some of the west-dipping listric faults. The late steeply dipping set in the map area have apparent offsets of no more than a few hundred metres. Most are dropped down on the west but some have west-side-up movement. Slickensides, where seen along faults, mostly have a steep plunge. The faults split and die out along strike suggesting they are hinged and that movements are transferred from one fault to another through minor adjustments on closely spaced inconspicuous fractures.

The Tertiary faulting gives a complex picture of east-west extension which seems to have developed and changed through time and to differ in style and complexity from place to place. The major elements described here are known to continue east to the Granby River fault and are probably also present in northern Washington (Parker and Calkins, 1964; Pearson, 1967).

PRE-TERTIARY STRUCTURE

Regionally, the pre-Tertiary rocks within the map area are in a zone of thrust faults in a depression accentuated by Tertiary faulting between the Kettle and Okanagan gneiss domes (Orr and Cheney, 1987). Identification of such faults was one incentive for remapping in this area. It seems probable that the zone of intense deformation in the southwest corner of the map area, which dips to the north and forms the structural base of the Knob Hill Group, is one such fault. Another fault, identified beneath the serpentinite in lower Ingram Creek and traced eastward toward Midway, truncates the Brooklyn Formation which lies beneath it. Projection of this fault to the west is speculative, but it seems possible that it follows the listwanite and serpentinite to lower Bubar Creek and appears again on the Kettle River about 2 kilometres north of Rock Creek. In this western part of the area the fault is within the Knob Hill Group. Another pre-Tertiary fault which strikes east and dips steeply, truncates Brooklyn(?) sharpstone conglomerate at the Kettle River Park but its regional significance is not known and it has not been identified to the east.

Folds have not been found in either the Knob Hill or Brooklyn rocks within the map area. The Brooklyn Formation in the northeastern part of the area strikes between 20 and 40 degrees and dips steeply east, flattening downward. These rocks cross the regional attitude of the Knob Hill Group which trends east and dips steeply. In this part of the area, before tilting on the Tertiary faults, the Brooklyn probably had low dips, was broadly folded, possibly on north-trending axes, and lay with marked unconformity above the Knob Hill Group. The Brooklyn Formation exposed west of Midway is in a lower fault slice than the Brooklyn rocks to the north and the relationships beween the two are not known.

CONCLUSION

The pre-Tertiary rocks of the map area are mainly late Paleozoic cherts, greenstones and related intrusions of diorite and ultramafic rocks of the Knob Hill Group. They form a thick suite truncated at the base by a north-dipping zone of deformation a kilometre thick, exposed in the southwestern corner of the map area. Other deformed zones, which may represent pre-Tertiary thrust faults, probably occur within the group but cannot be identified with certainty.

Rocks of the Triassic Brooklyn Formation, similar in stratigraphy to those in the Greenwood area, outcrop only in the northeastern part of the study area. Elsewhere only the basal sharpstone conglomerate is present except west of Midway where a thick but incomplete section of limestone and sharpstone conglomerate is exposed which may be part of the Brooklyn Formation at a lower structural level than the other sections.

The most significant Tertiary faults are moderate to gentle west-dipping listric normal faults, but the area is dominated by many later steeply dipping block faults trending between north and northeast.

ACKNOWLEDGMENTS

I am grateful to my wife for assistance in the field, to personnel of the Greenwood office of Kettle River Resources Ltd. for assistance with the logistics of the project and to W.R. Smyth, V.A. Preto and B.N. Church of the British Columbia Geological Survey Branch and J.W.H. Monger of the Geological Survey of Canada for useful discussions and encouragement. Background data and knowledge of the east half of the Greenwood area were obtained between 1982 and 1987 while I was working with Kettle River Resources Ltd. and Noranda Exploration Company, Limited, and these companies have given permission to use this work for publication. This project is supported by British Columbia Geoscience Research Grant Program.

REFERENCES

Church, B.N. (1986): Geological Setting and Mineralization in the Mount Attwood–Phoenix Area of the Greenwood Mining Camp, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1986-2, 65 pages.

Le Cheminant, A.N. (1966): Geology and Petrology of Three Intrusions of Rhomb-porphyry from the Rock Creek Area, South-central British Columbia, Unpublished B.Sc. Thesis, *Carleton University*.

Little, H.W. (1983): Geology of the Greenwood Map-area, British Columbia, *Geological Survey of Canada*, Paper 79-29, 37 pages.

Monger, J.W.H. (1968): Early Tertiary Stratified Rocks, Greenwood Map-area (82E/2), British Columbia, *Geological Survey of Canada*, Paper 67-42, 39 pages.

Orr, K.E., and Cheney, E.S. (1987): Kettle and Okanagan Domes, Northeast Washington and Southern British Columbia, *Washington Division of Geology and Earth Resources*, Bulletin 77, pages 55-71.

Parker, R.L. and Calkins, J.A. (1964): Geology of the Curlew Quadrangle, Ferry County, Washington, *United States Geological Survey*, Bulletin 1169, 95 pages.

Pearson, R.C. (1967): Geological Map of the Bodie Mountain Quadrangle, Ferry and Okanogan Counties, Washington, *United States Geological Survey*, Map GQ636.

Preto, V.A. (1970): Structure and Petrography of the Grand Forks Group, British Columbia, *Geological Survey of Canada*, Paper 69-22, 80 pages.

Seraphim, R.H. (1956): Geology and Copper Deposits of Boundary District, British Columbia, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 49, pages 684-694.

NOTES

GEOLOGY AND STRUCTURE OF THE KOBAU GROUP BETWEEN OLIVER AND CAWSTON, BRITISH COLUMBIA: WITH NOTES ON SOME AURIFEROUS QUARTZ VEINS* (82E/4E)

Urs Mäder, Peter Lewis and J.K. Russell
The University of British Columbia

KEYWORDS: Regional geology, Kobau Group, stratigraphy, structure, Oliver.

INTRODUCTION

The Fairview mining camp northwest of Oliver, British Columbia, has been the site of sporadic mineral exploration and production for over 90 years. The metal that has stimulated exploration in the past, and currently has renewed exploration interest, is gold associated with quartz veins. The quartz veins are hosted by metamorphic rocks of the Kobau Group or less commonly the Oliver and Fairview plutons (Okulitch, 1969). Despite the extensive examination of the of the camp geology, there has been little in-depth analysis of either the stratigraphy of the Kobau Group rocks or the controls on quartz vein emplacement. This study adds to present knowledge of the structural and metamorphic history of the area by concentrating on new mapping of the Kobau Group between the Oliver and Fairview plutons.

In the 1988 field season the two senior authors mapped the Fairview slopes south and west of the Oliver pluton and north and east of the Fairview granodiorite into the Similkameen Valley (Figures 1-2-1, 1-2-2 and 1-2-3). The area was mapped at a scale of 1:5000 using an orthophotographic base with 10-metre contour intervals, prepared for The Valhalla Gold Group Corporation. The study area between Cawston and Oliver covers 24 square kilometres within NTS map 82E/4E. The rationale for the study is:

- Much of the area, in particular the eastern part, has excellent bedrock exposure.
- All of the major lithologies previously described in the area are represented and well exposed, including the metamorphic rocks of the Kobau Group, and the Oliver and Fairview intrusions.
- Both the apparent stratigraphy and strutture of the Kobau Group as portrayed by Okulitch (1973) are fairly simple, therefore we anticipated that many of the stratigraphic and structural relationships between units could be resolved.
- Extensive quartz veining between the two intrusions makes the area of interest for mineral exploration.

Analytical results are described in this paper with the aid of a reduced version of the completed field map (Figures 1-2-2 and 1-2-3) and accompanying cross-sections (Figure 1-2-4). The full scale version of the field map is available as an Open File (Lewis *et al.*, 1989).

PREVIOUS WORK

The Fairview mining camp is one of the oldest exploration districts in British Columbia. Prospecting in the area began in the late 1880s and production by the early 1890s. Exploration and production continued sporadically until 1961 when the Fairview mine closed. The Fairview properties were reassessed in the early 1980s following the steep rise in the price of gold. This renewed interest has continued and is described by Crawford and Meyers (1987).

Regional geology of the area is described by Bostock (1940), Okulitch (1969, 1973) and has been reviewed most recently by Parkinson (1985). Okulitch's 1:16 000 map (1969) depicts the stratigraphy and structure of the Kobau Group and is the basis for a later publication which addresses regional geology of the Okanagan Valley (Okulitch, 1973). Sinclair *et al.* (1984) summarized field relationships and petrography of part of the Oliver pluton, focusing on the Gypo quartz vein. Parkinson (1985) concentrated on the geochronometry and regional geology of the southern Okanagan Valley. He investigated the petrologic variations within the Oliver pluton and the uranium-lead geochronometry of intrusions west and east of the Okanagan Valley fault. Finally, Godwin and Gabites (1988) have reported preliminary lead isotope work on mineralized quartz veins in the abandoned Susie mine in the Oliver pluton, and the reopened Stemwinder mine in the Kobau Group rocks.

GENERAL GEOLOGY

The map area lies within the Intermontane tectonic belt and the Quesnellia terrane (Armstrong, 1988). The area is underlain dominantly by polydeformed, regionally metamorphosed rocks of the Kobau Group (Bostock, 1940). The Kobau Group is areally restricted to the southern Okanagan Valley and is bounded by the Similkameen Valley to the west and the Okanagan Valley fault to the east. The age of the Kobau Group rocks is uncertain; however, they have been inferred to be post-Devonian to pre-Cretaceous in age and are intruded by Jurassic and, locally, mid-Cretaceous plutons (Okulitch, 1973). These inferences are based on similarities in lithology and in degree of deformation and metamorphism of dated rocks in adjacent areas.

Okulitch (1969, 1973) described Kobau Group rocks as highly deformed, low-grade metamorphic quartzite, phyllite, schist, greenstone and marble, and delineated nine mappable units comprising a 1900-metre structural succes-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

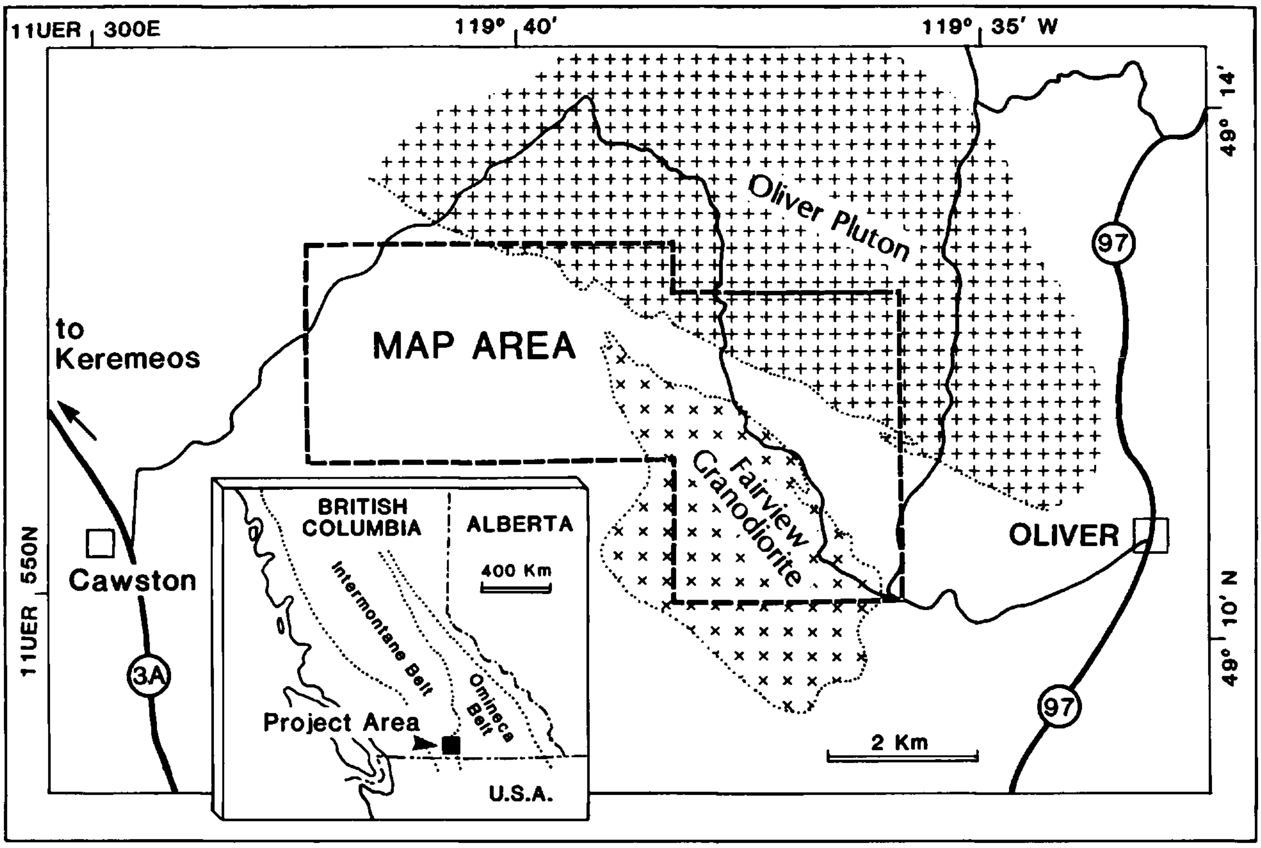


Figure 1-2-1. Location map of the project area. Inset shows relationship of the map area to regional geology.

sion. He assumed that at least one of the lithologies (phyllite-marble assemblage, Unit 6) occupies a single stratigraphic horizon and that there were no facies variations or unconformable relationships between lithologies within the Kobau Group. These assumptions were crucial to his interpretation of the structure and stratigraphy of the Mount Kobau geology and much of the structural complexity that appears on his map hinges on them.

Okulitch (1973) described three phases of folding within the Kobau Group. He recognized an initial phase of folding which was coincident with the regional metamorphism, whereas the later structures were interpreted to be related to the intrusive activity.

STRATIGRAPHY

INTRUSIVE ROCKS

In the Fairview mining camp the Kobau metamorphic rocks host two intrusions; the Fairview granodiorite and the Oliver granite (Figure 1-2-1). The age of the Fairview intrusion is constrained by geochronometry (potassium-argon radiometric age on biotite) to be older than 111 ± 5 Ma (unpublished date, courtesy R.L. Armstrong). The Oliver pluton crops out in the northeastern part of the map area and clearly cuts the lithologies and structures of the Kobau Group. In addition to the younger Fairview and Oliver plutons, the metasedimentary-volcanic package is cut by aplite dykes, small granitic, dioritic and mafic stocks, auriferous quartz veins which are most likely associated with the Jurassic intrusions, and Tertiary (White *et al.*, 1968), northeasterly trending mafic dykes. Some mafic or lamprophyric dykes within the metasedimentary rocks might be considerably older. Plagioclase-quartz-phyric biotite dacite dykes ("quartz latite" of Okulitch, 1969, 1973) occur in swarms within the Kobau Group rocks east of the Fairview intrusion (Lewis *et al.*, 1989). The dykes are parallel to the regional compositional layering in the Kobau Group, display a distinct foliation, and were subject to low-grade (contact?) metamorphism. Their age is uncertain, possibly older than the Jurassic intrusions, but certainly younger than the major pre-Jurassic deformation.

The Oliver pluton is heterogeneous (Parkinson, 1985) and comprises several distinct lithologies including biotite-hornblende diorite, porphyritic biotite granite, garnet-muscovite granite, porphyritic quartz monzonite and syenite. The map area is dominated by porphyritic granite and quartz monzonite phases with lesser amounts of diorite, syenite and muscovite granite. Mineralogically and chemically the Oliver pluton has affinities with S and I-type granitic rocks. The age of the pluton is based on a uranium-lead zircon date of 152 ± 3 Ma and a rubidium-strontium whole-rock date of 157 ± 8 Ma obtained on the youngest phase of the intrusion (Armstrong and Ryan, unpublished as cited by Parkinson, 1985).

LAYERED ROCKS OF THE KOBAU GROUP

The Kobau Group rocks comprise banded, foliated quartzite lithologies with minor mafic schists and thick, compositionally layered mafic schist units with intercalated quartzite bands, as well as metacarbonates and minor mafic metavolcanic flows or sills. Our proposed stratigraphy is summarized in a table of formations (Table 1-2-1). Although "tops" cannot be established, a structural section approximately 1500 metres in thickness can be documented across the map area. The structurally lowest rocks consist of a mafic schist containing thin (less than 10 metres) marble boudins and rare mafic sills and flows (KM1, Figure 1-2-1, Table 1-2-1). This schist is structurally succeeded by a banded quartzite (KQ1), which in turn is overlain by a second mafic schist and quartzite sequence (KM2 and KQ2). The lithologies of the quartzite units 1 and 2, as well as mafic schist 1 and 2, differ sufficiently to warrant these different structural positions. Our proposed structural succession differs from previous work (Okulitch, 1973) mainly in recognizing that mafic schist units containing marble lenses occur at more than one stratigraphic level.

The regional metamorphism of the Kobau Group in the study area appears to be synkinematic with respect to the main phase of pre-Jurassic deformation. The metamorphic grade did not exceed greenschist facies documented by actinolite-biotite-epidote-albite assemblages in mafic schists and calcite-tremolite assemblages in some carbonate rocks. Garnet is locally observed in semipelitic layers indicating that its presence or absence is largely controlled by bulk composition. The contact metamorphic overprint resulting from Jurassic intrusions is not obvious and merely obscured schistosities near intrusive contacts with secondary, unoriented growth of greenschist minerals. The protolith of Kobau Group rocks near Oliver is interpreted as thick successions of marine, fine-grained, stratified volcaniclastic sediments of predominantly mafic composition (mafic schists) with intercalated quartzofeldspathic sediments, minor limestones and abundant ribbon chert sequences (layered quartzite). Minor basaltic volcanic rocks occur as flows or sills. The sediments may have formed in a volcanic arc or eugeoclinal setting, distal to volcanic centres.

STRUCTURAL GEOLOGY

KOBAU GROUP

Metasedimentary rocks of the Kobau Group record a structural history involving at least three discrete folding events and later brittle faulting. The earliest structures preserved comprise isoclinal folds of compositional layering and an axial planar foliation defined by parallel alignment of platy and elongate minerals. Together, these represent a regional transposed foliation which dips moderately to steeply to the northeast, except in the Similkameen slopes area where it is reoriented about later structures. Flattening across the foliation is evident from boudinage of competent quartzite and marble lithologies and discontinuous stratigraphic contacts. Isoclinal folds typically have attenuated limbs and moderate thickening in hinges. These folds are limited to the mesoscopic scale, and total structural thickening attributed to them is uncertain. Fold axes plunge to the northeast and

TABLE 1-2-1
TABLE OF FORMATIONS

Period	Formation	Lithology
Tertiary, *ca.* 50 Ma	Mafic dykes	Prophyritic mafic dykes (augite, plagioclase, hornblende, biotite); some aphyric.
Jurassic(?)	Auriferous quartz veins	Veins near the Oliver pluton; veins within the Oliver pluton; generally massive, jointed, some ribboning; sulphide-poor; age relative to Fairview intrusion unknown.
Jurassic	Granitic, dioritic dykes and stocks	Aplite, aplitic granite, minor diorite and hornblende diorite; dykes and small stocks bordering the Oliver pluton or within Kobau Group rocks.
Jurassic, *ca.* 155 Ma	Oliver pluton (JOqm)	Complex, multiphase intrusion; K-feldspar-phyric quartz monzonite, granite and minor syenite; locally foliated border facies; locally agmatitic margin.
Jurassic(?)	Auriferous quartz veins (qz)	Vein systems along Fairview intrusion; sulphide-poor, locally containing pyrite, galena, sphalerite, chalcopyrite, graphite; commonly ribboned.
Jurassic(?)	Fairview granodiorite (JFgd)	Weakly foliated hornblende-bearing biotite granodiorite with minor granite and diorite; chlorite alteration common.
Pre-early Jurassic	Dacitic dykes	Plagioclase-quartz-phyric biotite dacite or plagidacite weakly foliated; 0.5-10 m thick; low-grade metamorphic overprint.
Pre-Jurassic		Polyphase deformation and metamorphism.
Pre-Jurassic	Kobau Group (KMI)	Tops unknown, listed from east to west. Mafic schist 1: Alternate mafic layers (actinolite, biotite, epidote, minor feldspar, quartz, chlorite) and quartzose or feldspathic layers (actinolite, biotite, epidote, sphene, calcite, white mica (mm-cm); some carbonate-rich sections (calcite, tremolite, epidote, feldspar, quartz); sections of quartz-feldspar-biotite schist: alternate biotite-rich (feldspar, quartz, epidote) and quartz-feldspar-rich (minor biotite, calcite) layers (mm-cm); lenses (1-50 m) of layered, foliated quartzite with thin biotite-rich laminae; boudins of massive quartzite; sections of uniformly mafic composition (10-100 m); calcite-marble boudins (2-15 m); rare lenses of augite-porphyritic mafic metavolcanic flows flows or sills (relict augite, actinolite-chlorite-epidote matrix).
	(KQ1)	Quartzite 1: Quartzite layers (1-5 cm) separated by biotite-rich layers (mm-cm), foliated; some biotite-rich sections; lenses of mafic schist.
	(KM2)	Mafic schist 2: Similar lithologies as in mafic schist 1; black, foliated biotite-quartzite; lenses of mafic metavolcanic flows or sills, coarse bedded, weakly foliated, primary textures obliterated; calcite marble (5-25 m) and minor calcite-tremolite marble.
	(KQ2)	Quartzite 2: Foliated quartzite with biotite-rich laminae, interbedded sections of mafic schist (1-20 m).

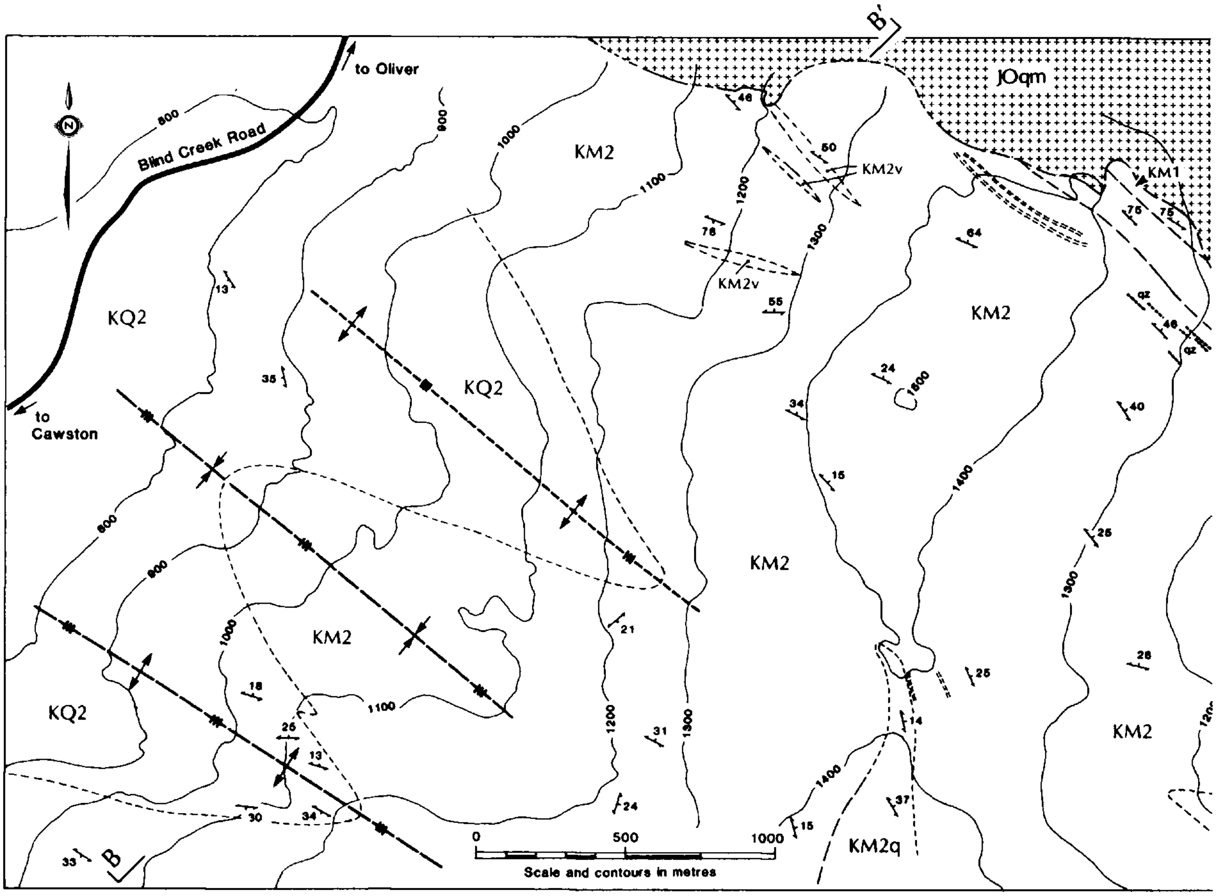


Figure 1-2-2. Simplified geological map of the western part of the project area (after Lewis *et al.*, 1989).

northwest, and no consistent patterns of vergence direction are observed.

The transposed foliation is refolded on all scales about second phase, tight to isoclinal structures with axial planes at low angles to the regional fabric. Mesoscopic folds occur in all quartzite and schist lithologies and, in some locations, have a weak associated crenulation cleavage. Fold axes consistently plunge steeply to the east-northeast and there is a moderate thickening of layers in hinge regions. Second phase map-scale folds are obscured by flattening in hinge regions and the discontinuous nature of the stratigraphy, but several are recognizable on the basis of stratigraphic repetition and vergence changes of mesoscopic folds. The most significant of these locally inverts a section at least 1000 metres thick in the Oliver slopes area; other map-scale closures are second order to this structure and only locally invert stratigraphy (Figure 1-2-4).

A third folding event formed megascopic open buckle folds which are limited to the Similkameen slopes area. These folds have very angular hinge regions, are mapped by abrupt changes in orientation of compositional layering and are not observed mesoscopically. Fold axes plunge shallowly to the northwest or southeast, with subvertical axial planes. Fold amplitude decreases rapidly to the southeast and mappable folds disappear completely near the contact with the Fairview granodiorite. Finally, a series of steeply dipping, north-trending faults locally offsets stratigraphic contacts on the Oliver slopes. Fault-plane grooves and offsets of recognizable markers indicate that the dominant motion on these surfaces was subhorizontal, left-lateral.

Quartz veins are ubiquitous in metasedimentary rocks and display varying degrees of deformation according to their age. Earliest formed veins are completely transposed into the regional foliation, whereas later structures maintain a planar geometry and cut all structural elements.

INTRUSIVE ROCKS

Intrusive contacts of the Oliver and Fairview plutons crosscut phase one and phase two folds, and their relationship to third phase structures is unclear. Structures within the plutons are limited to strong foliations along the margins of the Fairview pluton and strike-slip faults within both plutons. It is uncertain whether the foliation is igneous or tectonic in origin but intrusion postdates the major deformational events seen in Kobau Group rocks. The dacitic dykes contain a foliation parallel to the regional compositional layering; all other dykes lack internal deformation. Veins within the intrusive rocks are undeformed and are localized along fault zones.

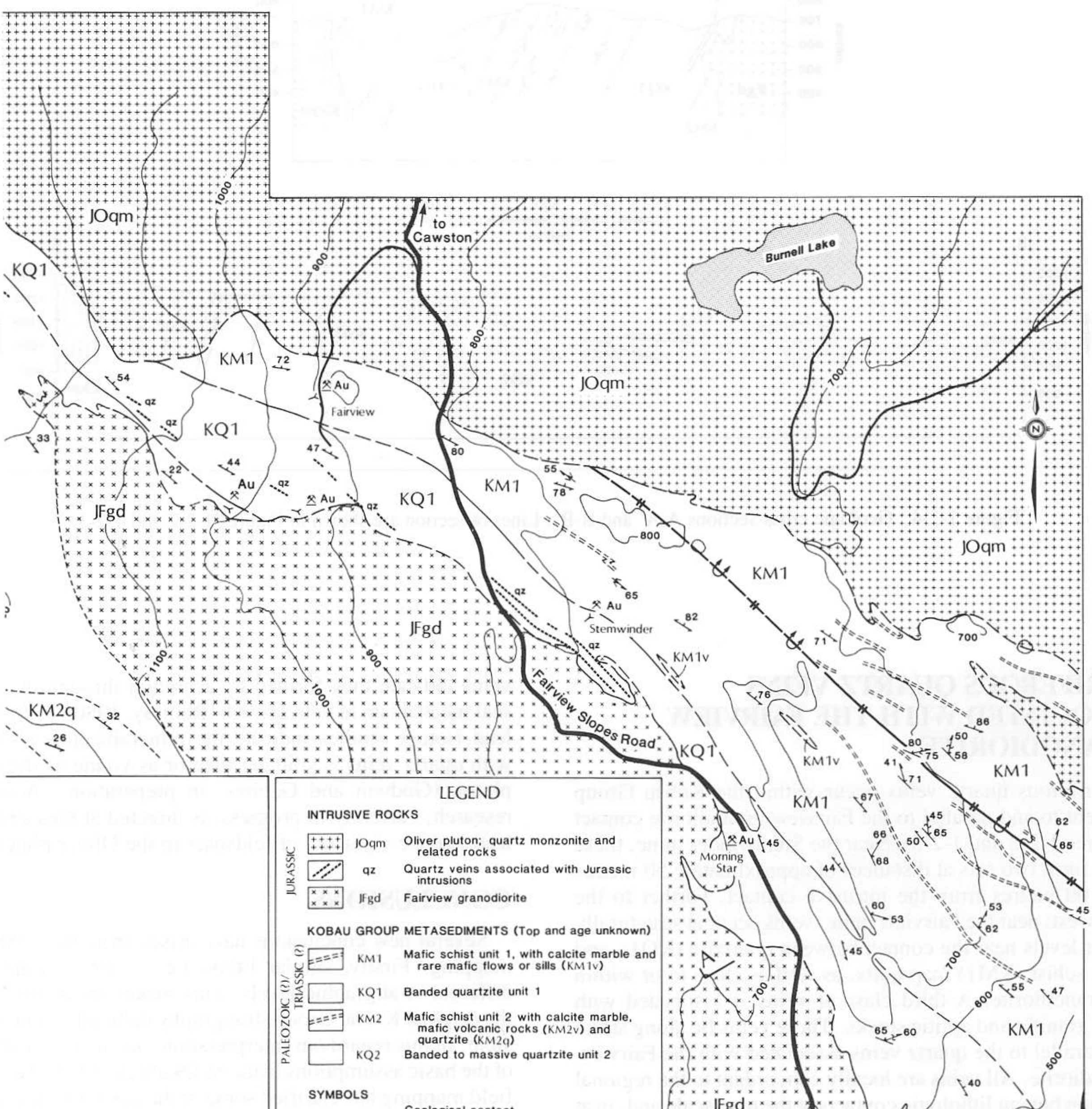


Figure 1-2-3. Simplified geological map of the eastern part of the project area (after Lewis *et al.*, 1989).

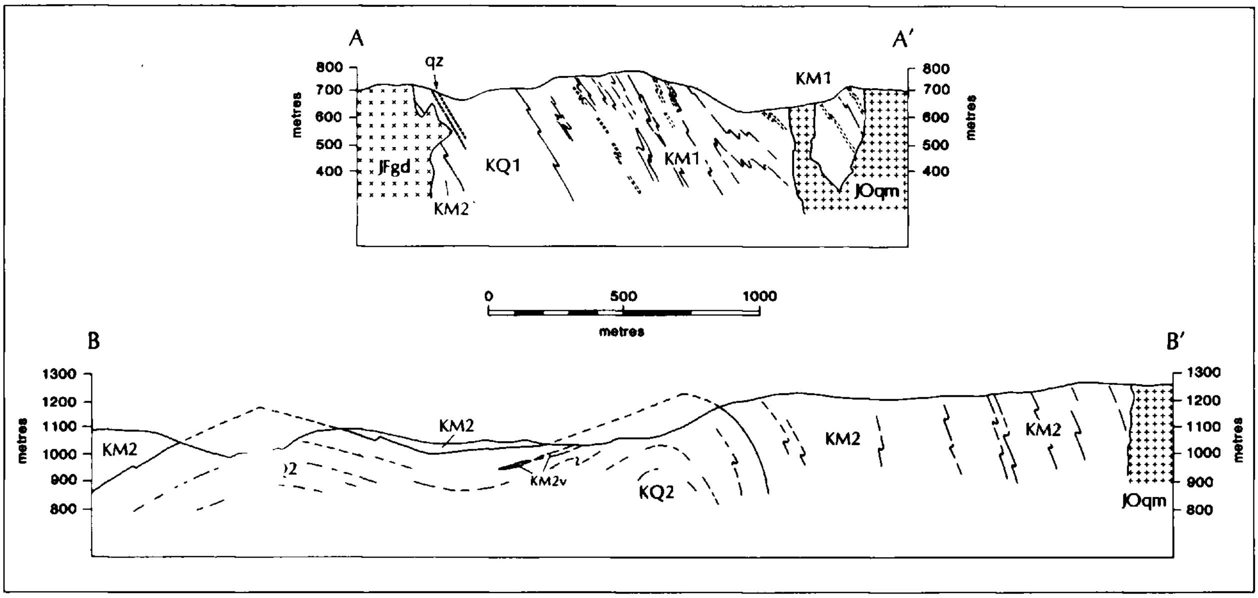


Figure 1-2-4. Geologic cross-sections A-A' and B-B'. Lines of section are shown in Figures 1-2-2 and 1-2-3.

AURIFEROUS QUARTZ VEINS ASSOCIATED WITH THE FAIRVIEW GRANODIORITE

Auriferous quartz veins occur within the Kobau Group adjacent to and parallel to the Fairview granodiorite contact (Figures 1-2-2 and 1-2-3). Near the Stemwinder mine, these veins form two sets at distances of approximately 50 metres and 100 metres from the intrusive contact. Further to the northwest, near the Fairview mine, veins occur at structurally higher levels near the contact between quartzite (KQ1), and mafic schist (KM1) map units, as well as close to or within the granodiorite. A third class of veins is associated with small granitic and aplitic stocks. These veins lie along strike and parallel to the quartz veins associated with the Fairview granodiorite. All veins are locally concordant to the regional foliation but cut lithologic contacts at the map scale and, in at least one outcrop, are found within intrusive rocks of the Fairview pluton. In general, they form planar bodies striking northwesterly and dipping to the northeast. Individual veins pinch and swell greatly, attain thicknesses up to 5 metres and may be traced up to 500 metres along strike.

Within veins, centimetre-scale banding, marked by concentrations of oxides, sulphides and graphite, is parallel to vein contacts. A strong parting, with spacing varying from 1 centimetre to 1 metre, also parallels vein contacts. These parting surfaces bound rare angular wallrock fragments up to 20 centimetres thick. Slickensides with shallow southeast plunges mark some parting surfaces, and uncommon stylolites are at moderate angles (10 to 50°) to vein walls.

The spatial relationship between the quartz veins and the Fairview pluton suggests the two may be genetically related. Spaced parting surfaces and wallrock fragments within the veins indicate they formed by accretion through the crack-seal mechanism of vein growth (Ramsay, 1980). Preliminary lead isotope studies indicate the mineralization associated with quartz veins is younger than or as young as the Oliver pluton (Godwin and Gabites, in preparation). Additional research, currently in progress, is directed at measuring the lead isotope signature of feldspars in the Oliver pluton.

CONCLUSIONS

Several new conclusions have arisen from the 1988 field mapping. Firstly, similar lithologies occupy a number of different stratigraphic levels. This makes reconstruction of the original Kobau Group stratigraphy difficult, if not impossible. In this regard our interpretations are at odds with some of the basic assumptions made by Okulitch (1973). Secondly, field mapping has clarified some of the age relationships and structural controls related to the emplacement of mineralized quartz veins. However, there remain a number of fundamental questions concerning the geology of the Fairview slopes area that this study has been unable to answer. These include:

(1) The relationship between this stratigraphy and the stratigraphic successions found to the south at Mount Kobau.

(2) The relationship between the sequence of deformational events described here and the regional geologic history.

(3) The absolute ages or age relationships between deformational events, metamorphism and intrusive activity.

These problems could be addressed by further research involving additional geologic mapping, detailed petrographic work involving microfabric analysis to constrain the deformational history of this group of rocks, and a geochronological and paleontological study to complement our inferred age relationships.

ACKNOWLEDGMENTS

This work was made possible by a 1988 Canada/British Columbia Mineral Development Agreement grant to J.K. Russell. We are grateful to Larry Nagy of The Valhalla Gold Group Corporation who provided the 1:5000 orthophoto coverage of the map area and to Dave Mehner for the time he spent with Urs Mäder and J.K. Russell in the field and underground. Urs Mäder and Peter Lewis were assisted in the field by Mark Stasiuk. Gordon Hodge drafted the figures.

REFERENCES

Armstrong, R.L. (1988): Mesozoic and Early Cenozoic Magmatic Evolution of the Canadian Cordillera, *Geological Society of America*, Special Paper 218, pages 55-91.

Bostock, H.S. (1940): Keremeos, *Geological Survey of Canada*, Map 342A.

Crawford, S.A. and Meyers, R.E. (1987): South-central District, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1986, Part A, pages A61-A67.

Godwin, C.I. and Gabites, J.E. (1988): Galena Lead Isotope Research at The University of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 529-534.

Lewis, P., Mäder, U. and Russell, J.K. (1989): Geology of the Kobau Group between Oliver and Cawston, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1989-2.

Okulitch, A.V. (1969): Geology of Mount Kobau, Unpublished Ph.D. Thesis, *The University of British Columbia*, 141 pages.

——— (1973): Age and Correlation of the Kobau Group, Mount Kobau, British Columbia, *Canadian Journal of Earth Sciences*, Volume 10, pages 1508-1518.

Parkinson, D.L. (1985): U-Pb Geochronometry and Regional Geology of the Southern Okanagan Valley, British Columbia: The Western Boundary of a Metamorphic Core Complex, Unpublished M.Sc. Thesis, *The University of British Columbia*, 149 pages.

Ramsay, J.G. (1980): The Crack-seal Mechanism of Rock Deformation, *Nature*, Volume 284, pages 135-139.

Sinclair, A.J., Moore, D. and Reinsbakken, A. (1984): Geology of Gypo Quartz Vein, Oliver, British Columbia (82E/4) *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Geological Fieldwork 1983, Paper 1984-1, pages 246-259.

White, W.H., Harakal, J.A. and Carter, N.C. (1968): Potassium-argon Ages of Some Ore Deposits in British Columbia, *Canadian Institute of Mining and Metallurgy*, Transactions, Volume 61, pages 1326-1334.

NOTES

THE GEOLOGY OF THE AVERILL PLUTONIC COMPLEX, GRAND FORKS, BRITISH COLUMBIA*
(82E/9W)

By Myra Keep and J.K. Russell
The University of British Columbia

KEYWORDS: Economic geology, Averill plutonic complex, Franklin mining camp, ultramafic, alkalic, syenite, platinum, palladium.

INTRODUCTION

The Averill plutonic complex is an informal name given to a suite of alkalic intrusive rocks exposed in the Franklin mining camp 70 kilometres north of Grand Forks, British Columbia (Keep and Russell, 1988). The complex comprises syenites to pyroxenites and is no younger than Eocene in age. The alkaline character of the rocks, the probable age of the intrusions and their regional setting suggest the complex is correlative to the Coryell intrusions centred around Grand Forks.

The 1988 field season saw the completion of a 1:5000-scale map of the Averill complex begun last year. This entailed extension of the field mapping and resulted in improved definition of lithologic contacts and understanding of their nature. The map presented here (Figure 1-3-1) is reduced from the final 1:5000 map produced through the two field seasons. This report discusses the petrology of the major map units and postulates an origin for the intrusive rocks.

PREVIOUS WORK

The Franklin mining camp has been known for its mineral potential since the early 1900s. C.W. Drysdale of the Geological Survey of Canada first mapped the area in 1911 (Drysdale, 1915) at which time most of the camp had already been extensively prospected. Drysdale's work was the first comprehensive study of the area and little subsequent mapping has been published.

In 1965, Franklin Mines Ltd. re-examined the property (Lisle and Chilcott, 1965) and in 1968 Newmont Mining Corporation of Canada undertook a regional study in the area (Norman, 1969). In 1986 the property came under the control of Longreach Resources Ltd. which completed a surface and underground drilling program. In the summer of 1987, Placer Dome Inc. began a regional exploration program in the area of the old Franklin camp which involved surface mapping, drilling and soil and heavy mineral geochemical sampling (Pinsent and Cannon, 1988).

REGIONAL GEOLOGY

The Averill plutonic complex lies at the southern end of the Omineca crystalline belt, which in southern British Columbia comprises basement gneisses, deformed and metamorphosed rocks of the North American continental margin sequence, allochthonous rocks of the Intermontane superterrane and Paleozoic, middle Jurassic, late Cretaceous and Paleogene granitic rocks, all of which have been affected by "widespread crustal extension superimposed on pre-existing compressive structures" (Parrish *et al.*, 1987). In the Grand Forks area there are also two late dyke swarms and late north-trending normal faults (Granby fault, Kettle River fault) sympathetic to structures related to Eocene extension in the Republic graben.

The oldest rocks exposed in the Franklin camp are Permo-Carboniferous tuffs, tuffites and sandstones of the Franklin (Anarchist) Group (Drysdale, 1915; Pinsent and Cannon, 1988) which are often difficult to distinguish in the field. These rocks have been intruded by Mesozoic granites and granodiorites (Figure 1-3-2). The Averill plutonic complex in turn intrudes the Mesozoic plutons and is unconformably overlain by conglomerates and fanglomerates of the Kettle River Formation, interpreted to be graben-fill sediments (Little, 1957). The end of Kettle River deposition is marked by an extrusive volcanic phase locally referred to as the McKinley rhyolite. Trachytes of the Marron Formation are the youngest rocks in the area, and lie disconformably over the Kettle River rocks (Pinsent and Cannon, 1988).

LOCAL GEOLOGY

The Averill plutonic complex (Figure 1-3-1) comprises seven intrusive phases (Units 1 to 7). Units 1 to 4 are the oldest and are distinguished on the basis of colour index. The lithologies grade from clinopyroxenite (Unit 1), through monzogabbro and monzodiorite (Units 2 and 3 respectively), to monzonite (Unit 4). Unit 5 is an alkaline syenite which cuts Units 1 to 4. Two late phases of dykes (Units 6 and 7) cut Units 1 to 5. The dykes are trachyte and plagioclase-rich porphyry respectively.

The boundaries between Units 1 to 4 outline a concentric zoning pattern which predates intrusion of the syenite of Unit 5 which is comprised of a coarsely crystalline core, with alkali feldspar phenocrysts 3 to 8 centimetres in length, mantled by a finer grained syenite. Brecciation of surrounding lithologies, especially Units 1 and 2, is evident where the syenite has intruded the ultramafic/alkalic suite. Syenite also occurs as ubiquitous veins and dykes within the older rocks. The late dykes cut Units 1 to 5 but do not cut each other. These dykes trend north to north-northeast, parallel to the trend of the Republic graben in northern Washington, immediately south of Grand Forks (Little, 1957).

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

Two smaller fault-bounded intrusions outcrop east of the main alkalic body (Pinsent and Cannon, 1988). The zoning in these smaller bodies is poorly developed, with Units 2 and 4 commonly missing from the sequence.

In the easternmost outlier (covered by the Tenderloin claim) the pyroxenite is poorly exposed and monzonite is missing from the sequence. Most of the claim area is underlain by monzodiorite and syenite with a coarsely crystalline syenite core (Figure 1-3-1). Both the trachyte and the plagioclase porphyry dykes intrude this area, although they are not as abundant as in the main part of the complex.

The second outlier (covered by the Maple Leaf claim) is comprised mainly of finely crystalline syenite, with a weakly developed rim of pyroxenite and monzodiorite (Figure 1-3-1) in contact with hornfelsed sediments of the Franklin Group. A dyke of pegmatitic syenite in this area is mineralized with chalcopyrite containing the highest concentrations of platinum and palladium found in the Franklin camp (Hulbert, personal communication, 1987).

PETROLOGY

Petrography of the Averill plutonic rocks is summarized in Table 1-3-1. Electron microprobe analyses of representative pyroxenes from all of the units are presented in Table 1-3-2 and the variation in composition is plotted in Figure 1-3-3.

PYROXENITE (UNIT 1)

The pyroxenites consist of primary augite, biotite, minor apatite, sphene, iron oxides and sulphides, and locally individual grains of alkali feldspar. Hornblende and biotite occur as secondary minerals and there is a very close spatial associ-

TABLE 1-3-1
MODAL MINERAL OCCURRENCE

Unit	Sample	Primary Mineralogy							Secondary Mineralogy					
No.	No.	Aug	Hb	Bt	K	Pe	Pl	Rh	Sp	Ap	Op	Q	Cc	Ser
5	88-2	x	x	x	x		x		x	x	x			x
5	88-4(i)	x			x	x	x	x	x	x	x			x
5	88-4(2)	x			x	x	x	x	x	x	x			x
4	88-7	x	x	x	x		x			x	x	x		x
3	88-8	x	x	x	x		x		x	x	x			x
2	88-10(i)	x	x	x	x		x			x	x		x	x
2	88-10(2)	x	x	x	x		x			x	x		x	x
1	88-11	x		x					x	x				
5	88-13	x		x	x	x		x	x	x	x		x	x
1	All	x		x	x						x			
2	182	x	x	x	x			x	x	x	x			
3	635	x		x	x		x			x	x			x
3	AA1C	x	x	x	x	x				x	x			

Aug = augite; **Hb** = hornblende; **Bt** = biotite; **K** = alkali feldspar; **Pe** = perthite; **Pl** = plagioclase; **Rh** = rhoenite; **Sp** = sphene; **Ap** = apatite; **Op** = opaques; **Q** = quartz; **Cc** = calcite; **Ser** = sericitic alteration.

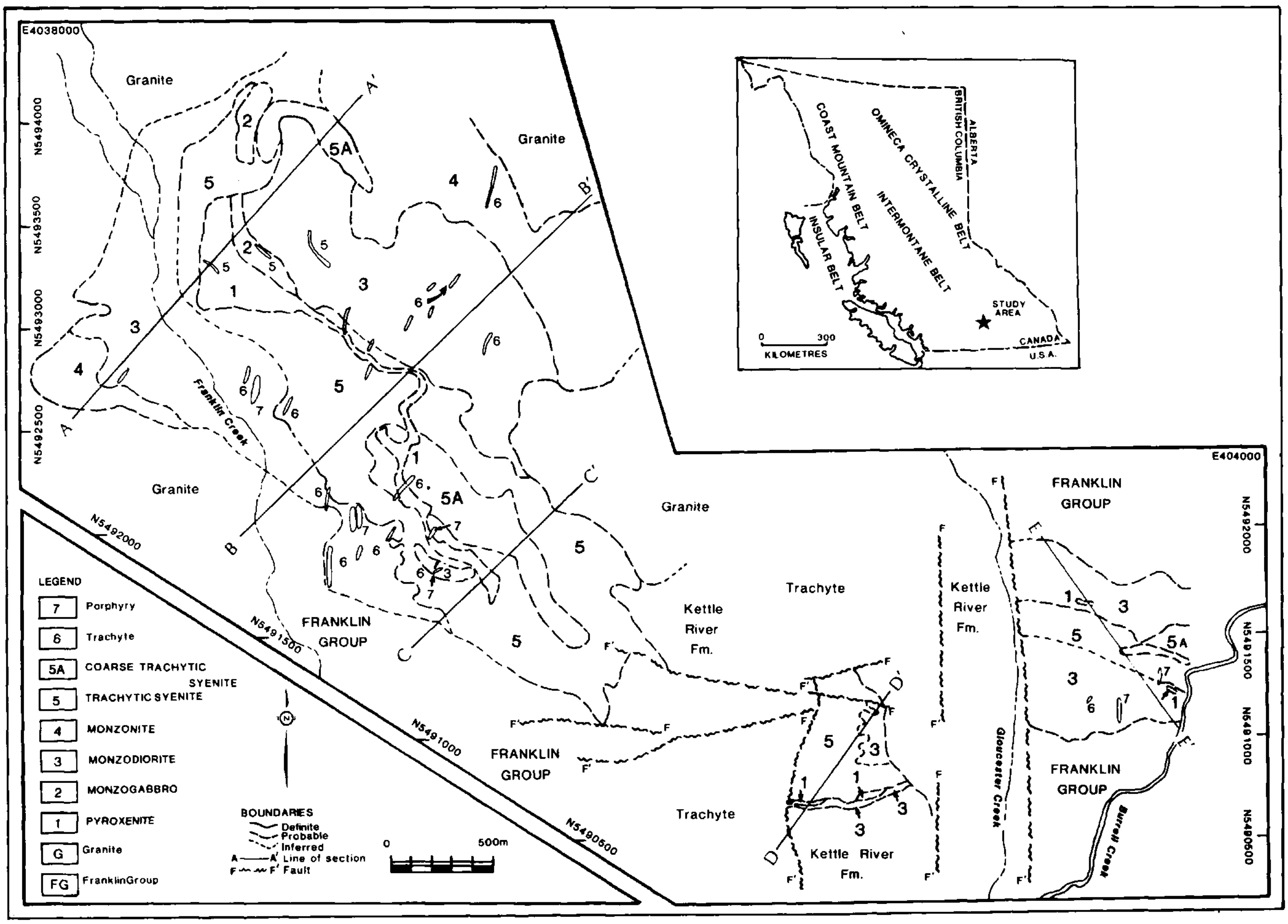


Figure 1-3-1. Geologic map of the Averill plutonic complex with location map showing major tectonic units in British Columbia.

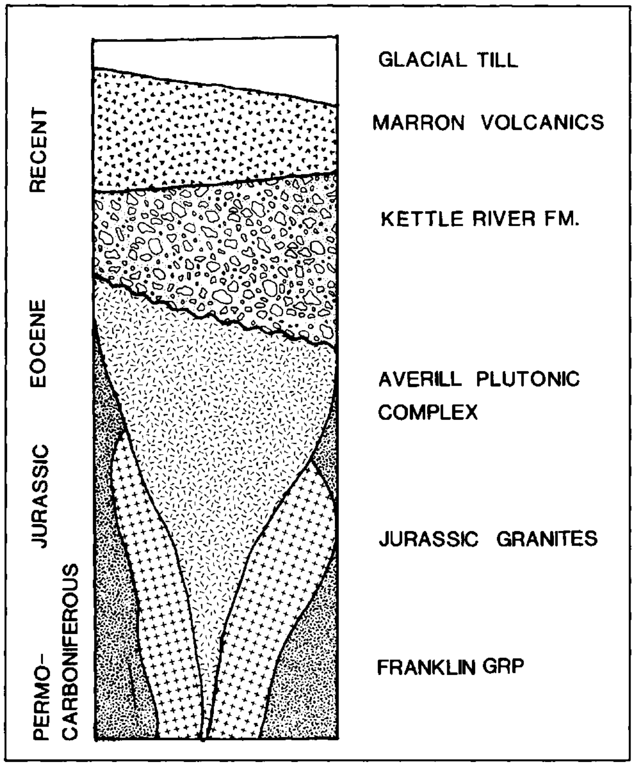


Figure 1-3-2. Stratigraphy of the Franklin mining camp.

ation between all mafic minerals. Two types of pyroxenite are recognized in the field. In general the pyroxenite comprises very fresh, well-formed augite crystals but in some outcrops pyroxene is completely replaced by biotite. Biotite-rich pyroxenite is commonly found near contacts with the syenites of Unit 5, and is thought to result from the hydrothermal effects of its intrusion.

Exposures of pyroxenite are somewhat limited and are mainly confined to pits and adits that have been driven through the syenite unit. Large outcrops, where they occur, are usually heavily vegetated and weathered.

MONZOGABBRO (UNIT 2)

The monzogabbro is identified in the field as having between 60 and 90 per cent mafic minerals, and there is a gradational boundary between it and Units 1 and 3. The mineralogy of this unit is essentially the same as Unit 1, consisting of primary augite, biotite, apatite, sphene, alkali feldspar and iron oxides and sulphides. The alkali feldspar occurs as interstitial grains, and veins of alkali feldspar and sometimes calcite are visible in thin section. Hornblende occurs as a secondary mineral. Variation in composition of the augites is very simllar to Unit 1 (Figure 1-3-3).

MONZODIORITE (UNIT 3)

This unit is the most abundant of the four units comprising the ultramafic/alkalic suite and is clearly gradational into both Units 2 and 4. The mineralogy is similar to Units 1 and 2 although the proportion of mafic minerals, by definition, is between 30 and 60 per cent. Augite is ubiquitous, and biotite and hornblende are common. Only a few samples have sphene, but apatite, iron oxides and sulphides are found in all samples. All of the alkali feldspar is interstitial.

MONZONITE (UNIT 4)

The monzonite unit is the most felsic of the ultramafic/alkalic sequence and is identified as having between 0 and 30 per cent mafic minerals. It has a gradational boundary with Unit 3 on one side and on the other side the contact with

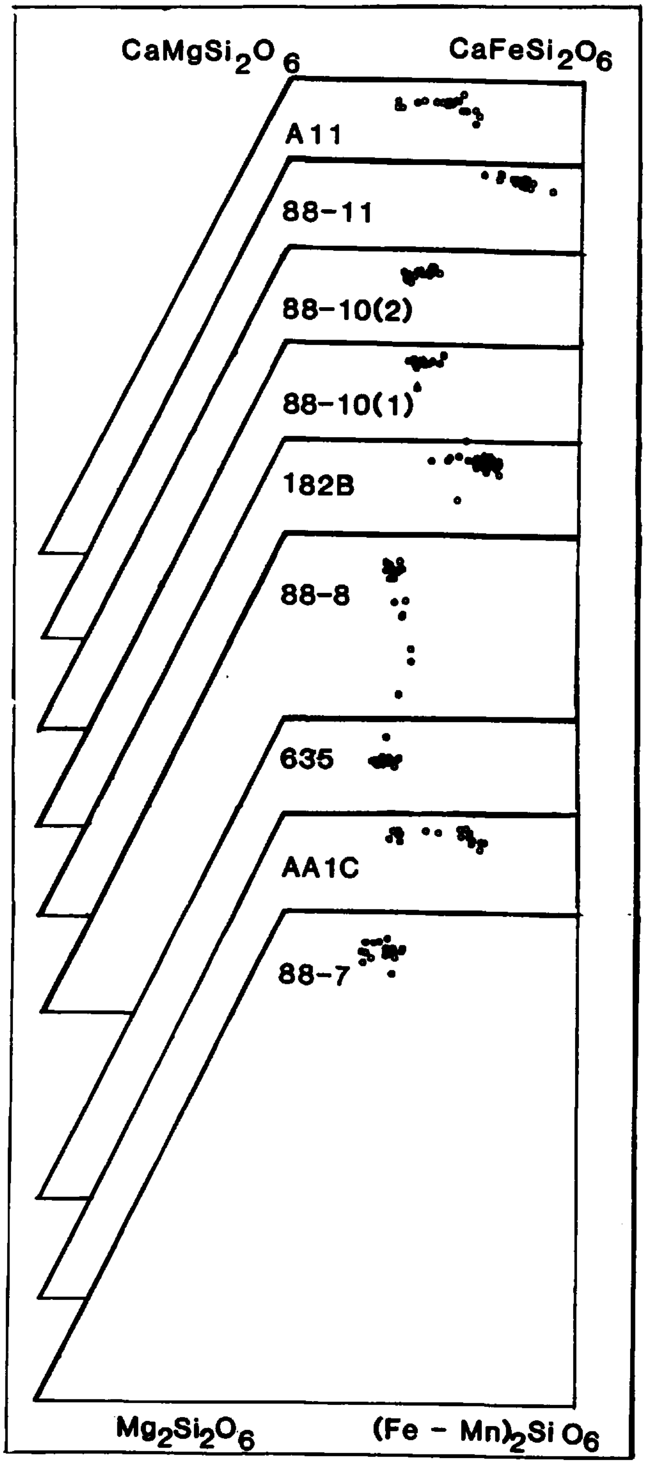
TABLE 1-3-2
PYROXENE ANALYSES

Representative pyroxene analyses of the plutonic rocks. The weight per cent of oxides in the pyroxenes are followed by the calculation of the number of ions in each grain analysed. Where there is sufficient chemical variation in a sample, both the most magnesium-rich (Mg) and the most iron-rich (Fe) analyses are shown.

Sample No.	**A11 (Mg)**	**A11 (Fe)**	**182 (Mg)**	**182 (Fe)**
Unit No.	**1**	**1**	**2**	**2**
SiO_2	52.28	49.73	48.41	48.10
TiO_2	0.31	0.70	1.07	1.19
Al_2O_3	0.94	2.38	3.33	3.63
FeO	7.34	10.68	13.03	13.31
MnO	0.35	0.35	0.44	0.42
MgO	14.17	11.77	10.49	9.88
CaO	22.93	22.95	22.49	22.47
Na_2O	0.92	0.96	0.97	1.17
Total	99.24	99.52	100.22	100.17
No. of ions on the basis of 6 oxygens				
Si	1.96	1.90	1.86	1.84
Ti	0.01	0.02	0.03	0.03
Al	0.04	0.11	0.15	0.21
Fe	0.23	0.34	0.42	0.40
Mn	0.01	0.01	0.01	0.02
Mg	0.79	0.67	0.60	0.60
Ca	0.92	0.94	0.93	0.90
Na	0.07	0.07	0.07	0.07
Total	4.03	4.06	4.07	4.07

Sample No.	**635 (Av)**	**88-7 (Av)**	**88-2 (Mg)**	**2 (Fe)**
Unit No.	**3**	**4**	**5**	**5**
SiO_2	51.28	52.46	51.60	47.55
TiO_2	0.15	0.00	0.00	0.00
Al_2O_3	1.70	2.62	2.31	4.69
FeO	7.57	8.33	13.38	16.11
MnO	0.47	0.45	0.51	0.62
MgO	14.81	14.48	9.83	7.57
CaO	22.91	20.89	20.30	21.41
Na_2O	0.52	0.65	2.34	1.42
Total	99.56	99.88	100.27	99.37
No. of ions on the basis of 6 oxygens				
Si	1.93	1.95	1.86	1.96
Ti	0.00	0.00	0.00	0.00
Al	0.08	0.11	0.22	0.10
Fe	0.24	0.26	0.53	0.43
Mn	0.02	0.01	0.02	0.02
Mg	0.82	0.80	0.44	0.56
Ca	0.91	0.83	0.90	0.83
Na	0.04	0.05	0.11	0.17
Total	4.04	4.01	4.08	4.07

The microprobe analyses of pyroxenes were obtained on a Cameca SX-50 microprobe at The University of British Columbia. The operating conditions were: (i) accelerating voltage of 15kv, (ii) beam current of 20na, (iii) count times of 10 seconds per element. Concentrations of eight major element oxides were measured and the structural formula for the data was reduced using the FORMULA-1 program developed by Dr. J.K. Russell and associates at The University of British Columbia (Mäder *et al.*, 1988).



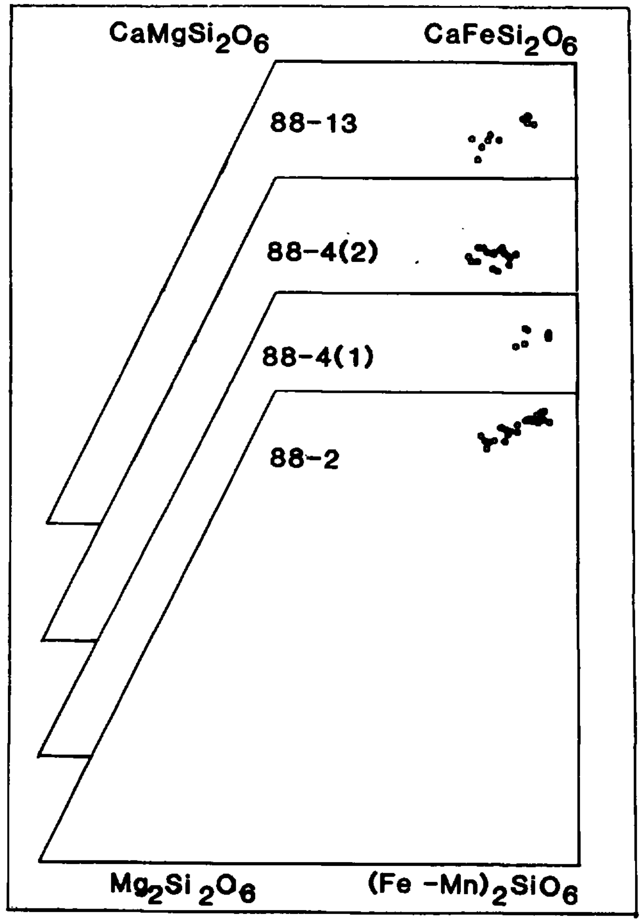


Figure 1-3-3. Composition variation of the pyroxenes in (a) the syenite series and (b) the ultramafic/alkalic series, grading from pyroxenite at the top to monzonite at the bottom. Samples 88-2, 4(i), 4(2) and 13 are syenites; 88-7 is a monzonite; 88-8, AA1C and 635 are monzodiorites; 88-10(i), 10(2) and 182 are monzogabbros; and 88-11 and A11 are pyroxenite samples.

Mesozoic granodiorites is well defined. The monzonites comprise augite, hornblende, biotite, apatite, orthoclase, and minor plagioclase and quartz.

TRACHYTIC SYENITE (UNIT 5)

Both the coarse and fine-grained syenites are characterized by a very well-developed trachytic texture which does not seem to define any coherent pattern. The individual laths of alkali feldspar vary between 1 and 8 centimetres in length. Coarse-grained syenites are defined as having feldspar laths greater than 3 centimetres long. The more coarsely crystalline material is confined to a narrow central core. Mafic minerals such as augite, hornblende, biotite, sphene, apatite and iron oxides and sulphides are present only in minor amounts, as interstitial grains. In some of the coarser material there are large grains of a mineral which appears to be garnet or rhoenite; plagioclase and perthite have also been identified. In the northernmost part of the area the coarse-grained core is not mantled by finer grained syenite but is in direct contact with Units 3 and 4.

TRACHYTE (UNIT 6) AND PLAGIOCLASE PORPHYRY (UNIT 7)

These units represent two later dyke phases which intrude the alkalic suite but have no interaction with each other. They are relatively unimportant although the porphyry does contain minor pyrite and chalcopyrite. There is a possibility that the trachyte may be related to the Marron volcanics which cap peaks in the area, but there is no visible contact between the two within the Franklin camp.

MINERALIZATION

Three styles of mineralization were first recognized in the Franklin camp by Drysdale (1915). These are:

(1) Platinum and palladium-bearing chaleopyrite mineralization associated with the pyroxenite phase (Unit 1) of the ultramafic sequence.

(2) Contact metamorphic skarn deposits which occur where rocks of the Franklin Group have been cut by later intrusions.

(3) "High-grade" precious and base metal mineralization associated with a later suite of quartz veins.

Only the first of these styles is seen in the Averill complex. Pyrite and chalcopyrite, together with malachite and azurite staining, are commonly found in the pyroxenite at or near contacts with syenite. These contacts are relatively common as the whole area is cut by veins and dykes of syenite. The association of platinum and palladium with copper mineralization derived from the syenite intrusion is also manifest in the resurlts of soil geochemical snrveys, where platinum, palladium and copper anomalies are closely associated and all three are restricted to the outcrop area of the syenite (Pinsent and Cannon, 1988).

CONCLUSIONS

The Averill plutonic complex consists of a mineralogically gradational ultramafic/alkalic pluton ranging in composition from pyroxenite to monzonite. The pyroxenite is thought to represent the core of the pluton with the composition becoming less mafic away from the centre. Shortly after emplacement the ultramafic sequence was intruded by a large body of syenite. This intrusion must have occurred when at least the inner parts of the concentrically zoned pluton were relatively cool, as the syenite clearly brecciates the pyroxenites.

The alkalic suite is cut by two later dyke swarms and is unconformably overlain by conglomerates and rhyolites of the Kettle River Formation. Above the Kettle River rocks are trachytes of the Marron Formation but there is no visible contact between the Coryell intrusions and the Marron in the Franklin camp.

CORRELATION TO THE CORYELL

Units 1 to 5 have similarities, both chemically and physically, to rocks of the nearby Coryell batholith. Unit 5 has identical mineralogy to known bodies of Coryell syenite and also has a similar regional setting. (Daly, 1912; Drysdale, 1915; Little, 1957, 1963). The Coryell intrusions have been dated as being between 54 and 60 Ma (Baadsgaard *et al.*, 1961).

ACKNOWLEDGMENTS

Funding for this study was provided by the Canada/British Columbia Mineral Development Agreement and Natural Sciences and Engineering Research Council operating grant A0820 to J.K. Russell. Logistical support was given by Placer Dome Inc., and by David and Diane Onions.

REFERENCES

Baadsgaard, H., Folinsbee, R.E. and Lipson, I.(1961): Potassium-argon Dates of Biotites from Cordilleran Granites, *Geological Society of America*, Bulletin 72, pages 689-702.

Daly, R.A. (1912): Geology of the North American Cordillera at the Forty-ninth Parallel, *Geological Survey of Canada*, Memoir 38, 857 pages.

Drysdale, C.W. (1915): The Geology of the Franklin Mining Camp, British Columbia, *Geological Survey of Canada*, Memoir 56, 246 pages.

Keep, M. and Russell, J.K. (1988): The Geology of the Averill Plutonic Complex, Grand Forks, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 49-53.

Lisle, T.E. and Chilcott, R.P. (1965): Report on Franklin Mining Camp, situated around Franklin Mountain in the Greenwood Mining Division, Province of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 637, 30 pages.

Little, H.W. (1957): Kettle River, East Half, British Columbia, *Geological Survey of Canada*, Map 6-1957.

——— (1963): Rossland Map-area, British Columbia, 82F/4 (West Half), *Geological Survey of Canada*, Paper 63-13, 8 pages.

Mäder, U., Thirugnanam, U. and Russell, J.K. (1988): FORMULA-1: A Turbo-Pascal Program for the Calculation of Mineral Structural Formulae, *The University of British Columbia*, Unpublished U.B.C. Software Documentation, 40 pages.

Norman, G.W.H. (1969): Geological Report on the Bear-Doe Group, Franklin District, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 1845, 6 pages.

Parrish, R.R., Carr, S.D. and Parkinson, D.L. (1987): Extensional Tectonics of the Southern Omineca Belt, British Columbia and Washington, *Tectonics*, Volume 7, pages 181-212.

Pinsent, R.H. and Cannon, R.W. (1988): Geological, Geochemical and Geophysical Assessment Report, Platinum Blonde Property, Franklin Creek Area, Greenwood Mining Division, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 248 pages.

NOTES

THE ROSSLAND GROUP, NELSON MAP AREA, SOUTHEASTERN BRITISH COLUMBIA (82F/6)

By Trygve Höy and Kathryn Andrew

KEYWORDS: Regional geology, Rossland Group, Ymir Group, Archibald Formation, Elise Formation, shoshonites, Hall Creek syncline, Silver King shear, gold skarn, gold veins, conformable gold.

INTRODUCTION

The Rossland project, hegun in 1987, continued during the 1988 season with three months field mapping in the Nelson area (Figure 1-4-1). The project focuses on the Lower Jurassic Rossland Group and the stratigraphic and structural setting of mineral deposits within it. During the 1988 season, approximately 400 square kilometres were mapped at a scale of 1:20 000, essentially covering the distribution of Rossland rocks in the Nelson sheet (82F/6). Work planned for the 1989 season will extend mapping to the south and west, primarily in the Salmo sheet (82F/3), and will eventually extend westward to cover the entire distribution of Rossland Group rocks, including those in the Rossland gold camp. Supporting laboratory work includes trace and whole-rock geochemistry of Rossland volcanic rocks, uranium-lead and potassium-argon isotope geochronology of both intrusive and extrusive rocks, fluid inclusion studies of mineral occurrences, and lead-lead isotope analyses of vein galena.

STRATIGRAPHY

The Rossland Group comprises a basal succession of dominantly fine-grained clastic rocks of the Archibald Formation, volcanic rocks of the Elise Formation and overlying clastic rocks of the Hall Formation. These rocks are Early Jurassic in age, bracketted by Sinemurian fossils in the Archibald (Frebold and Tipper, 1970; Tipper, 1984) and Pliensbachian and Toarcian fossils in the Hall (Frebold and Little, 1962, Tipper, 1984). The Ymir Group underlies the Elise Formation in the Nelson area. Based on lithologic similarity and superposition, the upper part of the Ymir Group is correlated with the Archibald Formation, and its lower part with the Late Triassic Slocan Group exposed on the north side of the Nelson batholith (Little, 1960). The Rossland and Ymir Groups are intruded by numerous small stocks that are probably correlative with the Middle to Late Jurassic Nelson Batholith, by many Tertiary rhyolite an lamprophyre dykes, and by Coryell alkalic intrusions of Eocene age.

YMIR GROUP

The Ymir Group is exposed as a broad arcuate belt of highly deformed, dominantly fine-grained clastic rocks in the east half of the Nelson map area. These rocks have been mapped by McAllister (1951) but complex structural relationships and repetitions have hindered detailed subdivision. Although the base of the Ymir Group is not exposed, the sequence has been estimated to be at least a kilometre thick.

The Ymir Group comprises greater than 120 metres of argillaceous quartzite overlain by more than 300 metres of grit, siltstone and argillite with discontinuous bands of massive to thin-bedded, impure limestone (McAllister, 1951). This lower succession is overlain by a fining-upward sequence of grit, siltstone, argillite and argillaceous quartzite over 500 metres thick that terminates with finely laminated argillite, feldspathic wacke and minor limy siltstone (Höy and Andrew, 1988). Augite porphyry sills or thin flows, up to 2 metres thick, also occur near the top of the Ymir Group. The Elise Formation conformably overlies the Ymir Group; the best exposure of the contact is in Ymir Creek.

ROSSLAND GROUP

ARCHIBALD FORMATION

The Archibald Formation, named after its type location in Archibald Creek (82F/3, Frebold and Little, 1962), is the lowermost unit of the Rossland Group. It is exposed in the limbs of an anticline in the Erie Creek area along the west side of the Nelson map area. Previously referred to as "the Sinemurian beds", the Archibald Formation has yielded several macrofossil collections with *Arnioceras* indicating both early and late Sinemurian ages. The exposed thickness of the formation is estimated to be at least 1000 metres; its base is not exposed.

The Archibald Formation generally comprises a fining-upward succession of interbedded siltstones, sandstones and argillites. The lower part of the section is characterized by over 200 metres of interbedded tan siltstone and impure grey sandstone in beds 3 to 4 centimetres thick. These are overlain by a finer grained sequence of rusty weathering, tan siltstones intercalated with grey to black silty argillite and minor black graphitic argillite. A few thin (2 to 10 metres) basaltic andesite flows or sills occur with increasing abundance near the top of the section in both the Erie Creek and Red Mountain areas. This succession of interbedded volcanic and sedimentary rocks correlates with a similar succession at the top of the Ymir Group.

The contact between the Archibald and Elise formations is gradational. It is mapped (Figure 1-4-2) where fine-grained interbedded siltstones and argillites with occasional thin flows give way to massive augite porphyry flows with fine argillaceous partings. The top of the Archibald Formation was previously located at a coquina bed, a few centimetres thick, within an agglomerate overlain by massive augite

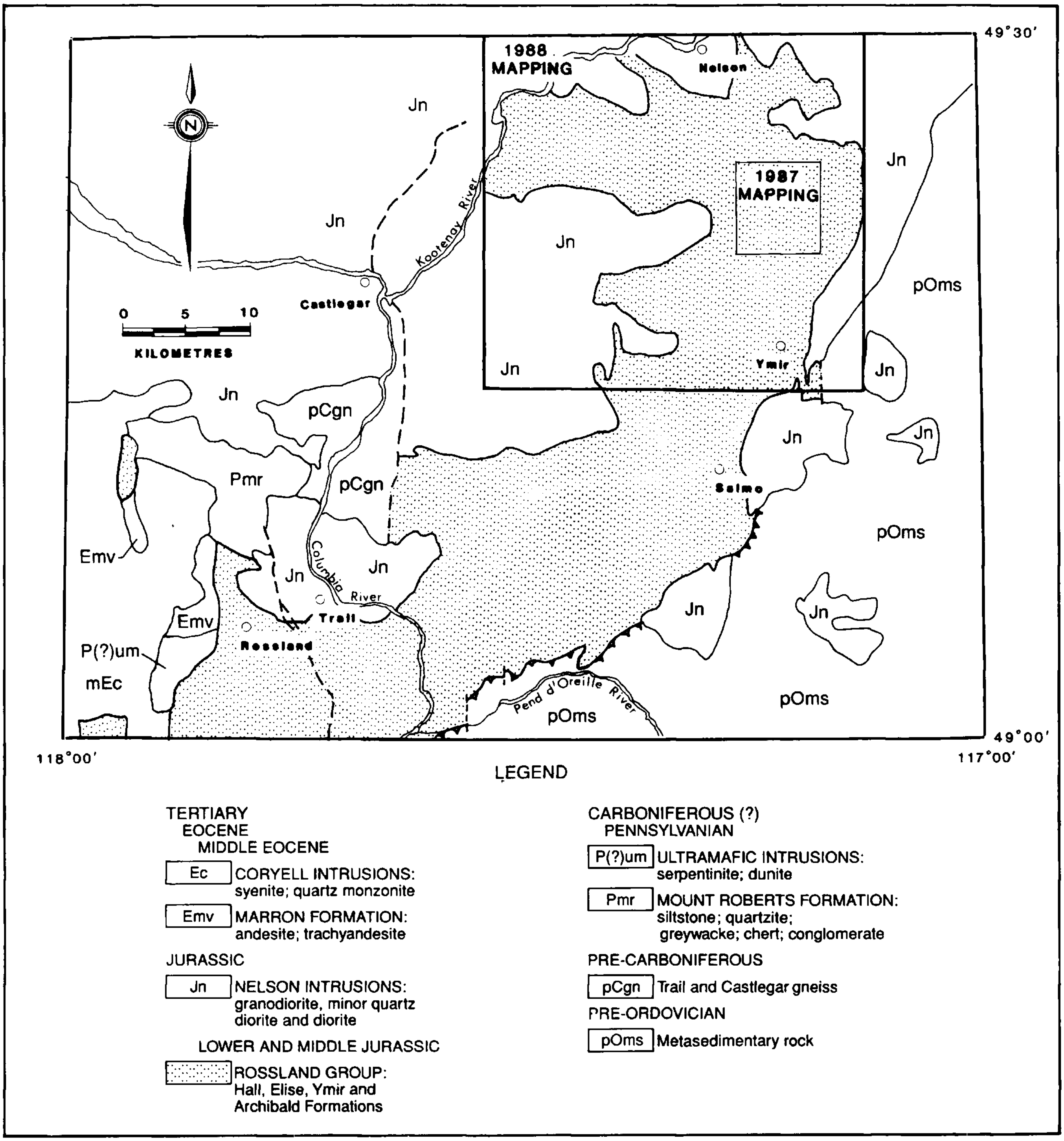


Figure 1-4-1. Map showing distribution of the Rossland Group in southeastern British Columbia and location of 1987 and 1988 map areas. Regional geology after Little (1960, 1964, 1982), Fyles (1984), Simony (1979), Corbett and Simony (1984), and Parrish (1984).

porphyry (Mulligan, 1952); however, this bed was not recognized during the course of our mapping.

Elise Formation

Description

The Elise Formation is characterized by a series of interfingering lenses of massive to brecciated flows, tuffs, subvolcanic porphyries and minor epiclastic deposits. These lenses pinch out laterally and vertically causing facies changes on both outcrop and regional scales. Despite such lithologic variations, the eastern facies of the Elise Formation can be broadly subdivided into a lower and an upper member (Andrew and Höy, 1988). The lower Elise comprises dominantly massive mafic flow-breccias, flows and coarse blocky pyroclastic rocks whereas the upper Elise is predominantly

Plate 1-4-1. Pyroclastic breccia informally referred to as the "Porto Rico tuffs", Cabin Peak area; note clasts are dominantly augite porphyry and augite-plagioclase porphyry in a fine to coarse crystal matrix.

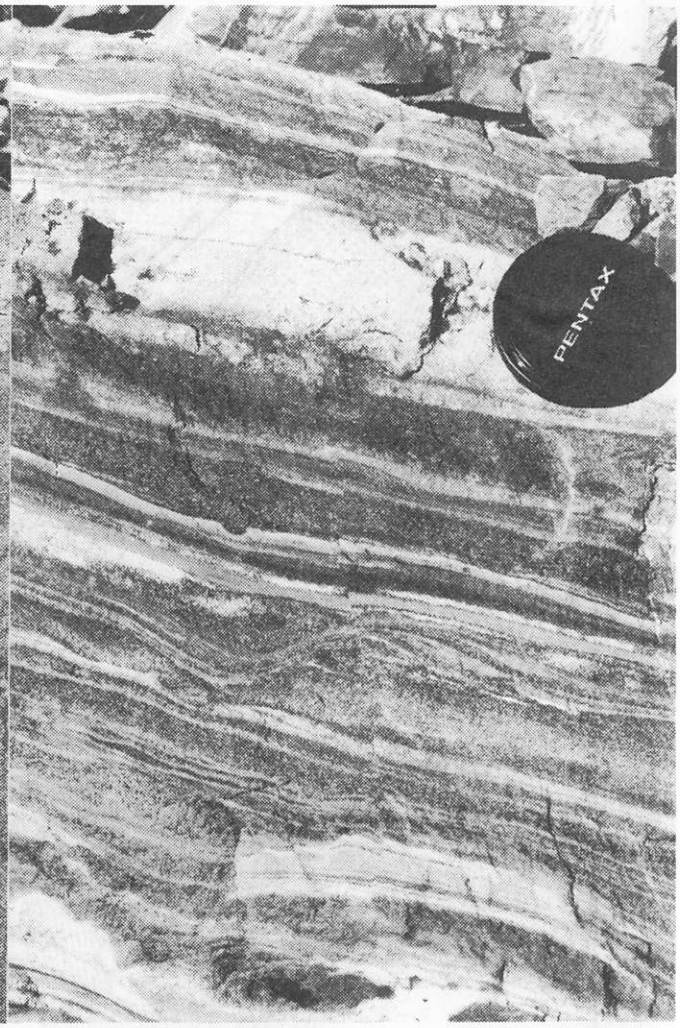


Plate 1-4-2. Well-bedded, mafic to intermediate lapilli, crystal and fine tuff, Cabin Peak area, note numerous structures, including graded or laminated beds, scours, channels and crosslaminations suggestive of subaqueous or base-surge deposition.

intermediate pyroclastic rocks, minor epiclastic rocks and some mafic flows.

The Elise Formation is exposed in the east and west limbs of the Hall Creek syncline. In the eastern limb, the formation is characterized by a lower section of mafic flow breccias and flows up to a kilometre thick, overlain by an upper section of dominantly intermediate volcanic and volcaniclastic rocks nearly 2.5 kilometres thick (Figure 1-1-4, Höy and Andrew, 1988). The flows and flow breccias in the basal member are characterized by augite phenocrysts commonly up to 1 centimetre in diameter, and subordinate finer grained plagioclase. Although the autoclastic fragments in the flow breccias typically include broken calcite and quartz-amygdaloidal pillows, pillow basalt flows are rare.

The upper Elise on the east side of the Hall Creek syncline contains a number of cyclical sequences of pyroclastic rocks that typically grade upward from lapilli tuff to crystal tuff or fine tuff. The tuffs are commonly crystal rich with 5 to 20 per cent plagioclase and several per cent augite crystals. Lapilli tuffs contain subrounded to subangular volcanic clasts of dominantly intermediate composition. The upper Elise is intruded by a number of plagioclase porphyries including the Silver King porphyry. These are intensely deformed and are locally incorporated as fragments in Elise epiclastic rocks, compelling evidence for a comagmatic origin.

The distinction between the upper and lower Elise Formation in the Cabin Peak and Mammoth Peak areas on the west limb of the Hall Creek syncline is less evident. The total thickness of the formation in this area is approximately 1.5 to 2 kilometres. It comprises primarily mafic coarse pyroclastic breccia interlayered with minor augite porphyry flows and prominent sections of waterlain crystal and lapilli tuff (Figure 1-4-3). Pyroclastic breccias and flow breccias of intermediate composition, similar to those that characterize much of the upper Elise east of the Hall Creek syncline (Unit 7, Andrew and Höy, 1988), are uncommon.

The mafic pyroclastic breccias, informally referred to as the "Porto Rico tuffs", mainly comprise clasts of mafic

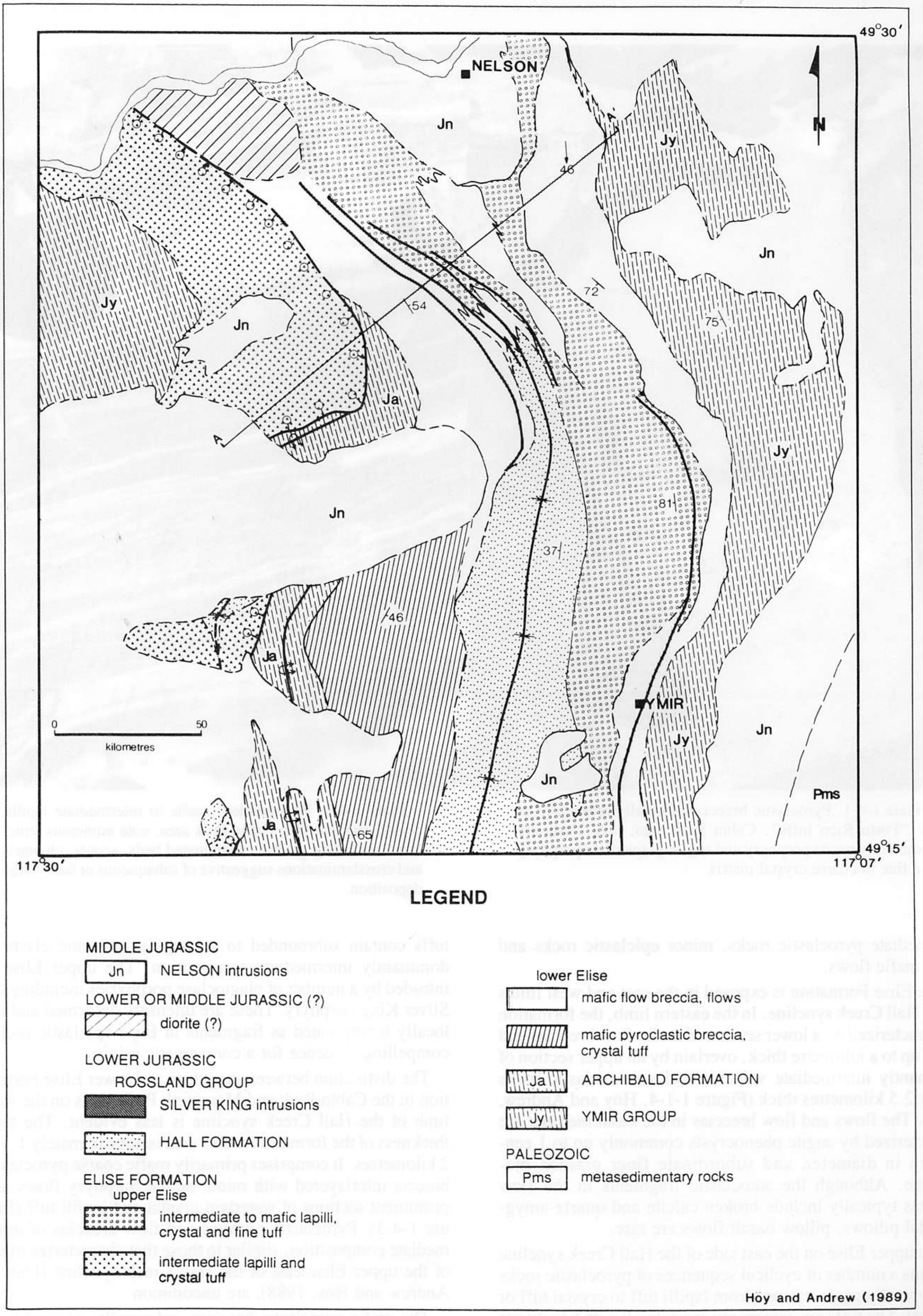


Figure 1-4-2a. Geology of the Nelson map area.

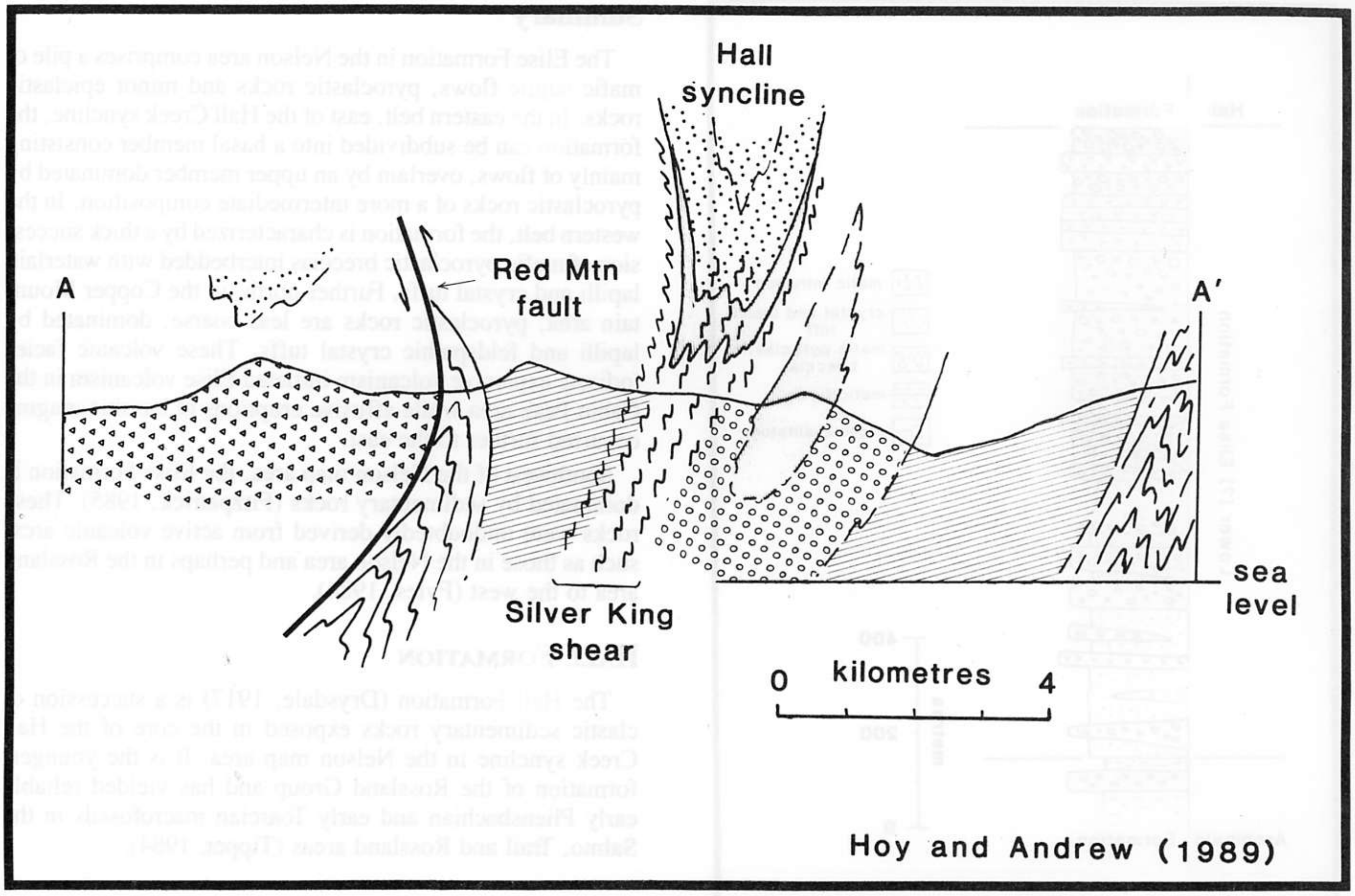


Figure 1-4-2b. Schematic vertical section through the northern part of the Nelson sheet; location is shown on Figure 1-4-2a.

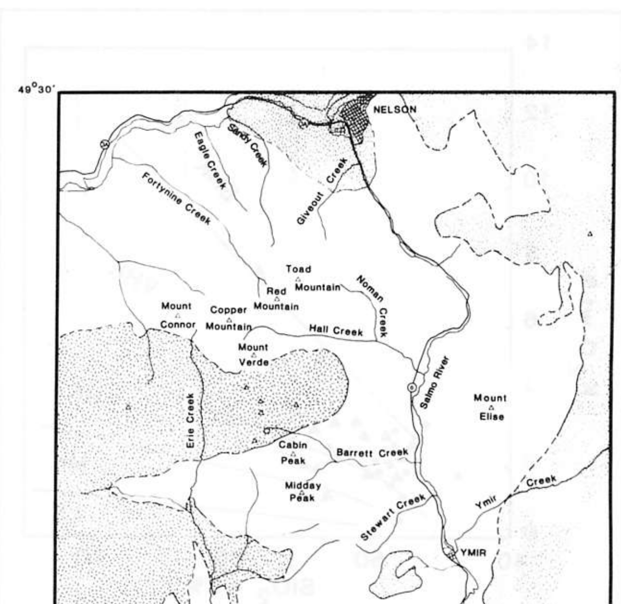


Figure 1-4-2c. Location map.

augite porphyry and minor augite-plagioclase porphyry in a fine to coarse crystal matrix (Plate 1-4-1). They are best exposed in the Cabin Peak area where clasts commonly exceed 20 to 30 centimetres in diameter. The size of pyroclasts decreases to the north and south suggesting the Cabin Peak area is close to an explosive volcanic centre. A prominent mafic intrusion at Cabin Peak may also indicate proximity to a volcanic vent.

The pyroclastic breccias are interbedded with sections dominated by well-bedded, mafic to intermediate lapilli, crystal and fine tuff (Figure 1-4-3). These units are occasionally massive but more commonly contain numerous structures, including graded or laminated beds, scours, channels and crosslaminations suggestive of subaqueous deposition (Plate 1-4-2). Although we interpreted them to be primarily pyroclastic deposits that are reworked into turbidites, it is possible that they also include base-surge deposits; their distribution is areally restricted, unusual for turbidites, and they are closely associated with a proximal vent facies.

Further north, in the Copper Mountain–Fortynine Creek area, the upper Elise typically comprises massive pale grey-green feldspathic tuff, coarse crystal tuff and tuff-breccia. The crystal tuff has prominent white euhedral plagioclase crystals set in a dark tuffaceous matrix such that the rock resembles a subvolcanic intrusive porphyry; however, small lithic fragments and broken crystals indicate a pyroclastic origin. Occasional lenses of tuffaceous conglomerate with clasts of feldspar porphyry, mudstone, chert and mafic volcanic rock occur near the top of the section.

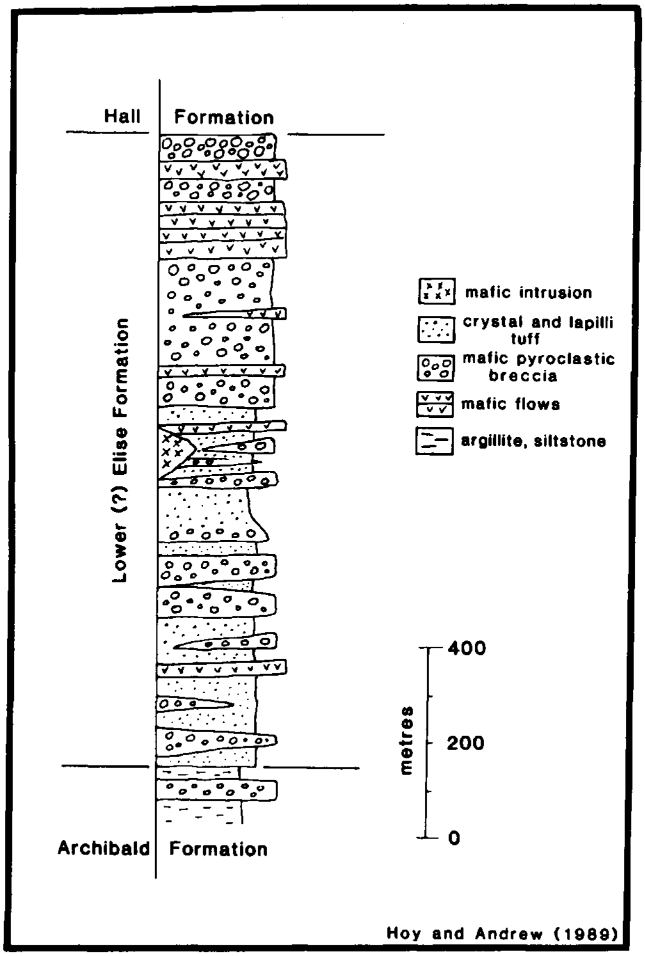


Figure 1-4-3. Composite volcanic succession of the Elise Formation in the Cabin Peak area, west of the Hall Creek syncline.

Geochemistry

The Elise volcanic suite has very high potassium content (Figure 1-4-4) and unusually low titanium content (TiO_2 less than 1 per cent). The volcanic rocks are not significantly metasomatised as most samples plot in the "unaltered" field on an MgO-CaO plot (Höy and Andrew, 1988) from de Rosen-Spence (1976); however, they are locally intensely altered near some mineral deposits.

Most analyses of Elise rocks fall in the alkaline field on the alkali versus silica diagram (Figure 1-4-5), due mainly to the very high potassium content. However, on plots using essentially incompatible trace elements (Figure 1-4-6) they plot as subalkaline andesite and basalt. The contradicting whole-rock and trace-element geochemistry, low titanium contents, high potassium-sodium ratios (Mackenzie and Chappell, 1972) and low titanium-vanadium ratios (Shervais, 1982) support a shoshonitic association for the Elise volcanic rocks, as has been shown by Beddoe-Stephens and Lambert (1981) and de Rosen-Spence (1985). Although tectonic discrimination diagrams are not well defined for shoshonitic rocks, they are interpreted to be formed in volcanic arcs (de Rosen-Spence, 1985).

Summary

The Elise Formation in the Nelson area comprises a pile of mafic augite flows, pyroclastic rocks and minor epiclastic rocks. In the eastern belt, east of the Hall Creek syncline, the formation can be subdivided into a basal member consisting mainly of flows, overlain by an upper member dominated by pyroclastic rocks of a more intermediate composition. In the western belt, the formation is characterized by a thick succession of mafic pyroclastic breccias interbedded with waterlain lapilli and crystal tuffs. Further north, in the Copper Mountain area, pyroclastic rocks are less coarse, dominated by lapilli and feldspathic crystal tuffs. These volcanic facies indicate explosive volcanism initiated Elise volcanism in the Cabin Peak area while effusive eruptions of basaltic magma occurred further to the east.

Southwest of the Nelson map area, the Elise Formation is dominated by sedimentary rocks (Fitzpatrick, 1985). These rocks were undoubtedly derived from active volcanic arcs, such as those in the Nelson area and perhaps in the Rossland area to the west (Fyles, 1984).

Hall Formation

The Hall Formation (Drysdale, 1917) is a succession of clastic sedimentary rocks exposed in the core of the Hall Creek syncline in the Nelson map area. It is the youngest formation of the Rossland Group and has yielded reliable early Pliensbachian and early Toarcian macrofossils in the Salmo, Trail and Rossland areas (Tipper, 1984).

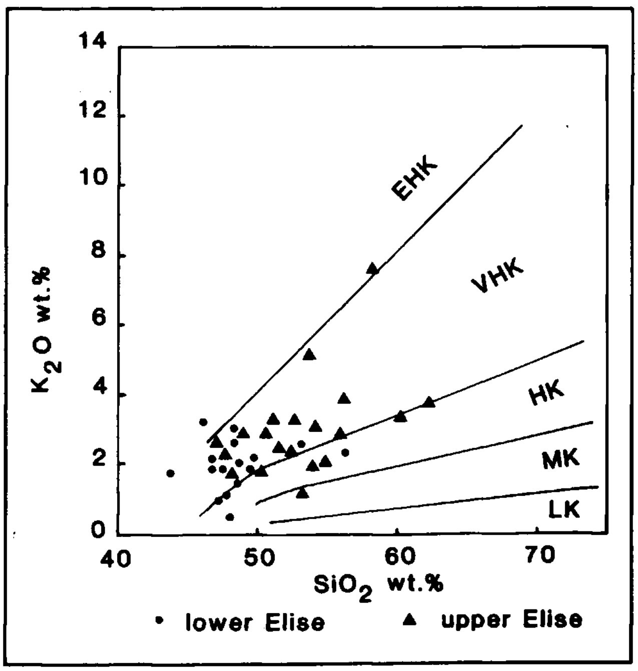


Figure 1-4-4. K_2O/SiO_2 plot demonstrating the consistantly very high K_2O content of Elise Formation volcanic rocks. Low (LK), medium (MK), and high (HK) K_2O domains are from Gill (1981); very high (VHK) and extremely high (EHK) K_2O domains, from de Rosen-Spence (1985).

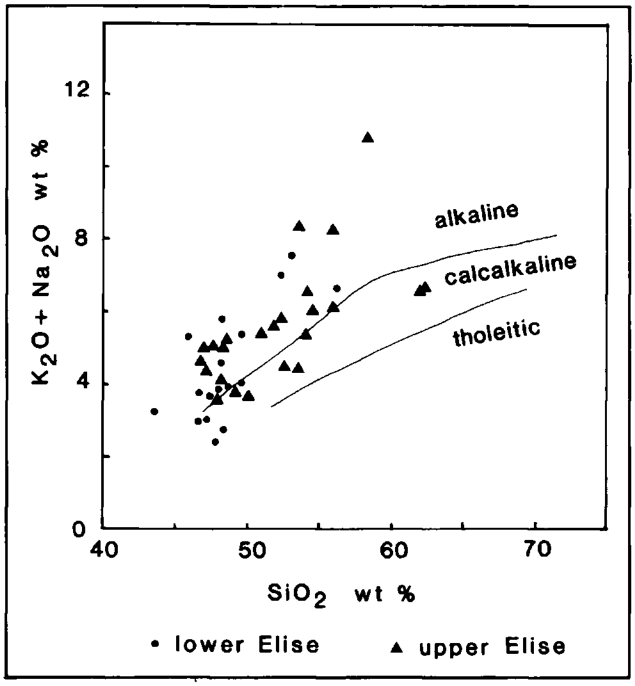


Figure 1-4-5. Alkali-silica plot of Elise Formation volcanic rocks showing the distinct alkaline trend; field boundaries from Kuno (1966).

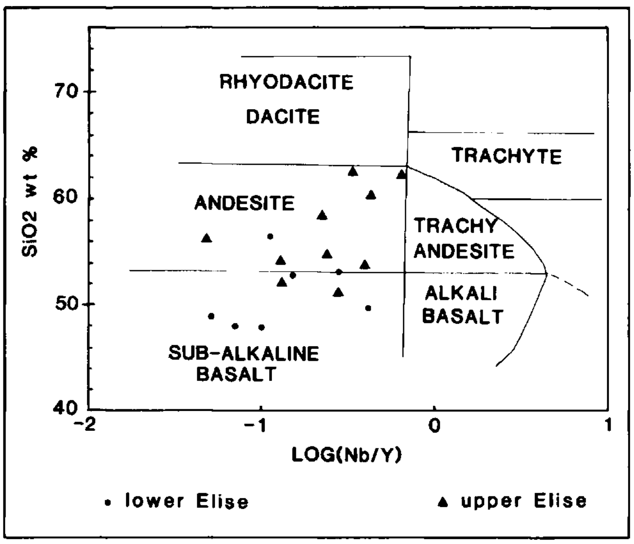


Figure 1-4-6. SiO_2-Nb/Y diagram illustrating the subalkaline nature of Elise volcanic rocks; lower Elise, dominantly basaltic; upper Elise, dominantly andesitic; field boundaries from Winchester and Floyd (1977).

The thickness of the Hall Formation is at least 1400 metres; its top is not exposed. It generally rests conformably on volcanic rocks of the Elise Formation although locally an erosional unconformity, marked by a few metres of conglomerate with pebbles derived from the underlying volcanic rocks, is at the base. In the eastern part of the map area, a number of diorite sills parallel the Hall-Elise contact.

The Hall Formation comprises a lower coarsening-upward sequence of argillites, siltstones, grits and conglomerates overlain by a succession of interbedded siltstone and argillite. The lower part of the sequence is characterized by over 300 metres of black argillite with minor siltstone and rare limy argillaceous layers, overlain by over 200 metres of tan siltstone. These grade upward into over 300 metres of coarse sandstone interlayered with conglomerate, grit and pebble conglomerate, locally with a carbonate cement. The upper part of the section is an interlayered sequence of argillaceous laminated siltstone, silty argillite and argillite. Locally, impure limestones and mud-chip breccias occur near the top of the formation.

STRUCTURE

The structure of the Nelson map area is dominated by northerly trending tight folds and associated shears. The intensity of deformation increases toward the east. The Ymir Group near the eastern edge of the map area is folded into numerous tight to isoclinal west-dipping overturned folds whereas folds in the Archibald and Elise formations in the Copper Mountain and Cabin Peak areas are more open. These structures involve the Silver King intrusive rocks but are truncated by rocks correlative with the Nelson batholith. Small-scale open folds, locally associated with a crenulation cleavage, are superimposed on the early, northerly trending structures.

The Hall Creek syncline is the most prominent fold in the map area. It is a tight, south-plunging, west-dipping overturned fold, cored by the Hall Formation, that extends from west of Nelson to southwest of Ymir (Figure 1-4-2). A pronounced cleavage in clastic rocks of the Hall Formation and a penetrative foliation in the Elise Formation parallel the axial plane of the syncline. Northwest of the closure of the Hall Formation, between the headwaters of Noman and Giveout creeks, the core of the syncline forms a zone of intense shearing more than a kilometre in width. The shear zone, informally referred to as the Silver King shear, continues northwestward into intrusive rocks and more highly metamorphosed rocks of the Elise Formation near Eagle and Sandy creeks, and appears to die out to the south in rocks at a higher structural level along the limbs of the Hall Creek syncline.

Other zones of intense shearing are recognized in the Elise Formation and Ymir Group east of the Hall Creek syncline. The most prominent follows the western slope of Mount Elise and crosses Highway 6 south and west of Ymir (Figure 1-4-2). It dips to the west, essentially parallel to the prominent foliation, cuts down section to the south, and has an apparent net reverse displacement.

An overturned anticline occurs in the Archibald Formation near the western edge of the map area. It is truncated by apophyses of the Nelson batholith near Erie Creek and appears to be cut by the Red Mountain fault in the Mount Verde–Red Mountain area. The Archibald Formation on the east slope of Red Mountain is an east-facing upright succession on the east limb of the anticline; on the eastern and northern slopes of Mount Verde, a number of small folds verge northward towards the hinge of the anticline. Numer-

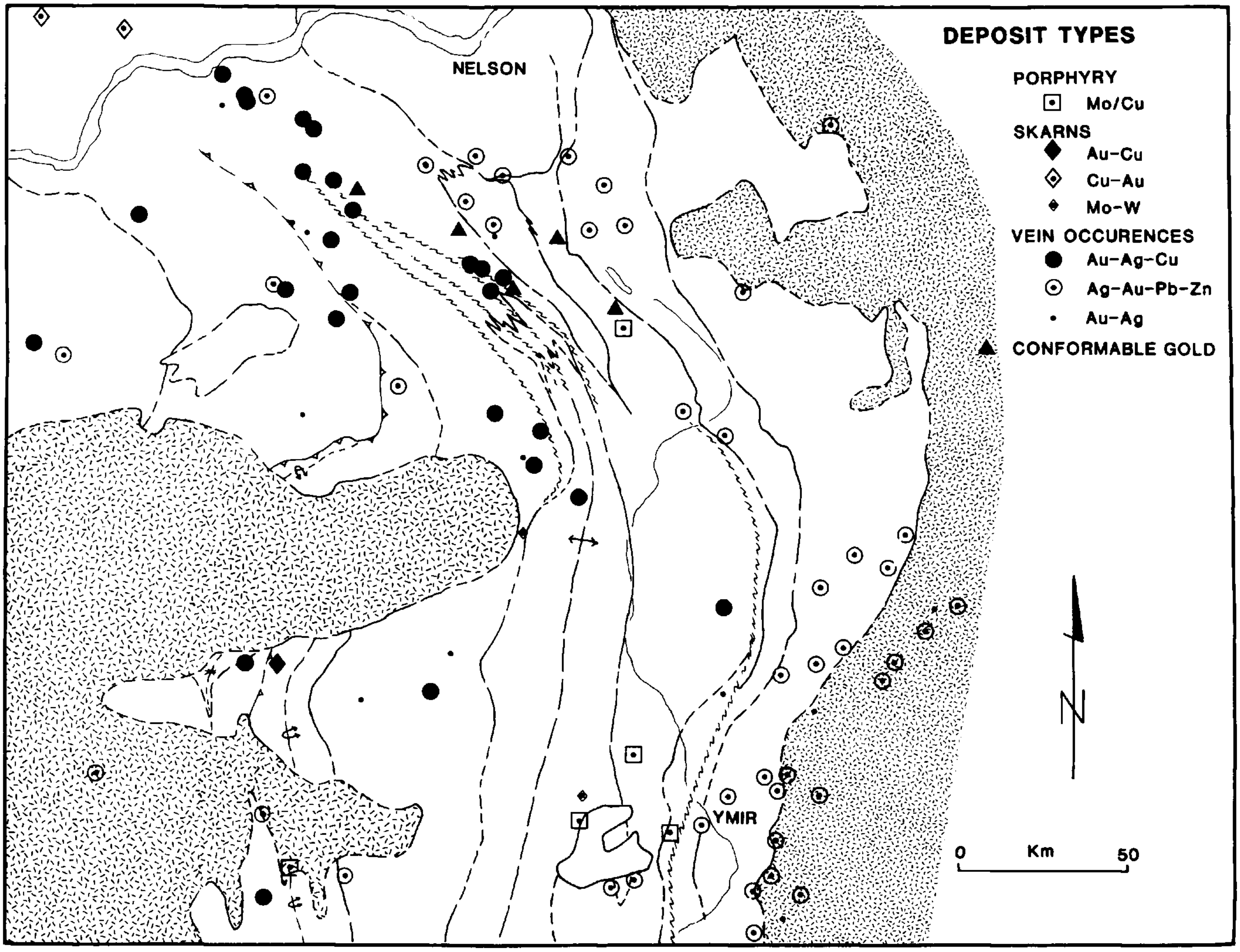


Figure 1-4-7. Metallic mineral deposit types of the Nelson map area.

ous Cretaceous or Tertiary porphyry, aplite and granitic dykes intrude the Archibald Formation in the Erie Creek area.

The Red Mountain fault extends from Fortynine Creek south to Erie Creek. It dips to the north with a normal displacement in the Mount Verde–Copper Mountain area, but is overturned in Fortynine and Erie creeks where its apparent displacement is reverse (*see* cross-section, Figure 1-4-2). It may be a large listric normal fault that juxtaposes upper Elise volcanic rocks in its western hangingwall against more intensely folded Archibald rocks to the east. It is younger than the intense folding and associated shearing, but older than the Nelson granitic rocks.

MINERAL OCCURRENCES

The distribution of metallic mineral occurrences and deposits in the Nelson map area is shown in Figure 1-4-7. These deposits have produced more than 16 750 kilograms of gold and 190 000 kilograms of silver, primarily from vein deposits in the Ymir camp. This compares with more than 84 000 kilograms of gold and 105 000 kilograms of silver recovered from the Rossland Camp, the second largest gold-producing camp in British Columbia.

Mineral occurrences in the Nelson and Ymir areas can be subdivided into four main types:

(1) porphyry or stockwork molybdenum-copper
(2) skarn molybdenum, tungsten, copper, gold
(3) vein gold, silver, copper; gold, silver, lead, zinc
(4) "conformable gold".

Porphyry, skarn and vein occurrences are closely associated with late granitic intrusions, whereas deposits referred to as "conformable gold" are more closely associated with Rossland Group lithologies and early structures.

The most significant porphyry occurrences in the Nelson area are the Stewart and Bobbi prospects just west of Ymir (MINFILE 082FSW229 and 250). These occurrences contain zones of intense alteration and brecciation in a quartz monzonite stock and adjacent rocks of the Elise and Hall formations contain disseminated, vein and stockwork molybdenite, pyrite and minor powellite mineralization.

Three main types of skarn deposits are recognized in the area. These are molybdenum or tungsten skarns, copper skarns and a gold-enriched skarn. The Mammoth showing (MINFILE 082FSW311) is a small molybdenum-copper skarn with minor lead-zinc-silver and trace gold in mafic augite flows of the Elise Formation and hornfelsed argillites of the Hall Formation, adjacent to the Bonnington pluton. Skarn gangue minerals include pyrite, pyrrhotite, quartz, epidote, potassium feldspar, garnet and actinolite. The Arrow Tungsten prospect (MINFILE 082FSW311) is a tungsten-molybdenum-garnet-diopside skarn in Hall Formation metasedimentary rocks on the north side of the intrusive complex that hosts the Stewart deposit. A number of copper skarns, comprising coarse-grained diopside-garnet-quartz-epidote with pyrrhotite, chalcopyrite, magnetite and bornite, occur in the Hall Formation along the margin of the Nelson batholith west of Nelson.

The only deposit that may be classed as a gold-enriched skarn is the Second Relief (MINFILE 082FSW187). It comprises a number of "fissure veins" that carry pyrite, pyrrhotite, chalcopyrite and minor molybdenite in "greenstone" adjacent to a diorite porphyry sill (Cockfield, 1936). Skarn minerals in the country rock include coarse-grained garnet, epidote, biotite, quartz and magnetite. The Second Relief produced 3118 kilograms of gold and 866 kilograms of silver from 1902 to 1959, ranking it as one of the larger gold skarns in British Columbia and one of the few, other than those in the Hedley camp, that produced gold as its primary commodity.

Vein deposits are widely distributed throughout the Elise and Archibald Formations, the Ymir Group and Nelson granitic rocks (Figure 1-4-7). Many of these veins have a preferred orientation parallel to either bedding or foliation, AC jointing, or extension joints (Höy and Andrew, 1988). Vein mineralogy appears to have a lithologic control; veins that carry lead and zinc in addition to gold and silver are preferentially distributed in metasedimentary rocks of the Ymir Group or correlative Archibald Formation and within or adjacent to Nelson granitic rocks, whereas copper-gold-bearing veins are more common in Elise volcanic rocks (Figure 1-4-7). Most copper-gold-bearing veins are within or close to large faults or shear zones snch as the Silver King shear. The gangue of the these veins is predominantly quartz, with minor carbonate, chlorite, trace tourmaline and rare scheelite. Sulphides include pyrite, pyrrhotite, chalcopyrite and, in some veins, arsenopyrite and galena.

"Conformable gold" is an informal name applied to a variety of deposits that are conformable with either foliation or bedding in the host Elise Formation. They include the Great Western, Shaft and Cat showings, Kena, some showings in the Star area, and perhaps the Silver King deposits (Figure 1-4-7). In contrast with other deposits, conformable gold deposits are sheared and foliated together with their host rocks. Many appear to be associated with synvolcanic intrusions thar range in composition from rhyodacite(?) to diorite, and all have extensive alteration halos.

The Great Western showings, located just southwest of Nelson, were extensively trenched and drilled by Lectus Developments Ltd. in 1987. One of the best mineralized intercepts included approximately 7 metres containing 9.7 grams per tonne gold (DDH 87-10); the highest reported assay was 58 grams per tonne gold over 0.9 metre (DDH 87-3), (George Cross Newsletter, November 17, 1987). The showings consist of a number of elongate zones of intense carbonate-silica-sericite-pyrite alteration up to several metres to several tens of metres thick. A number of the zones include thin lenses of quartz-eye rhyodacite or granular dacite. The zones are hosted by highly sheared mafic tuffs, lapilli tuffs and possible augite flows of the upper Elise Formation.

The Shaft-Cat property, currently being drilled by South Pacific Gold Corporation, is centred on an elongate, fine to medium-grained intrusive diorite complex. The diorite is locally brecciated and extensively altered to a chlorite-epidote-carbonate assemblage that contains magnetite, chalcopyrite and pyrite. Surface grab samples assayed an average of 6.2 grams per tonne gold and 1 per cent copper (O. Janout, personal communication, 1988).

SUMMARY AND DISCUSSION

The Elise Formation exhibits marked facies changes throughout the district. In the eastern part of the Nelson map area, Elise volcanic rocks record an early phase of effusive volcanism followed by eruptions of pyroclastic rocks. Further west, in the Copper Mountain area, explosive volcanism characterizes the entire formation. In contrast, the formation is dominated by sedimentary rocks southwest of Salmo (Fitzpatrick, 1985), that were probably derived from volcanic centres in the Nelson area, and possibly, the Rossland area (Fyles, 1984).

The Rossland Group was subjected to intense compressional deformation, particularly in the east close to its contact with Paleozoic miogeoclinal rocks. This deformation is bracketed by a late Early Jurassic age for the Rossland Group and a post-tectonic, late Middle Jurassic age for the Nelson batholith (Ghosh, 1986; Carr *et al.*, 1987).

The shoshonitic nature of the Elise Formation supports the suggestion that the Rossland Group was deposited in a volcanic arc environment (de Rosen-Spence, 1985; Ray and de Rosen-Spence, 1986). Shoshonitic volcanism appears to be associated with disturbance or steepening of a subduction zone, possibly due to plate collision (Joplin, 1969; Gill, 1970). The Rossland Group shoshonitic rocks may therefore record arc volcanism as a subduction zone was dying just prior to plate collision, possibly involving accretion of Quesnellia in Terrane I (Monger *et al.*, 1982) to the North American craton in Jurassic time. Continued compressional tectonics may have resulted in the intense regional deformation in Rossland Group rocks.

Mineral occurrences and deposits in the Nelson area include gold-silver-copper-lead-zinc veins, a number of porphyry molybdenum-copper deposits, "conformable gold" occurrences and skarn deposits. The recognition of a major gold-enriched skarn deposit within the Nelson area, the Second Relief, considerably increases the exploration potential for gold-bearing skarn deposits in the Rossland Group. The Second Relief produced more than 3100 kilograms of gold, which ranks it as the third largest skarn producer in the province, after the Nickel Plate and Phoenix mines.

ACKNOWLEDGMENTS

We would like to thank C. Lund and M. Holmes for their reliable and enthusiastic assistance during field mapping. Many prospectors and company geologists contributed valuable ideas, led property tours and provided general information on the Nelson map area. In particular we wish to thank O. Janout, J. Jenks, R. Bourden, E. Denny, M. Kaufman, A. Fraser, R. Wong, L. Addie, P. Santos and the crew of Lectus Developments Ltd. Field visits by W.R. Smyth, V.A. Preto, and G.E. Ray, and discussions with G. Nixon and J. Fyles were both helpful and stimulating; the manuscript was improved by the editorial comments of J.M. Newell and B. Grant.

REFERENCES

Andrew, K. and Höy, T. (1988): Preliminary Geology and Mineral Occurrences in the Rossland Group, between Nelson and Ymir, Southeastern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File Map 1988-1.

Beddoe-Stephens, B. and Lambert, R. St. J. (1981): Geochemical, Mineralogical, and Isotopic Data relating to the Origin and Tectonic Setting of the Rossland Volcanic Rocks, Southern British Columbia, *Canadian Journal of Earth Sciences*, Volume 18, pages 858-868.

Carr, S.D., Parrish, R.R. and Brown, R.L. (1987): Eocene Structural Development of the Valhalla Complex, Southeastern British Columbia, *Tectonics*, Volume 6, Number 2, pages 175-196.

Cockfield, W.E., (1936): Lode Gold Deposits of Ymir-Nelson Area, British Columbia, *Geological Survey of Canada*, Memoir 191, 78 pages.

Corbett, C.R. and Simony, P.S. (1984): The Champion Lake Fault in the Trail-Castlegar Area of Southeastern British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 84-1A, pages 103-104.

de Rosen-Spence, A.F. (1976): Stratigraphy, Development and Petrogenesis of the Central Noranda Volcanic Pile, Noranda, Quebec, Unpublished Ph. D. Thesis, *University of Toronto*, 116 pages.

——— (1985): Shoshonites and Associated Rocks of Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 426-442.

Drysdale, C.W. (1917): Ymir Mining Camp, British Columbia, *Geological Survey of Canada*, Memoir 94, 175 pages.

Fitzpatrick, M. (1985): The Geology of the Rossland Group in the Beaver Valley Area, Southeastern British Columbia, Unpublished M.Sc. Thesis, *University of Calgary*, 150 pages.

Frebold, H. and Little, H.W. (1962): Paleontology, Stratigraphy, and Structure of the Jurassic Rocks in Salmo Map-area, British Columbia, *Geological Survey of Canada*, Bulletin 81.

Frebold, H. and Tipper, H.W. (1970): Status of the Jurassic in the Canadian Cordillera of British Columbia, Alberta, and Southern Yukon, *Canadian Journal of Earth Sciences*, Volume 7, Number 1, pages 1-20.

Fyles, J.T. (1984): Geological Setting of the Rossland Mining Camp, *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Bulletin 74, 61 pages.

Gill, J.B. (1970): Geochemistry of Viti Levu and its Evolution as an Island Arc, *Contributions to Mineralogy and Petrology*, Volume 27, pages 179-203.

Gill, J.B. (1981): Orogenic Andesites and Plate Tectonics, *Springer-Verlag*, New York, 390p.

Ghosh, D.K. (1986): Geochemistry of the Nelson-Rossland Area, Southeastern British Columbia, Unpublished Ph.D. Thesis, *University of Alberta*.

Höy, T. and Andrew, K. (1988): Preliminary Geology and Geochemistry of the Elise Formation, Rossland Group, between Nelson and Ymir, Southeastern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 19-30.

Joplin, C.A. (1968): The Shoshonite Association: A Review, *Geological Society of Australia*, Volume 15, pages 274, 275.

Kuno, H. (1966): Lateral Variation of Basalt Magma Types Across Continental Margins and Island Arcs, *Bulletin of Volcanology*, Volume 29, pages 195-222.

Little, H.W. (1960): Nelson Map-area, West-half, British Columbia, *Geological Survey of Canada*, Memoir 308, 205 pages.

——— (1964): Geology, Ymir Map-area, British Columbia, *Geological Survey of Canada*, Map 1144A.

——— (1982a): Geology, Bonnington Map-area, British Columbia, *Geological Survey of Canada*, Map 1571A.

——— (1982b): Geology, Rossland-Trail Map-area, British Columbia, *Geological Survey of Canada*, Paper 79-26, 38 pages.

Mackenzie, D.E. and Chappell, B.W. (1972): Shoshonitic and Calc-alkaline Lavas from the Highlands of Papua, New Guinea, *Contributions to Mineralogy and Petrology*, Volume 35, pages 50-62.

McAllister, A.L. (1951): Ymir Map-area, British Columbia, *Geological Survey of Canada*, Paper 51-4, 58 pages.

Monger, J.W.H., Price, R.A. and Templeman-Kluit, D.J. (1982): Tectonic Accretion and the Origin of the Two Major Metamorphic and Plutonic Welts in the Canadian Cordillera, *Geology*, Volume 10, pages 70-75.

Mulligan, R. (1952): Bonnington Map-area, British Columbia, *Geological Survey of Canada*, Paper 52-13, 37 pages.

Parrish, R. (1984): Slocan Lake Fault: A Low Angle Fault Zone Bounding the Valhalla Gneiss Complex, Nelson Map-area, Southern British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 84-1A, pages 323-330.

Ray, G.E. and de Rosen-Spence A. (1986): The Potassium-rich Volcanic Rocks at Tillicum Mountain–Their Geochemistry, Origin, and Regional Significance, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 45-49.

Shervais, J.W. (1982): Ti-V plots and the Petrogenesis of Modern and Ophiolitic Lavas, *Earth and Planetary Science Letters*, Volume 59, pages 101-118.

Simony, P.S. (1979): Pre-Carboniferous Basement near Trail, British Columbia, *Canadian Journal of Earth Sciences*, Volume 16, Number 1, pages 1-11.

Tipper, H.W. (1984): The Age of the Jurassic Rossland Group of Southeastern British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 84-1A, pages 631-632.

Winchester, J.A. and Floyd, P.A. (1977): Geochemical Discrimination of Different Magma Series and their Differentiation Products using Immobile Elements, *Chemical Geology*, Volume 20, pages 325-343.

NOTES

Sm/Nd Geochronology of the Moyie Intrusions, Moyie Lake Map Area, British Columbia (82G/5)

By R.A. Burwash and P.A. Wagner, University of Alberta, Edmonton

KEYWORDS: Geochronology, Moyie intrusions, samarium, neodymium, East Kootenay, Purcell Supergroup.

INTRODUCTION

Middle Proterozoic basaltic magmatism in the East Kootenay area marks a period of crustal instability in the Belt-Purcell basin. Uranium-lead dating of zircons from the Lumberton sill, north of Moyie Lake (Höy, 1988), gives a time of crystallization of 1445 ± 10 Ma. Zartman *et al.* (1982) reported a uranium-lead zircon age from the Crossport sill in Idaho of 1433 ± 13, a number within the analytical error of the age reported by Höy. The object of our program is to confirm these dates with a samarium-neodymium isochron. Samarium-neodymium analyses also provide data on the nature of the mantle at the time of intrusion and the evolution of the magma prior to crystallization.

The geochronology of the Purcell Supergroup has been the subject of study at the University of Alberta for many years. Potassium-argon dating of biotite and hornblende separates from the Moyie intrusions gave values ranging from 670 to 1580 Ma (Hunt, 1962). The wide spectrum was attributed to a combination of argon loss from biotite during Phanerozoic thermal events and excess argon incorporated into hornblende at the time of intrusion of the sills. A cluster of values near 1100 Ma was inferred to be the probable age of the sills.

In 1983, the authors sampled a sill within the Siyeh Formation at Lake Alderson in Waterton Park for rubidium-strontium dating. The data were inconclusive, with inferred limits of 1320 and 1665 Ma (Harrison, 1984). Assimilation of the country rock probably caused the scatter of data points.

Samarium-neodymium model ages for metasedimentary rocks of the Purcell Supergroup are close to 2.0 Ga (Frost and O'Nions, 1984). The underlying crystalline basement (Frost and Burwash, 1986) and overlying Windermere Supergroup (Burwash *et al.* 1988) give older samarium-neodymium model ages.

During the Lake Alderson fieldwork, a brief visit was made to sample the Lumberton sill. Preliminary isotopic analyses by Wagner in 1987 suggested that the range of $^{143}Nd/^{144}Nd$ ratios was sufficiently wide for a samarium-neodymium isochron to be attempted; the current study is the result.

FIELDWORK

A thick sill of Moyie metagabbro is exposed intermittently for almost half a kilometre in a series of railway cuts along British Columbia Highway 3, 18 kilometres south of the Cranbrook Canadian Pacific Railway station. Grain size and textural variations make this a regular stop on student field excursions, with samples also taken for teaching collections.

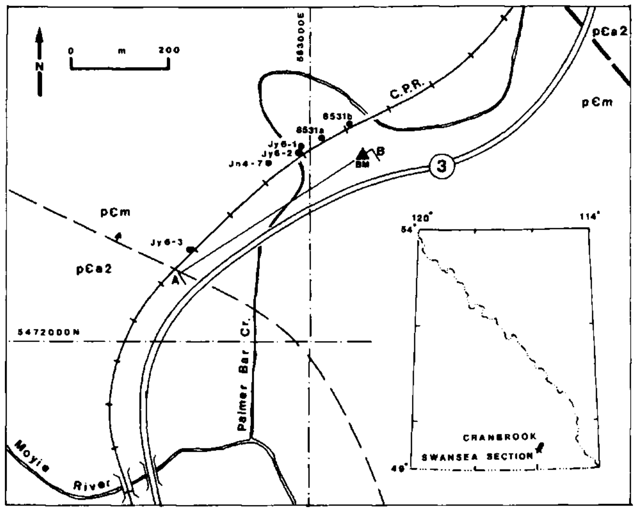


Figure 1-5-1. Location of samples used for Sm-Nd dating of Lumberton sill, Swansea section. Based on Energy, Mines and Resources Canada (1984) and Höy and Diakow (1982). BM is Bench Mark 85 CO 42; pC a2–Middle Aldridge, pC m–Moyie intrusions.

The presence of a felsic pegmatitic phase of the Moyie intrusion in these railway cuts led to resampling in 1983. The section was designated "Swansea section" from the abandoned railway siding 1.6 kilometres north of the base of the sill (Energy, Mines and Resources Canada, 1984; Höy and Diakow, 1982).

Fieldwork in 1988 was aimed primarily at finding a mafic-rich differentiated phase of the sill which could be used to extend the range of $^{147}Sm/^{144}Nd$ values away from the felsic pegmatites. To this end, particular attention was paid to the basal portions of the sill exposed on both sides of Palmer Bar Creek (Figure 1-5-1). Samples Jn 4-1 to Jn 4-7 are from outcrops outside the blasted railway cuts. Criteria for selection were that the rock showed limited fracturing and no visible weathering. Accurate estimation of mafic content proved difficult in the field due to variation in the degree of deuteric alteration of hornblende to epidote and chlorite. Thin-section studies subsequently indicated the presence of significant amounts of fine-grained biotite as well. From the outcrop and thin-section observation it was concluded that:

The samples which cluster close together in Figure 1-5-3 (8531a, 8531b and Jy 6-3) give model ages of 1.43, 1.44 and 1.45 Ga respectively. Their average value is concordant with the zircon date. The concept of neodymium-samarium model ages implies that these three analysed samples represent material derived from the mantle at 1.44 Ga. Furthermore, the source had a composition which had not been depleted in samarium and neodymium, but conformed to the CHUR model of mantle evolution. The E values near zero reflect a mantle which has not lost material to sialic crustal differentiates.

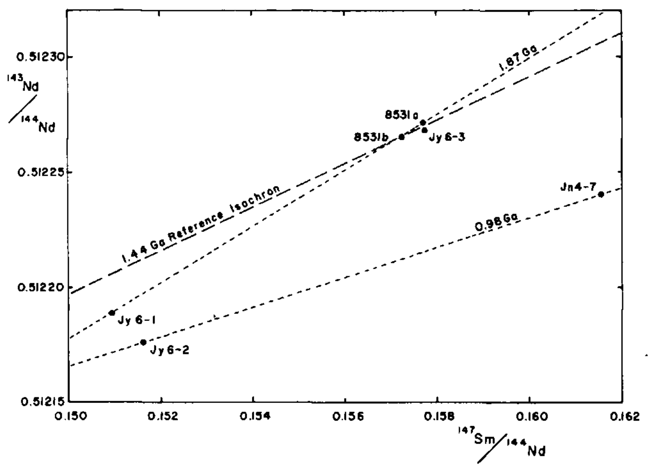


Figure 1-5-3. Sm-Nd analyses plotted on $^{143}Nd/^{144}Nd$ vs $^{147}Sm/^{144}Nd$. Four samples give an apparent age of 1.87 Ga. The two remaining samples lie on a 0.98 Ga line. A reference isochron through the clustered points suggests assimilation of country rock by magma for three samples below this line.

With respect to the cross-section of the sill (Figure 1-5-2), the three points which cluster on the isochron plot represent the two samples closest to the top of the sill and the sample closest to the base. When a reference isochron for 1.44 Ga is plotted through this cluster it is apparent that the three other points must have crystallized from melts with lower $^{143}Nd/^{144}Nd$ ratios or from the same melt with contamination. The T^{CHUR} values and small negative ϵ^{1440} CHUR values support assimilation of older crustal material.

When a pegmatitic phase was observed in the section of the Lumberton sill it was assumed that it represented a magmatic differentiate. This idea was strengthened by the abundance of granophyre in thin section. An anomaly is evident in Table 1-5-2: the two pegmatitic samples Jy 6-1 and Jy 6-2 have the highest neodymium and samarium contents. Normally felsic differentiates have lower contents of these elements than their parent magma as the rare earths are concentrated in the mafic minerals. This anomaly, coupled with the T^{CHUR} and ϵ^{1440} CHUR values seems to confirm that samples Jy 6-1 and Jy 6-2 are not differentiates but are the result of assimilation of older felsic material. The most obvious candidate is the siltstone of the enclosing Aldridge Formation. The augmented samarium and neodymium may be from the argillite units.

Interpretation of the petrogenesis of sample Jn 4-7 remains uncertain. Its neodymium and samarium bulk composition falls within the range of the samples with T^{CHUR} values near 1.44 Ga, yet it has a distinctly higher T^{CHUR} of 1.72 Ga. None of our field observations indicate a multiple rather than simple mode of intrusion for the Lumberton sill. If Jn 4-7, in fact, represents a separate injection of magma after the main body of the sill was in place, this late magma might have assimilated mafic material from the base of the crystalline basement ($T^{CHUR} \equiv 2.8$ Ga) during its assent. Much more work would be required to substantiate this hypothesis.

CONCLUSIONS

Samarium-neodymium model ages confirm the uranium-lead zircon date of the intrusion of the Lumberton sill at 1440 ± 10 Ma. The six samples analysed, representing the full range of textural, mineralogical and spatial variables in the sill, did not define a valid isochron. Three samples which cluster on the $^{143}Nd/^{144}Nd$ versus $^{147}Sm/^{144}Nd$ plot have almost identical model ages; 1.43, 1.44 and 1.45 Ga. Isotopically, they also represent a mantle source for this magma which had not been depleted in samarium and neodymium prior to 1440 Ma.

A lens of pegmatitic material, inferred from field observations to be a magmatic differentiate, is proved by isotopic data to be the result of assimilation of the enclosing strata. A single anomalous point, with a crustal residence age of 1.72 Ga, may be a late injection of melt which assimilated crystalline basement.

ACKNOWLEDGMENTS

This project was supported by grants to R.A. Burwash from the National Sciences and Engineering Research Council and the British Columbia Ministry of Energy, Mines and Petroleum Resources. Laboratory facilities were provided by G.L. Cumming, Department of Physics, University of Alberta. Brock M. Burwash contributed greatly to the efficiency of sample collection, and R.W. Burwash provided technical and editorial help.

REFERENCES

Burwash, R.A., Krupicka, J., Basu, A.R. and Wagner, P.A. (1985): Resetting of Nd and Sr Whole-rock Isochrons from Polymetamorphic Granulites, Northeastern Alberta, *Canadian Journal of Earth Sciences*, Volume 22, No.7, pages 992-1000.

Burwash, R.A., Cavell, P.A. and Burwash, E.J. (1988): Source Terranes for Proterozoic Sedimentary Rocks in Southern British Columbia: Nd Isotopic and Petrographic Evidence, *Canadian Journal of Earth Sciences*, Volume 25, pages 824-832.

DePaolo, D.J. (1978): Study of Magma Sources, Mantle Structure and the Differentiation of the Earth from Variations of $^{143}Nd/^{144}Nd$ in Igneous Rocks. Unpublished Ph.D. thesis, *California Institute of Technology*, Pasedena.

Energy, Mines and Resources Canada (1984): Moyie Lake, British Columbia, 1:50 000, Edition 3.

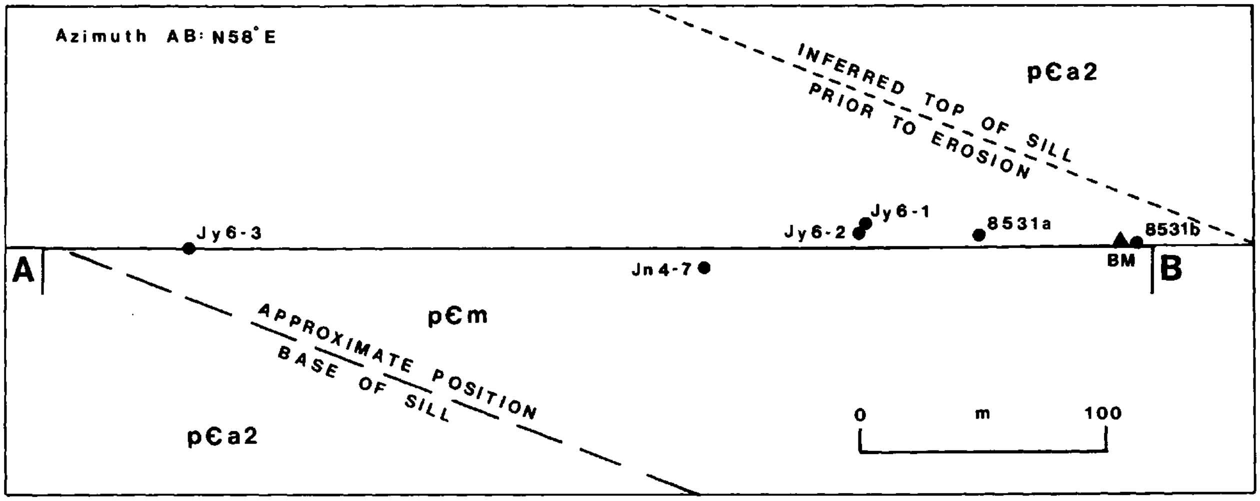


Figure 1-5-2. Cross-section of Swansea section of Lumberton sill ("D" sill of Höy and Daikow, 1982). Relative stratigraphic position of dated samples projected onto AB through Bench Mark 85 CO 42. C.P.R. line is datum.

(1) we had not succeeded in finding a mafic differentiate formed by gravitational settling, analogous to that in the Palisade sill, New Jersey (Walker, 1940).

(2) the samples from near the base of the sill showed evidence of assimilation of argillite from the enclosing Aldridge Formation, expressed by increased biotite content.

Sample Jn 4-7 was collected from the topographic depression below the railway embankment and corresponded closely to the mid-point of the sill section (Figure 1-5-2). In subsequent thin-section studies of samples from the Swansea section, it showed the least evidence of deuteric alteration and was therefore added to the suite for samarium-neodymium analysis. Brief petrographic data for the dated samples shown on the cross-section of the sill (Figure 1-5-2) are given in Table 1-5-1.

ANALYTICAL METHODS

Hand specimens were cleaned, crushed and pulverized to −200 mesh. One gram splits were tumbled for 24 hours and divided into two fractions, one for ^{144}Nd/^{143}Nd initial isotopic ratio (IR) measurement and the other for the determination of the samarium and neodymium concentrations (ID).

IR samples were decomposed according to the method used by Wagner (1982) and the ID samples using standard teflon bomb teohniques. Samarium and neodymiun separation, isolation and purification was accomplished using a modified version of the process used by DePaolo (1978).

Individual rare-earths were converted to perchlorate form, dissolved in water and loaded onto the side filament of a double Rhenium filament assembly and analysed in a fully automated Aldermaston VG 354 mass spectrometer operating in a multi-collection configuration. Data are presented in Table 1-5-2.

INTERPRETATION

Data in Table 1-5-2 show the isotopic ratios of ^{143}Nd/^{144}Nd and ^{147}Sm/^{144}Nd are confined to a limited range, despite a moderate range in total neodymium and samarium concentrations. The attempt to define an isochron failed, mainly because of the limited ranges of isotopic ratios, but also because of the scatter of points (Figure 1-5-3). A best-fit line through three points gives 1.87 Ga, a value which does not agree with the uranium-lead zircon discordia date.

The scatter of points is well beyond analytical error and must reflect some geologic factors. Clues to these are evident in the model ages (T^{CHUR}) and values of E^{CHUR} calculated for a time of 1440 Ma. The value of 1440 Ma is chosen to accommodate the data of Zartman *et al.* (1982) as well as that of Höy (1988).

TABLE 1-5-1
LITHOLOGY OF ANALYSED SAMPLES

Sample Number	Height Above Base of Sill	Texture	Grain Size (average)	Colour Index
Jy 6-3	20 m	Diabasic	1.5 mm	65
Jn 4-7	90	Diabasic	1	55
Jy 6-2	125	Pegmatitic	4	35
Jy 6-1	130	Pegmatitic	6	35
8531a	140	Diabasic	3	50
8531b	160	Diabasic	1	55

TABLE 1-5-2
ISOTOPIC ANALYTICAL DATA

Sample I.D.	^{143}Nd/^{144}Nda	^{147}Sm/^{144}Nda	Nd ppm	Sm ppm	CHURb	CHURb
RAB 83Jy6-1	0.512188	0.150941	19.508	4.8761	1.50	−0.41
RAB 83Jy6-2	0.512176	0.151610	30.212	7.5849	1.56	−0.77
RAB 83Jy6-3	0.512268	0.157745	7.1469	1.8669	1.45	−0.10
UA 8531a	0.512271	0.157718	9.4267	2.4620	1.43	−0.11
UA 8531b	0.512265	0.157246	8.1590	2.1246	1.44	−0.06
RAB 88Jn4-7	0.512240	0.161559	7.5500	2.0199	1.72	−0.34

a: Ratios are normalized to ^{146}Nd/^{144}Nd = 0.7219: estimated error in ^{143}Nd/^{144}Nd ±.000012 (2); in ^{147}Sm/^{144}Nd ±.00008 (2).

b: Bulk Earth parameters used for calculation are: ^{143}Nd/^{144}Ndchur(0) = 0.512638; ^{147}Sm/^{144}Ndchur = 0.1967. References for methods of calculation are given by Burwash *et al.*, 1985.

Frost, C.D. and Burwash, R.A. (1986): Nd Evidence for Extensive Archean Basement in the Western Churchill Province, Canada, *Canadian Journal of Earth Sciences*, Volume 23, pages 1433-1437.

Frost, C.D. and O'Nions, R.K. (1984): Nd Evidence for Proterozoic Crustal Development in the Belt-Purcell Supergroup, *Nature (London)*, Volume 312, pages 53-56.

Harrison, J.E. (1984): Session on Geochronology and Geophysics, Summary; *in* The Belt, *Montana Bureau of Mines and Geology*, Special Publication 90, pages 87-100.

Höy, T. and Diakow, L. (1982): Geology of the Moyie Lake Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 49.

Höy, T. (1988): Early Tectonic and Magmatic Evolution of the Middle Proterozoic Purcell Basin, Southeastern Canadian Cordillera, *Geological Association of Canada*, Pacific Margin Section, Abstract, March 1988.

Hunt, G. (1962): Time of Purcell Eruption in Southeastern British Columbia, *Journal of the Alberta Society of Petroleum Geologists*, Volume 10, pages 438-442.

Wagner, P.A. (1982): Geochronology of the Ameralik Dykes at Isua, West Greenland. Unpublished M.Sc. thesis, *University of Alberta*, Edmonton, 79 pages.

Walker, F. (1940): Differentiation of the Palisade Diabase, New Jersey, *Geological Society of America* Bulletin, Volume 51, pages 1059-1106.

Zartman, R.E., Peterman, Z.E., Obradovich, J.D., Gallego, M.D. and Bishop, D.T. (1982): Age of the Crossport C Sill near Eastport, Idaho, in *Society of Economic Geologists*, Coer d'Alene Field Conference, R.R. Reid and G.A. Williams, Editors, *Idaho Bureau of Mines and Geology*, Bulletin 24, pages 61-69.

GEOLOGY OF THE WEST MARGIN OF THE SHUSWAP TERRANE NEAR SICAMOUS IMPLICATIONS FOR TERTIARY EXTENSIONAL TECTONICS (82L, M)

By B.J. Johnson
Carleton University and Ottawa-Carleton Geoscience Centre

KEYWORDS: Regional geology, Shuswap terrane, Eagle River fault, Hunters Range, structural cross-section, extensional tectonics.

INTRODUCTION

Recent field and geochronological investigations, in conjunction with LITHOPROBE seismic surveys, have led to the recognition of crustal-scale, low to moderate-angle, Eocene extensional faults and shear zones in the southern Omineca Belt. The present study focuses on documentation of the Eagle River fault, an extensional shear zone that delineates the western boundary of the Shuswap metamorphic terrane (Figure 1-6-1). The geometry and the tectonic history of the Eagle river fault place important constraints on crustal cross-sections through the southern Omineca Belt.

The Shuswap terrane consists of polydeformed rocks that have been metamorphosed in the sillimanite zone of the amphibolite facies. The western margin of the Shuswap terrane is a sharp metamorphic discontinuity, for which various interpretations have been offered. Jones (1959) mapped the boundary as a high-angle fault. Campbell (1971) documented closely spaced isograds, but no fault. Okulitch (1979) showed the boundary between rocks of contrasting metamorphic grade to be cut locally by high-angle faults. Fyson (1970) suggested that the high-grade rocks of the Shuswap terrane formed as a hot metamorphic infrastructure, separated from cold, brittly deformed upper-crustal rocks by a steep geothermal gradient. A detailed study of the structure and metamorphism in the Mara Lake area by Nielsen (1978, 1982) seemed to support the hypothesis of a steep metamorphic gradient with no major structural break.

These studies were completed before the concept of crustal-scale, low-angle normal faults, for example, Wernicke (1981), had gained much attention. More recently, low-angle normal faults have been documented in the Columbia River valley (Read and Brown, 1981; Lane, 1984), the Okanagan Valley (Bardoux, 1985; Parkinson, 1985a, 1985b; Parrish *et al.*, 1985; Templeman-Kluit and Parkinson, 1986), and on both east and west flanks of the Valhalla Complex (Parrish, 1984; Carr, 1986; Carr *et al.*, 1987) (Figure 1-6-1).

Uranium-lead zircon ages of synkinematic granites (Solberg, 1976; Carr *et al.*, 1987; Parrish *et al.*, 1988) have established Eocene histories of ductile shearing and subsequent brittle deformation in each of these fault zones. Potassium-argon mineral dates consistently record an early Tertiary thermal history in the high-grade footwall rocks, whereas the low-grade, brittly deformed hangingwall rocks preserve Mesozoic cooling ages (*see* Parrish *et al.*, 1988, for a summary).

The present investigation was prompted by reconnaissance mapping by Journeay and Brown (1986) which led to the discovery of mylonites in the Eagle River valley near Sicamous.

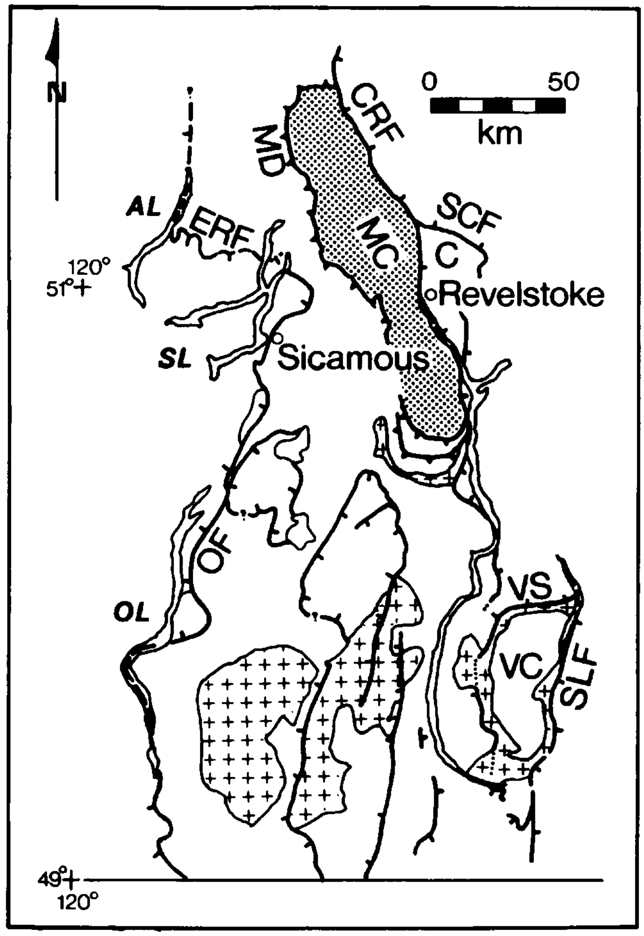


Figure 1-6-1. Tectonic map of the southern Omineca Belt, modified after Parrish *et al.* (1988). C: Clachnacuddain allochthon; **CRF**: Columbia River fault; **ERF**: Eagle River fault; **MC**: Monashee Complex; **MD:** Monashee décollement; **OF**: Okanagan fault; **SCF**: Standfast Creek fault; **SLF**: Slocan Lake fault; **VC**: Valhalla Complex; **VS**: Valkyr shear zone; **AL**: Adams Lake; **OL**: Okanagan Lake; **SL**: Shuswap Lake.

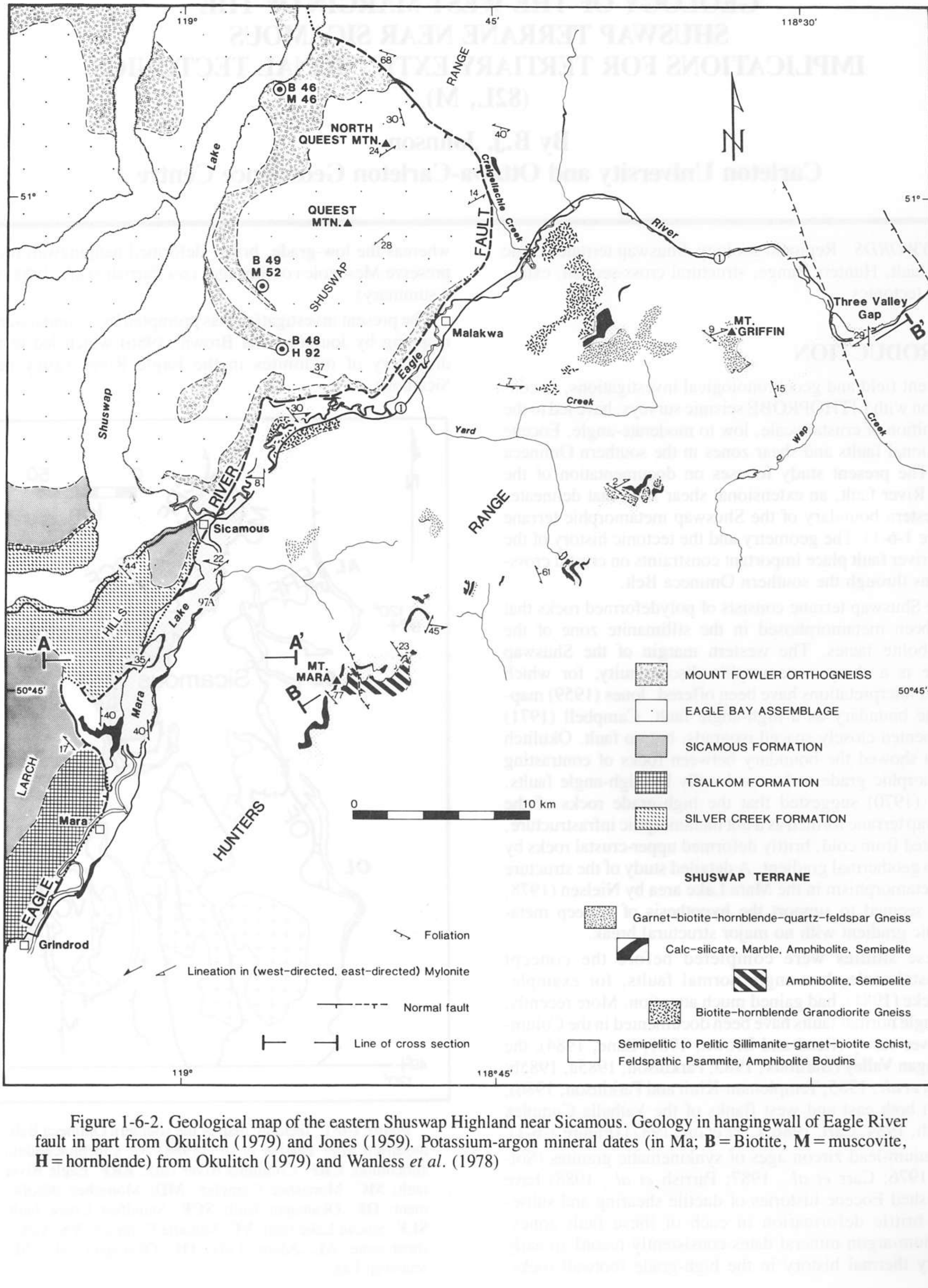


Figure 1-6-2. Geological map of the eastern Shuswap Highland near Sicamous. Geology in hangingwall of Eagle River fault in part from Okulitch (1979) and Jones (1959). Potassium-argon mineral dates (in Ma; **B** = Biotite, **M** = muscovite, **H** = hornblende) from Okulitch (1979) and Wanless *et al.* (1978)

EAGLE RIVER FAULT

The Eagle River fault (Journeay and Brown, 1986) is a ductile-brittle normal fault that juxtaposes low to medium-grade metamorphic rocks of the Mount Ida Group (Jones, 1959) against migmatitic paragneiss of the Shuswap terrane (Figure 1-6-2). Mylonites in the immediate footwall exhibit C/S fabrics, rotated feldspar porphyroclasts with asymmetric recrystallized tails, and shear bands that consistently indicate relative westward movement of the upper plate.

Shear fabrics in mylonites near Sicamous and along the east side of Mara Lake are defined by garnet-biotite-sillimanite-potassium-feldspar assemblages. Sillimanite and quartz-feldspar aggregates define a strong west-trending stretching lineation. Some discrete shears contain retrograde chlorite after biotite, and local cataclastic zones display slickensides with west-directed chlorite fibre lineations subparallel to the stretching lineation. About 150 metres beneath the projected position of the brittle detachment on the west side of Mara Lake, retrograded west-verging mylonites exhibit slickensided shear planes, spaced about 2 millimetres apart, defined by chlorite and relict sillimanite.

These field relationships are consistent with models for mid-crustal extensional simple shear zones, for example, Davis, 1983; Davis *et al.*, 1986), which predict that footwall mylonites quenched at high metamorphic grade are overprinted by lower grade metamorphism, and eventually brittle shears, during uplift through the brittle-ductile transition zone in the crust.

Calc-silicate and amphibolite rocks in the Larch Hills near the southwest end of Mara Lake were inferred to be correlative with similar rocks on the east side of the lake by Nielsen (1978). These rocks are probably part of the footwall of the Eagle River fault, exposed in a small antiformal culmination. South of the Mara Lake, the fault trace follows the Shuswap River beyond Grindrod, and probably merges with the Okanagan Valley fault as suggested by Journeay and Brown (1986).

Northeast of Sicamous, the fault trace parallels the Eagle River valley as far as Craigellachie Creek, where it turns northwestward. On a logging road near North Queest Mountain, fractured and weathered sillimanite-biotite-muscovite schist of the footwall is separated from hangingwall granitoid gneiss of the Mount Fowler batholith by 50 metres of cataclasite and clay gouge. Unfoliated to weakly foliated pegmatite intrudes both the footwall and hangingwall, and is intensely fractured and weathered within the fault zone. The fault zone and foliation in the footwall rocks dip about 55 degrees southwest.

Continuity of the Eagle River fault between Craigellachie Creek and Adams Lake is inferred on the basis of the close spacing of garnet and sillimanite isograds mapped by Campbell (1971). Its position is approximated in Figure 1-6-1 by the margin of the Shuswap terrane as mapped by Okulitch (1979), modified slightly to agree with new mapping. Near the east shore of Adams Lake, chloritic phyllites of the Eagle Bay assemblage are exposed within 200 metres of coarse-grained biotite-muscovite schists, which are crossed by the sillimanite isograd about 5 kilometres away. Retrograded sillimanite migmatites near the mouth of Momich River, 8 kilometres from the north end of Adams Lake, display intense west-directed C/S fabrics and westerly rotated feldspar porphyroclasts.

Potassium-argon geochronolocal studies of biotite from Devonian and Cretaceous plutons in the hangingwall west of Adams Lake indicate Cretaceous cooling ages (Wanless *et al.*, 1966; Campbell and Tipper, 1971; Belik, 1974; Okulitch, 1979; Jung, 1986). In hangingwall plutons west of Craigellachie Creek, biotite and muscovite potassium-argon dates are mid-Eocene (Wanless *et al.*, 1978; Okulitch, 1979), whereas Mount Fowler orthogeniss southwest of Queest Mountain has yielded a Cretaceous hornblende date (Okulitch, 1979) (Figure 1-6-2). The mica dates suggest the hangingwall of the Eagle River fault near Craigellachie Creek did not cool below 280 to 350°C until the mid-Eocene, based on closure temperatures of radiogenic argon in biotite (Harrison *et al.*, 1985) and muscovite (Purdy and Jäger, 1976; Wagner *et al.*, 1977). West of Adams Lake, these systems must have closed in the Cretaceous.

FOOTWALL GEOLOGY

STRATIGRAPHY

The structural panel between the Eagle River fault and the Monashee décollement (Figure 1-6-1) consists mainly of quartzofeldspathic gneiss and leucopegmatite. The pegmatite forms condordant sheets and undeformed, discordant dykes; although its age has yet to be determined, much of it is probably related to the Eocene Ladybird suite (*see* Parrish *et al.*, 1988). For the most part, exposure is sparse and stratigraphic control is poor, although stratigraphic successions have been mapped on the highest ridges of the Hunters Range, south of the Trans-Canada Highway (Figure 1-6-2). Similarity between successions on different ridges has enabled tentative correlation of a kilometre-thick section of metasedimentary and metavolcanic strata to be made across the Hunters Range. These correlations are compatible with the available structural data. If they are correct, then the rocks along the Trans-Canada Highway between Three Valley Gap and Sicamous constitute a mildly folded succession no more than 2 kilometres thick, within which there are no major structural breaks (Figure 1-6-3).

The metasedimentary/metavolcanic succession consists of semipelitic units separated by distinctive amphibolite, calc-silicate and hornblende gneiss (Figure 1-6-2). The semipelitic units include interlayered garnet-biotite semipelite and psammite, pelitic garnet-biotite-sillimanite schist, and a few layers of quartzite up to 50 centimetres thick. Boudins of amphibolite and hornblende gneiss up to 15 metres across are spectacularly exposed in semipelite along the Trans-Canada Highway at Three Valley Gap and on ridges near Mount Mara. The semipelitic units commonly contain over 50 per cent pegmatite by volume.

A distinctive amphibolite unit is about 100 metres thick at Mount Mara. The amphibolite is composed of alternate layers of biotite-hornblende ± garnet and diopside-plagioclase, and is interlayered with semipelites. Semipelite above the amphibolite unit is in turn structurally overlain by a succession, up to 50 metres thick, of diopsidic calc-silicate gneiss diopside-plagioclase-hornblende amphibolite, marble

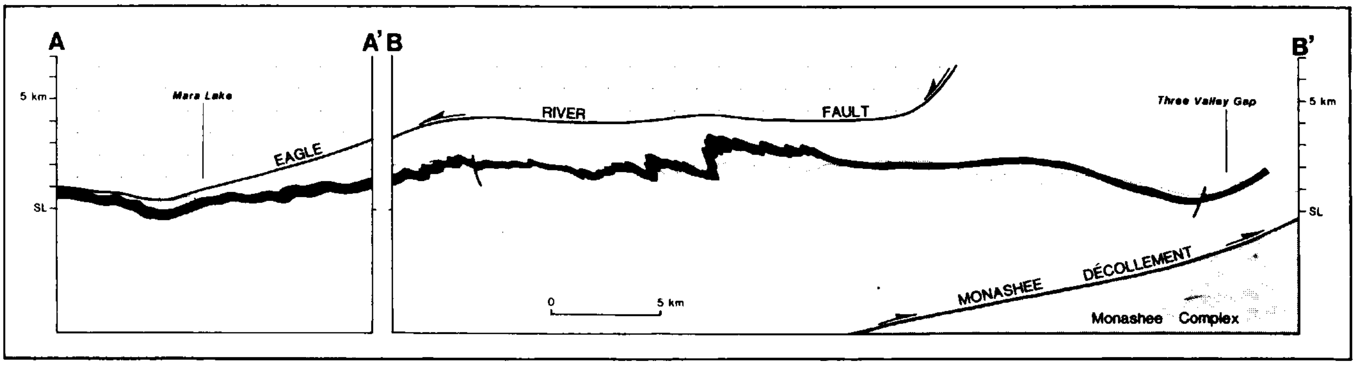


Figure 1-6-3. Composite structural cross-section through the Hunters Range between Sicamous and Three Valley Gap. Top of heavy black line beneath Eagle River fault represents top of calc-silicate unit described in text.

and semipelite. another semipelite unit separates the calc-silicate unit from garnet-biotite-hornblende-quartz-feldspar gneiss which caps Mount Griffin and ridges north and south of Yard Creek. This gneiss forms the structurally highest unit, contrary to a previous report that it lay structurally beneath rocks south of Yard Creek and at Mount Mara (Johnson, 1988). Biotite-hornblende granodiorite gneiss, containing rare interlayered paragneiss, is exposed on the northwestern slopes of Mount Griffin and along the Trans-Canada Highway southwest of Craigellachie.

Ages and stratigraphic facing of footwall rocks are unknown, but the semipelitic units with amphibolite boudins are probably correlative with monotonous semipelite-amphibolite successions of the Late Proterozoic Horsethief Creek Goup in the Kootenay Arc.

STRUCTURE

Compositional layering and subparallel penetrative foliation are deformed on mesoscopic scales by tight to isoclinal, generally southward-verging folds (F_2). Hinges of these folds are nearly parallel to an east-northeast-trending stretching lineation defined by aligned inequant minerals and mineral aggregates. A younger set of upright to overturned, west-verging inclined folds (F_3) deforms the early folds and the stretching lineation. These folds typically are open, although minor folds in pelites are close to tight and are chevron shaped. Discrete west-directed shears locally cut F_3 folds, and hence the folds may be as young as Eocene.

Mylonitic pegmatites in the northeastern part of the Hunters Range exhibit asymmetric feldspar porphyroclasts and shear bands indicative of east-directed shear. These fabrics are presumably older than the non-annealed, chlorite-grade, west-directed sheares of probable Tertiary age that cut pelitic rocks in the same area. The east-directed mylonites and F_2 folds are inferred to be Mesozoic (or Paleocene) compressional structures. East-northeast-trending stretching lineations may be analogous to similarly oriented lineations of compressional origin associated with the Monashee décollement (Journeay, 1986; Journeay and Brown, 1986). Stretching lineations that are clearly related to west-directed ductile shearing in the Eagle River fault zone have more easterly trends (Figure 1-6-2). Both sets of lineations formed in the sillimanite zone.

HANGINGWALL GEOLOGY

STRATIGRAPHY

The hangingwall of the Eagle River fault contains low to medium-grade metasedimentary and metavolcanic strata of the Mount Ida Group (Jones, 1959), which is represented by four stratigraphic packages. The most completely studied of these packages is the Eagle Bay assemblage, which comprises micaceous quartzite, mica schist, graphitic and chloritic phyllite, marble and metavolcanic rocks. Archaeocyathids indicate a Cambrian age for the marble, and other rocks of the assemblage have been dated as Devono-Mississippian, making correlation with the Badshot Formation and Lardeau Group of the Kootenay Arc likely (Schiarizza and Preto, 1987). Quartz-muscovite sehist and quartzite of the Silver Creek Formation are presumably of Cambro-Ordovician age and may be equivalent to part of either the Lardeau Goup (Okulitch, 1979) or the Hamill Goup. The Tsalkom Formation consists of discontinuous greenstones of unknown age. It is overlain by phyllitic marble and caieareous phyllite of the Sicamous Formation. Campbell and Okulitch (1973) inferred the Sicamous Formation to be of Triassic age but the rocks closely resemble marble and phyllite of the Eagle Bay assemblage and are probably early Paleozoic (Preto and Schiarizza, 1985; A.V. Okulitch, personal communication, 1986). The Silver Creek, Tsalkom and Sicamous formations each have lithological equivalents within the Eagle Bay assemblage and therefore probably all are correlative with Kootenay Arc strata.

The Mount Ida Group is intruded by Devonian orthogneiss of the Mount Fowler batholith and by the Cretaceous Baldy and Raft batholiths. Eocene volcanic rocks unconformably overlie the older rocks.

STRUCTURE AND METAMORPHISM

All rocks of the Mount Ida Goup exhibit a strong foliation, which is deformed by early north to east-northeast-trending folds (Okulitch, 1979). Later northwest-trending folds and crenulations with steeply dipping axial planes formed in conjunction with southeast-directed thrusting and metamorphism in the Late Jurassic and Early Cretaceous

(Schiarizza and Preto, 1987). Metamorphic grade ranges between the chlorite and (near North Queest Mountain) staurolite zones.

STRUCTURAL CROSS-SECTION

Figure 1-6-3 shows a cross-section through the Hunters Range between Three Valley Gap and Mara Lake. Precambrian basement gneisses and mantling metasedimentary strata of the Monashee Complex (Read and Brown, 1981) form the lowermost of three tectonic panels, separated from the overlying Shuswap terrane by the Monashee décollement. The Monashee décollement, an exhumed mid-crustal shear zone, was the locus of Middle Jurassic compressional shearing and large-scale east-directed overthrusting culminating in the Late Cretaceous or Paleocene (Journeay, 1986; Brown and Journeay, 1987). The position of the décollement in the section is based on Brown and Journeay (1987).

The Shuswap terrane forms the middle panel, between the Monashee décollement and the Eagle River fault. The heavy black line near the topographic surface is a first-order approximation of the form surface defined by the stratigraphic sucession described earlier. The top of this line corresponds to the calc-silicate unit and is constrained by down-plunge projections. The thickness of the line is partly schematic, but it corresponds to the base of the thick amphibolite unit where it can be constrained. The position of the Eagle River fault, which forms the "lid" to this middle panel, is estimated from apparent dips of the fault in the Eagle River valley, north of the section.

Relationships that are readily apparent from Figure 1-6-3 are: (1) the panel of Shuswap terrane between the Monashee décollement and the Eagle River fault is weakly to mildly folded, and apparently contains no major structural breaks; (2) the Monashee décollement ramps upward in the direction of transport, cutting up-section in its hangingwall; (3) the Eagle River fault cuts down-section in its footwall. The geometry of the Eagle River fault bears a striking similarity to the arched profile of a mature detachment terrane that has rebounded isostatically in response to denudation (*see* Wernicke, 1985, Figure 3d). The validity of this section awaits testing by the LITHOPROBE project.

ACKNOWLEDGMENTS

Fieldwork was supported by British Columbia Geoscience Research Grant RG88-02, and by a LITHOPROBE Supporting Geoscience Grant and Natural Sciences and Engineering Research Council operating grant A2693 to R.L. Brown. This paper is LITHOPROBE Contribution No. 87. Lise Bender assisted me faithfully in the field and with Meg Coleman, helped with some of the drafting of figures for this report. Dick Brown, Sharon Carr, Vicki Coleman and Andrew Okulitch have shared numerous ideas and observations.

REFERENCES

Bardoux, M. (1985): The Kelowna Detachment Zone, Okanagan Valley, South-central British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 85-1A, pages 333-339.

Belik, G. (1974): Geology of the Harper Creek Copper Deposit, Unpublished M.Sc. Thesis, *The University of British Columbia*.

Brown, R.L. and Journeay, J.M. (1987): Tectonic Denudation of the Shuswap Metamorphic Terrane of Southeastern British Columbia, *Geology*, Volume 15, pages 142-146.

Campbell, R.B. (1971): Geological Map of Part of the Southeastern Cordillera, *in* Structural Style of the Southern Canadian Cordillera, J.O. Wheeler, R.B. Campbell, J.E. Reesor and E.W. Mountjoy, Editors, Volume XXIV, *International Geological Congress*, Field Excursion Guidebook A-01, X-01, Montreal, 1972.

Campbell, R.B. and Okulitch, A.V. (1973): Stratigraphy and Structure of the Mount Ida Group, Vernon (82L), Adams Lake (82M/W1/2) and Bonaparte Lake (92P) Map-areas, British Columbia, *in* Report of Activities, April to October, 1972, *Geological Survey of Canada*, Paper 73-1, Part A, pages 21-23.

Campbell, R.B., and Tipper, H.W. (1971): Geology of the Bonaparte Lake Map-area, British Columbia, *Geological Survey of Canada*, Memoir 363.

Carr, S.D. (1986): The Valkyr Shear Zone and the Slocan Lake Fault Zone: Eocene Structures that Bound the Valhalla Geneiss Complex, Southeastern British Columbia, Unpublished M.Sc. Thesis, *Carleton University* 106 pages.

Carr, S.D., Parish, R.R. and Brown, R.L. (1987): Eocene Structural Development of the Valhalla Complex, Southestern British Columbia, *Tectonics*, Volume 6, pages 175-196.

Davis, G.A., Lister, G.S. and Reynolds, S.J. (1986): Structural Evolution of the Whipple and South Mountains Shear Zones, Southwestern United States, *Geology*, Volume 14, pages 7-10.

Davis, G.H. (1983): Shear-zone Model for the Origin of Metamorphic Core Complexes, *Geology*, Volume 11, pages 342-347.

Fyson, W.K. (1970): Structural Relations in Metamorphic Rocks, Shuswap Lake Area, British Columbia, in Structure of the Southern Canadian Cordillera, J.O. Wheeler, Editor, *Geological Association of Canada*, Special Paper 16, pages 107-122.

Harrison, T.M., Duncan, I. and Mcdougall, I. (1985): Diffusion of ^{40}Ar in Biotite: Temperature, Pressure and Compositional Effects, *Geochemica et Cosmochimica Acta*, Volume 49, pages 2461-2468.

Johnson, B.J. (1988): Progress Report: Stratigraphy, and Structure of the Shuswap Metamorphic Complex in the Hunters Range, Eastern Shuswap Highland, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 55-58.

Jones, A.G. (1959): Vernon Map-area, British Columbia, *Geological Survey of Canada*, Memoir 296, 186 pages.

Journeay, J.M. (1986): Stratigraphy, Internal Strain and Thermo-tectonic Evolution of the Northern Frenchman Cap Dome: an Exhumed Duplex Structure, Omineca Hinterland, S.E. Canadian Cordillera, Unpublished Ph.D. Thesis, *Queen's University*, 400 pages.

Journeay, M. and Brown, R.L. (1986): Major Tectonic Boundaries of the Omineca Belt in Southern British Columbia: a Progress Report, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 86-IA, pages 81-88.

Jung, A. (1986): Geochronometry and Geochemistry of the Thuya, Takomkane, Raft and Baldy Batholiths, West of the Shuswap Metamorphic Complex, South-central British Columbia, Unpublished B.Sc. Thesis, *The University of British Columbia*, 101 pages.

Lane, L.S. (1984): Brittle Deformation in the Columbia River Fault Zone near Revelstoke, Southeastern British Columbia, *Canadian Journal of Earth Sciences*, Volume 21, pages 584-598.

Nielsen, K.C. (1978): Tectonic Setting of the Northern Okanagan Valley at Mara Lake, British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*, 150 pages.

——— (1982): Structural and Metamorphic Relations between the Mount Ida and Monashee Groups at Mara Lake, British Columbia, *Canadian Journal of Earth Sciences*, Volume 19, pages 288-307.

Okulitch, A.V. (1979): Lithology, Stratigraphy, Structure and Mineral Occurrences of the Thompson - Shnswap - Okanagan Area, British Columbia, *Geological Survey of Canada*, Open File 637.

Parkinson, D. (1985a): U-Pb Geochronology and Regional Geology of the Southern Okanagan Valley, British Columbia: the Western Boundary of a Metamorphic Core Complex, Unpublished M.Sc. Thesis, *The University of British Columbia*, 149 pages.

——— (1985b): Geochronology of the Western Side of the Okanagan Metamorphic Core Complex, southern British Columbia, Abstracts with Programs, Cordilleran Section, *Geological Society of America*, Volume 17, page 39.

Parrish, R.R. (1984): Slocan Lake Fault: a Low Angle Fault Zone bounding the Valhalla Gneiss Complex, Nelson Map Area, Southern British Columbia, *Geological Survey of Canada*, Paper 84-IA, pages 323-330.

Parrish, R.R., Carr, S.D. and Parkinson, D.L. (1985): Metamorphic Complexes and Extensional Tectonics, Southern Shuswap Complex, Southeastern British Columbia, *in* Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera, D.J. Tempelman-Kluit, Edictor, *Geological Society of America*, Cordilleran Section Guidebook, Vancouver, British Columbia, pages 12-1 to 12-15.

——— (1988): Eocene Extensional Tectonics and Geochronology of the Southern Omineca Belt, British Columbia and Washington, *Tectonics*, Volume 7, pages 181-212.

Preto, V.A. and Schiarizza, P. (1985): Geology and Mineral Deposits of the Adams Plateau - Clearwater Region, *in* Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera, D.J. Tempelman-Kluit, Editor, *Geological Society of America*, Cordilleran Section Guidebook, Vancouver, British Columbia, pages 16-1 to 16-11.

Purdy, J.W. and Jger, E. (1976): K-Ar Ages on Rock-forming Minerals from the Central Alps, *Memorie Degli Istituti di Geologia e Mineralogia dell'Università di Padova*, Volume XXX, pages 1-31.

Read, P.B. and Brown, R.L. (1981): Columbia River Fault Zone: Southeastern Margin of the Shuswap and Monashee Complexes, Southern British Columbia, *Canadian Journal of Earth Sciences*, Volume 18, pages 1127-1145.

Schiarizza, P. and Preto, V.A. (1987): Geology of the Adams Plateau - Clearwater - Vavenby Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 19878-2, 88 pages.

Solberg, P. (1976): Structural Relations Between the Shuswap and "Cache Creek" Complexes near Kalamalka Lake, Southern British Columbia, Upublished M.Sc. Thesis, *The University of British Columbia*, 90 pages.

Tempelman-Kluit, D. and Parkinson, D. (1986): Extension Across the Eocene Okanagan Crustal Shear in Southern British Columbia, *Geology*, Volume 14, pages 318-321.

Wagner, G.A., Reimer, G.M. and Jager, E. (1977): Cooling Ages Derived by Apatite Fission-track, Mica Rb-Sr and K-Ar Dating: the Uplift and Cooling History of the Central Alps, *Memorie Degli Istituti di Geologia e Mineralogia dell'Università di Padova*, Volume XXX, pages 1-27.

Wanless, R.K., Stevens R.D., Lachance, G.R. and Delabio, R.N. (1978): Age Determinations and Geological Studies, K-Ar Isotopic Ages, Report 13, *Geological Survey of Canada*, Paper 77-2.

Wanless, R.K., Stevens, R.D., Lachange, G.R. and Rimsaite, R.Y.H. (1966): Age Determinations and Geological Studies, Part 1, Isotopic Ages, Report 6, *Geological Survey of Canada*, Paper 65-17.

Wernicke, B. (1981): Low-angle Normal Faults in the Basin and Range Province: Nappe Tectonics in an Extending Orogen, *Nature*, Volume 291, pages 645-647.

——— (1985): Uniform-sense Normal Simple Shear of the Continental Lithosphere, *Canadian Journal of Earth Sciences*, Volume 22, pages 108-125.

STRATIGRAPHY ALONG THE NORTH FLANK OF FRENCHMAN CAP DOME, SOUTH OMINECA BELT, BRITISH COLUMBIA (82M/10, 15)

By Robert J. Scammell and John M. Dixon
Queen's University

KEYWORDS: Regional geology, Selkirk allochthon, Shuswap metamorphic complex, Horsethief Creek Group, Ruddock Creek, lead-zinc.

INTRODUCTION

An understanding of the stratigraphy in the south-central part of the Omenica Belt has played a major role in deciphering the structure and tectonic evolution in the region (Simony *et al.*, 1980; Raeside and Simony, 1983; Brown *et al.*, 1986; Brown and Lane, 1988). Several stratigraphic packages of the North American continental terrace prism have been traced from zones of low metamorphic grade into the high-grade core zone of the Columbian orogen (Pell and Simony, 1987) which straddles the suture zone between autochthonous North American rocks and accreted terranes. Within this zone, metamorphism, crustal anatexis (Raeside, 1982; Sevigny *et al.*, in press) and intense deformation obscure the original character of the sedimentary rocks.

The field area lies within the north-central part of the Shuswap metamorphic complex in the southern Omenica Belt (inset Figure 1-7-1). These little-studied rocks have been mapped on a reconnaissance scale by Wheeler (1965), and in local detail in the vicinity of the Ruddock Creek lead-zinc deposit by Fyles (1970). This area physically links defined stratigraphy and structures in the Selkirk allochthon west of Mica Dam and in the Selkirk Mountains, to the Monashee Complex (Read and Brown, 1981). Therefore, knowledge of its rocks will provide an improved basis for stratigraphic, structural and tectonic interpretation and will aid mineral exploration and resource evaluation in the region.

Work during the 1988 field season included 17 days of sampling and detailed mapping (1:20 000) of approximately 80 square kilometres of alpine exposures best accessed by helicopter from Revelstoke. Continued research will include uranium-lead dating, lead isotope studies, $^{40}Ar/^{39}Ar$ isotopic analysis, the application of various geothermometers and geobarometers, and further detailed mapping. This contribution deals with the stratigraphy of the area.

REGIONAL TECTONIC SETTING

Major tectonic elements identified in the southern part of the Omenica Belt include, in ascending structural order: the Monashee Complex, Monashee décollement, Selkirk allochthon, Quesnel Lake fault and Quesnel Lake thrust sheet. These elements are interpreted to be part of a large-scale system of overthrusting along low-angle westerly rooting shear zones (Brown *et al.*, 1986). The Monashee Complex, one of several metamorphic core complexes (Crittenden *et al.*, 1980) within the southern Omenica Belt, is exposed through a tectonic window in the Selkirk allochthon and Monashee décollement. It is cored by early Proterozoie paragneisses and granitic orthogneisses, unconformably overlain by mantling gneisses composed dominantly of metamorphosed platformal sedimentary rocks. Protoliths of the latter are inferred to be at least late Proterozoic to early Cambrian in age (Höy and Godwin, in press; Parrish and Scammell; in press). The Monashee Complex constitutes a suspect terrane, and has been interpreted as compressed, initially attenuated North American continental crust and early platform sediments (Brown *et al.*, 1986; para-autochthonous terrane of Monger *et al.*, 1985). Rocks of the complex are polydeformed and record two distinct synkinematic metamorphic episodes (Journeay, 1986; Scammell, 1986). Reworked basement rocks also make up the Malton gneiss to the north.

The Monashee décollement is a fundamental regional tectonic boundary. It is a mylonitic shear zone, which records easterly directed motion of its upper plate (Brown and Murphy, 1982; Lane, 1984; Journeay, 1986; Scammell, 1986; Bosdachin and Harrap, 1988). It forms the upper boundary of the Monashee Complex, and truncates structures, isograds and lithostratigraphic units in both plates. Recent work by Journeay (1986) and Scammell (1986) suggests that it records early high-pressure and later low-pressure displacements.

The Selkirk allochthon is a composite tectonic sheet in the hangingwall of the Monashee décollement (Read and Brown, 1981). It is composed of rocks ranging in age from Proterozoic to Middle Jurassic. Stratigraphic divisions of Late Proterozoic Horsethief Creek Group rocks, considered correlative with the Windermere Supergroup, have been traced north from the Purcell Mountains, through the Selkirk and Monashee mountains (some 15 kilometres north of the field area) to the Cariboo Mountains (*see* Pell and Simony, 1987). Major southwest-verging nappes that predate Middle Jurassic regional metamorphism and east and west-verging second-phase folding have been documented (Cairns nappe, Brown and Lane, 1988; Scrip nappe, Raeside and Simony, 1983). These structures control the megascopic distribution of rock units in the allochthon. High-pressure Barroviantype assemblage zones and crustal anatexis characterize rocks of the Selkirk allochthon in the vicinity of the map area.

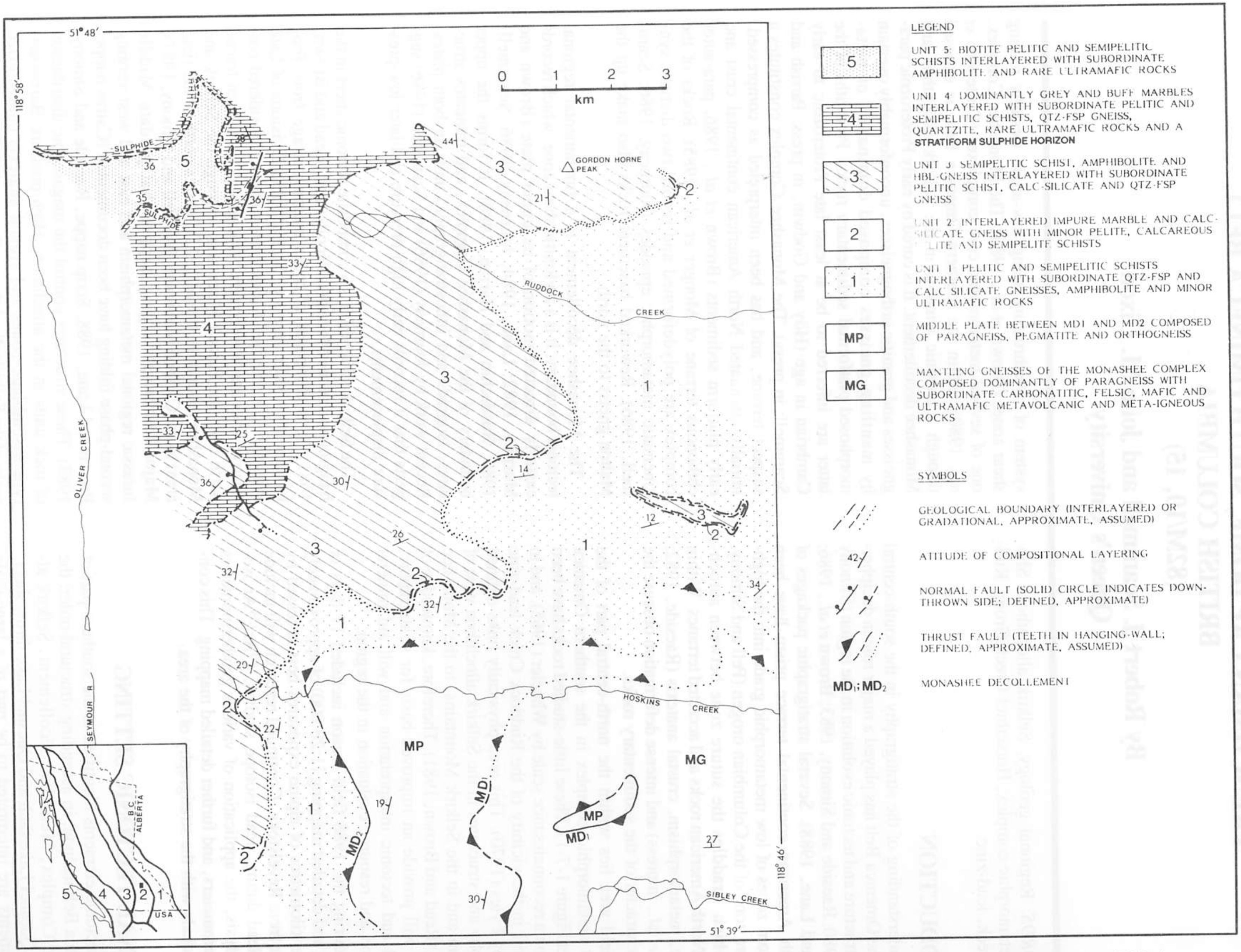


Figure 1-7-1. Stratigraphic map of the north flank of Frenchman Cap dome. Data compiled from Fyles (1970), Wheeler (1965), Journeay (unpublished data, 1987), Scammell (unpublished data, 1988) and Scammell (1986). Note that the numbers of units imply structural order. Inset map of British Columbia displays five morpho-tectonic belts of the Canadian Cordillera: (1) Foreland Fold and Thrust Belt, (2) Omenica Belt, (3) Intermontane Belt, (4) Coast Belt, and (5) Insular Belt. The approximate location of the field area is shown as a black rectangle in the Omenica Belt.

The Quesnel Lake fault is a mylonitic east-directed overthrust (Rees and Ferri, 1983). Rocks in its hangingwall comprise ophiolitic rocks of the eastern terrane and late Paleozoic to early Jurassic island-arc rocks of the Quesnellia terrane.

LITHOLOGY

The map area is underlain by a stratified sequence composed of a wide range of metamorphic rock types including pelitic, quartzofeldspathic, siliceous, calcareous, calc-silicate, mafic and ultramafic varieties. These individual rock types show little variation throughout the sequence, and are described in a general manner.

Pelites are layered on a scale of tens of centimetres to metres. They are generally discontinuous, but some can be traced for several hundred metres. Discontinuous and continuous finer laminations are defined by changes in grain size and/or modal proportions of constituent minerals. Pelites are commonly extensively weathered with heavy iron oxide staining. Grain size generally ranges from 2 to 10 millimetres with garnet porphyroblasts reaching diameters of 5 centimetres. They are composed of quartz, feldspar, biotite, muscovite, chlorite, garnet and fibrous sillimanite intergrown with biotite. Pelitic rocks comprise greater than 50 per cent phyllosilicates, and 5 to 50 per cent quartz and feldspar. Lithochemical variation and changes in metamorphic grade have resulted in some pelitic schists which do not contain one or a combination of garnet, sillimanite or muscovite. Individual layers exhibit both sharp and gradational margins. While gross layering is a product of primary deposition of aluminous sediments, fine layers are products of both primary sedimentation and dynamothermal processes.

Pelites are commonly interlayered with semipelitic schist (less than 50 per cent mica), quartzofeldspathic gneiss and siliceous rocks, on a scale of centimetres to metres. Semipelitic rocks have a higher proportion of quartz and feldspar, and less sillimanite, but otherwise are similar in most aspects to pelitic rocks. Layers of quartzofeldspathic gneiss consist of abundant coarse-grained (greater than 2 millimetres) feldspar and quartz with accessory minerals including mica, amphibole, pyroxene and garnet. Variation in the proportion of quartz, feldspar and accessory minerals defines millimetre-scale discontinuous laminations. These gneisses are believed to be metamorphosed greywackes and feldspathic sandstones. Siliceous rocks are rare. Coarse-grained quartzites occur as discontinuous layers 10 centimetres to 2 metres thick. Concentrations of accessory minerals including garnet, hornblende, diopside, muscovite and biotite define millimetre-scale laminations. These quartzites represent metamorphosed quartz arenites.

Calcareous rocks are the best marker horizons in the map area. Most common are impure marbles layered on a centimetre to metre scale and outlined by alternating resistant and recessive grey and buff layers. Fresh surfaces are buff, light grey and rarely white, and give off a fetid odour. Although they are dominantly composed of coarse-grained calcite and minor dolomite, highly strained varieties may be fine grained. The concentration of accessory phases including quartz, diopside, plagioclase, garnet, graphite and epidote defines faint centimetre-scale laminations with gradational boundaries. These calcareous rocks are most commonly interlayered with calc-silicate gneisses (less than 50 per cent calcite) which comprise gross metre-scale units more finely layered on a millimetre to centimetre scale with alternating carbonate and silicate-rich layers. These rocks typically contain coarse-grained calcite, quartz, plagioclase, epidote, phlogopite, garnet, diopside, sphene, hornblende and rare sulphides. Together with calcareous rocks they represent interlayered pure limestones, dolostones, shaly or quartz-bearing limestones and dolostones.

Grey to black-weathering coarse-grained mafic rocks are present throughout the sequence. Hornblende-rich (greater than 70 per cent) amphibolites commonly form centimetre to metre-scale layer-parallel boudins around which metasedimentary rocks have been deformed. Original contact relationships have generally been obscured by strain. Accessory phases, which are not always present, include garnet, biotite and diopside. Hornblende-rich varieties generally do not display fine laminations. Some amphibolites are so deficient in plagioclase that they constitute hornblendites. Others exhibit fine layering defined by discontinuous alternating plagioclase and hornblende-rich layers. These latter amphibolites exhibit both sharp and gradational contacts with surrounding metasedimentary rocks. Although some of the mafic rocks may represent metamorphosed siliceous shaly dolomites, most are believed to represent an array of basaltic or gabbroic sills and transposed dykes, flows, tuffs and reworked volcaniclastic material. Sevigny (1987) has made this interpretation to the north.

Rare ultramafic rocks are exposed sporadically within the succession as massive metre-scale boudins. They exhibit a wide variety of textures. Fine-grained ultramafic rocks are weakly foliated, and weather greenish grey, locally with up to 10 per cent weakly rusty spots (olivine?) 5 to 10 millimetres across. Thin-section examination is required to identify their mineralogy. Coarse-grained varieties display spectacular radiating laths of ortho-amphibole 1 to 5 centimetres long, and other presently unidentified apple-green to brown lath-shaped minerals set in a matrix of talc, serpentine, phlogopite and iron oxides. These rocks represent metamorphosed peridotites, dunites and possibly pyroxenites.

STRATIGRAPHY

High-strain, sillimanite-grade metamorphism, migmatization and granitic intrusion have obliterated all primary structures apart from gross compositional layering. A regional stratigraphy has been delineated on the basis of typical associations and facies relationships, the local preponderance of certain rock types, and the presence of rare laterally persistent marker horizons. Five composite lithostratigraphic units have been mapped (Figure 1-7-1). Contacts are most commonly interlayered and less commonly gradational or sharp. No obvious breaks or unconformities were observed in the stratigraphic sequence, and it is therefore presently considered to be one coherent succession.

Attenuation of the sequence is evidenced by the discontinuous nature of most lithologic units, boudinage of more competent layers, mylonitic fabrics and a penetrative west-trending mineral-stretching lineation. Three phases of folding have been recognized. The first two, found throughout the map area, are metre to kilometre scale and generally thin the section along their limbs. Their higher-order structures thin and thicken sections locally. Third-phase folds are locally developed and have relatively little effect on section thickness.

Apparent passive intrusion of subconcordant granitic bodies has not generally disrupted the orientation of the metamorphic foliation in the host rocks. These granitic rocks may comprise more than 50 per cent of the rock type at the megascopic scale. Consequently, original stratigraphic thicknesses are not known. Megascopic thicknesses quoted include intrusive granites and deformation effects, and are therefore only first approximations. Medium-grained granites, pegmatites and other leucosomes are present throughout the succession and are not considered to be part of the original stratigraphic succession but rather a metamorphic effect superimposed on the original sequence and are consequently not described. The succession is described in ascending structural order from the uppermost splay in the Monashee décollement (Journeay, 1986; Journeay and Brown, 1986).

UNIT 1

This unit lies in fault contact with the Monashee décollement (Journeay and Brown, 1986; Journeay, unpublished data, 1987). It is approximately 600 to 2000 metres thick, and comprises an interlayered succession dominated by pelitic and semipelitic schists with minor quartzofeldspathic gneiss, amphibolite, calc-silicate and ultramafic rocks. Journeay (unpublished data, 1987) has recognized one discontinuous composite subunit composed dominantly of interlayered calc-silicate gneiss and amphibolite which hosts sporadic boudins of brown-weathering ultramafic rocks. This subunit is 0 to 500 metres thick, and lies in the central part of Unit 1.

UNIT 2

This calcareous unit constitutes one of the few reliable marker horizons, and can be traced for more than 10 kilometres. It is composed of interlayered centimetre-thick impure marbles and calc-silicate gneiss wtih minor pelite, calcareous pelite and semipelite schists. Although locally discontinuous, it may reach more than 10 metres in thickness. It is interlayered with bounding units.

UNIT 3

This unit, approximately 1500 to 2300 metres thick, is composed dominantly of semipelitic schists, amphibolite and hornblende gneiss interlayered with subordinate pelitic schists, calc-silicate and quartzofeldspathic gneisses. These rocks are interlayered on a scale of centimetres to metres. Although generally discontinuous on a 10-metre scale, some subunits dominated by amphibolites and rusty pelitic schists can be traced for several kilometres. Thin interlayered marble and calc-silicate horizons appear towards the top of the unit. Unit 3 is capped by a sillimanite-rich rusty horizon of pelitic schists 5 to 30 metres thick.

UNIT 4

Rusty pelitic schists of Unit 3 are overlain along an interlayered contact by a succession of dominantly thick grey and buff marbles interlayered with subordinate rusty pelitic schists, semipelitic schists, quartzofeldspathic gneiss, quartzite and ultramafic boudins. This calcareous succession forms a distinctive horizon from east of the headwaters of Oliver Creek to west of Gordon Horne Peak. It ranges from 900 to 1000 metres thick. Individnal metre-scale marble horizons can be traced along strike for several kilometres. Although at least five of these horizons have been mapped, some may represent repetitions due to folding. The Ruddock Creek lead-zinc sulphide horizon (Wheeler, 1965; Fyles, 1970) appears to be one of the structurally highest subunits of Unit 4. This 2 to 5-metre-thick discontinuous stratiform sulphide-bearing member outlines a type-3 fold interference pattern. It comprises two sulphide layers 0.5 to 5 metres thick, composed of sphalerite, pyrrhotite, galena, pyrite and chalcopyrite, interlayered with calc-silicate gneisses, impure marbles, semipelitic and pelitic schists, and rare lenses of fluorite and barite (Fyles, 1970). Layer-parallel lenticular pods and boudins of ultramafic rocks are found above and below the sulphide-bearing subunit. Discontinuous metre-scale marble horizons mark the top of Unit 4.

UNIT 5

This unit cores the synformal structure outlined by the sulphide-bearing subunit in Unit 4. It is at least 300 metres thick and dominated by pelitic and semipelitic biotite schists interlayered with minor amphibolite and rare ultramafic lenses.

DISCUSSION

Rocks in the map area comprise part of Wheeler's (1965) map unit E which extends south from west of the Big Bend in the Columbia River to west of the Monashee Complex with no known structural breaks. Brown (1980) has suggested that these rocks are correlative with the late Proterozoic Horsethief Creek Group present in the Selkirk allochthon. Comparison of the sequence of rocks in the map area with published descriptions of Horsethief Creek rocks (Simony *et al.*, 1980; Raeside and Simony, 1983; Pell and Simony, 1987) reveals strong similarities and suggests specific correlations with rocks of the Horsethief Creek Group.

North of the study area Horsethief Creek rocks comprise a succession of pelitic and semipelitic schists, amphibolites, marbles, calc-silicate and quartzofeldspathic gneisses 4 to 5 kilometres thick. These rock types are typical of the study area. Raeside and Simony (1983) describe five subdivisions which include, in ascending stratigraphic order: lower pelite, lower marble, semipelite-amphibolite, main marble (middle marble), and upper clastic divisions. They describe the lower marble subdivision as an asymmetric sequence with amphibolite at its base, overlain by rusty pelite capped by interlayered marble and calc-silicate. Rocks in the upper part of Units 1 and 2 show a similar asymmetry comprising a subunit dominated by amphibolite and calc-silicate rocks overlain by interlayered semipelite and pelitic schists capped by calcareous rocks of Unit 2. Semipelitic and pelitic schists and minor amphibolite in the lower part of Unit 1 comprise a sequence similar to rocks in the lower pelite division. The semipelite-amphibolite subdivision is characterized by massive semipelites with interlayered pelites and thin amphibolites; a succession similar to Unit 3 of the study area. Overlying rocks in both areas (Unit 4 and the main marble or middle marble) comprise sequences dominated by marbles interlayered with pelitic and semipelitic schists. This calcareous sequence is much thicker in the field area than to the north. The present database on this structurally complex part of the section does not allow determination of the original stratigraphic thickness, or confident positioning of the lead-zinc horizon and Unit 5 in a stratigraphic sequence. Lead-zinc-bearing sequences similar to the Ruddock Creek deposit are not described elsewhere in Horsethief Creek stratigraphy but Unit 5 is similar to semipelite, pelite and psammitic rocks interlayered with minor amphibolites at the base of the upper clastic division.

Simony *et al.* (1980), Raeside and Simony (1983), and Sevigny and Simony (in press) have mapped a southwest-verging nappe (Scrip nappe) in the Horsethief Creek Group, with an overturned limb in excess of 50 kilometres long. An underlying syncline links the nappe to upright Horsethief Creek stratigraphy in the vicinity of the Malton gneiss. The nature of these structures implies that the underlying syncline and upright stratigraphy should extend to the south.

The above discussion outlines the similarity between the stratigraphic succession established to the north and the structural succession in the field area. In the region which links these two areas Wheeler (1965) has mapped marble horizons that are most likely correlative with Units 2 and 4 of the study area. It is therefore proposed that rocks in the map area generally comprise (with the possible exception of the Roddick Creek horizon and Unit 5) part of a succession of Horsethief Creek stratigraphy in the upright limb of the syncline which underlies the Scrip nappe. Assessment of this proposal requires more detailed data from the region to the north of the field area.

ACKNOWLEDGMENTS

We acknowledge financial support from the Natural Sciences and Engineering Research Council; Energy, Mines and Resources Canada; and the British Columbia Geoscience Reseach Grant Program. T. Duffy is thanked for his assistance in the field. R. Parrish, R.L. Brown and V. Coleman are thanked for their visits and stimulating discussions. J.M. Journeay has kindly provided and permitted presentation of some unpublished data, and is also thanked for his ideas and opinions.

REFERENCES

Bosdachin, R. and Harrap, R.M. (1988): Stratigraphy and Structure of the Monashee Complex and Overlying Rocks Adjacent to the Trans-Canada Highway, West of Revelstoke, British Columbia, *Geological Survey of Canada*, Paper 88-1E, pages 19-23.

Brown, R.L. (1980): Frenchman Cap Dome, Shuswap Complex, British Columbia: a Progress Report, *Geological Survey of Canada*, Paper 80-1A, pages 47-51.

Brown, R.L., Journeay, J.M., Lane, L.S., Murphy, D.C. and Rees, C.J. (1986): Obduction, Backfolding and Piggyback Thrusting in the Metamorphic Hinterland of the Southeastern Canadian Cordillera, *Journal of Structural Geology*, Volume 8, Numbers 3/4, pages 255-268.

Brown, R.L. and Lane, L.S. (1988): Tectonic Interpretation of West-vergent Folds in the Selkirk Allochthon of the Southern Cordillera, *Canadian Journal of Earth Sciences*, Volume 25, pages 292-300.

Brown, R.L. and Murphy, D.C. (1982): Kinematic Interpretation of Mylonitic rocks in part of the Columbia River Fault Zone, Shuswap Terrane, British Columbia, *Canadian Journal of Earth Sciences*, Volume 19, pages 456-465.

Crittenden, Jr., M.D., Coney, P.J. and Davis, G.H. (1980): Cordilleran Metamorphic Core Complexes, *Geological Society of America*, Memoir 153, 490 pages.

Fyles, J.T. (1970): Jordan River Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 57, 64 pages.

Höy, T. and Godwin, C. (in press): Significance of a Galena Lead Isotope Cambrian Age Date for Stratiform Cottonbelt Deposit in the Monashee Complex, Southeastern British Columbia, *Canadian Journal of Earth Sciences*, Volume 25.

Journeay, J.M. (1986): Stratigraphy, Internal Strain and Thermo-tectonic Evolution of Northern Frenchman Cap Dome: an Exhumed Duplex Structure, Omineca Hinterland, S.E. Canadian Cordillera, Unpublished Ph.D. Thesis, *Queen's University*, 316 pages.

Journeay, J.M. and Brown, R.L. (1986): Major Tectonic Boundaries of the Omenica Belt in Southern British Columbia: a Progress Report, *Geological Survey of Canada*, Paper 86-1A, pages 81-88.

Lane, L.S. (1984): Deformation History of the Monashee Décollement and Columbia River Fault Zone, Unpublished Ph.D. Thesis, *Carleton University*, 218 pages.

Monger, J.W.H. (Principal compiler), Woodworth, G.J., Price, R.A., Clowes, R.N., Riddihough, R.P., Currie, R., Höy, T., Preto, V.A.G., Simony, P.S., Snavely, P.D. and Yorath, C.J. (1985): Transect B2, Southern Canadian Cordillera, North American Continent-ocean Transects, *Geological Society of America*, Decade of North America Program.

Parrish, R. and Scammell, R.J. (in press): The Age of the Mount Copeland Syenite Gneiss and its Metamorphic Zircons, Monashee Complex, Southeastern British Columbia, *in* Radiogenic Age and Isotopic Studies: Report 2, *Geological Survey of Canada*, Paper 89-2.

Pell, J. and Simony, P.S. (1987): New Correlations of Hadrynian Strata, South-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 24, pages 302-313.

Raeside, R.P. (1982): Structure, Metamorphism, and Migmatization of the Scrip Range, Mica Creek, British Columbia, Unpublished Ph.D. Thesis, *University of Calgary*, 204 pages.

Raeside, R.P. and Simony, P. (1983): Stratigraphy and Deformational History of the Scrip Nappe, Monashee Mountains, British Columbia, *Canadian Journal of Earth Sciences*, Volume 20, pages 639-650.

Read, P.B. and Brown, R.L. (1981): Columbia River Fault Zone: Southeastern Margin of the Shuswap and Monashee Complexes, Southern British Columbia, *Canadian Journal of Earth Sciences*, Volume 18, pages 1127-1145.

Rees, C.R. and Ferri, F. (1983): A Kinematic Study of Mylonitic Rocks in the Omenica-Intermontane Belt Tectonic Boundary in East-central British Columbia, *Geological Survey of Canada*, Paper 83-1B, pages 121-125.

Scammell, R.J. (1986): Stratigraphy, Structure and Metamorphism of the North Flank of the Monashee Complex, Southeastern British Columbia: a Record of Proterozoic Extension and Phanerozoic Crustal Thickening, Unpublished M.Sc. Thesis, *Carleton University*, 205 pages

Sevigny, J.H. (1987): Field and Stratigraphic Relations of Amphibolites in the Late Proterozoic Horsethief Creek Group, Northern Adams River Area, British Columbia, *Geological Survey of Canada*, Paper 87-1A, pages 751-756.

Sevigny, J.H., Parrish, R.R. and Ghent, E.D. (in press): Petrogenesis of Peraluminous Granites, Monashee Mountains, Southeastern Canadian Cordillera, *Journal of Petrology*.

Sevigny, J.H. and Simony, P.S. (in press): Geometric Relationship between the Scrip Nappe and Metamorphic Isogrades in the Northern Adams River Area, Monashee Mountains, British Columbia, *Canadian Journal of Earth Sciences*.

Simony, P.S., Ghent, E.D., Craw, D., Mitchell, W. and Robbins, D.B. (1980): Structural and Metamorphic Evolution of the Northeast Flank of the Shuswap Complex, Southern Canoe River Area, British Columbia, *in* Cordilleran Metamorphic Core Complexes, M.D. Crittenden, P.J. Coney and G.H. Davis, Editors, *Geological Society of America*, Memoir 153, pages 445-462.

Wheeler, J.O. (1965): Big Bend Map-area, British Columbia, *Geological Survey of Canada*, Paper 64-32, 37 pages.

GEOLOGY OF THE ALBERNI — NANAIMO LAKES AREA, VANCOUVER ISLAND* (92F/1W, 92F/2E and part of 92F/7)

By N.W.D. Massey and S.J. Friday

KEYWORDS: Vancouver Island, Sicker Group, Duck Lake Formation, Cowichan uplift, thrusts, massive sulphide, gold.

INTRODUCTION

A 4-year program of 1:50 000-scale regional mapping was initiated by the Geological Survey Branch in southern Vancouver Island in 1986, under the Canada/British Columbia Mineral Development Agreement. The program was planned to cover three 1:50 000 NTS sheets centred on the main Sicker Group outcrop area within the Cowichan uplift (Figure 1-8-1). The 1988 field season saw the completion of the field component of this project. Previous mapping in the Cowichan Lake (92C/16) and Duncan (92B/13) areas has been reported on (Massey and Friday, 1987, 1988) and released as Open Files (Massey *et al.*, 1987, 1988).

During 1988, fieldwork was concentrated in the area around Fourth Lake (92/F1W) and west to Alberni Inlet (92F/2E), extending northwards to Horne Lake (92F/7). Road access is good with Highway 4 passing through the northern part of the area and the Bamfield road running along the western margin. An extensive network of logging roads, in various states of upkeep, provides access along most of the valleys and adjacent slopes.

PREVIOUS WORK

The Sicker Group was first defined as the Mount Sicker Series by Clapp (Clapp, 1912; Clapp and Cooke, 1917) within the Duncan area, although erroneously interpreted as younger than the Karmutsen Formation (Vancouver Series). Later workers in the Buttle Lake and Cowichan Lake areas recognized that the Sicker Group is indeed older (Gunning, 1931; Fyles, 1955). Muller and colleagues mapped large portions of Vancouver Island including the Alberni area (Muller and Carson, 1969). Detailed investigations of the China Creek area were reported on by Stevenson (1945).

Stratigraphic studies of the Sicker Group were conducted by Yole (1963, 1964, 1969) and Muller (1980). A major revision of the stratigraphy of the Sicker Group of the Cowichan uplift has been suggested by Sutherland Brown, based on 1:50 000 mapping in the Alberni-Bamfield corridor undertaken by the Geological Survey of Canada in support of the LITHOPROBE 1 Project (Sutherland Brown and Yorath, in preparation; Sutherland Brown *et al.*, 1986). A similar revision has also been made independently by Juras in the Buttle Lake uplift (Juras, 1987). Biostratigraphic and radiometric dating of the rocks of southern Vancouver Island has been summarized by Muller and Jeletzky (1970), Brandon *et al.*, (1986), and Armstrong *et al.*, (unpublished preprint).

REGIONAL SETTING

The Alberni–Nanaimo Lakes area is situated at the northwestern end of the Cowichan uplift, one of a series of major geanticlines constituting the structural fabric of southern Vancouver Island (Figure 1-8-1). The area lies within the Wrangellia terrane, which on Vancouver Island comprises three thick volcano-sedimentary cycles (Paleozoic Sicker Group, Upper Triassic Vancouver Group and the Jurassic Bonanza Group) overlapped by late Cretaceous sediments of the Nanaimo Group. The geology and structure of the area are summarized in Figures 1-8-2 and 1-8-3.

STRATIGRAPHY

The oldest rocks in the area belong to the Paleozoic Sicker Group (Figure 1-8-2) which contains volcanic and sedimentary units ranging in age from Middle Devonian(?) to Early Permian. These are intruded by mafic sills and dykes coeval with overlying basaltic volcanics of the Late Triassic Karmutsen Formation. Micritic limestone of the Quatsino Formation and volcanic rocks of the Early Jurassic Bonanza Group overlie the Karmutsen Formation. All these sequences have been subsequently intruded by granodioritic stocks of the Middle Jurassic Island intrusions. Late Cretaceous sediments of the Nanaimo Group lie unconformably on the older sequences and are the principal host to Late(?) Eocene porphyry sills.

SICKER GROUP

Since the initial work of Clapp (1912) there have been several attempts to formally subdivide the Sicker Group. Muller (1980) proposed four subdivisions which, in ascending stratigraphic order, are the Nitinat Formation, the Myra Formation, an informal sediment-sill unit and the Buttle Lake Formation. Recent paleontological and radiochronological studies (Brandon *et al.*, 1986), coupled with newer mapping (Sutherland Brown *et al.*, 1986; Sutherland Brown and Yorath, 1985; Juras, 1987), have thrown some doubt on these subdivisions and their universal applicability. New stratigraphic subdivisions have been proposed by Sutherland Brown for the Cowichan uplift, based on work in the Alberni area (Sutherland Brown and Yorath, in preparation). Apart from one major change outlined below, these formational subdivisions have also proven to be applicable in the Cowichan Lake and Duncan areas and have been adopted for this project (Massey and Friday, 1988; Massey *et al.*, 1987, 1988). A composite stratigraphic section for the Sicker Group in the Alberni–Nanaimo Lakes area is illustrated in Figure 1-8-4.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

Sutherland Brown has also suggested that the Sicker Group be redefined to include only the lower volcanic-volcaniclastic rocks, with the younger epiclastic sediments and limestones comprising a new Buttle Lake Group. There is great merit in this suggestion although, for convenience, the older, broader usage of "Sicker Group" has been retained here.

Duck Lake Formation

This is a newly defined stratigraphic unit within the Sicker Group, comprising a dominantly pillowed basalt sequence. Amygdaloidal basalts within the Sicker Group of the Cowichan uplift were first described by Fyles (1955) but were not formally separated as a stratigraphic unit. The pillow lavas were ascribed by Muller and Carson (1969) to the Karmutsen Formation and to either the Sicker Group or Karmutsen Formation by Laanela (1966). Sutherland Brown (1986, and Sutherland Brown and Yorath, in preparation) recognized that these pillows were of Sicker Group age but included them within the McLaughlin Ridge Formation.

Detailed mapping on behalf of Westmin Resources Limited on the Debbie property in the early 1980s documented a package of pillowed basalts that passed up through a discontinuous unit of cherts and felsic tuffs into pyroxene-plagioclase-phyric flows and volcaniclastics (R. Walker, personal communication, 1988). The whole package was thought to be part of the Myra Formation, using Muller's terminology, and younger than the Nitinat Formation. The results of mapping on a more regional scale by the authors

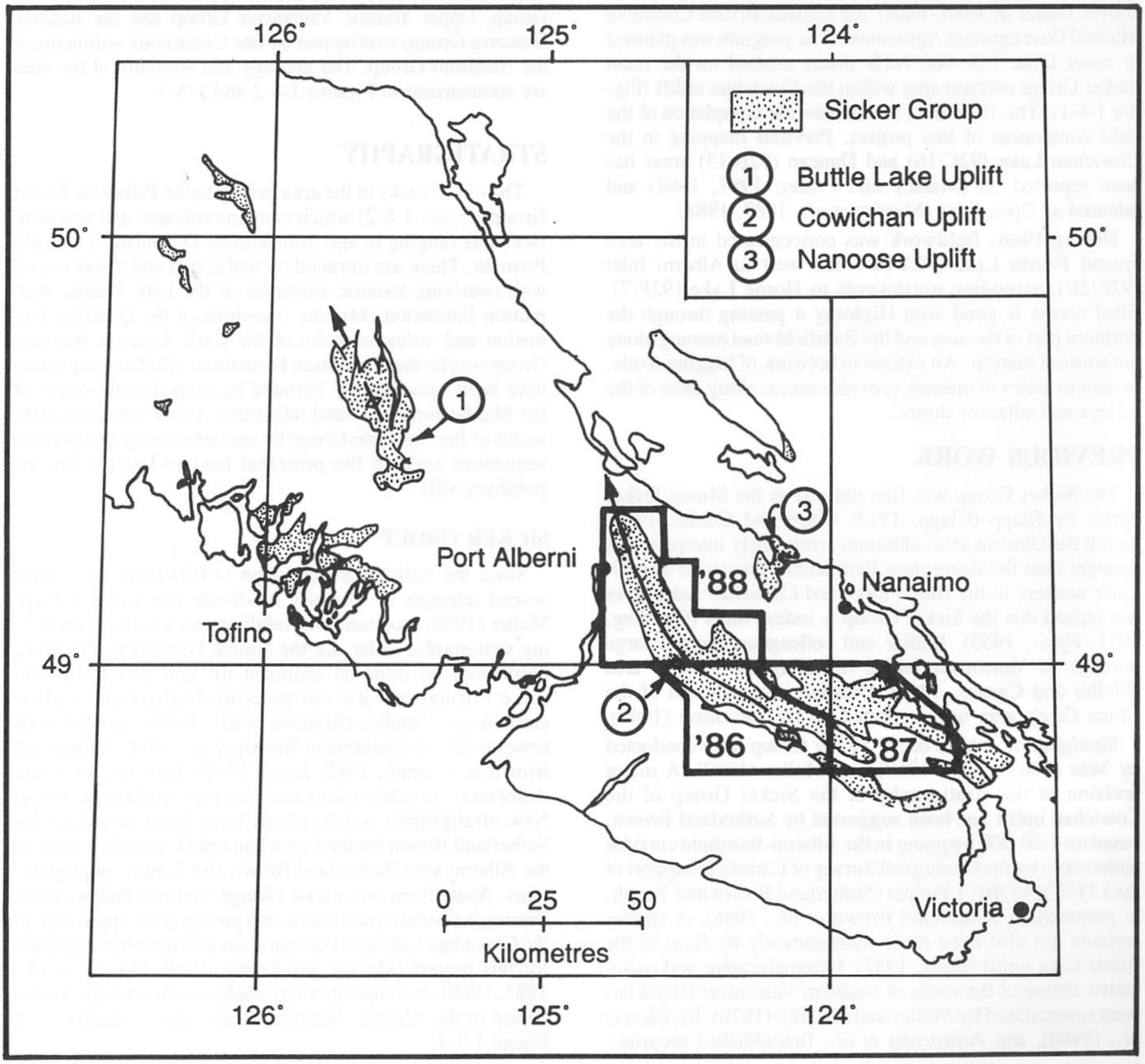


Figure 1-8-1: Location of the Sicker Project area, southern Vancouver Island, in relation to the three major geanticlinal uplifts cored by Sicker Group rocks (after Brandon *et al.*, 1986). 1986-88 field seasons are indicated.

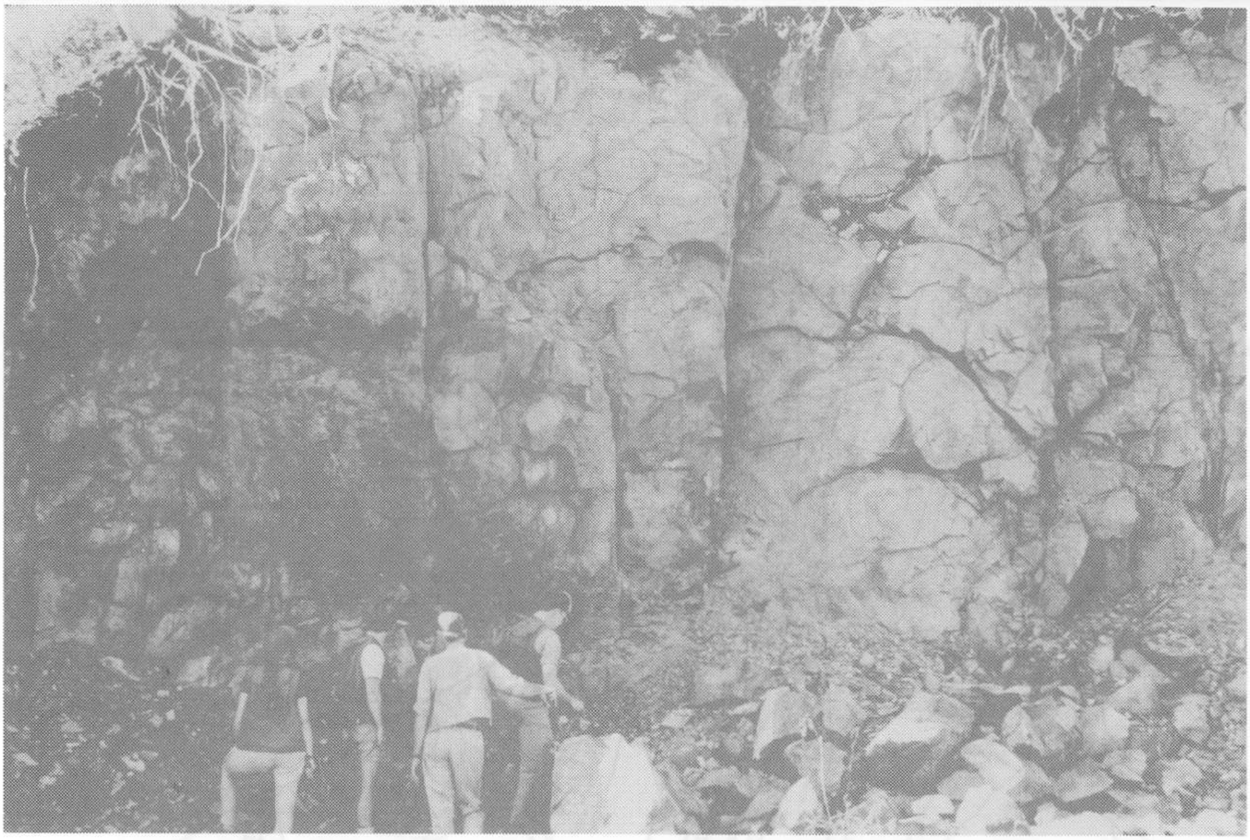


Plate 1-8-1: Pillow lavas of the Duck Lake Formation, Sicker Group, Duck Main.

confirm the relationships found by Westmin but correlate the overlying pyroxene-phyric volcanics with the Nitinat Formation.

The pillow lavas are thus considered to be older and significant enough to define a new formational unit. The proposed name Duck Lake Formation is taken from the Duck Lake road leading south from China Creek, along which Sutherland Brown measured and described a reconnaissance type-section (Sutherland Brown and Yorath, in preparation). A lower stratigraphic limit to the formation has not yet been recognized and the Duck Lake Formation is the oldest known exposed unit on Vancouver Island. Small patches of pillowed and massive aphyric basalt were mapped in the Cowichan Lake and Duncan areas in previous years and included in the Nitinat Formation (Massey and Friday, 1987, 1988). These may more correctly belong to the Duck Lake Formation.

The Duck Lake Formation consists dominantly of grey to maroon pillowed and massive basaltic flows (Plate 1-8-1). They show significant lithological differences to the younger Karmutsen Formation pillow lavas (Table 1-8-1). Typically the Duck Lake flows are aphyric and amygdaloidal, although variolitic and feldspar-phyric varieties are common. Pillows, although usually uniform in size within a particular flow, range from 30 centimetres to 3 metres in diameter. Shapes vary from spherical to ellipsoidal and elongate. Amygdules often form concentric zones which are thicker in the curved tops of pillows and are infilled with calcite, chlorite, epidote and quartz. Veins of quartz and epidote are also common. Epidote alteration patches may occur within some pillows and along selvages. Variolitic zones are coincident with, or inside the amygdaloidal zones. Pillow selvages are thin, 50 to 100 millimetres, and chloritic. The pillows are usually tightly packed with very little space between them. Where present, the space is infilled with chert, jasper, tuff, or rarely hyaloclastite.

Monolithic basaltic breccias and pillow breccias occur as interbeds within the flows (Plate 1-8-2). Like the flows, clasts in the breccias are aphyric, amygdaloidal basalt. The matrix is usually chloritic and tuffaceous, but occasional hyaloclastite is present. Chert, jasper and cherty tuff interbeds are also found, particularly near the top of the sequence. These are usually well bedded and laminated with occassional magnetite and hematite laminae. Well-bedded felsic tuffs (Plate 1-8-3) and lapilli tuffs are sometimes seen associated with cherts and jaspers at the top of the Duck Lake Formation, for example, at the "900 Zone" on Mineral Creek and the Microwave Tower north of Summit Lake. This horizon is potentially of major significance for gold and base metal exploration in the area.

Massive dacite-rhyolite bodies are found in several places associated with the pillow lavas. They appear in the most part to be dykes and sills. The dacite is fine grained, aphyric and cherty in appearance. It is dark to medium grey in colour, weathering white with some red stains on fracture surfaces. Similar-looking dacite dykes, though rare, also intrude the Nitinat Formation.

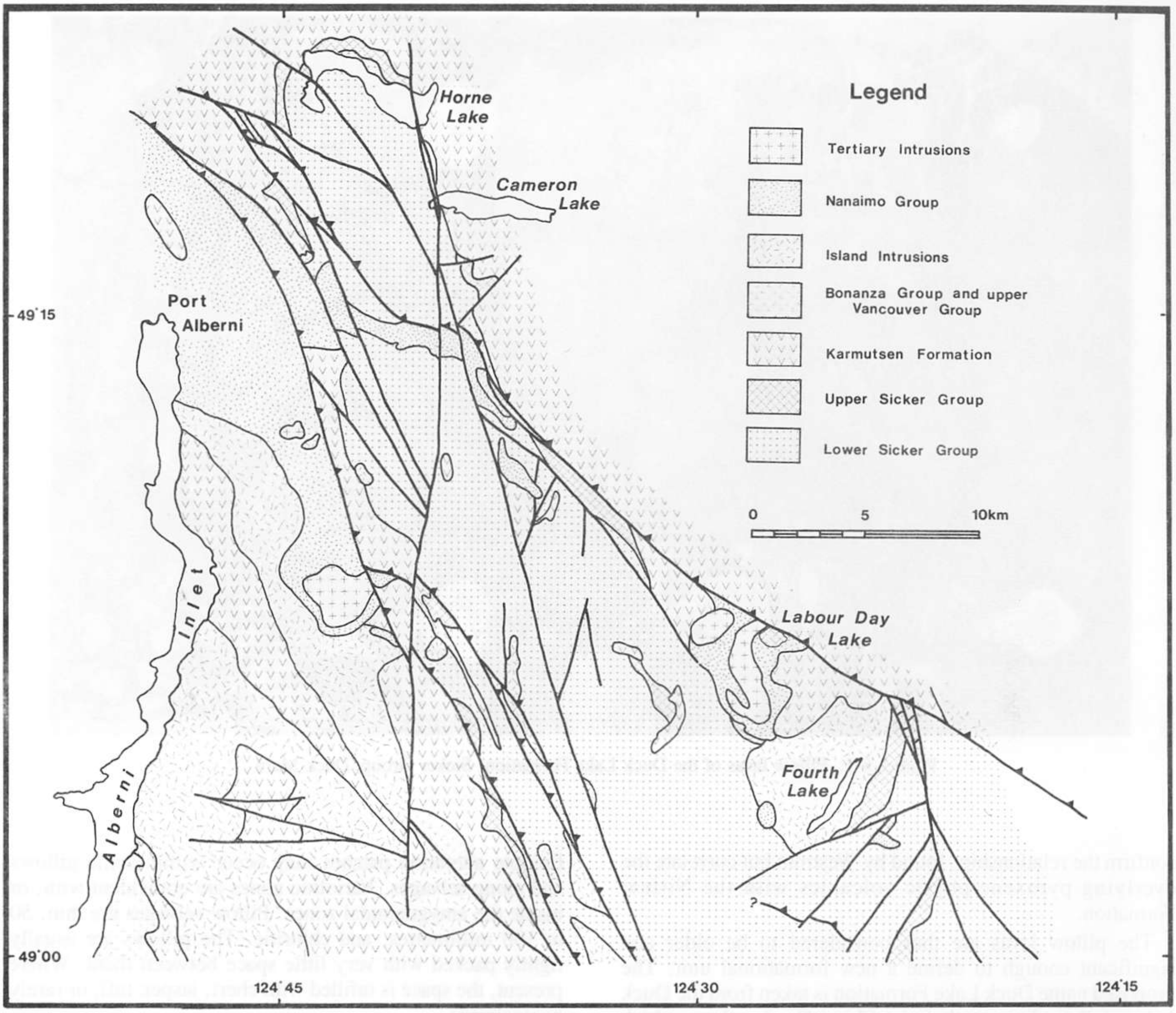


Figure 1-8-2: Geology of the Alberni–Nanaimo Lakes area.

Nitinat Formation

Overlying the Duck Lake Formation is the Nitinat Formation, a volcanic package characterized by pyroxene-feldspar-porphyritic basaltic andesites, typically occurring as agglomerates, breccias, lapilli tuffs and crystal tuffs. However, pyroxene-phyric, amygdaloidal, pillowed and massive flows are developed in several areas, for example Nitinat Pass and the West Fork of the Nitinat River. Pyroxenes may be large, up to 1 centimetre in diameter, euhedral to subhedral, and comprise 5 to 20 per cent of the rock. They are variably uralitized. Plagioclase is often as abundant as pyroxene, but phenocrysts are usually smaller, ranging up to 5 millimetres in diameter. Amygdules present in flows and clasts in coarser pyroclastics are infilled with chlorite, quartz, epidote or calcite. Non-pyroxene-phyric breccia, tuffaceous sandstone and laminated tuff are also found locally, interbedded with the pyroxene-phyric rocks.

This volcanic unit is equivalent to the Nitinat Formation of Muller (1980).

McLaughlin Ridge Formation

The Nitinat Formation passes upwards transitionally into the McLaughlin Ridge Formation, a sequence of volcaniclastic sediments dominated by thickly bedded, massive tuffites and lithic tuffites with interbedded laminated tuffaceous sandstone, siltstone and argillite (Figure 1-8-4). Associated breccias and lapilli tuffs are usually heterolithic and include aphyric and porphyritic (feldspar, pyroxene, hornblende) lithologies, commonly mafic to intermediate in composition. Felsic tuffs are rare.

The McLaughlin Ridge Formation is equivalent to the lower parts of the Myra Formation of Muller (1980).

Cameron River Formation

The upper part of the Sicker Group is made up of a dominantly epiclastic and bioclastic sedimentary sequence comprising the Cameron River, Mount Mark and St Mary's

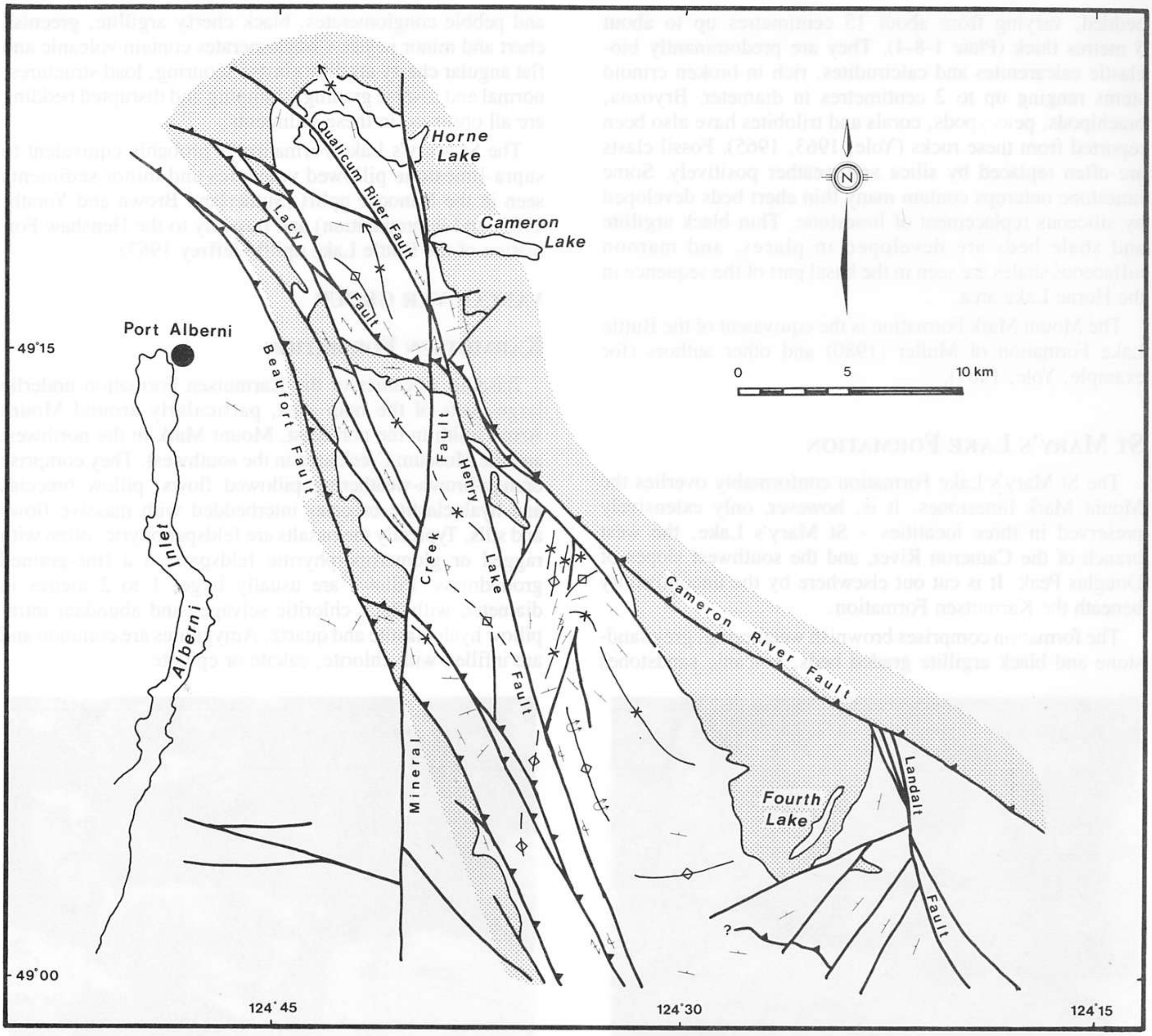


Figure 1-8-3: Major structural elements of the Alberni–Nanaimo Lakes area. Post-Sicker Group rocks indicated by shading.

Lake formations (Figure 1-8-4). This sedimentary package is apparently conformable on the underlying volcanics along the northeastern limb of the Cowichan uplift, for example, in the upper Cameron River valley and the Chemainus valley, but is unconformable along the southwestern limb both in the Alberni and Cowichan areas.

The Cameron River Formation comprises mostly thin-bedded, often cherty sediments. These vary from green and red ribbon cherts, black cherty argillites, green and white cherty tuffs, grey and green siltstones and argillites, to thicker bedded green volcanic sandstones. Chert breccias with a sandy matrix occur near the base of the formation; intercalated argillite and calcarenite beds up to 1 metre thick, dominate the upper part.

The Cameron River Formation is equivalent to the upper parts of Muller's Myra Formation together with the sediments of the informal sediment-sill unit (Muller, 1980). Chronologically, it is correlative, in part, with the volcanics of the Thelwood and Flower Ridge formations of the Buttle Lake upift (Juras, 1987) and probably with units PSc and PSd of the Nanoose uplift (Sutherland Brown and Yorath, 1985).

Mount Mark Formation

The Mount Mark Formation conformably overlies and laterally interfingers with the Cameron River Formation. However, in places along the southwest limb of the uplift, for example west of Rift Creek and on the south slopes of Douglas Peak, it lies directly and unconformably on the lower Sicker Group volcanics.

The formation consists of massive limestone beds with minor argillite and chert interbeds. The limestones are well bedded, varying from about 15 centimetres up to about 5 metres thick (Plate 1-8-4). They are predominantly bioclastic calcarenites and calcirudites, rich in broken crinoid stems ranging up to 2 centimetres in diameter. Bryozoa, brachipods, pelecypods, corals and trilobites have also been reported from these rocks (Yole, 1963, 1965). Fossil clasts are often replaced by silica and weather positively. Some limestone outcrops contain many thin chert beds developed by siliceous replacement of limestone. Thin black argillite and shale beds are developed in places, and maroon tuffaceous shales are seen in the basal part of the sequence in the Horne Lake area.

The Mount Mark Formation is the equivalent of the Buttle Lake Formation of Muller (1980) and other authors (for example, Yole, 1969).

St Mary's Lake Formation

The St Mary's Lake Formation conformably overlies the Mount Mark limestones. It is, however, only extensively preserved in three localities – St Mary's Lake, the west branch of the Cameron River, and the southwest slopes of Douglas Peak. It is cut out elsewhere by the unconformity beneath the Karmutsen Formation.

The formation comprises brownish weathering, grey sandstone and black argillite graded beds, volcanic sandstones and pebble conglomerates, black cherty argillite, greenish chert and minor jasper. Conglomerates contain volcanic and flat angular cherty argillite clasts. Scouring, load structures, normal and inverse grading, slumping and disrupted bedding are all observed in these sediments.

The St Mary's Lake Formation is probably equivalent to supra-limestone pillowed volcanics and minor sediments seen in the Nanoose uplift (Sutherland Brown and Yorath, 1985, and in preparation) and possibly to the Henshaw Formation of the Buttle Lake uplift (Jeffrey 1967).

VANCOUVER GROUP

Karmutsen Formation

Basaltic volcanics of the Karmutsen Formation underlie large parts of the map area, particularly around Mount Arrowsmith in the northeast, Mount Mark in the northwest and the Museum Creek area in the southwest. They comprise orange-brown-weathering pillowed flows, pillow breccias and hyaloclastite breccias interbedded with massive flows and sills. Typically the basalts are feldspar phyric, often with ragged or glomeroporphyritic feldspars in a fine-grained groundmass. Pillows are usually large, 1 to 2 metres in diameter, with thick chloritic selvages and abundant intrapillow hyaloclastite and quartz. Amygdules are common and are infilled with chlorite, calcite or epidote.

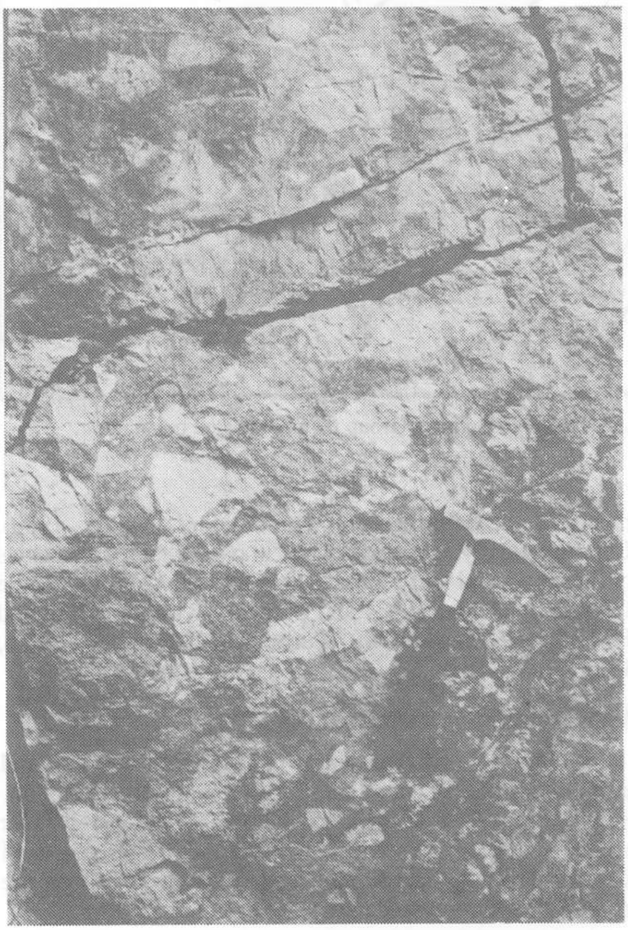


Plate 1-8-2: Pillow breccia, Duck Lake Formation, Sicker Group, Rift Creek area.

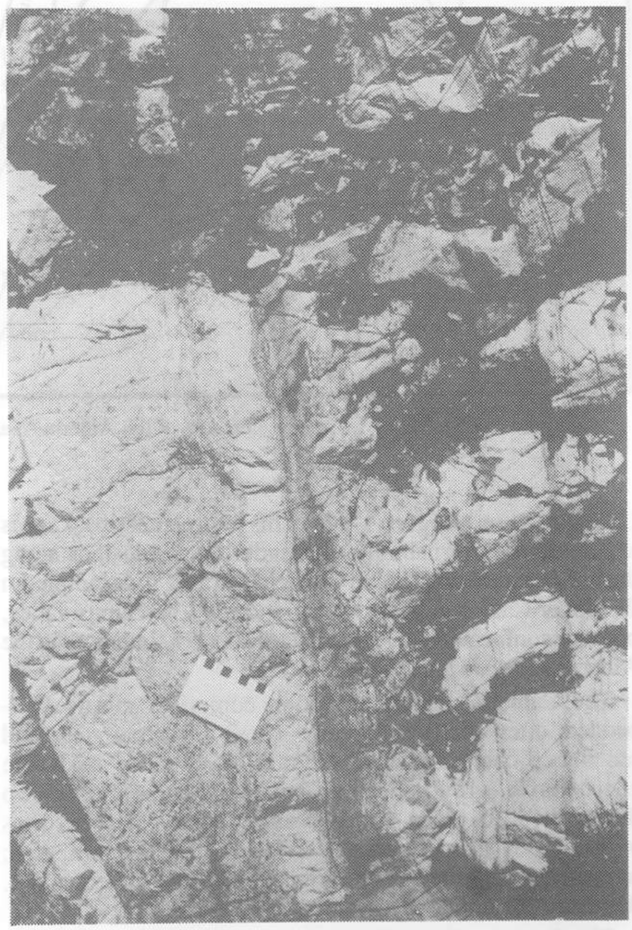


Plate 1-8-3: Well-bedded felsic tuffs, Duck Lake Formation, Sicker Group, Microwave Tower.

Diabase and gabbro dykes of probable Triassic age are widespread in the area, intruding Sicker Group rocks of all types. They are medium to coarse-grained diabase, gabbro, and leucogabbro with minor diorite, equigranular to porphyritic with feldspar phenocrysts. The glomeroporphyritic clusters typical of gabbros in the Duncan area (Massey and Friday, 1988) are rare in the Alberni area. Mafic phenocrysts are absent.

UPPER VANCOUVER GROUP

Outcrops of the Quatsino, Parson Bay and Sutton formations are restricted in the map area. Massive, pale-weathering, dark grey micrite of the Quatsino Formation outcrops along the Bamfield road south of Parsons Creek. A massive, poorly bedded limestone, with abundant silicified corals and other fossils along bedding planes, is associated with medium-grained, grey, limey sandstone on the south side of Mount Spencer. These rocks probably belong to the Parson Bay and Sutton formations. Cobbles of Parson Bay Formation(?) black calcareous argillite with ammonite remains are also found in the creeks draining this area.

BONANZA GROUP

Bonanza Group volcanic rocks overlie the Upper Vancouver Group sediments and are similarly restricted in outcrop. On Mount Spencer, basal, pale green feldspar-crystal tuffs and maroon tuffs and lapilli tuffs are overlain by pyroxene-feldspar crystal and crystal lapilli tuffs.

NANAIMO GROUP

Clastic sediments of the Nanaimo Group unconformably overlie older volcanic units and the Island intrusions. They are most thickly developed in the Alberni valley, although poorly exposed, except around the margin, due to Quaternary cover. Other major outcrop areas are around Labour Day Lake and the Cameron River–Summit Lake area. The sediments of the Nanaimo Group constitute major fining-upward cycles (Muller and Jeletzky 1970), of which the first, the Comox-Haslam, is developed in the map area.

COMOX FORMATION

The basal Benson member of the Comox Formation is a coarse, poorly bedded pebble and boulder conglomerate which is absent in many places. The conglomerates have rounded clasts which consist of a variety of volcanic and intrusive lithologies of immediate local origin; larger boulders are often angular. Minor red hematitic siltstone interbeds are occasionally seen.

Overlying sandstones are medium to coarse grained, grey with rusty weathered surfaces. They contain feldspar crystals and abundant lithic fragments, mostly volcanic rocks of local provenance. Black plant-fragments are characteristic of many beds. Calcareous cement is common. A few granule and pebble conglomerate beds are interbedded with the sandstones. Several sandstone beds yielded abundant fossil faunas, including gastropods, pelecypods and possible broken ammonites and nautiloids.

HASLAM FORMATION

The Haslam Formation consists of characteristic rusty weathering, black argillite and siltstone. It is fine to silty, often poorly bedded and friable, fracturing to pencil-shaped pieces. Interbeds of fine to medium-grained, grey silty sandstone up to 1 metre thick may occur within the argillites. Calcareous concretions may be found and replacement was extensive enough in one outcrop southwest of Mount Patlicant to result in a massive limestone that grades laterally into argillite. Fossils are present within the Haslam Formation, though poorly preserved due to the ubiquitous pencil-and-rod fracturing, and include gastropods, pelecypods, ammonites and plant material.

INTRUSIONS

ISLAND INTRUSIONS

Several granodioritic plutons and stocks of Middle Jurassic age occur in the area. These bodies are usually elongate in shape, although the Fourth Lake stock is roughly circular. The intrusions show considerable lithological varia-

TABLE 1-8-1
COMPARISON OF PILLOW LAVAS IN THE DUCK LAKE AND KARMUTSEN FORMATIONS

	Duck Lake Formation	Karmutsen Formation
Lithology	Green-grey to maroon, mostly aphyric basalt, variolites common, feldspar basalt less abundant.	Black-weathering orange-brown, feldspar basalts (feldspars ragged) dominate, aphyric basalts common. Variolites rare.
Pillows—shape	Tightly packed, rounded.	More loosely packed, rounded to irregular.
—size	30 cm–2 m; uniform within a flow	Average 1 m; some variability within flow units.
—selvages	Thin, 1 cm.	Thick chloritic, 2–3 cm.
—intra-pillow	Poorly developed, jasper, chert or quartz infillings, hyaloclastite rare.	Very common, hyaloclastite, "dallasite" chlorite or quartz infillings.
Associated lithologies	i Monolithic basaltic breccia, pillow breccia common. Hyalclastite rare.	Pillow breccia, hyaloclastite clastite breccia and isolated pillow hyaloclastite clastite breccia common.
	ii Massive flows, sills common	Massive flows and sills common.
	iii Well-bedded cherts, jasper, magnetite-hematite-chert, cherty tuff, common in upper parts of formation.	Cherty tuffs rare.
	iv Felsic volcanics sporadic at top of unit; dacite-rhyolite dykes common.	Felsic material absent.

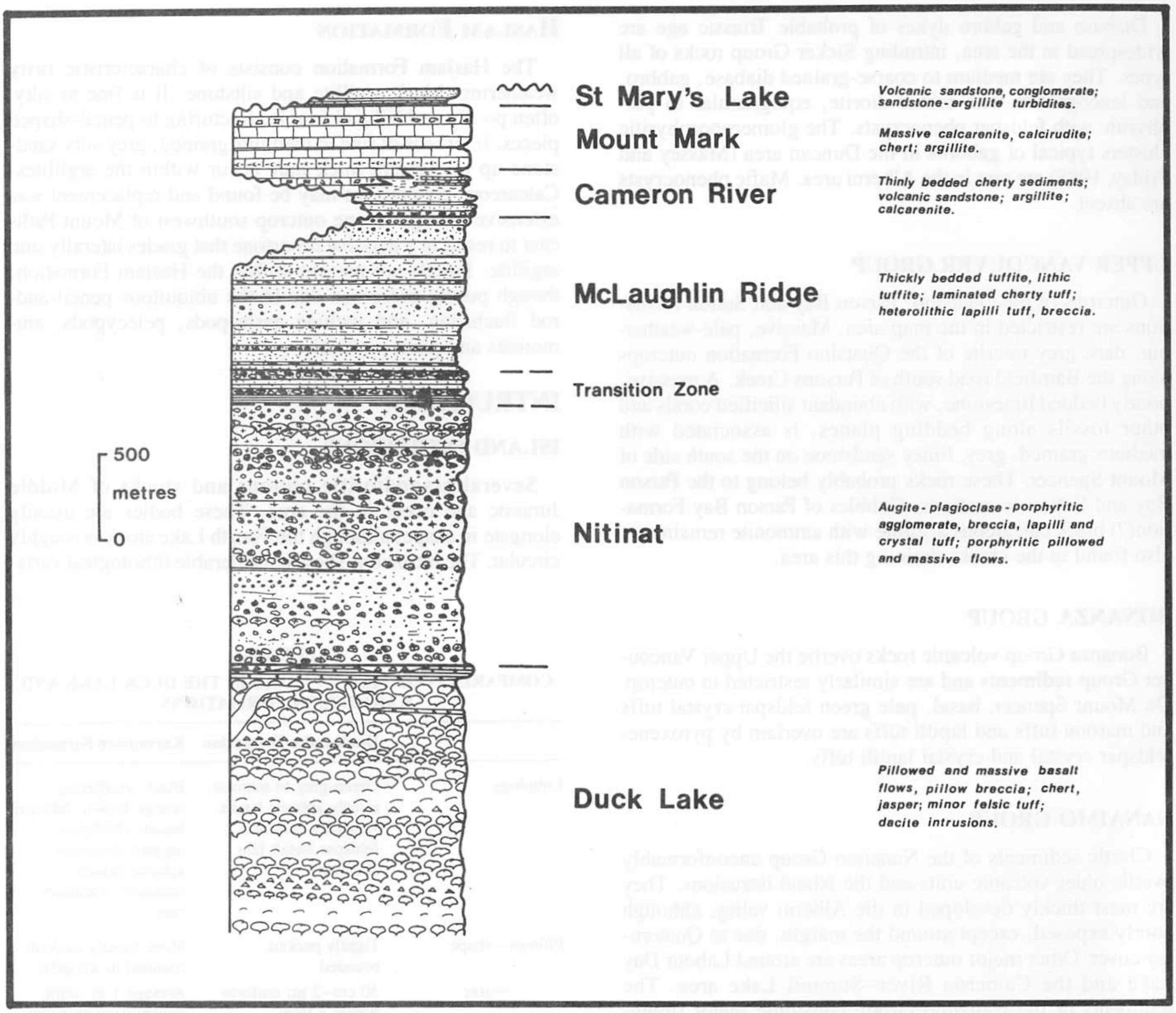


Figure 1-8-4: Composite stratigraphic section of the Sicker Group (scale approximate). Lithographic symbols are schematic.

tion. The Port Alberni pluton is fairly uniform throughout, comprising granodiorite and quartz diorite. The Fourth Lake stock is also apparently uniform in outcrop, but displays a gradual compositional variation from diorite and monzonite in the north to quartz diorite and granite in the south. The Corrigan pluton, in contrast, is heterogeneous and composite, comprising a mix of diorite, quartz diorite, granodiorite and monzogranite phases with abundant minor intrusive dykes.

The dominant lithology in most bodies is a medium to coarse-grained, equigranular granodiorite to quartz diorite with a characteristic "salt-and-pepper" texture. Quartz is usually irregular in shape, often interstitial to the feldspars. Feldspars are white, though some pink staining is seen on weathered surfaces, and usually form subhedral laths. Hornblende is the principal mafic mineral. It is tabular to acicular, black to greenish black in colour and may be slightly larger in size than the feldspars. Where present, black to brown biotite books are subordinate to hornblende. Chlorite replaces hornblende and biotite in altered rocks. Colour index varies from 10 to 20 in the granodiorites, but may range up to 40 in diorites. White fine-grained aplite dykelets and veins cut the granodiorites.

Most of the intrusive bodies are rich in inclusions, particularly in marginal zones where agmatitic intrusive breccias are developed. The angular to subrounded xenoliths are of local country rock lithologies showing a range of amphibolitization and assimilation features. The xenoliths are normally randomly oriented.

A variety of dykes and small irregular intrusions occur throughout the area. They are probably coeval with the Island intrusions with which they are spatially related. Lithologically, they include intermediate feldspar porphyry, hornblende-feldspar porphyry and minor diabase.

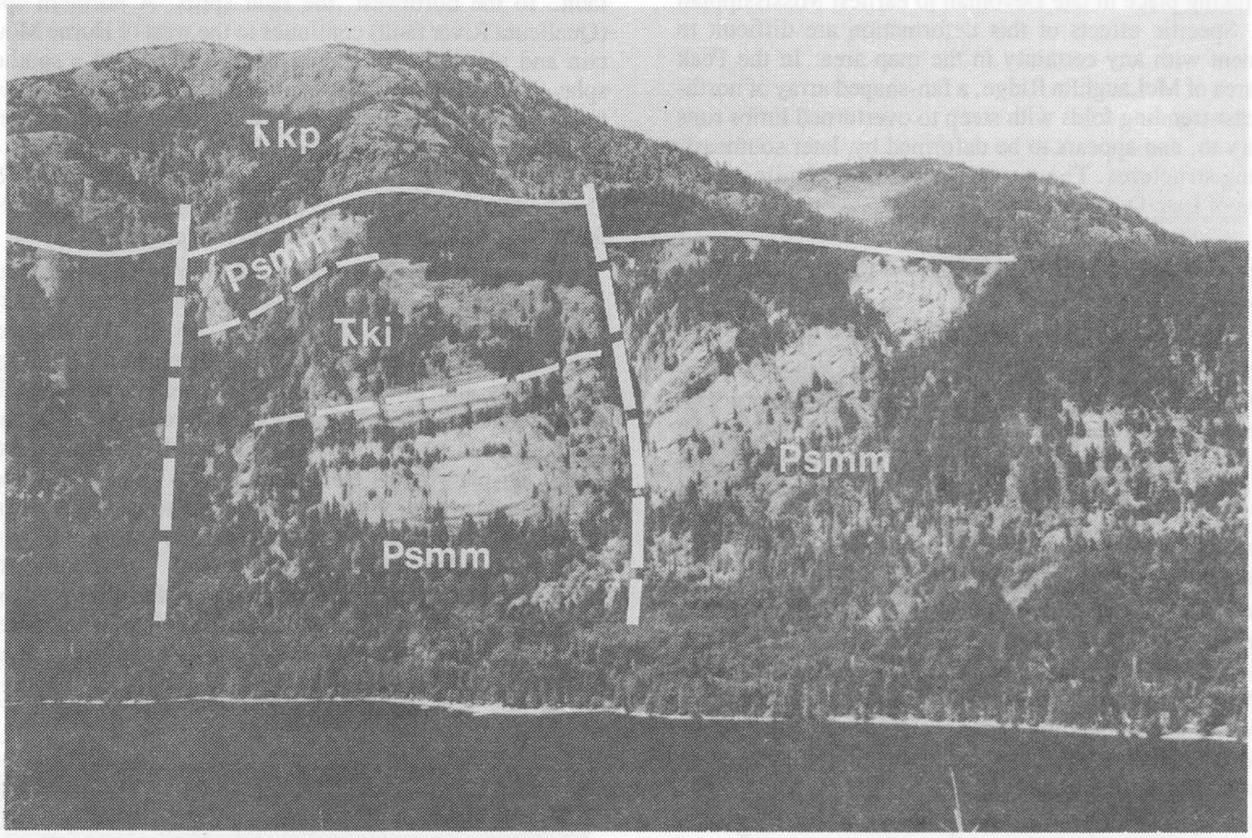


Plate 1-8-4: View northwards across Horne Lake to Mount Mark. Mount Mark Formation (PSmm) in east limb of Horne Lake syncline is intruded by gabbro sills (TrKi) and unconformably overlain by Karmutsen Formation pillow lavas (TrKp).

TERTIARY INTRUSIONS

Porphyritic dacite sills and dykes occur throughout the map area (Plate 1-8-5). Though no geochronometric ages are yet available for these intrusions, they are comparable to "Catface intrusions" seen elsewhere on Vancouver Island and thus probably of late Eocene to early Oligocene age. The prophyries contain varying proportions of feldspar and hornblende phenocrysts in a fine-grained, light to medium grey groundmass (Plate 1-8-6). Feldspar is white plagioclase typically forming subhedral to euhedral laths up to 1 centimetre long but averaging 1 to 2 millimetres. Hornblende occurs as elongate laths or needles up to 1.5 centimetres long. Phenocrysts vary in both absolute proportions (from about 10 to 30 per cent of the rock) and in relative proportions of hornblende to feldspar. Aphyric dacite is uncommon.

The Tertiary intrusions occur as dykes up to 3 metres wide, intruding most older lithologies. Dykes are also found intruding major fault zones, which appear to have acted as passage ways for the magmas. Where the porphyries have penetrated the Nanaimo Group sediments, they have spread out as thick sills, for example, at Patlicant Mountain and Labour Day Lake.

STRUCTURE AND TECTONICS

The Alberni–Nanaimo Lakes area has a complex tectonic history involving at least five major deformational events. These events have often rejuvenated previous structures rendering specific analysis of their effects difficult. The present map pattern is dominated by the effects of Tertiary(?) faulting, though older events are important in establishing relationships within fault blocks (Figure 1-8-3).

PHASE 1 — LATE DEVONIAN

The unconformity between the upper Sicker Group sediments and the underlying volcanics, along the southwestern limb of the Cowichan uplift, points to a major deformational

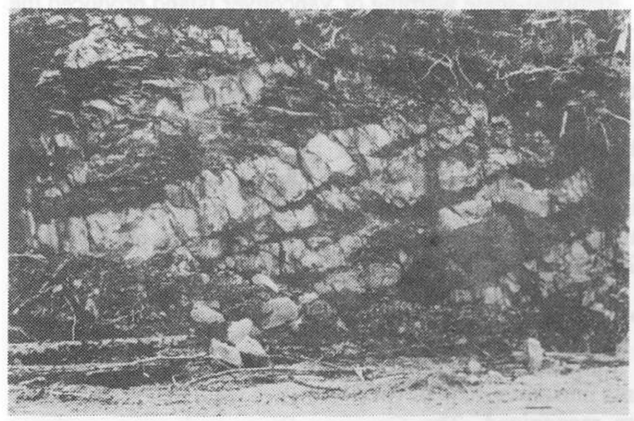


Plate 1-8-5: Tertiary hornblende-feldspar porphyry sills intruding Comox Formation sandstones and siltstones,southwest of Labour Day Lake.

event taking place in late Devonian to earliest Mississippian times. Specific effects of this deformation are difficult to document with any certainty in the map area. In the Peak Lake area of McLaughlin Ridge, a fan-shaped array of north-northeast-trending folds with steep to overturned limbs runs contrary to, and appears to be deformed by, later southeast-trending structures. These north-northeast-trending folds may be of Late Devonian age.

PHASE 2 — MIDDLE PERMIAN — PRE-MIDDLE TRIASSIC

All Sicker Group rocks have been affected by a series of southeast-trending, upright to overturned, southwest-verging folds with abundant parasitic minor folds. Major fold axes are often difficult to locate in the field but can be estimated from regional map patterns. Overturning of beds is seen locally in minor folds throughout the area and on the southern limb of a regional anticlinal fold in the Nitinat River area (see Fig 1-8-3). The folds are truncated by the overlying Karmutsen Formation (Plate 1-8-4).

Penetrative axial planar foliation is generally absent throughout most of the area. However, Sicker Group volcanics to the west of the Mineral Creek fault and south of the Lacy fault have a well-developed north-northwest-trending schistosity with generally steep northeasterly dips. Rare chlorite crenulation lineations and elongation of pillows are subhorizontal to shallow dipping.

Faulting accompanied or postdated folding. On McLaughlin Ridge several north to northeast-trending faults crosscut the folds, but are themselves truncated by Tertiary(?) faults. Their age is unknown but may be pre-Triassic. On the east side of the West Cameron River valley, small-scale faults offset Sicker Group sediments but do not affect the unconformably overlying Karmutsen Formation.

PHASE 3 — LATE TRIASSIC

Extensive crustal dilation accompanied the evolution of Karmutsen Formation lavas and intrusions. However, deformation specifically associated with this event has not yet been documented within the Alberni area.

PHASE 4 — MIDDLE JURASSIC

Regional-scale warping of Vancouver Island produced the three major geanticlinal uplifts cored by Sicker Group rocks (Figure 1-8-1), including the Cowichan uplift. Plutons and stocks of the Middle Jurassic Island intrusions are often elongate parallel to the uplifts, although they apparently show little or no affects of the deformation themselves, suggesting the intrusions were syntectonic to postdeformation. Uplift and erosion followed sometime in the Late Jurassic to Middle Cretaceous, establishing the pre-Nanaimo Group topography.

PHASE 5 — TERTIARY(?)

Large-scale northwesterly trending thrusts cut the map area into several slices (Figure 1-8-3). Two major fault zones are recognized. The Cameron River fault runs southeast along the Cameron River valley, north of Labour Day Lake, past Third Lake and down Dunsmuir Creek to join the Fulton fault. To the northwest, the fault splits. A northern splay (Qualicum River fault) continues to the west of Horne Mountain and along the Qualicum River valley, and a southern splay (Lacy fault) runs west near Summit Lake and northwest to Lacy Lake and Esary Lake. The Beaufort fault zone trends southeast along the Beaufort Ranges, passes just east of Bainbridge Lake and Patlicant Mountain and down Rift Creek valley, continuing to the southwest as the Cowichan fault. This fault zone contains several splays.

Where exposed, these thrusts are high-angle reverse faults which dip between 45 and 90 degrees to the east or north-northeast. Slip planes may be relatively sharp and narrow, but wide schistose zones have formed in receptive lithologies and splays and imbricate zones are well developed. The thrusts generally place older rocks over younger and become listric at mid-crustal depths (Sutherland Brown and Yorath, 1985). Displacements along fault planes are undetermined. Lithological and stratigraphical comparison along the Cameron River fault suggests that offsets are probably in the order of 5 to 10 kilometres horizontally and 1 to 2 kilometres vertically. Other faults are not expected to differ markedly from this. Direction of motion is suspected to be westwards; slickensides on fault planes indicate latest movement was horizontal and northwesterly directed.

Plate 1-8-6: Tertiary hornblende-feldspar porphyry, Labour Day Lake.

The Henry Lake fault connects the Cameron River and Beaufort fault zones, and may have a similar reverse fault geometry although this is speculative at this time. The north-trending Mineral Creek fault offsets the Cameron River and Beaufort faults. It is a subvertical shear zone with apparent sinistral displacements of less than 1 kilometre. Vertical displacements are undetermined.

The age of faulting is unknown at this time. The faulting involves sediments of the Nanaimo Group as young as the Cedar District Formation. However, the faults are intruded by Tertiary porphyry dykes which show only minor late-stage brittle fracturing. It is suspected that most of the faulting took place during the Tertiary (pre-Oligocene), possibly during crustal shortening accompanying the accretion of the Pacific Rim and Crescent terranes to the south and west of the project area.

METAMORPHISM

The metamorphic grade in the area is generally quite low, but increases with the age and structural position of the rocks. Nanaimo Group sediments are essentially unmetamorphosed showing only diagenetic alteration in detrital iron oxides and calcareous cements. Basalts of the Karmutsen Formation show amygdule infillings and veins of chlorite, calcite, epidote and quartz, and alteration assemblages typical of the prehnite-pumpellyite facies. Intrusive rocks are unaltered except in chloritic shear zones.

Sediments of the Sicker Group are essentially unmetamorphosed except where involved in intense shearing where chlorite and sericite have developed along foliation planes. Sicker Group volcanic rocks, however, show the effects of greenschist metamorphism. Intermediate to mafic rocks have chloritic schistose matrixes with epidote alteration of feldspars and variable uralitization of pyroxenes. Secondary quartz, calcite, chlorite and epidote are common in veins and amygdules.

Jurassic granodiorite stocks and plutons in the map area show only sporadic development of contact metamorphic aureoles around their perimeters. The effects of this are most vividly illustrated in the skarning of limestone of the Mount Mark Formation around the Fourth Lake stock. Minor hornfelsing of volcanics and sediments is apparent around some smaller stocks, for example in the upper Franklin River valley, and amphibolitization of xenoliths is common.

MINERAL DEPOSITS

Exploration and mining in the Alberni–Nanaimo Lakes area started as early as 1862 with small-scale placer-gold mining on China Creek. Activity increased in the 1890s, principally along Alberni Inlet, China Creek, Mineral Creek and in King Solomon Basin. Several gold veins were staked and modest production was acheived from the Victoria property. A lull in exploration ensued until the 1930s when prospecting for gold was renewed, resulting in limited production from the Victoria, Havilah, Thistle, WWW and Black Panther claims (see Table 1-8-2). Activity declined again after World War II. The 1960s witnessed another round of exploration, focused on the search for porphyry copper and iron-copper skarn deposits, and the regional evaluation of the Esquimalt and Nanaimo Railway Land Grant. No production resulted, however. The present cycle of exploration followed the discovery of the HW polymetallic massive sulphide orebody at Buttle Lake. All areas of Sicker Group outcrop in the Alberni–Nanaimo Lakes area have since been staked and numerous exploration targets defined by mining companies and local prospectors. Extensive drilling has been carried out on many properties and Westmin Resources Limited collared a 2-kilometre exploration adit on the Mineral Creek zone in 1988.

TABLE 1-8-2
MINERAL PRODUCTION IN THE ALBERNI AREA

Property	Production Years	Tonnes	Au g	Ag g	Cu kg	Pb kg
Victoria	1898, 1934–36	365	9,425	1,679	88	
Havilah	1936 & 1939	949	8,056	43,669	1,925	5,750
Thistle	1938–42	6,283	85,874	65,969	309,088	
Black Panther	1947–48, 1950	1,715	15,832	29,642	226	5,588
WWW	1899, 1935, 1940–41	106	14,650	15,552	244	1,100
B D Q	1940	1	62	156	11	
Kitchener	1929	168	124	653	5,366	

Unrecorded production of marble has also taken place from the Horne Lake property.

Several types of mineral deposit are present in the Alberni–Nanaimo Lakes area.

Volcanogenic, polymetallic massive sulphides and exhalative oxides: Polymetallic massive sulphide deposits have been a major target within the Sicker Group since the successful development of the Westmin Resources Limited mine in the Buttle Lake area in the late 1960s. Within the Cowichan uplift, deposits have been found associated with felsic volcanics in the McLaughlin Ridge Formation (for example, Lara, Mount Sicker). However, in the Alberni area the McLaughlin Ridge Formation is dominated by mafic to intermeditate volcaniclastic sediments and appears barren of syngenetic mineralization.

Cherts, jaspers, manganiferous cherts and massive sulphides of probable exhalative origin are found within the map area, occurring interbedded with and overlying pillowed basalts of the Duck Lake Formation. Minor felsic tuffs may overlie them. The most important showing so far discovered in this unit is the "900 Zone" on Westmin Resource's Debbie property. A lean iron formation with a magnetite-rich base is locally isoclinally folded with fold axes plunging south-southeast. Beneath and crosscutting the chert horizon is a quartz-vein stockwork which may be younger (Tertiary ?) in age. Native gold, pyrite, magnetite and arsenopyrite occur in quartz veinlets in the chert and jasper and also in narrow carbonate veinlets that crosscut the quartz veinlets. Similar iron amd manganese-rich cherts have been prospected in the Summit–Horne Lake area, for example, Lacy Lake, and occur at many other localities, for example, upper China Creek and the Butler Peak–Green Mountain area (Mountain/ Jubilee property).

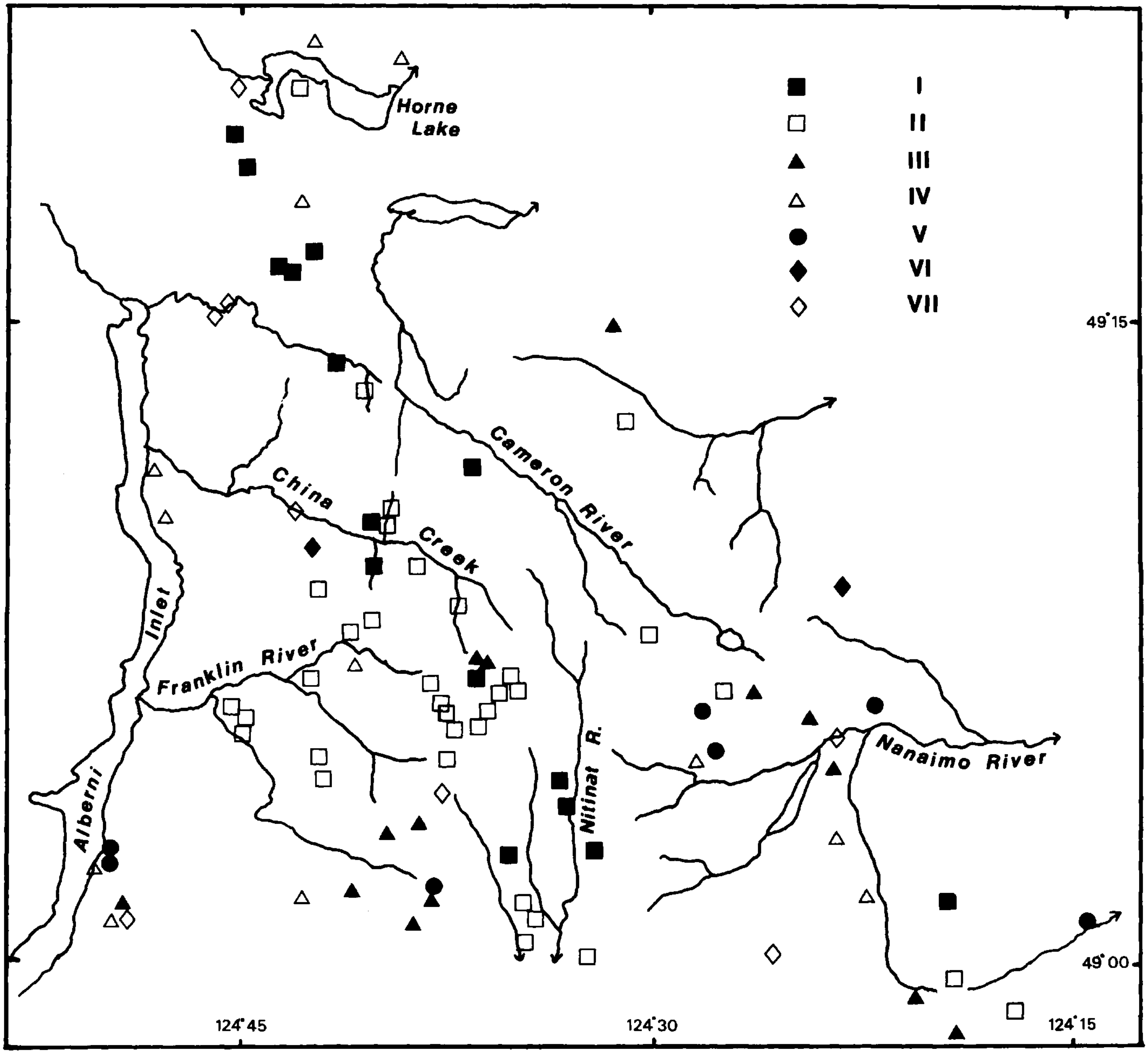


Figure I-8-5: Distribution of mineral deposits in the Alberni–Nanaimo Lakes area. I Volcanogenic polymetallic massive sulphides and exhalative oxides; II Gold-bearing quartz-carbonate veins along shears; III Copper-molybdenum veins and stockworks: IV Other base-metal veins; V Iron-copper skarns; VI Epigenetic quartz-arsenic(-antimony) veins; VII Other mineral deposits.

Massive sulphides also occur at this stratigraphic level, although they may have been remobilized during later shearing. The major areas of development are on McLaughlin Ridge (Regina, Cop Creek) and in the Nitinat River – Raft Creek area (Kitkat, Raft). Sulphides are also reported in felsic volcanics on the Main/Railway showing north of Stokes. None of these occurrences has yet proven economic.

Gold-bearing pyrite-chalcopyrite-quartz-carbonate veins along shears: As in the Cowichan Lake and Duncan areas, many of the faults and shears cutting the Alberni–Nanaimo Lakes map area are veined by rusty orange-weathering quartz-carbonate. The more economically important veins are localized along the Tertiary(?) thrusts and crossfaults, for example, the Victoria vein on the Mineral Creek fault and the Black Panther vein on the Beaufort fault zone. The quartz veins are variable in strike length and range up to about 1 metre wide. Carbonate alteration zones up to several metres wide border the veins and may extend into the hangingwall and footwall. Mineralization has taken place episodically during motion on the faults, with earlier veins and alteration being disrupted and reveined. Unaltered porphyry dykes often crosscut veins, suggesting mineralization is pre-Late Tertiary in age. Commonly reported sulphides are pyrite, pyrrhotite, chalcopyrite and arsenopyrite. Sphalerite and galena are less common. The carbonate is principally ankerite and calcite. Clots of dark green fuchsite or mariposite occur occasionally with the carbonate. Gold is found both in the discrete quartz veins and in the alteration haloes where it appears to be associated with the sulphides.

Most of the mineral production in the area has been from these quartz-carbonate shear-zone deposits and they are presently the targets of much exploration activity, for example, the Debbie (Mineral Creek zone), Thistle, Black Panther and Lizard Lake properties.

Copper-molybdenum quartz veins and stockworks: Sulphide-bearing quartz veins occur in granodiorite and adjacent country rock on several properties in the map area. Most of these are associated with the Corrigan Creek pluton (for example, Andy and WWW), but other showings have been found in the Mount McQuillan stock (Sol and Havilah), the Fourth Lake stock (Surprise and WO 7), the Nanaimo Lakes batholith (Louishman-Maureenah) and the Mount Buttle stock (Allies and Close). Most of the showings are veins but well developed stockwork features are seen on the Andy property and disseminated sulphides on the Starlight. The quartz veins generally contain pyrite or pyrrhotite with chalcopyrite and lesser molybdenite.

Other base-metal veins: Several chalcopyrite-pyrite-quartz vein deposits are hosted in Sicker Group (Rush and Nan), Karmutsen Formation (Lofstrom and Qualicum) or Bonanza Group (Union Jack and MOR) lithologies. Although poorly documented, these veins appear to be related to shears but lack the ankeritic alteration associated with the Late Eocene(?) gold-copper veins, and are not obviously related to Jurassic stocks. The PD showing consists of sphalerite-arsenopyrite-bearing veins in Mount Mark Formation limestone. Undoubtedly, several ages and styles of mineralization are grouped together here and more documentation is needed to separate them.

Skarns: Jurassic Island intrusion granodiorites often produce skarns when they intrude limey rocks and skarning may be associated with some of the copper-molybdenum vein deposits (Mary), and with the mined ore at the Thistle mine (Stevenson 1945). Iron-copper skarns, similar to those in the Cowichan area (Blue Grouse) are also found in the Alberni–Nanaimo Lakes area. These received some attention in the past for their copper potential but are now undergoing re-evaluation for gold (Ettlinger and Ray, 1987). The host rocks include limestones from both the Mount Mark Formation (Skarn and Tangle 1) and the Quatsino Formation (Kitchener) as well as limey units within the upper part of the Karmutsen Formation. Sulphides (pyrite, chalcopyrite) and iron oxides (magnetite) occur as irregular pods, lenses and veins within the calc-silicate skarn. Gangue minerals include yellow to brown garnet, dark green pyroxene, epidote, calcite, quartz and chlorite.

On the Villalta property, the main exploration target is a stratiform aurifeous hematitic cap developed on the skarn. This subhorizontal cap unconformably overlies post-skarn karstic collapse breccias, although hematite veins crosscut the skarn and hematite also replaces garnet. The cap is overlain by Nanaimo Group conglomerate and may be of middle Cretaceous age.

Epigenetic quartz-arsenic(-antimony) veins: Realgar, stibnite and pyrite are variably developed in Tertiary sills and Haslam Formation argillites on at least two properties (Coal and Grizzly) in the area. Strong to moderate clay-carbonate alteration and silicification accompany the mineralization and affect the porphyry sills and the argillites. Mineralization on the Coal claims is probably spatially related to the Moriarty fault. These veins, although slightly younger, are probably genetically related to the quartz-ankerite shear veins of Group 2 above.

Other deposits: Various nonmetallic deposits have been exploited in the area, particularly Quaternary gravels for aggregate. Marble was quarried on the Horne Lake property. Subeconomic grades of clay, shale, rhodonite and limestone have been reported from various localities in the area.

ACKNOWLEDGMENTS

The authors acknowledge the enthusiastic and capable assistance provided by Janet Riddell and Sandra Dumais both in the field and the office. Invaluable discussions of the regional geology with Athol Sutherland Brown, Christopher Yorath, Timothy England, Stephen Juras and many others have enriched this project. This season's fieldwork could not have proceeded without the cooperation of MacMillan-Bloedel Limited (Cameron Division) and Crown Forest Limited (Nanaimo Lakes Division). This manuscript was improved by editorial suggestions of John Newell and Brian Grant.

REFERENCES

Armstrong, R.L., Isachsen, C., and Scott, K. (1986): Rb-Sr and Sr Isotopic Study and U-Pb Dating of Vancouver Group Igneous Rocks and Related Island Intrusions and of the Coast Plutonic Complex and Early Cenozoic Igneous Rocks of Vancouver Island, British Columbia, Unpublished Preprint.

Brandon, M.T., Orchard, M.J., Parrish, R.R., Sutherland Brown, A., and Yorath, C.J. (1986): Fossil Ages and Isotopic Dates from the Paleozoic Sicker Group and Associated Intrusive Rocks, Vancouver Island, British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 86-1A, pages 683-696.

Clapp, C.H. (1912): Southern Vancouver Island, *Geological Survey of Canada*, Memoir 13, 208 pages.

Clapp, C.H. and Cooke, H.C. (1917): Sooke and Duncan Map-areas, Vancouver Island, *Geological Survey of Canada*, Memoir 96, 445 pages.

Ettlinger, A.D. and Ray, G.E. (1987): Gold-enriched Skarn Deposits of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 263-279.

Fyles, J.T. (1955): Geology of the Cowichan Lake Area, Vancouver Island, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 37, 79 pages.

Gunning, H.C. (1931): Buttle Lake Map-area, Vancouver Island, *Geological Survey of Canada*, Summary Report 1930, Part A, pages 56-78.

Jeffrey, W.G. (1967): Buttle Lake, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File Report, June 21-67.

Juras, S. (1987): Geology of the Westmin Resources Myra Falls Mine-area, Vancouver Island, British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*.

Laanela, H. (1966): Mineral Occurrences on E. & N. Land Grant, Vancouver Island, internal company reports for Gunnex Limited, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Property Files.

Massey, N.W.D. and Friday, S.J. (1987a): Geology of the Cowichan Lake Area, Vancouver Island (92C/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 223-229.

Massey, N.W.D., Friday, S.J., Tercier P.E. and Rublee V.J. (1987b): Geology of the Cowichan Lake Area, NTS 92C/16, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-2.

——— (1988a): Geology of the Chemainus River–Duncan Area, Vancouver Island (92C/16; 92B/13), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 81-91.

Massey, N.W.D., Friday, S.J., Tercier, P.E., and Potter, T.E. (1988b): Geology of the Duncan and Chemainus River Area, NTS 92B/13 and 92C/16E, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-8.

Muller, J.E. (1980): The Paleozoic Sicker Group of Vancouver Island, British Columbia, *Geological Survey of Canada*, Paper 79-30, 23 pages.

Muller, J.E. and Carson, D.J.T. (1969) Geology and Mineral Deposits of Alberni Map Area, Vancouver Island and Gulf Islands, *Geological Survey of Canada*, Paper 68-50, 52 pages (includes Map 17-1968).

Muller, J.E., and Jeletzky, J.A. (1970): Geology of the Upper Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia, *Geological Survey of Canada*, Paper 69-25, 77 pages.

Stevenson, J.S. (1945): Geology and Ore Deposits of the China Creek Area, Vancouver Island, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Annual Report, 1944, pages 5-26.

Sutherland Brown, A. and Yorath, C.J. (1985): LITHOPROBE Profile Across Southern Vancouver Island: Geology and Tectonics, *in* Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera, *Geological Society of America*, Cordilleran Section Meeting, Vancouver, B.C., May 1985.

Sutherland Brown, A. and Yorath, C.J. (in preparation): Stratigraphy, *in* LITHOPROBE Phase 1, Southern Vancouver Island: Geology and Geophysics, Yorath, C.J. (Editor), *Geological Survey of Canada*, Bulletin.

Sutherland Brown, A., Yorath, C.J., Anderson, R.G., and Dom, K. (1986): Geological Maps of Southern Vancouver Island, LITHOPROBE 1, *Geological Survey of Canada*, Open File 1272, 10 sheets.

Yole, R.W. (1963): An Early Permian Fauna from Vancouver Island, British Columbia, Bulletin, *Canadian Petroleum Geologists*, Volume 11, pages 138-149.

——— (1964): A Faunal and Stratigraphic Study of Upper Paleozoic Rocks of Vancouver Island, British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*.

——— (1969): Upper Paleozoic Stratigraphy of Vancouver Island, British Columbia, *Geological Association of Canada*, Proceedings, Volume 20, pages 30-40.

GALENA LEAD ISOTOPE MODEL FOR VANCOUVER ISLAND*

By Anne Andrew and Colin I. Godwin
The University of British Columbia

KEYWORDS: Geochronology, galena lead isotope, terrane-specific models, deposit origin, deposit age, Wrangellia, Vancouver Island.

INTRODUCTION

This paper demonstrates how a galena lead isotope model can be used to make decisions about the age and origin of ore deposits on Vancouver Island. To build this model we draw on the galena data of Table 1-9-1 (*compare* Andrew and Godwin, in press a, b, c and Godwin *et al.*, 1988).

Galena lead isotope data from Vancouver Island do not show a systematic evolution with time. Therefore they cannot be interpreted using existing lead isotope models [for example, Stacey and Kramers (1975), Doe and Zartman (1979), Godwin and Sinclair (1982), and Andrew *et al.* (1984)]. Godwin *et al.* (1988) have drawn attention to the need for terrane-specific models for lead isotope interpretation. The model presented here is applicable to Wrangellia, of which Vancouver Island is a part.

GENERAL GEOLOGY OF VANCOUVER ISLAND

The magmatic history of Vancouver Island can be simplified into four major episodes: (1) formation of the Paleozoic volcanic arc of the Sicker Group, (2) extrusion of the Triassic tholeiitic flood basalts of the Karmutsen Formation, (3) development of the Jurassic volcanic arc of the Bonanza Group and related Island intrusions, and (4) Tertiary volcanic and plutonic activity including emplacement of the Tertiary Catface intrusions.

Sicker Group anticlinoria consist of volcanic and volcaniclastic rocks and greywackes that constitute a Paleozoic volcanic arc. The lowermost part of the Sicker Group consists of the gabbroic and basaltic Nitinat Formation (Muller, 1980; Sutherland Brown *et al.*, 1986); this might be host to gold deposits in the Port Alberni area (for example, Debbie; R. Walker, personal communication, 1986). The middle part, the Myra Formation, consists mainly of more felsic volcanic and volcaniclastic rocks that host volcanogenic massive sulphide ore deposits at the south end of Buttle Lake (Buttle Lake camp; Walker, 1980; Juras, 1987) and at Mount Sicker (Lenora and Tyee; Massey and Friday, 1988). The top of the Sicker Group is delimited by limestone of the Buttle Lake Formation, which contains Middle Pennsylvanian fusilinids (Sada and Danner, 1974), and Early Permian conodont assemblages (Brandon *et al.*, 1986).

Massive outpourings of tholeiitic basalt of the Karmutsen Formation occurred in the Late Triassic. These basalts unconformably overlie the Sicker Group, forming a thick (up to 6 kilometres) sequence of massive, pillowed and brecciated flows and sills (Carlisle and Suzuki, 1974; Muller, 1980). The Karmutsen Formation is overlain conformably by the Late Triassic Quatsino and Parsons Bay formations, dominantly of limestone and shale respectively (Muller, 1980).

An Early to Middle Jurassic island arc assemblage is made np of volcanic and volcaniclastic rocks known as the Bonanza Group. Coeval with Bonanza volcanism was the emplacement of major quartz diorite to granodiorite batholiths, known as the Island intrusions. The Island Copper porphyry copper-molybdenum deposit is related to this magmatic episode.

Cretaceous sedimentary rocks of the Nanaimo Group overlie all preceding units with marked angular unconformity.

Tertiary teetonic events involved truncation of Vancouver Island to the west and south, and accretion of several small terranes. The Pacific Rim complex, a Mesozoic subduction complex analogous to the Franciscan of California, was accreted along the western margin of Vancouver Island during the Paleocene (65 to 55 Ma; Brandon and Massey, 1985). The Leech River complex was accreted to the south of the San Juan fault in the Late Eocene or Early Oligocene (40 to 30 Ma; Rusmore and Cowan, 1985). The paleogeography of southern Vancouver Island was further modified by accretion of the Eocene Metchosin volcanic rocks south of the Leech River fault (post 40 Ma; Rusmore and Cowan, 1985).

Relationships between the above Tertiary (about 40 Ma) tectonic events, and the small Eocene Catface quartz diorite intrusions throughout Vancouver Island (Carson, 1973) are not known unequivocally. Ewing (1981), Isachsen (1984), Sutherland Brown and Yorath (1985), and R.L. Armstrong *et al.* (*in preparation*), relate them to magmatism in the arc-trench gap between a Cenozoic subducting plate and the coeval Kamloops Group volcanism. They are also coeval with amphibolite-grade metamorphism in the Leech River complex (Rusmore and Cowan, 1985), and with a major reorganization of plate motions in the Pacific (Ewing, 1981; Brandon and Massey, 1985). Gold-quartz veins in the Zeballos district are related to this plutonic episode (Hansen and Sinclair, 1984; Andrew and Godwin, *in press* c).

THE MODEL

Galena lead isotope data (Table 1-9-1) from Paleozoic, Triassic, Jurassic and Tertiary episodes of mineralization are plotted on Figure 1-9-1. Also shown are whole-rock initial ratios for the Jurassic Island intrusions and Tertiary Catface intrusions. Where these plutons directly contribute lead to deposits, there should be similarities in lead isotopes. Three fields are defined in both the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plots in Figure 1-9-1. A lower field in both of these plots is defined by

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

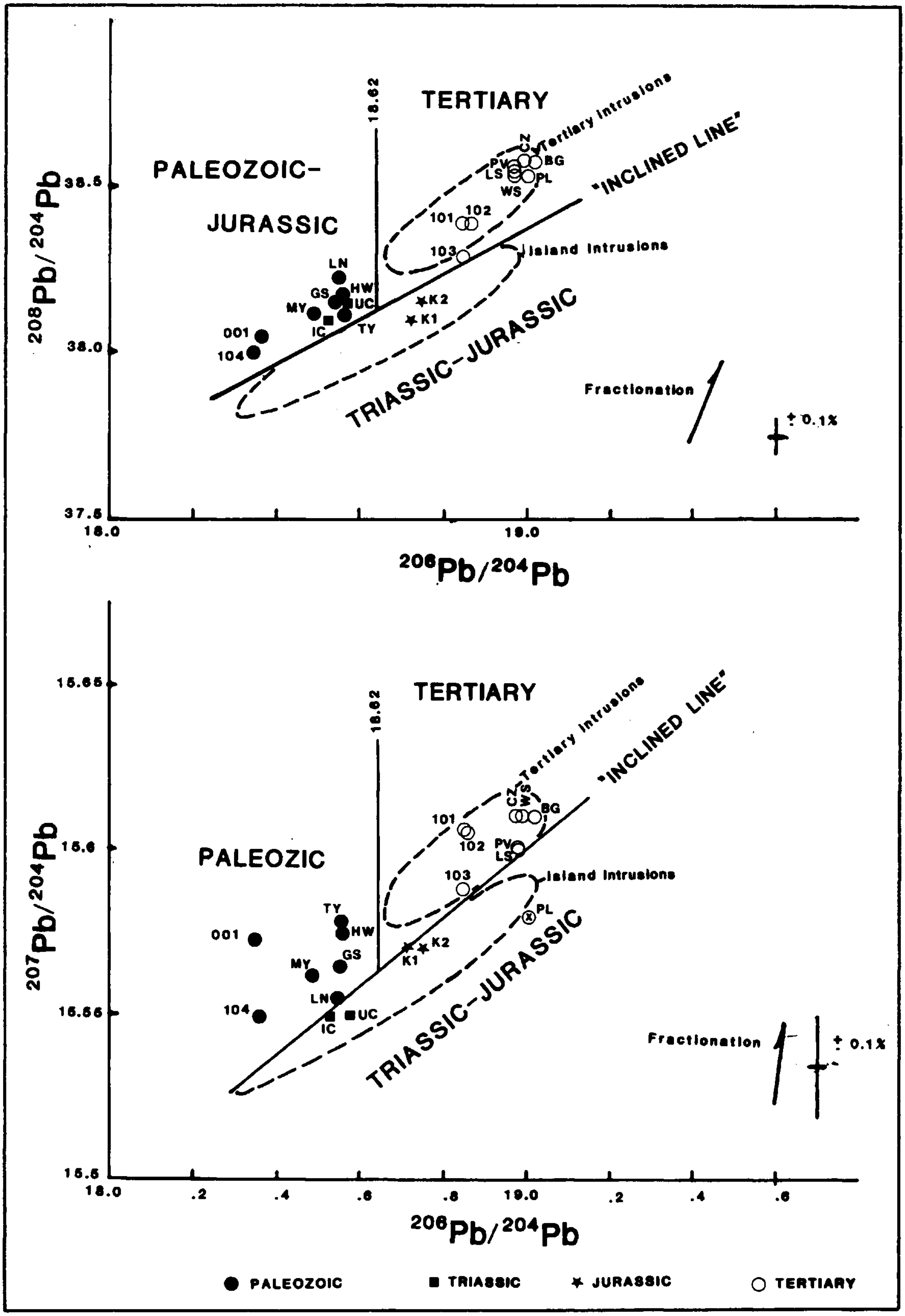


Figure 1-9-1. Lead-lead plots of galena lead isotopes from mineral deposits on Vancouver Island. Data and codes identifying deposits plotted are in Table 1-9-1. Also shown are whole-rock initial ratios for the Jurassic Island intrusions and the Tertiary Catface intrusions (data from Andrew, 1987). Three fields define and distinguish the age of most deposits on the Island.

TABLE 1-9-1
GALENA LEAD ISOTOPE ANALYSES[1] FROM ORE DEPOSITS, VANCOUVER ISLAND

Sample No.[1]	Analyst[2]	Deposit Name	Fig. Code	Lat. North (decimal deg.)	Long. West (decimal deg.)	Lead Isotope Ratios $^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
PALEOZOIC: Buttle Lake – Sicker-hosted sulphides								
30443-GS-AVG	1	G and S zones (n = 5)	GS	49.58	125.61	18.55	15.57	38.15
30443-HW-AVG	1	HW main orebody (n = 4)	HW	49.57	125.57	18.56	15.58	38.19
30443-MY-AVG	1,2	Myra high grade (n = 4)	MY	49.58	125.60	18.49	15.56	38.12
PALEOZOIC: Mount Sicker – Sicker-hosted sulphides								
30702-LN-AVG	2	Lenora (n = 2)	LN	48.87	123.78	18.55	15.56	38.22
30702-002	2	Tyee	TY	48.87	123.78	18.56	15.58	38.12
PALEOZOIC: Debbie – Sicker-hosted massive sulphides								
30457-001	1	Debbie	001	49.24	124.69	18.35	15.57	38.00
30457-101	1	Debbie	101	49.24	124.69	18.85	15.61	38.39
30457-102	1	Debbie	102	49.24	124.69	18.86	15.61	38.39
30457-103	1	Debbie	103	49.24	124.69	18.85	15.59	38.28
30457-104	1	Debbie	104	49.24	124.69	18.36	15.55	38.05
TRIASSIC: Karmutsen-hosted cogenetic(?) sulphides								
30314	1	Starlight	K1	49.06	124.71	18.66	15.57	38.23
30335	1	Nutcracker (Texada Island)	K2	49.75	124.59	18.71	15.57	38.27
JURASSIC: Island intrusion and Bonanza volcanic related mineralization								
30432	1	Utlah Creek	UC	50.30	127.45	18.58	15.55	38.19
30699	1	Island Copper	IC	50.61	127.48	18.53	15.55	38.09
TERTIARY: gold-quartz veins related to Zeballos intrusions								
30317	1	Lone Star/Rey Oro	LS	50.02	126.79	18.98	15.60	38.55
30318	1	White Star	WS	50.03	126.81	18.99	15.61	38.58
30320	1	Peerless	PL	50.04	126.84	19.00	15.58	38.53
30349	1	Privateer	PV	50.03	126.81	18.98	15.60	38.56
30484	1	Central Zeballos	CZ	50.04	126.78	18.98	15.61	38.57
30487	1	Bragg	BG	50.04	126.78	19.01	15.61	38.59

[1] Sample numbers with the suffix -AVG are average values; all others are single analyses. (*See also* listings in Godwin *et al.*, 1988, Tables 5.5I and 5.6I).
[2] 1 = analyses by A. Andrew, done in the Geochronology Laboratory, The University of British Columbia.
2 = analyses by B. Ryan, reported in Andrew (1982); these were done in the Geology-Geophysics Laboratory, The University of British Columbia.

the "inclined line" that forms the upper envelope to initial whole-rock lead for the Jurassic Island intrusions. Above this inclined line two fields are defined that are either less than or greater than $^{206}Pb/^{204}Pb$ = 18.62. Deposits with galena lead values that plot on this line are not known. If such lead was found on or very close to this line, its classification would be indeterminate.

Paleozoic mineralization can be identified firstly by "fingerprinting" the lead against the Buttle Lake and Mount Sicker galena lead (Table 1-9-1; Figure 1-9-1). Paleozoic galena lead plots in Figure 1-9-1 above the inclined line and has $^{206}Pb/^{204}Pb$ less than 18.62. On the $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot, Jurassic galena lead and Paleozoic lead overlap in the upper-left field, but are distinguishable on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot.

Triassic Karmutsen Formation basalts have heterogeneous isotope ratios and the initial ratio field for the Karmutsen Formation is poorly defined (Andrew, 1987). Two galena analyses (Table 1-9-1), UC and IC, that we think are cogenetic with the Karmutsen Formation are shown on Figure 1-9-1. Their isotopic compositions are within the field of initial ratios for the Island intrusions. Thus, it appears to be difficult to positively identify Triassic mineralization using lead isotopes alone.

Tertiary galena lead plots above the inclined line on both the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plots, and has a $^{206}Pb/^{204}Pb$ greater than 18.62 (Figure 1-9-1). All the galena lead plots within the field of initial ratios from whole-rock lead, indicating a direct genetic relationship between plutons and gold mineralization. Leads from gold deposits associated with the Zeballos plutons are tightly clustered around $^{206}Pb/^{204}Pb$ = 19.0, $^{207}Pb/^{204}Pb$ = 15.6, and $^{208}Pb/^{204}Pb$ = 38.5; Tertiary galena from the Debbie deposit group near $^{206}Pb/^{204}Pb$ = 18.85, $^{207}Pb/^{204}Pb$ = 15.6, and $^{208}Pb/^{204}Pb$ = 38.55 (*see* following section).

EXAMPLE

Five samples from the Debbie gold property (Westmin Resources Limited) near Port Alberni are reported in Table 1-9-1. Two of these (Table 1-9-1 and Figure 1-9-1: 001 and 104), from the southern part of the property, plot above the inclined line and have low $^{206}Pb/^{204}Pb$ ratios (less than 18.6). This suggests that the mineralization is Paleozoic and therefore syngenetic with respect to its Sicker Group host rocks. Three others (101, 102 and 103) have $^{206}Pb/^{204}Pb$ greater than 18.8 and plot in the Tertiary fields in Figure 1-9-1. Thus it can be shown using lead isotopes that two different ages of mineralization exist at the Debbie property. This is consistent with other geological findings (R. Walker, personal communication, 1988).

DISCUSSION

The above model relies on simple comparison of lead isotope ratios of galena from a deposit of unknown age and origin, with ratios for galenas from known ore deposits. This "fingerprinting" technique relies on the recognition of isotopic differences between the rocks associated with the different mineralizing episodes. A detailed study of the lead and strontium characteristics of the major igneous rock units of Vancouver Island (Andrew, 1987; Andrew and Godwin, *in press* a, b, c) has shown that significant isotopic differences do exist among them. Galena lead isotope ratios of the ore deposits reflect these differences; it also can be demonstrated that the galena lead isotope ratios fall within the whole-rock initial ratio fields of the related plutonic rocks (Andrew, 1987; Andrew and Godwin, *in press* a, b, c). Volcanogenic massive sulphides contain lead which is similar to that in cogenetic volcanic rocks (Brevart *et al.*, 1981). Indeed, galena lead from the Sicker-hosted deposits occupies the same general trend as whole-rock lead isotope data from the Sicker Group (Andrew, 1987; Andrew and Godwin, *in press* a, b, c). Thus, for Vancouver Island the isotopic compositions of the ore deposits are more dependent on the origin of the lead than they are on the age of the deposit; no systematic increase in the ratios with time is observed. A growth-curve model for the evolution of lead on Vancouver Island is therefore inappropriate.

The fields on Figure 1-9-1 are defined by a limited number of analyses. Additional analyses from ore deposits and rocks of known age and origin could enlarge these fields. However, the general isotopic characteristics for each "episode" are robust. For example, although there is only one case of Jurassic galena (Island Copper), others are likely to have the same low $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ signature that characterizes the Jurassic arc-building episode.

CONCLUSIONS

Galena lead isotope composition can be used to determine the age and origin of lead in many mineral deposits on Vancouver Island. Dating, and determination of an epigenetic versus a cogenetic origin to mineralization, has important exploration applications, and can guide important exploration decisions. Potential applications of the lead isotope model presented here include:

- Paleozoic massive sulphide deposits and related feeder veins are isotopically distinct from epigenetic veins related to Mesozoic or Tertiary plutonic activity.
- Jurassic mineralization related to either Bonanza Group volcanic rocks or Island intrusions (such as the Island Copper porphyry deposit) can be distinguished isotopically from Paleozoic mineralization related to the Sicker Group.
- Gold-bearing veins related to Tertiary plutonic activity are isotopically different from mineralization related to Jurassic plutonic activity.

ACKNOWLEDGMENTS

The writers thank reviews of earlier versions of this manuscript by R.L. Armstrong, R.D. Russell, A.J. Sinclair and W.F. Slawson. J.E. Gabites and B. Ryan did some of the analyses reported here. R. Walker of Westmin Resources Limited encouraged application of galena lead isotope analyses in the Debbie area. Financial support to the senior author by a Natural Sciences and Engineering Research Council of Canada Scholarship, a University Graduate Fellowship, the Aaro Aho Award and a Research Assistantship are gratefully acknowledged. Support to C.I. Godwin was received from the British Columbia Ministry of Energy, Mines and Petroleum Resources, the Canada/British Columbia Mineral Development Agreement, and the British Columbia Science Council funded the laboratory costs.

REFERENCES

Andrew, A. (1987): Lead and Strontium Isotope Study of Five Intrusive and Volcanic Rock Suites, Vancouver Island, British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*, 254 pages.

Andrew, A. and Godwin, C.I. (*in press*, a): Isotope Geochemistry of the Sicker Group and Bonanza Group Volcanic Rocks, and Island Intrusions, Vancouver Island, British Columbia, *Canadian Journal of Earth Sciences*.

——— (*in press*, b): Isotope Geochemistry of the Karmutsen Formation, Vancouver Island, British Columbia, *Canadian Journal of Earth Sciences*.

——— (*in press*, c): Isotope Geochemistry of the Tertiary Catface Intrusions, Vancouver Island, British Columbia, *Canadian Journal of Earth Sciences*.

Andrew, A., Godwin, C.I. and Sinclair, A.J. (1984): Mixing Line Isochrons: a New Interpretation of Galena Lead Isotope Data from Southeastern British Columbia, *Economic Geology*, Volume 79, pages 919-932.

Brandon, M.T. and Massey, N.W.D. (1985): Early Tertiary Tectonics of Pacific Northwest: Truncation and Rifting Within a Transform Plate Boundary, Abstract, *Lithoprobe Project Publication*, Number 10, pages 8-9.

Brandon, M.T., Orchard, M.J., Parrish, R.R., Sutherland Brown, A. and Yorath, C.J. (1986): Fossil Ages and Isotopic Dates from the Sicker Group and Associated Intrusive Rocks, Vancouver Island, B.C., *in* Current Research, Part A, *Geological Survey of Canada*, Paper 86-1A, pages 683-696.

Brevart, O., Dupre B. and Allegre, C.J. (1981): Metallogenesis at Spreading Centers: Lead Isotope Systematics for Sulfides, Manganese-rich Crusts, Basalts and Sediments from the Cymex and Alvin Areas (East Pacific Rise), *Economic Geology*, Volume 76, pages 1205-1209.

Carlisle, D. and Suzuki, T. (1974): Emergent Basalt and Submergent Carbonate-clastic Sequences Including the Upper Triassic Dilleri and Welleri Zones on Vancouver Island, *Canadian Journal of Earth Sciences*, Volume 11, pages 254-379.

Carson, D.J.T. (1973): The Plutonic Rocks of Vancouver Island, *Geological Survey of Canada*, Paper 72-44, 70 pages.

Doe, B.R. and Zartman, R.E. (1979): Plumbotectonics: the Phanerozoic, *in* Geochemistry of Hydrothermal Ore Deposits, H.L. Barnes, Editor, Second Edition, pages 22-70, *John Wiley and Sons*, New York 798 pages.

Ewing, T.E. (1981): Geology and Tectonic Setting of the Kamloops Group, South-central British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*, 225 pages.

Godwin, C.I., Gabites, J.E. and Andrew, A. (1988): LEAD-TABLE: A Galena Lead Isotope Data Base for the Canadian Cordillera, With a Guide to its Use by Explorationists, *B.C. Ministry of Energy Mines and Petroleum Resources*, Paper 1988-4, 188 pages.

Godwin, C.I. and Sinclair, A.J. (1982): Average Lead Isotope Growth Curve for Shale-hosted Lead-zinc Deposits, Canadian Cordillera, *Economic Geology*, Volume 77, pages 675-690.

Hansen, M.C. and Sinclair, A.J. (1984): A Preliminary Resource Assessment of Zeballos Mining Camp: a MINDEP project, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 219-232.

Isachsen, C. (1984): Geology, Geochemistry and Geochronology of the Westcoast Crystalline Complex and Related Rocks, Vancouver Island, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 144 pages.

Juras, S. (1987): Geology of the Polymetallic Volcanogenic Buttle Lake Camp, with Emphasis on the Price Hillside, Central Vancouver Island, British Columbia, Canada, Unpublished Ph.D. Thesis, *The University of British Columbia*, 216 pages.

Massey, N.W.D. and Friday, S.J. (1988): Geology of the Chemainus River – Duncan Area, Vancouver Island (92C/16; 92B/13), *B.C. Ministry of Energy Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 81-92.

Muller, J.E. (1980): The Paleozoic Sicker Group of Vancouver Island, British Columbia, *Geological Survey Canada*, Paper 79-30, 23 pages.

Rusmore, M.E. and Cowan, D.S. (1985): Jurassic-Cretaceous Rock Units along the Southern Edge of the Wrangellia Terrane on Vancouver Island, *Canadian Journal of Earth Sciences*, Volume 22, pages 1223-1232.

Sada, D. and Danner, W.R., (1974): Early and Middle Pennsylvanian Fusulinids from Southern British Columbia, Canada, and Northwestern Washington, U.S.A., *Transactions of the Proceedings of the Palaeontological Society, Japan*, New Series, Number 93, pages 249-265.

Stacey, J.S. and Kramers, J.D. (1975): Approximation of Terrestrial Lead Isotope Evolution by a Two-stage Model, *Earth and Planetary Science Letters*, Volume 26, pages 207-221.

Sutherland Brown, A. and Yorath, C.J. (1985): LITHOPROBE Profile across Southern Vancouver Island: Geology and Tectonics, *Geological Society of America*, Cordilleran Section Meeting, Field Guide Book, Trip 8, Vancouver, B.C.

Sutherland Brown, A., Yorath, C.J., Anderson, R.G. and Dom, K. (1986): Geological Maps of Southern Vancouver Island, LITHOPROBE 1, *Geological Survey of Canada*, Open File 1272.

Walker, R.R. (1980): Western Mines - Lynx, Myra and Price Deposits: a Discussion, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 73, Number 824, pages 86-89.

NOTES

TERTIARY LOW-ANGLE FAULTING AND RELATED GOLD AND COPPER MINERALIZATION ON MOUNT WASHINGTON, VANCOUVER ISLAND (92F/11, 14)

By J.E. Muller
Consulting Geologist

KEYWORDS: Economic geology, Mount Washington, Vancouver Island, low-angle normal faults, fault-related mineralization, gold, copper.

INTRODUCTION

The structural style of Vancouver Island, as perceived by the author in the course of reconnaissance mapping for the Geological Survey of Canada, 1963 to 1981, was one of rather rigid tilted blocks, separated by numerous high-angle faults. That concept has now been shown to be incomplete and in need of revision.

Firstly, deep seismic soundings carried out in 1984 under the LITHOPROBE program, have been interpreted as demonstrating a series of northeast-dipping low-angle thrust faults, imbricating the island's crust (Sutherland Brown and Yorath, 1985). In addition, post-retirement work by the writer, initially undertaken to revise geological mapping of the Alberni map area (Muller and Carson, 1969), has yielded field evidence of low-angle fault zones. Some of these faults occur within Triassic (Karmutsen) volcanic rocks, others are at the base of the Upper Cretaceous Nanaimo Group and had previously been considered as minor dislocations parallel to the unconformity. Lastly, but most importantly, renewed mineral exploration on Mount Washington by Better Resources Ltd. has confirmed the existence of a major set of interfingering near-horizontal faults at about the 1450-metre elevation.

These new findings, combined with data obtained on preliminary review-excursions into the Beaufort Range and Nanaimo Lakes area, strongly suggest low-angle faults are a widespread and important feature of the island's structure.

Low-angle, normal or detachment faults have been recognized in the last decade in several parts of western North America, especially the Basin and Range structural province. There they have been identified as conduits for hydrothermal mineralizing fluids and as the present site of precious and base metal ore deposits (Wilkins and Heidrick, 1982; Spencer and Welty, 1986). Recognition of such faults is therefore of prime importance to mineral exploration.

The present study was undertaken to establish more clearly the existence of detachment faults on Vancouver Island. Mount Washington, with its now well-explored low-angle fault, presented an obvious starting point. The fault is described in detail in a paper by R. Dahl (in preparation) and this paper deals mainly with roeks and structures below the fault.

The report is of a preliminary nature and lacks the refinements and confirmation provided by petrological, geochemical or geophysical data. Nor has any but the most minimal use been made of the extensive footage of diamond drilling completed over many years by several mining companies. Nevertheless, where appropriate, data of earlier workers have been used in preparing the map (Figures 1-10-1A and B) and report. It is hoped that geologists concerned with the geology and structure of Mount Washington in particular, and of Vancouver Island in general, will seriously consider the proposed interpretations. This may require the proverbial "Leap of Faith" but may lead to new approaches toward understanding the complex geology and contribute to exploration of the mineral deposits of Mount Washington as well as other parts of Vancouver Island.

LOCATION AND ACCESS

The map area shown on Figures 1-10-1A and B is about 15 kilometres by road northwest of Courtenay. Its northeastern part lies within Tree Farm Licence No. 2 of Crown Forest Ltd. (formerly Crown Zellerbach Co. Ltd.) and its southwestern part in Strathcona Provincial Park. The dividing line of these two domains runs from Ramparts Creek to the top of Mount Washington and thence almost due west to Buttle Lake.

Road access is by several adequately maintained unpaved mainline logging roads from Courtenay or Campbell River and by Crown Forest Branch 62. The latter road has become the main road to Mount Washington Ski Village and the adjacent part of Strathcona Park.

HISTORY OF EXPLORATION AND MINING

The following historical data are summarized from earlier accounts by Carson (1960), McGuigan (1975) and company assessment or annual reports. Placer gold was panned during the Thirties from the Oyster River, draining a small part of Mount Washington. Gold-quartz veins were discovered and staked on the Central and West Arms in 1940 by the brothers McKay and exploratory work was done on these in 1941 by K.J. Springer. In 1944-1945 The Consolidated Mining and Smelting Company of Canada, Limited (Cominco) performed further work involving trenching and driving of a short adit into what is now called the Domineer zone. In 1951 Noranda Exploration Company, Limited diamond drilled 13 holes in the general area of the present pit but considered the results discouraging.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

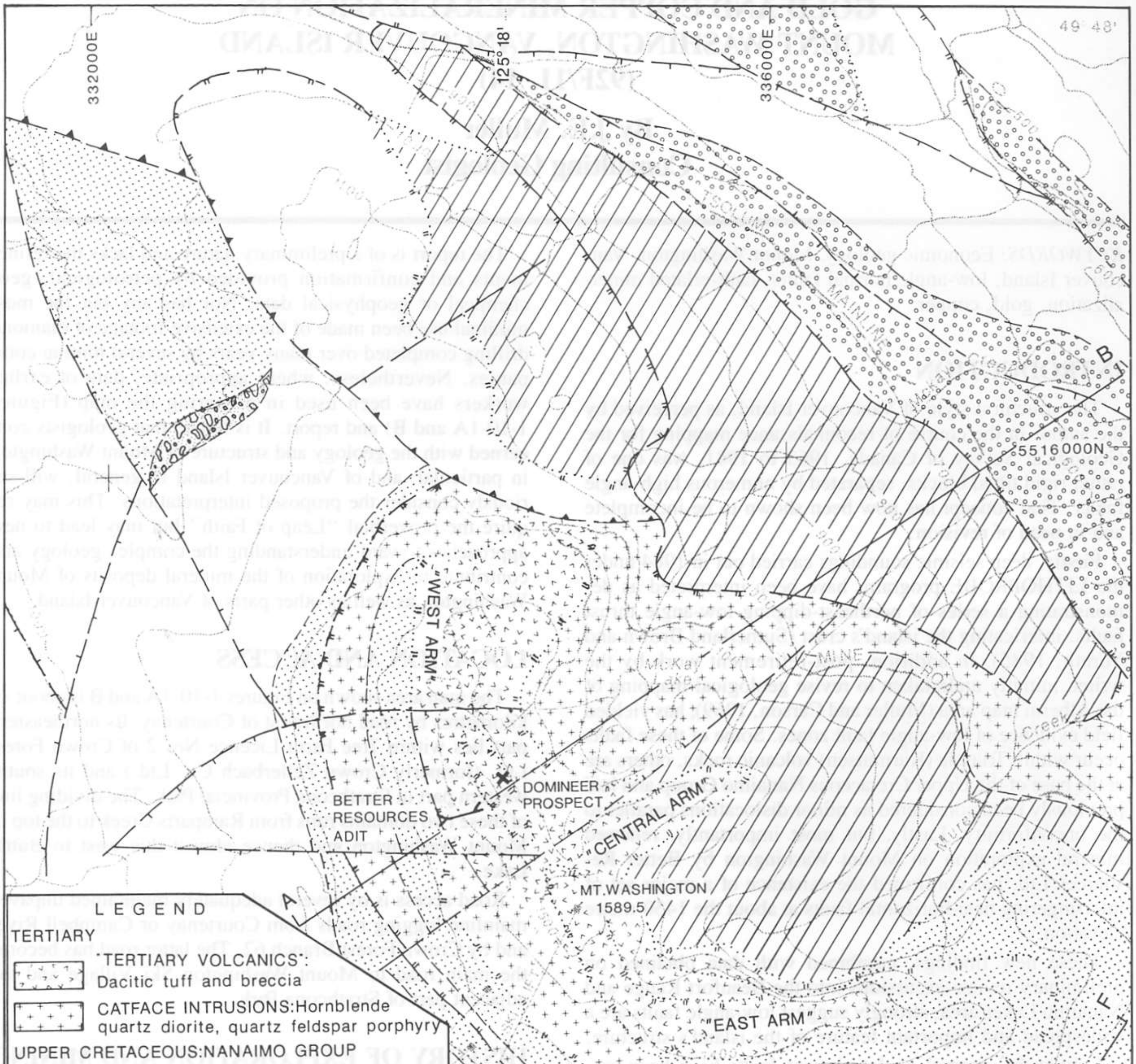


Figure 1-10-1A. Geological map of Mount Washington, west side.

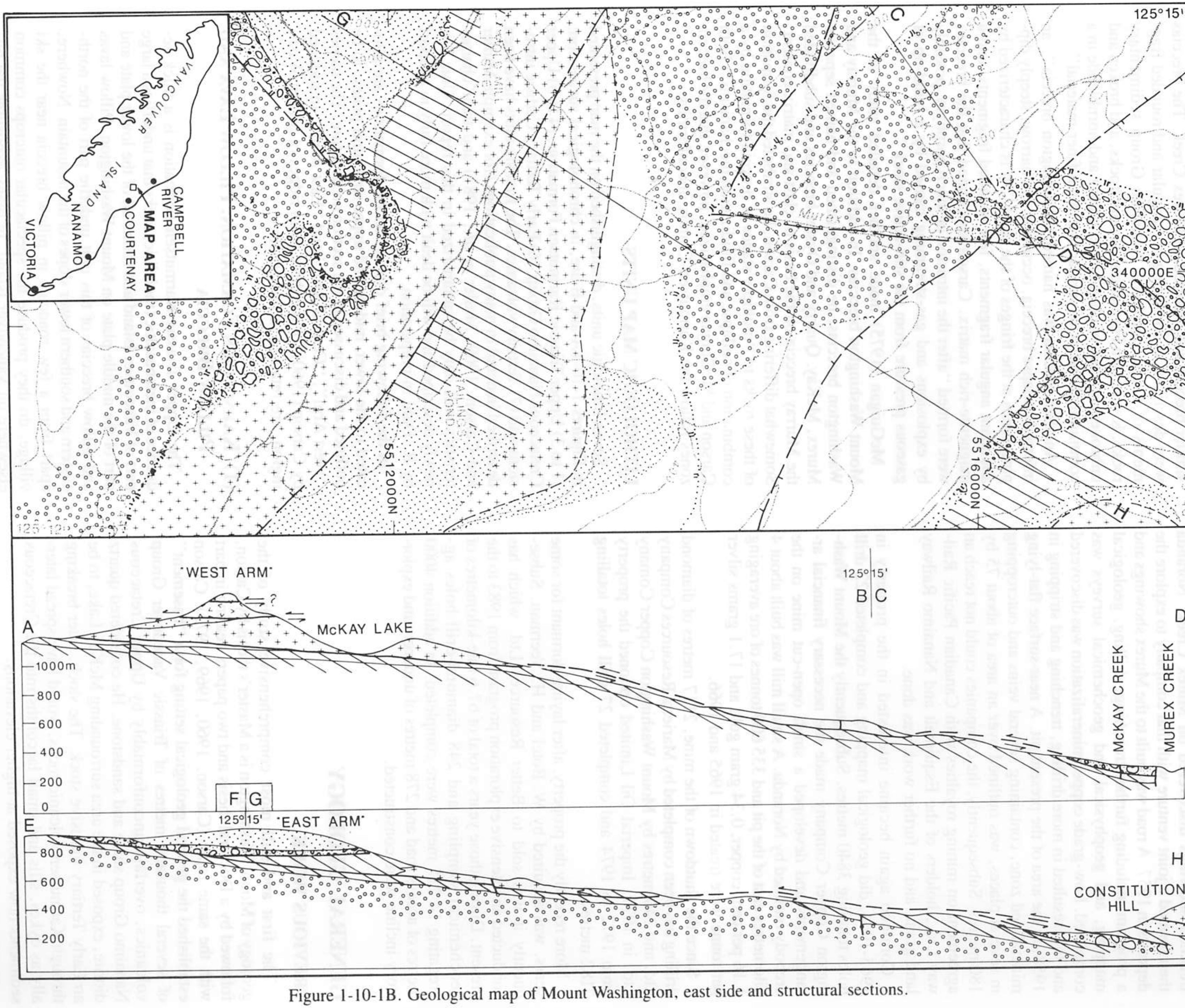


Figure 1-10-1B. Geological map of Mount Washington, east side and structural sections.

In 1956 the newly formed Mount Washington Copper Company Ltd. built the access road to the West Arm and trenched showings discovered on Murex Creek. Noranda then formed a joint venture with that company to explore the deposits in 1957. A road was built to the Murex showings and a program including further trenching, drilling, geological mapping, and geophysical and geochemical surveys was completed. Low-grade copper mineralization was discovered and this resulted in more drilling, trenching and stripping in 1958, in the area of the present pit. A near-surface flat-lying mineralized zone, containing several veins and outcropping in several places, was outlined over an area of about 75 by 180 metres. Subsequently, the companies could not reach an agreement on mining royalties with Canadian Pacific Railway Ltd., holders of the Esquimalt and Nanaimo Railway land grant, and no further work was done.

Cominco again became interested in the property in 1963-1964, did geological mapping and completed 22 drill holes totalling 3840 metres. Subsequently the Mount Washington Copper Company made the necessary financial arrangements and developed a small open-cut mine on the orebody outlined by Noranda. A small mill was built about 4 kilometres east of the pit and 335 600 tonnes of ore averaging 1.16 per cent copper, 0.34 gram gold and 17.1 grams silver per tonne were treated in 1965 and 1966.

Since the shutdown of the mine, 2117 metres of diamond drilling has been completed by Marietta Resources Company Ltd. and 240 metres by Mount Washington Copper Comany Ltd. in 1971. Imperial Oil Limited optioned the property from 1972 to 1974 and completed 27 drill holes totalling 2182 metres.

More recently the property, after laying dormant for some years, was acquired by W. Botel and H. Veerman. Subsequently it was sold to Better Resources Ltd. which has conducted an intensive exploration program from 1983 to the present. During those years a total of 67.6 line-kilometres of geochemical sampling and 248 diamond-drill holes aggregating 14 215 metres were completed. In addition 4000 metres of access road and 278 metres of underground exploratory incline were constructed.

GENERAL GEOLOGY

PREVIOUS WORK

The first and still most comprehensive study of the geology of Mount Washington is a Master's thesis by Carson, followed by a Doctoral thesis and two papers dealing in part with the same topic (Carson, 1960, 1969, 1973). Carson established the general geological setting for a "basement" of several thousand metres of Triassic Vancouver Group volcanics, overlain unconformably by Upper Cretaceous Nanaimo Group shale and sandstone. He considered quartz diorite, exposed in the area surrounding McKay Lake, to be an Early Tertiary intrusive stock. The stock, after breaking through Karmutsen volcanic rocks, would have spread laterally as dykes, sills and small laccoliths into the Cretaceous sediments now exposed at higher elevations.

He also distinguished several types of breccia, presumably related to the intrusion. He described the "Murray breccia", exposed at the top of the West Arm, as "an oval, pipe-shaped diatreme, about 2500 by 800 feet in surface dimensions" and "shown by diamond drilling to extend at least 700 feet". A similar breccia was reported on Murex Creek. The breccias were described as consisting of "angular and rounded fragments of dacite porphyry, Nanaimo Group sedimentary rocks, Karmutsen Formation volcanic rocks, and broken and unbroken crystals of plagioclase, quartz and hornblende in a comminuted matrix of similar but much finer material".

Another breccia was named "Washington breccia", an inferred collapse breccia, occurring "in narrow, steeply dipping zones at the fringes of the stock". It is characterized by abundant angular fragments, few rounded fragments, and a magnetite-rich matrix. Carson speculated that the breccias were formed "after the intrusion of much porphyry, possibly by explosions and gas-streaming caused by a build-up of gaseous pressure from the still-active stock".

McGuigan (1975) made another detailed study of the Mount Washington breccias. In addition to the Murray and Washington breccias, he distinguished and named separate Murex, McKay, Quarry and Oyster breccias and subdivided the Murray breccia on the basis of clast and matrix content. Somewhat differing from Carson, he attributed the formation of these rocks to "multiple stages of breccia formation by a combination of collapse and fluidization mechanisms". Both Carson and McGuigan emphasized, however, that the breccia zones follow the Karmutsen-Comox unconformity.

LITHOLOGIC MAP UNITS

Seven lithologic units, distinguished on the map presented in Figures 1-10-1A and B are, in chronological succession: (1 to 3) Upper Triassic Karmutsen Formation, (4 to 5) Upper Cretaceous Nanaimo Group, (6) Early Tertiary Catface intrusions and (7) Tertiary volcanics. The first six units have been described in detail in many publications (for example Muller and Carson, 1969; Muller *et al.*, 1981) and their characteristics will only be summarized in this report. Unit 7 is newly described and will be dealt with more fully in a report by R. Dahl in preparation.

In the following brief discussion the formations are allocated to the lower, middle and upper structural plates, to be outlined and discussed in the section on structure. The names "West Arm", "Central Arm" and "East Arm", introduced by Carson (1960) for the three main ridges of Mount Washington, are retained in this report.

(1) KARMUTSEN FORMATION: PILLOW LAVA AND PILLOW BRECCIA

The Upper Triassic Karmutsen Formation is a thick sequence of metabasaltic (tholeiitic) rocks that underlies a large part of Vancouver Island and forms all of the lower plate and part of the middle plate on Mount Washington. Pillow lavas and pillow breccias of this unit underlie part of the northeastern and southern lower slopes of the mountain. Nowhere, apart from a few roadcuts in pillow breccia near the ski village, do they produce the spectacular outcrops common elsewhere on Vancouver Island. In many exposures the pillows and original pillow fragments have been deformed and brecciated and can only be identified by a few remaining characteristic shapes and lighter coloured pillow rims. Nests of quartz and epidote, so common as space-filling between pillows elsewhere, are also lacking. In many instances field identification of pillow breccia and aquagene tuff is still possible on the evidence of small devitrified, silica-rimmed lava pellets, visible with a hand-lens, in the matrix on a fresh surface. Low-grade metamorphism of the basaltic rocks to prehnite-pumpellyite grade is generally believed to have occurred in pre-Tertiary time and some retrograde change to yet lower chlorite grade may have attended Tertiary faulting.

(2) Karmutsen Formation: Lava Flows

Metabasaltic lava flows form the upper part of the Karmutsen Formation wherever the volcanic stratigraphy can be established. The flows outcrop on the northeastern and northwestern slopes of Mount Washington and form parts of the lower and middle plates. They are typically distinguished by amygdules of quartz and/or a dark green mineral, probably pumpellyite, and less commonly by plagioclase phenocrysts less than 2 millimetres long. Subdiabasic texture may be detected with a hand-lens. Flow-tops and clear separation of flows were rarely observed in this area. However, in several exposures there is a crude separation into irregular layers by horizontal fracturing and slip within the structural plate.

(3) Karmutsen Formation: Brecciated and/ or Hornfelsic Metabasalt

The rocks of a large part of the Karmutsen Formation have been transformed to an extent where attribution to either Unit 1 or 2 is impossible. The changes are due to two different, not necessarily related events. First, emplacement of Catface intrusions into the Karmutsen in early Tertiary time produced a contact aureole of microdiorite and hornfelsic metabasalt. In one instance, exposures of dioritized volcanic rocks with a few veins and dykes of fine-grained quartz diorite alternate with limited outcrops of the intrusive rock.

More importantly, the rocks have been intensely fractured into breccia and cataclasite. Viewed with a hand-lens the massive, generally well-indurated rocks are seen to be composed of subangular fragments and porphyroclastic feldspars in a matrix of dark green chloritic material, commonly pervaded by stringers and lenticles of a black serpentinous substance. These rocks are quite distinct from aquagene tuffs due to the absence of green, white-rimmed globules of devitrified glass. Detailed petrographic work will be required to properly identify and describe the cataclasites.

(4) Nanaimo Group: Benson Conglomerate

The Upper Cretaceous Nanaimo Group unconformably overlies all older formations on Vancouver Island and the basal conglomerate is known as the Benson member of the Comox Formation. In the mapped area the conglomerate is mainly exposed to the southeast, where it forms the base of the middle plate. Its contact with the Karmutsen Formation is, in the structural framework proposed here, considered to be a detachment fault that has locally followed the unconformity.

Clasts in the conglomerate are predominantly metavolcanic, presumably Karmutsen rocks. They are generally well rounded and vary in size from pebbles up to about 5 centimetres in diameter, to boulders up to 30 centimetres across. Unlike conglomerates in the main Nanaimo and Comox sedimentary basins, these rocks are well indurated and fracture across the clasts rather than showing rounded clasts on rock faces. Not uncommonly, quartz occurs in veins and forms envelopes around individual clasts. In the matrix, sandy to gritty greywacke has been converted to a dark green pseudo-metavolcanic substance. Near the fault zone the rocks are commonly hematitic and/or limonitic.

Boulder conglomerate at the base of Cretaceous sandstone in the northwest corner of the map area may be autochthonous and is deeply weathered, highly fractured and loosely consolidated.

(5) Nanaimo Group: Comox Sandstone and Siltstone

Metasandstone and metasiltstone, several hundred metres thick, make up most of the middle plate on the East Arm. Toward the northwest the thickness decreases to less than 100 metres but there sandstone is also part of the lower plate. The sandstones are mainly medium grained, well-cemented to quartzitic arkose or, in the lower part of the unit, greywacke. Bedding is poorly developed and many apparent bedding planes are in fact shear planes. Crossbedding, characteristic of these sandstones elsewhere, may have been obliterated by internal dislocation. On the other hand, anastomosing non-depositional shear-laminations are common. Deep limonitic and hematitic staining is also a general characteristic rarely encountered in the Nanaimo Lowlands sedimentary basins.

Metasiltstones overlie sandstones on the East Arm and are also exposed on the Central and West arms of Mount Washington. Well-preserved fern leaves in carbonaceous siltstone in a small pit at the end of logging spur 62F (5512840N, 337440E) are also used to delimit the base of the upper plate (Table 1-10-1). They also indicate that some of these rocks, although slightly metamorphosed, are part of the Comox Formation. A sequence of grey, silicic, quartzofeldspathic metasiltstones, forming the crest of East and Central Arm and the steep walls of the upper Murex Creek valley was included in the Comox Formation by Carson (1960) and McGuigan (1975). These rocks, in several places interlayered with quartz feldspar porphyry, are tentatively included with Tertiary tuff of Unit 7, on the basis of lithological resemblance.

(6) Catface Intrusions: Quartz Diorite and Quartz-Feldspar Porphyry

The name "Catface intrusions" was introduced for all high-level plutons, sills and dykes of Vancouver Island (Muller *et al.*, 1981) and is applicable to the Mount Washington intrusive rocks of Tertiary age. The crystalline rocks form the base of the middle plate, above the 1200-metre level in the West Arm area, and extend northeast to the middle reaches of the Murex Creek drainage. Similar rocks also form the bulk of Constitution Hill, northeast of the area of Figure 1-10-1B. The outcrop area around McKay Lake, more than 1 kilometre in width, has been considered a central stock that forced its way upward through Karmutsen volcanics and laterally into the Cretaceous strata (Carson, 1960, 1973). Good exposures of the intrusive contact with Karmutsen volcanics are seen on the mine road, 300 metres northwest of the crossing of McKay Creek (5515250N, 335050E); on the easterly branch of Murex Creek, just above the crossing of logging spur 101-I (5514450N, 339830E); and in the creek draining the old tailings pond, downstream from the crossing of Branch 101 (5514200N, 340350E). In the latter location the creek appears to follow the contact zone for about 500 metres, and exposures of dioritized volcanic rocks with a few veins and dykes of fine-grained quartz diorite alternate with limited exposures of the intrusive rock. On the other hand none but faulted subhorizontal contacts between the intrusion and Cretaceous strata were seen in this study.

The crystalline rocks have been studied and described in detail by Carson *(ibid.)*. Away from the contact zones the rocks are fine to medium-grained equigranular hornblende diorite. Adjacent to intrusive contacts, and in dykes, sills and apophyses, the rocks are quartz-feldspar-hornblende porphyry with conspicuous hornblende needles varying in length from about 2 to 10 millimetres.

(7) Tertiary Volcanic Rocks

Volcanic rocks of probable Tertiary age have not been reported previously on Mount Washington. They were recently identified, with some degree of certainty, by R. Dahl in the course of detailed fieldwork on the upper western slopes. Thus far they appear to have been variously identified as intrusive rock, as Murray (diatreme) breccia and as Cretaceous clastic sediments. Several roadcuts on the higher part of the West Arm provide convincing evidence of pyroclastic origin. Layered white-weathering dacite tuff, varying from fine-grained ash to coarse-grained crystal tuff and breccia, is exposed in several cuts.

In anticipation of conclusive identification by more fieldwork and detailed petrographic study, the rocks are here assumed to be tuff and volcanic breccia, genetically related to Catface intrusions. The areal distribution of these Tertiary volcanic rocks is uncertain. Some rocks, shown on earlier geological maps as Cretaceous metasiltstone, are probably fine-grained tuff while others, previously identified as quartz-feldspar porphyry, may be crystal tuff. Rounded quartz grains and broken feldspar crystals, noted by Carson (1960), could be an indication of pyroclastic origin. Of all the breccias described by Carson (1960) and McGuigan (1975) the Murray breccia which, as Carson noted, is crudely layered, is most likely a part of the extrusive sequence. The rocks of the upper plate, except for its lower part on the East Arm, have provisionally been mapped as Unit 7 Tertiary volcanics in this study. Possibly Unit 7 includes some sediments of Unit 5 and intrusive rocks of Unit 6. Conversely, areas mapped as Units 5 and 6 may include rocks of Unit 7.

Breccias

The rocks of Mount Washington include many different types of fragmental rocks that have been subdivided, named and described by Carson and later McGuigan. Carson introduced Murray and Washington breccia and McGuigan added the names Murex, McKay, Glacier, Quarry and Oyster brec-

Table 1-10-1
EXPOSURE AND LOCATIONS OF LOW-ANGLE FAULTS

(1) General Location and Type of Outcrop	(2) Northing, Easting	(3) Hanging, Footwall Lithology	(4) Attitude	(5) Breccia?
1. Oyster River [Eagle Canyon] (S)	5524800N 332850E	B.Cgl. K.Pbr.	350/30N	R
2. Br.181, SW side of Helldiver Lake (R)	5523500N 337425E	N.E. K.F.	Flat	R
3. MB. Oyster Main-line, 0.1 km N of Br. 8	5521200N 325900E	B.Cgl. K.Pl. + P.Bay	Undulating	N
4. Gully above MB Br. 8, 1.3 km S of Oyster Main-line (S)	5520125N 325050E	B.Cgl. K.Cl.	040E	N
5. Rossiter Main, creek crossing (R,S)	5519350N 330475E	K.F. K.F.	Antiformal	R
6. Br. 160, 0.15 km S of Br. 160A (R,Q)	5518925N 330075E	K.F. K.F.	Flat to dip 10 E	R
7. Sharp left bend of Murex Creek (S)	5518100N 339975E	B.Cgl. B.Cgl.	90/25S	R
8. Br. 161, 0.8 km N of Piggot Ck. bridge (R)	5517700N 328975E	K.Pl. K.F.	Flat	N
9. Creek near end of Br. 105F (S)	5517475N 337325E	K.F. K.Br.	350/30N	R
10. Piggott Ck., 0.8 km S of bridge [Elnora] (S)	5516325N 329925E	K.F. K.F.	240/10NW	R
11. Main-line, 0.4 km NNW of NW end of Wolf Lake [Lupus] (Q)	5516275N 341750E	N.E. K.F.	Antiformal	R
12. Junction of Br. 126 and Br. 130C2 (Q)	5515900N 334000E	Q.D. C.A.	Flat	N
13. Mine road, sharp turn N of old mine (Q)	5515700N 334600E	N.E. Q.D.Cl.	Undulating	N
14. Creek 0.8 km S of N tip of Wolf Lake [Ref. Hurst, 1927]	5515150N 341725E	C.S.? K.Br.?	Dip 30 E	S
15. Better Resources adit	5513900N 333900E	T.V. C.A.	Slight dip	S
16. Murex Creek prospect	5514450N 337675E	K.Cl. K.Br.	55/40SE	S
17. 0.75 km NNW of summit [Domineer] (A)	5514200N 334375E	T.V. T.V.	Antiformal	S
18. N flank of Central Arm, prospect	5514100N 335150E	T.V.? Q.D.	0/30E	S
19. Near end of Br. 62F (fault unexposed; Q,R)	5513000N 337700E	C.A. C.Cl.	Flat?	N
20. Ski area service road and quarry (Q,R)	5512550N 335075E	Q.D. N.E.	20/20SE, 90/25S	R
21. Ramparts Ck., above ski access road [Photon (R,S)	5511200N 335350E	C.S. K.Pbr.	Steep NE?	R
22. Br. 53, near forks with Br. 53E	5509425N 342425E	N.E. K.Cl.	320/40NE	R
23. Browns River, 3.5 km W of logging bridge	5506200N 346575E	C.S. K. or Q.D.	Flat	N

Column (1): Main roads and numbered branches (Br.) are of Crown Forests Ltd. Roads marked "MB" are of MacMillan Bloedel Ltd.
Prospect or claim names shown in [brackets]; Ref.: *see* references
(A) = Adit; (Q) = Quarry; (R) = Roadcut and/or roadbed; (S) = streambed and/or cut.
Column (2): Northings and eastings measured from field map locations.
Column (3): B.Cgl. = Benson Conglomerate; C. = Comox; C.Cl. = mylonitic siltstone; C.A. = argillite; C.S. = sandstone/siltstone; K. = Karmusten; K.Br. = brecciated; K.Cl. = cataclasite; K.F. = flows; K.Pbr. = pillow breccia; K.Pl. = pillow lava; N.E. = not exposed; Q.D. = quartz diorite; T.V. = Tertiary volcanics.
Column (4): Azimuth of strike/degrees and direction of dip of fault zone if measurable.
Column (5): Distinctive fault rocks; N = no mineralization seen; R = Rosewall breccia; S = sulphide mineralization.

cia. Most of these varieties are typical of a specific outcrop area and further distinctions seem to be made on the basis of composition, size and shape of the clasts and matrix, and contact relationships with adjacent rocks. Both Carson and McGuigan appear to favour the genesis of all these varieties by intrusive emplacement in semi-fluid state or as a result of collapse in a subvolcanic environment.

This study has not focused specifically on the various breccias of Mount Washington but a few general observations must be made. Two distinct and different modes of brecciation should now be considered in addition to subvolcanic quasi-intrusive emplacement. First, the Murray and perhaps the Washington breccia, exposed at higher elevations, are more likely extrusive pyroclastic deposits rather than diatreme fillings. Second, the other named varieties of fragmented rocks are probably, in large part, neither intrusive nor volcanic but tectonic breccias formed as a result of detachment faulting. The newly named Rosewall breccia, referred to in a subsequent section and not previously distinguished in this area, is everywhere associated with a low-angle fault.

STRUCTURAL GEOLOGY

CHARACTERISTICS OF LOW-ANGLE NORMAL FAULTS

Before introducing the concept of detachment faulting to the structure of Mount Washington (and possibly a large part of Vancouver Island), a brief review of this structural style is in order.

In the southwestern United States the structural character of the Basin and Range geological province was traditionally viewed to be fashioned exclusively by high-angle normal faulting. However, mapping and structural analysis since about 1970 has shown that this region is pervaded by low-angle normal-slip faults. These faults, also termed detachment faults, are generally Oligocene-Miocene in age (Davis, 1984). In contrast to thrust faults, they superpose younger on older rocks and are the result of structural extension rather then compression.

A great number of studies of these structures are now available, dealing mainly with mountain ranges on both sides of the Colorado River in California and Arizona. Detachment faults in the Whipple Mountains of California and Rawhide, Buckskin, and Harcuvar mountains of Arizona have been a prime object of investigation (for example, Davis *et al.*, 1980, 1986; Gross and Hillemeyer, 1982; Wilkins and Heidrick, 1982). There, the autochthonous lower plate is structurally overlain by an allochthonous upper plate, resting on a flat, commonly undulating detachment surface. It is now well established that northeastward movement of the allochthonous plate in the order of tens of kilometres has occurred. The upper plate is fragmented into many separate fault blocks by normal faults terminating at, or converging with, the detachment fault. Commonly there is a second detachment fault, a few hundred metres above the main fault, dividing the allochthonous rocks into a middle and upper plate.

In the Colorado River region the lower plate is mainly composed of Precambrian and younger crystalline rocks; the upper plate consists of a heterogeneous assemblage of Mesozoic and Tertiary crystalline, metasedimentary and metavolcanic rocks that may include late Tertiary volcanic and sedimentary deposits.

A readily mappable, resistant unit typically marks the sole of the fault. Its detachment surface has been described as a "dense, compact, flinty, comminuted microbreccia that weathers dark reddish brown to patina". Below the fault "the flinty microbrecciated surface grades downward to various combinations of shatter, crush, and crackle breccia; a relationship consistently found by [several other authors]" (Wilkins and Heidrick, 1982). The breccia is commonly bleached and chloritized and may extend to over 300 metres below the detachment surface ("chlorite breccia zone"). Brecciation of upper-plate rocks is much less pervasive and commonly limited to the first few metres above the fault plane (Phillips, 1982).

A special class of mineral deposits, genetically and spatially related to detachment faults, is now well established. The deposits occur in fault-associated breccia zones (Drobeck *et al.*, 1986) and may be preferentially located on synformal and antiformal "megagrooves" of the detachment surface. A sequence of early copper and iron sulphides, followed by massive specular hematite, in turn followed by fracture-filling chrysocolla and malachite has been cited (Spencer and Welty, 1986). Mineralization by hydrothermal fluids may have occurred during faulting as a result of unusually high geothermal gradients, but does not appear to be directly related to magmatic activity. Metals produced are predominantly copper with additional lead and zinc as well as gold and silver. Manganese is concentrated at higher levels of the fault zone and locally occurs in vein and stratabound deposits.

SOME KEY EXPOSURES OF LOW-ANGLE FAULTS

The author became aware of the possible existence of low-angle faults in the summer of 1986, on Rosewall Creek in the Beaufort Range between Cameron and Comox lakes. In 1987 more representative exposures were identified adjacent to the present study area and three typical outcrops are described in the following section. In addition Table 1-10-1 shows locations of 23 representative exposures of these faults.

INTRA-KARMUTSEN FAULT

On Rosewall Creek, 50 kilometres southeast of Mount Washington and a short distance upstream from the bridge of the B.C. Forestry road (5477950N, 356580E), a conspicuous red breccia is exposed. It is seen both in the bed of the creek and further upstream in the wall of a small canyon headed by a waterfall. The breccia is generally composed of angular, highly altered, strongly hematitic to limonitic rock fragments in a matrix of massive or vuggy quartz and calcite. In some places it includes irregularly laminated layers of microbreccia. Identifiable pillow lava is exposed above and below the fault zone which encloses at least one layer of cataclastic metabasaltic rock and is inclined about 20 degrees to the northeast. The breccia is also exposed in several places on old logging roads adjacent to Rosewall Creek and its tributary Roaring Creek, where pillow lava forms the hangingwall in several instances. The brecciated rocks are clearly not part of the normal Karmutsen sequence and can only be explained as evidence of a low-angle fault. For conveniece they are informally named Rosewall breccia. The fault zone and breccia can be traced intermittently across Mount Schofield toward Horne Lake.

Cretaceous Comox Strata on Triassic Karmutsen Rocks

Low-angle faults within the Karmutsen Formation could be interpreted as thrust faults but an important outcrop on Browns River (Table 1-10-1, No. 23) exposes an unequivocal low-angle normal fault. The fault was noted during earlier mapping but ignored as a minor disturbance following the unconformity. The hangingwall, downstream and east of the fault zone, is composed of gently northeast-dipping sandstone, grading downward into siltstone and coaly shale with some plant fragments. The lowest undisturbed Comox beds are rubbly siltstone and flaky shaly coal, composed mainly of flattened plant stems, dipping 10 degrees northeast. The upper part of the fault zone is composed of sedimentary material that grades downward into a mélange of metavolcanic material. The clasts are light green, entirely altered (chlorite-albite?), more or less ellipsoidal fragments, up to about 50 centimetres long. They are locally distinctly imbricated at a strike of 310 degrees. Flatly undulating glide surfaces are also well exposed in the stream bed and the fault zone is cut by vertical faults striking 060 degrees. Further upstream and lower down in the fault zone there are cataclastic fragments of quartz diorite (also exposed on the hill south of the river) and some pink-coloured Rosewall-type breccia. Karmutsen metavolcanic rocks, structurally underlying the fault zone, are exposed in the canyon further upstream.

Cretaceous Benson Conglomerate on Karmutsen Metavolcanics

A third example of a low-angle fault is on the Eagle Gorge claim in the canyon of Oyster River (Table 1-10-1, No. 1). There Rosewall breccia, up to 2 metres thick and overlying Karmutsen pillow lava and aquagene breccia, is exposed east of a rock island in the middle of the canyon. The fault zone is in part irregular unstructured breccia but the middle part is a well-layered mylonitic rock striking 350 degrees and dipping 30 degrees east-northeast. Benson boulder conglomerate, dipping 20 degrees northeast, overlies the fault zone a short distance downstream.

The lithology of this fault zone was described in detail by Northcote (1984) and is quoted verbatim. "The zone appears to be bleached and has a porcellain-like appearance. It has been crackled and filled with quartz and chalcocite with lesser pyrite. These veins are irregular in attitude and range from hairline to 1 or 2 centimetres of massive chalcocite. [Thin sections show] a breccia of altered, partly devitrified, porphyritic, microlitic volcanic glass. The breccia matrix has been veined and impregnated by quartz with lesser sericite. A polished thin section under reflected light shows sieve-like aggregates of chalcocite grains forming irregular elongate masses several millimetres in length in quartz gangue. The chalcocite contains myrmekitic intergrowths of bornite and chalcopyrite. Aggregates of covellite grains form small masses generally isolated in quartz gange." An assay of a random chip sample of mineralized material yielded: copper, 7.78 per cent; silver, 19.54 grams per tonne; gold, 0.14 gram per tonne. The volcanic glass observed by Northcote may indicate pseudotachylite was formed in the fault zone.

SUBDIVISION IN STRUCTURAL PLATES

The Mount Washington area is structurally divided into three major units; a lower plate of autochthonous "basement" and middle and upper plates inferred to have been emplaced by lateral dislocation. The writer believes this novel structural model to be supported by convincing evidence. However, the preliminary interpretation clearly needs substantial review, elaboration and clarification in field and office. For the purpose of this discussion the three structural plates are subdivided into Areas A to H (Figure 1-10-2).

Lower Plate

The lower plate is predominantly composed of Karmutsen pillow lava, pillow breccia and lava flows. Near the contact with the sole fault of the middle plate the rocks are generally highly deformed and fractured, and display cataclastic textures.

Area A is at the northwest edge of the Forbidden Plateau and includes all the area southwest of the basal fault trace that encircles Mount Washington. In the northwest, Karmutsen flows are overlain by a veneer of Benson conglomerate and Comox sandstone and siltstone. In the south, pillow lavas and pillow breccias as well as lava flows are exposed.

Area E is a structural window, traversed by McKay Creek and its tributaries, and bordered by middle-plate Karmutsen metabasalt of Area F to the northeast and by quartz diorite and Karmutsen rocks of Areas B and D to the southwest. In Area E the rocks assigned to Unit 3 are largely brecciated and cataclastic, presumably as a result of proximity to the now-eroded middle-plate sole fault. Area G is bracketed between middle-plate Cretaceous strata to the northeast and middle-

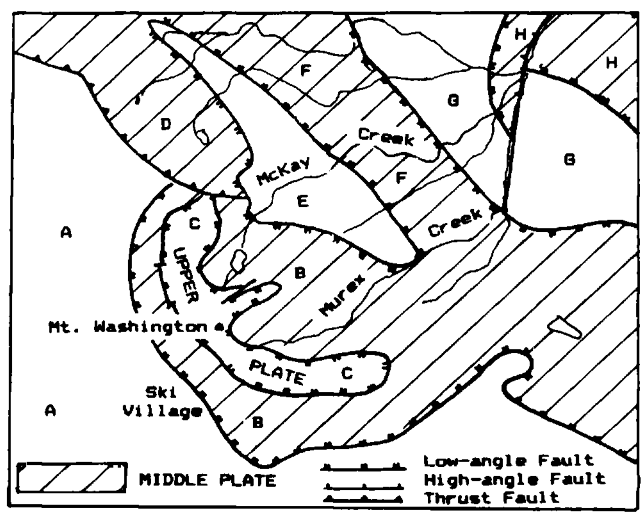


Figure 1-10-2. Structural sketch map of Mount Washington.

plate Triassic and younger rocks to the southwest. This area is also underlain by rocks of Units 1 and 2.

Lower plate rocks are offset by several northwest-striking high-angle faults and a few faults striking almost due north. One fault, conspicuous in the topography, is occupied by Murex Creek above its confluence with McKay Creek. It offsets the middle-plate sole fault and overlying conglomerate of Area H, but terminates against the trace of the sole fault in Area F.

Middle-Plate Sole Fault

The basal fault of the middle plate is presumed to be a major detachment fault, and is pivotal to the structural model presented here. Unlike Arizona, where such faults may be well marked and conspicuous in the landscape, the Vancouver Island terrain tends to conceal the faults by overburden and vegetation. Only a limited number of stream and roadcuts expose the faults and in many outcrops the footwall or the hangingwall is not seen. Table 1-10-1 lists examples of available outcrops of the basal faults of both middle and upper plates.

Exposures of Rosewall breccia, discussed in a foregoing section, were found to be useful markers of low-angle faults while gossans and limonitic stain zones may be related to both low and high-angle faults. Dark brown flinty cataclasite, with or without porphyroclastic feldspars, is also a common marker of the fault zones. These rocks form ledges, waterfalls and canyons providing good exposures. A zone of brecciated and chloritized rocks, extending up to 300 metres below the sole fault, has been described in the Basin and Range Province. Similarly rocks underlying the fault zone in the Mount Washington area are extensively fractured and form wide zones of brecciation that are mainly mapped as Unit 3. Thick zones of breccia have also been encountered in many diamond-drill holes, but have generally been interpreted as non-structural breccia.

Rocks a few metres above the fault zone tend to be largely intact with original textures or fossils well preserved. Open subhorizontal fractures in hangingwall layered rocks, including sandstone, lava flows and also some pillow lavas, give many vertical cuts an appearance of loosely stacked slabs.

The middle-plate sole fault appears to be an excellent aquifer and large parts of its trace are well marked by elongate lakes or marshy areas. In several instances streams follow the fault zone, but unlike streams on steep faults, that continuously cut down into the fault zone, watercourses on low-angle faults may oscillate across the zone between the lower and upper plates. For instance, at Location 9 (Table 1-10-1) the edge of the middle plate of Karmutsen amygdaloidal lavas forms a steep cliff, well washed by the stream. A 20-centimetre band of Rosewall breccia marks the fault at the base. Above it one encounters alternating areas of smooth, well-polished unbroken flows and areas of rough, hummocky, dark rusty weathering breccia; northeast-dipping shear zones, almost parallel to the slope, can be seen in the sidewall. Clearly, the slope of the cliff and the stream are nearly coincident with the fault. Similarly, on Murex Creek at the south end of the McKay Creek structural window (Table 1-10-1, No. 12) the creek meanders across the fault zone for a considerable distance.

Middle Plate

The middle plate underlies the largest part of the study area (Areas B, D, F and H). Area B covers the middle elevations of Mount Washington, between 1000 and 1300 metres. In the northeast, at Murex Creek, it merges with Area F. Catface quartz diorite is the nucleus of the plate and forms the base in the West Arm–McKay Lake area. According to Carson (1960) the McKay Lake quartz diorite is a central stock that produced, as offshoots, the sills and breccia pipes underlying the highest parts of the mountain. This interpretation has, until the present time, been accepted by later workers including the writer. However, the structural model presented here demands that the intrusive body is rootless and severed from its original base. Examples of this type of detached structural relationship are common in the Basin and Range Province.

The intrusive rocks are overlain by hornfelsic, dioritized and brecciated basaltic rocks (Unit 3) in the upper Murex Creek area. The contact is intrusive and in many places dykes and apophyses of light-coloured quartz diorite can be seen invading dark metavolcanic rock in the contact zone. Presumably the metavolcanic rocks represent the roof and sidewalls of the intrusive body, carried along as it became dislocated. Upper Cretaceous sediments, composed of a thin sequence of metaconglomerate (Unit 4), succeeded by metasandstone (Unit 5), rest on either quartz diorite or metavolcanic rocks, and in the south part of Area B form the sole of the plate.

Area D of the middle plate is composed of metabasalt flows of Unit 2 and breccia and cataclasite of Unit 3. In this area the rocks are entirely different in composition from those of Area B and the two zones may well have moved independently. Rocks in Area D have been thrust southwestward over those of Area B. They are also in thrust contact with the lower plate consisting of Triassic flows overlain by Cretaceous conglomerate and sandstone of Area A. Within Area D "The Oyster Breccia zone is a 1200-foot [360 metre] diameter collapse breccia with Comox breccia fragments collapsed at least 700 feet [200 metre] into the surrounding Karmutsen volcanics" (Better Resources Ltd., Annual Report, 1988). Although sufficient data are not available, the structural model presented in this report may allow a different interpretation of the Oyster breccia. Comox rocks, intersected in diamond-drill holes below Karmutsen volcanics of the middle plate, may be part of a brecciated Comox sandstone of the lower plate, coextensive with sandstone exposed directly to the west in Area A.

Area F is a belt of flat-lying to gently dipping Karmutsen metabasalts, partly pillow lava and pillow breccia (Unit 1) and partly amygdaloidal and/or porphyritic flows (Unit 2). The northwest-striking belt is regarded as a thin skin of middle-plate rocks, sitting on rocks of the same formation in the lower plate. To the south the volcanics are in intrusive contact with quartz diorite and overlain by Comox sediments.

Area H is a small area in the northeast corner of the map but extends far into the lowlands underlain by Cretaceous strata. It also includes the quartz diorite of Constitution Hill. The basal part of the zone is boulder conglomerate and metaconglomerate, well exposed on McKay and Murex creeks near their confluence. Steep faults intersect and offset the trace of the sole fault and form the contact between conglomerate and metabasalt of the lower plate in several stream exposures. The sole fault is not exposed but is projected to intersect McKay Creek about 400 metres southwest of the Rossiter Main bridge (5516950N, 339225E). There sheared, cataclastic, barely recognizable pillow lava is separated by a covered interval from a hematitic to limonitic, irregularly deformed conglomerate. The low-angle fault between Benson conglomerate and Karmutsen metavolcanics is well exposed beyond the area of Figure 1-10-1, on and near Oyster River (Table 1-10-1, Nos. 1 and 3).

Subsidiary low-angle faults within the Benson conglomerate are well exposed in a canyon 600 metres downstream from the junction of McKay and Murex creeks (Table 1-10-1, No. 7). A major fault, exposed in a sharp bend of the canyon, displays a zone of Rosewall breccia 30 centimetres thick, composed mainly of irregularly banded hematitic quartz, dipping 25 degrees to the south. A second fault plane is exposed in the next bend of the creek and forms a broad arch, undercut by the stream. The cobble layers in these cuts occur in fault-bounded lenses, separated by strongly imbricated hematitic silt layers with a rhomboid fracture pattern. Considerable low-angle dislocation within the formation is plainly apparent in these exposures.

Quartz diorite of Constitution Hill, overlying a narrow belt of Karmutsen metabasalt and Comox sandstone, is inferred to be in thrust-fault contact with the conglomerate. The thrust fault and the sole fault presumably converge southeastward towards Wolf Lake, just east of the study area, where two mineral prospects (Table 1-10-1, Nos. 11 and 14) are related to low-angle faults.

Thus the middle plate, as tentatively outlined in the preceding paragraphs, is composed of several dissimilar fragments. It can be argued that the core of the plate is a dislocated mass of Tertiary intrusive rock, to which underlying Triassic volcanics as well as overlying Cretaceous sediments are more or less firmly attached by intrusive contacts.

Further investigation should determine if similar structures exist in other parts of Vancouver Island. Preliminary field data suggest that similar low-angle faulting may be present in the Beaufort Range and may continue into the area of Tertiary sills north of Nanaimo Lakes.

Upper Plate Basal Fault

Better Resources Ltd. drove an exploratory incline into the west flank of the West Arm at about 1325 metres elevation in 1987. It follows the basal fault of the upper plate for almost its full length of 278 metres, providing proof of the existence and detailed information on the nature of a low-angle fault system in the Mount Washington area, and by extension, on Vancouver Island. A detailed analysis of the geology in the tunnel and its vicinity is provided in the report of R. Dahl in preparation. The fault zone consists of several interfingering fault planes that, according to the Better Resources 1988 Annual Report, generally have a slight westerly dip. The fault is clearly the locus of mineralization and has been intersected as an altered, locally mineralized shear zone in numerous drill holes. Beyond the exploration area the present study has tentatively identified the fault in several places at elevations above 1100 metres on the three spurs of the mountain (Table 1-10-1, Nos. 13, 15, 17, 18, 19 and 20). As projected, the fault plane has an overall northeasterly dip of 5 to 8 degrees, but may arch to a gentle westerly dip towards the west slope of the mountain. On the West Arm the shear zone that hosted the orebody at the old Mount Washington mine forms part of the fault. Further north several cuts and pits adjacent to the mine road (Table 1-10-1, No. 13) expose dark brown flinty cataclasite indicative of the fault zone. Prospect pits (Table 1-10-1, No. 18) provide a location for the fault on the Central Arm. Further southeast, on the East Arm, the trace of the fault is projected near the end of Branch 62-F (Table 1-10-1, No. 19). There roadcuts expose mylonitized siltstone forming the presumed top of the middle plate and which are separated by a short covered interval from coaly argillite, with well-preserved fossil leaves, exposed in a small pit and interpreted as the basal part of the upper plate. Lastly, at the eastern edge of the Mount Washington ski area, Rosewall breccia is exposed along the service road and at the base of quartz feldspar porphyry in a small quarry.

The Domineer prospect (Table 1-10-1, No. 17) is considered by the Better Resources geologists to be associated with the same fault zone exposed in their exploratory tunnel. Figure 1-10-1 shows a subsidiary fault, tentatively projected about 100 metres above the basal fault of the upper plate, to include the Domineer together with other indications of a low-angle fault at that level on the Central and East Arm.

Upper Plate

The upper plate is composed of rocks that up to the present time have been identified as Comox sediments, quartz diorite, quartz diorite porphyry, Murray breccia and Washington breccia (Carson, 1960, 1973; McGuigan, 1975). The present investigation has not dealt with these rocks in detail but the writer acknowledges that most or all of them are probably extrusive pyroclastic volcanic rocks. Thus all upper plate rocks of the West Arm have tentatively been categorized as Tertiary volcanics (Unit 7). On the East Arm the plate is inferred to consist of a basal section of Comox sediments overlain by Tertiary volcanics, and in the ski area to the southwest the volcanics overlie intrusive rock. These contacts are arbitrary and subject to reinterpretation.

CONCLUSION

Two major low-angle faults separate Mount Washington into lower, middle and upper plates. The lower plate is composed of Upper Triassic (Karmutsen) metavolcanics; the middle plate is made up of diverse segments with Karmutsen volcanics, Cretaceous (Nanaimo) sediments and Tertiary (Catface) quartz diorite; and the upper plate is inferred to include Tertiary volcanics together with some Cretaceous sediments and Tertiary quartz diorite. The plane of the lower sole fault appears to slope northeastward, intersecting the northeast slope of the mountain at several levels. Thus alternating areas of lower and middle-plate rocks are exposed at the surface. Although no data are available it seems possible that the sole fault extends eastward, at or below the base of Cretaceous sediments, in the Nanaimo Lowlands of eastern Vancouver Island.

The fault zones are clearly good conduits for epithermal fluids and are locally well mineralized. It seems, however, that of all mineral claims staked on fault-related mineralized breccias, those adjacent to Tertiary intrusions and/or the associated volcanic rocks have shown the most promise.

Despite a considerable amount of fieldwork by the author in the small area of Figure 1-10-1 and previous work by many others, more detailed fieldwork is yet required to consolidate and improve the structural model presented here. Extension of these investigations into the eastern ranges and Nanaimo Lowlands of Vancouver Island is also needed to probe the extent of detachment faulting. Such fieldwork will need support by petrographic, and perhaps geophysical and dating studies. It is hoped other research and exploration geologists and their organizations will be encouraged to carry forward the study of these structures. They yield a fertile field for both research and mineral exploration.

ACKNOWLEDGMENTS

Financial support for this project was provided by the British Columbia Ministry of Energy, Mines and Petroleum Resources and is gratefully acknowledged. Within the Ministry special thanks are due to V.A. Preto and H.P. Wilton for their interest, encouragement and valuable comments. I am also indebted to J.F. Bristow, C.C. Rennie and Angela Stanta of Better Resources Ltd. for friendly cooperation and valuable information provided. D.J. Tempelman-Kluit first drew my attention to new research in detachment faults and their genetic relationship to precious metal deposits, and Richard Dahl was instrumental in the recognition of Tertiary volcanics on Mount Washington. Crown Forests Ltd. and MacMillan Bloedel Ltd. gave free access to their timberlands, and Jan Harwijne of the former company assisted with road maps and information on terrain conditions.

REFERENCES

Carson, D.J.T. (1960): Geology of Mount Washington, Vancouver Island, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 116 pages.

——— (1969): Tertiary Mineral Deposits of Vancouver Island, *Canadian Institute of Mining and Metallurgy*, Transactions, Volume 72, pages 116-125.

——— (1973): The Plutonic Rocks of Vancouver Island, British Columbia; their Petrography, Chemistry, Age and Emplacement, *Geological Survey of Canada*, Paper 72-44, 70 pages.

Davis, G.A., Anderson, J.L., Frost, E.G. and Shackleford, T.J. (1980): Mylonitization and Detachment Faulting in the Whipple-Buckskin-Rawhide Mountains Terrane, Southeastern California and Western Arizona, *in* Cordilleran Metamorphic Core Complexes, M.D. Crittenden *et al.*, Editors, *Geological Society of America*, Memoir 153, pages 79-130.

Davis, G.A., Lister, G.S. and Reynolds, S.J. (1986): Structural Evolution of the Whipple and South Mountains Shear Zones, Southwestern United States, *Geology*, Volume 14, pages 7-10.

Davis, G.H. (1984): Structural Geology of Rocks and Regions, *John Wiley and Sons*, New York, Toronto, 492 pages.

Drobeck, P., Frost, E.C., Hillemeyer, F.L., Frost, E.G. and Liebler, G.S. (1986): The Picacho Mine: A Gold-mineralized Detachment in Southeastern California, *Arizona Geological Society*, Digest, Volume 16, pages 187-221.

Gross, W.W. and Hillemeyer, F.L. (1982): Geometrical Analysis of Upper-plate Fault Patterns in the Whipple-Buckskin Detachment Terrane, *in* Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, E.G. Frost and D.L. Martin, Editors, *Cordilleran Publishers*, San Diego, California, pages 256-266.

McGuigan, P.J. (1975): Certain Breccias of Mount Washington Property, Vancouver Island, Unpublished B.Sc. Thesis, *The University of British Columbia*, 66 pages.

Muller, J.E., Cameron, B.E.B. and Northcote, K.E. (1981): Geology and Mineral Deposits of Nootka Sound Map-area, Vancouver Island, British Columbia, *Geological Survey of Canada*, Paper 80-16, 53 pages.

Muller, J.E. and Carson, D.J.T. (1969): Geology and Mineral Deposits of Alberni Map-area, British Columbia (92F), *Geological Survey of Canada*, Paper 68-50.

Northcote, K.E. (1984): Geological Report on Eagle Gorge 1, 2 and 3 Claims, Nanaimo Mining Division, NTS 92F/14W, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 13602.

Phillips, J.C. (1982): Character and Origin of Cataclasite Developed along the Low-angle Whipple Detachment Fault, Whipple Mountains, California, *in* Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, E.G. Frost and D.L. Martin, Editors, *Cordilleran Publishers*, San Diego, California, pages 109-116.

Spencer, J.E. and Welty, J.W. (1986): Possible Controls of Base and Precious-metal Mineralization Associated with Tertiary Detachment Faults in the Lower Colorado River Trough, Arizona and California, *Geology*, Volume 14, pages 195-198.

Sutherland Brown, A. and Yorath, C.J. (1985): LITHOPROBE Profile across Southern Vancouver Island: Geology and Tectonics, *in* Fieldguides to Geology and Mineral Deposits in the Southern Canadian Cordillera, D.J. Tempelman-Kluit, Editor, *Geological Society of America*, Cordilleran Section Meeting, Vancouver, B.C., May 1985, pages 8-1 to 8-23.

Wilkins, J., Jr. and Heidrick, T.L. (1982): Base and Precious Metal Mineralization Related to Low-angle Tectonic Features in the Whipple Mountains, California and Buckskin Mountains, Arizona, *in* Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, E.G. Frost and D.L. Martin, Editors, *Cordilleran Publishing*, San Diego, California, pages 182-204.

Wilkins J., Jr., Beane, R.E. and Heidrick, T.L. (1986): Mineralization Related to Detachment Faults: a Model, *Arizona Geological Society*, Digest, Volume 16, pages 108-117.

NOTES

GEOLOGY ALONG THE LITHOPROBE TRANSECT BETWEEN THE GUICHON CREEK BATHOLITH AND OKANAGAN LAKE (92I/1, 2, 7, 8; 82L/3, 4, 5, 6)

By John M. Moore
Carleton University and
Ottawa-Carleton Geoscience Centre

KEYWORDS: Regional geology, Intermontane Belt, LITHOPROBE, Central Nicola horst, Nicola Group, Kamloops Group, Chapperon Group, Tertiary tectonics, mineral deposits, gold-bearing veins.

INTRODUCTION

This account is a progress report on geological mapping and field data compilation around part of the southern Cordillera LITHOPROBE transect in the Intermontane Belt. Objectives included integrating and improving the surface geological database for interpretation of the 1988 Vibroseis survey and reassessing the geological setting of mineral occurrences in the area. The transect route lies in the Nicola Valley and adjacent Nicola Plateau, crossing the Okanagan Highlands eastward to the northern end of the Okanagan Valley. The Coquihalla Highway, connecting Merritt and Kamloops (Figure 1-11-1), crosses the west side of the area and access is also provided by secondary, ranch and forestry roads. Low-lying regions are semi-arid grassland whereas highlands are forested; bedrock exposure is highly variable. Fieldwork, carried out in July and August of 1988, involved reconnaissance of the entire transect segment and local 1:50 000 mapping, mainly in the vicinity of the Central Nicola horst.

PREVIOUS INVESTIGATIONS

Regional mapping of the study area was first carried out by the Geological Survey of Canada at 1:253 440 scale. W.E. Cockfield (1948) mapped the Nicola area between 1939 and 1944 and A.G. Jones (1959) the Vernon map sheet from 1945 to 1951. These authors have summarized the earlier work in the area, including classic studies by G.M. Dawson and R.A. Daly. More recently, detailed mapping of parts of the Nicola Group was reported by Schau (1968), Preto (1979) and McMillan (1981). Okulitch (1979) contributed new reconnaissance mapping and recompiled the regional geology of the eastern part of the area at 1:250 000; Monger and McMillan (1984) published new regional mapping of the western part at 1:125 000. Church (1980) published a 1:50 000 map of the Tertiary volcanic rocks near Okanagan Lake. Ewing (1980, 1981) studied the Eocene volcanic rocks of the region and published an important synthesis of the early Tertiary tectonics.

REGIONAL GEOLOGY

The study area (Figure 1-11-1) is part of Quesnellia, extending almost to its eastern boundary where it is juxtaposed against high-grade metamorphic rocks of the Omineca terrane along the Okanagan shear zone (Bardoux, 1985; Parrish *et al.*, 1988). The western part of the area is underlain primarily by late Triassic arc-volcanic and volcanogenic rocks of the Nicola Group intruded by Triassic and Jurassic calcalkaline plutons, among which the Guichon Creek batholith (McMillan, 1976, 1978) bounds the western end of the transect segment. The eastern half of the area is underlain mainly by Paleozoic rocks of oceanic affinity, in both unconformable and faulted contact with the Nicola Group, that are cut by granitic plutons ranging in age from Triassic to Cretaceous. The Paleozoic and early Mesozoic stratified rocks are complexly faulted and typically metamorphosed to lower greenschist grade. They are overlain by relatively flat-lying clastic and volcanic rocks of Jurassic to Tertiary age; Eocene Kamloops Group volcanics underlie large parts of the Okanagan Highlands.

There are two main sets of major faults: northwest-striking, at least in part contractional features that are probably Mesozoic, and north to north-northeast-striking Tertiary extensional faults. The latter appear to have controlled Eocene sedimentation (Ewing, 1980) and are overlapped by Miocene(?) basalts. The eastern margin of the Guichon Creek batholith and both sides of the Central Nicola horst (Figure 1-11-2) are bounded by steep Tertiary faults.

CENTRAL NICOLA HORST

Termed the "Central Nicola Batholith" in earlier studies, the Central Nicola horst is actually a complex comprising at least Mesozoic and early Tertiary plutonic rocks as well as metamorphosed supracrustal rocks of several ages. It is separated from the surrounding Nicola Group rocks (uTn; Figure 1-11-2) by steep, brittle Tertiary faults: the Coldwater – Clapperton Creek fault zone on the west side, the Quilchena Creek – Stump Lake fault system on the east and unnamed faults to the south. The north end is overlain by Tertiary basalt. Fault zones exhibit complex, closely spaced fracturing, slickensides and local hydrothermal alteration (*see* Mineral Deposits, below). With one exception, no ductile strain is evidently associated with them: an extensional fault at the southwest end of Nicola Lake has an early history of ductile shear, overprinted by brecciation. The Central Nicola horst separates major contrasting facies of the Nicola Group (Preto, 1979) all of which are metamorphosed to lower greenschist facies. The western belt includes mafic to felsic volcanic rocks, clastic sediments and limestone; the central belt, principally augite porphyry flows and coarse vol-

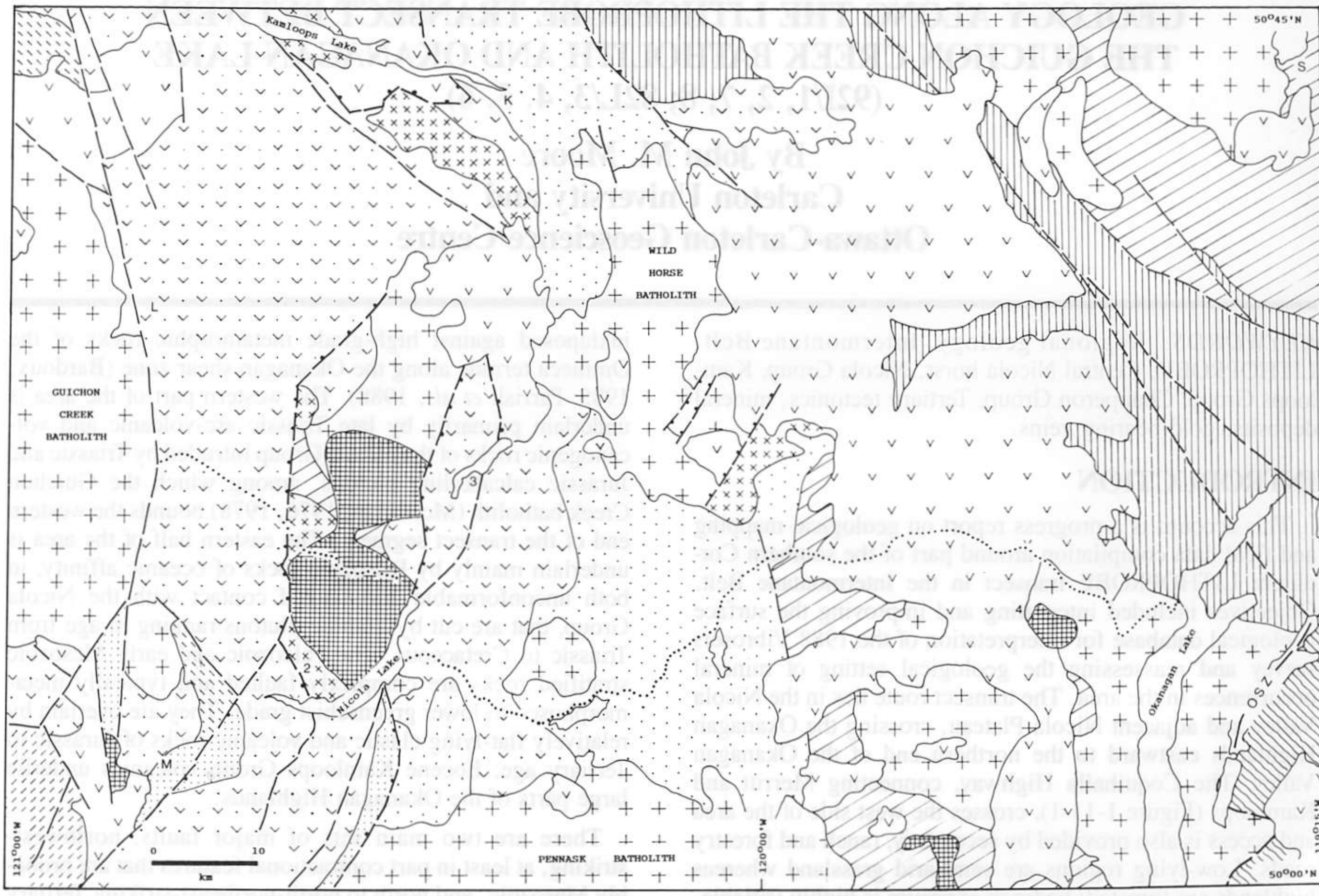


Figure 1-11-1. Regional geology around the LITHOPROBE transect (dotted line) in the eastern part of the Intermontane Belt. Compiled from Jones (1959), Okulitch (1979), McMillan (1981), Monger and McMillan (1984), and field data of B.J. Johnson, M. Bardoux and the writer, not previously published. Tertiary volcanic rocks on and west of the Wild Horse batholith may be as young as Miocene.

caniclastics, is mainly north and south of the horst; and the predominantly epivolcaniclastic eastern belt borders the horst on the east.

The apparently oldest rocks in the horst are highly strained quartzite/(chert?)-pebble metaconglomerate, black pelitic schist, and grey metatonalite and tonalite porphyry (Psm and tm, Figure 1-11-2; all plutonic rocks were identified on the basis of potassic-feldspar staining in the field). The metasediments are not comparable to any unit of the Nicola Group but do resemble certain rocks of the "Harper Ranch Group" to the east (J.W.H. Monger, personal communication, 1988), except that the latter are much less deformed. Metamorphosed augite porphyry and thin-bedded mafic volcaniclastics (uTnm), closely comparable to units of the nearby Nicola Group, but metamorphosed to lower amphibolite facies, contain the same fabric as the metasediments and metatonalite: a northwesterly striking foliation and moderately west-plunging stretching lineation that is consistent in orientation across the horst (Figure 1-11-2). Scarce kinematic indicators in these rocks suggest easterly directed thrusting.

On the west side of the horst the above-mentioned rocks are bordered by relatively uniform metamorphosed gabbro, diorite and minor quartz diorite (dm). Intrusive contacts are not exposed but the much less homogeneous and less intense strain in the metadiorite (restricted mainly to anastomosing ductile shear zones, centimetres to decimetres wide) implies that it is younger. At the one locality where the contact with metatonalite is closely defined, on the northwest shore of Nicola Lake (Figure 1-11-2), it is abrupt and appears to be faulted.

The bulk of the Central Nicola horst is occupied by medium to coarse-grained granitic rocks, predominantly granodiorite but ranging from biotite granite to hornblende-biotite tonalite, mainly as a function of the concentration of coarse potassic-feldspar megacrysts. Despite their superficial uniformity these rocks are of two distinct ages. Rocks in the northern third of the horst (Jgdm) have yielded a rubidium-strontium isochron at *circa* 190 Ma and are thus Early Jurassic (R.L. Armstrong, personal communication, 1988). Zircons from a sample from the southern part of the horst (Tgd), 6 kilometres west of the north end of Nicola Lake, are dated as Paleocene by uranium-lead (64.5 ± 0.5 Ma; R.R. Parrish, personal communication, 1988). The northern samples are all augen textured and exhibit transitional ductile-brittle deformation in thin section, whereas the southern samples are little strained (R.L. Armstrong, personal communication, 1988). Mapping by the writer confirms the Paleocene granodiorite is in sharp intrusive contact

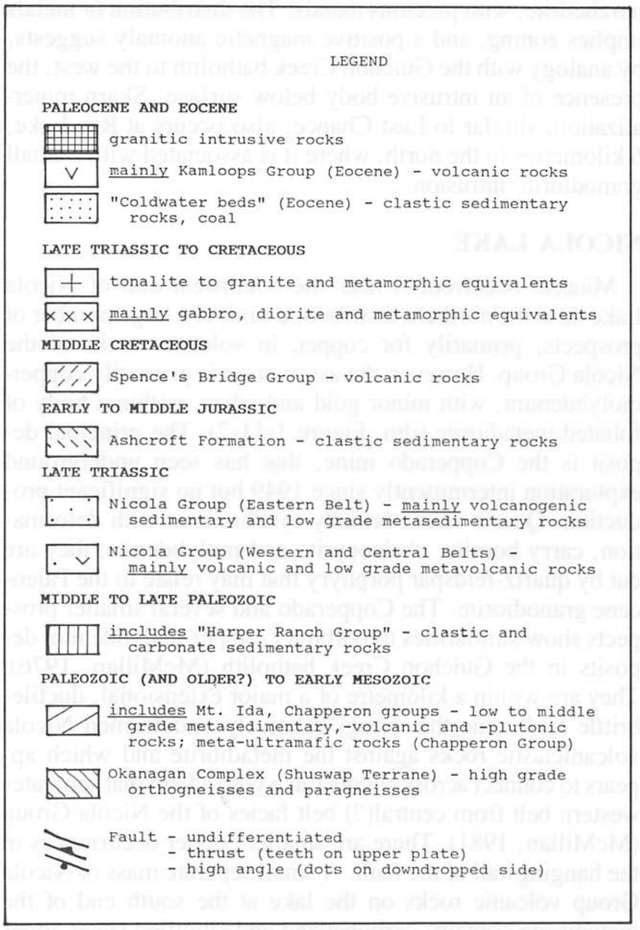


Figure 1-11-1a. Legend for Figure 1-11-1.

with adjacent units and is megascopically unstrained, save for one locality near its west contact where it contains gently west-dipping extensional shear bands. Its contact with the Jurassic body remains poorly defined. Rubidium-strontium (R.L. Armstrong, personal communication, 1988) and potassium-argon (Preto *et al.*, 1979; Monger and McMillan, 1984) hornblende and biotite dates from both units are almost all in the range of 52 to 70 Ma. The Rey Lake stock, a small body similar to the Paleocene granodiorite, but located near the LITHOPROBE transect 20 kilometres to the west, has a potassium-argon biotite age of 69 Ma (Preto *et al.*, 1979).

The Central Nicola horst was identified as a metamorphic core complex by Ewing (1980) and considered to result from early Tertiary extension in the southern Cordillera. Although the contrast in metamorphic grade between the horst and its surroundings, and the age of the bounding faults, are consistent with this proposal, it is apparent that most of the ductile strain in the horst is not spatially related to the Tertiary bounding faults, is no younger than Paleocene and, on the present evidence, is contractional. By contrast, the Tertiary ductile shearing in the Omineca terrane to the east is extensional and Eocene (45-58 Ma; Parrish *et al.*, 1988). It appears that the horst is providing a "window" into a deformed terrane below the present erosional level of the enclosing Nicola Group rocks; like the Mount Lytton complex 50 kilometres to the west (Monger, *in press*), it affords a view into the probable roots of the Nicola arc. It may be that its entire ductile history is Mesozoic and related not to Tertiary extension but rather to westerly subduction or, more probably, to easterly obduction of the arc complex. Reset mineral dates imply later uplift and cooling in Eocene time. Further age determinations are in progress in an attempt to better delimit the timing of intrusive and metamorphic events in the Central Nicola horst.

RELATIONSHIPS BETWEEN NICOLA GROUP AND CHAPPERON GROUP

Existing regional maps are inconsistent in their portrayal of the contact relationships of the Mesozoic and Paleozoic rocks near the LITHOPROBE transect. In the vicinity of 120° west (Figure 1-11-1), Jones (1959) mapped an unconformity in the Salmon River canyon between underlying schists, limestone and ultramafic rocks of the Chapperon Group (of unknown age) and overlying sedimentary rocks which he assigned to the Cache Creek Group on the basis of their lithology. He considered the younger rocks to extend westward into the Nicola map area where Cockfield (1948) had also given them a Permo-Carboniferous age, again without fossil control. South of the Salmon River, on the present transect route, Jones mapped the boundary between the two groups as a fault.

Read and Okulitch (1977) confirmed the Salmon River unconformity but the overlying rocks were correlated with the Nicola Group on the basis of Late Triassic conodonts. The Chapperon Group was suggested to be Middle Carboniferous. Okulitch (1979) identified clastic and carbonate

Figure 1-11-2. Geology of the Central Nicola horst. Compiled from Monger and McMillan (1984 and original traverse maps) and fieldwork by the writer.

sedimentary rocks of the Permo-Carboniferous "Thompson Assemblage", lying between the Nicola Group and the Chapperon Group south of the Salmon River and along the LITHOPROBE transect, but this age assignment is not supported by any fossil evidence. The nearest fossils bearing on the supposed Late Paleozoic age of these rocks were collected 20 kilometres to the south near Dome Mountain, from rocks lithologically correlated but not structurally continuous with the succession on the transect. Monger and McMillan (1984) assigned all the rocks in this area, west of 120° (virtually all the rocks immediately above the Chapperon Group) to sedimentary facies of the Nicola Group, again without local fossil control but on the basis of strong lithologic and structural similarity to dated Nicola rocks north of Kamloops, separated from those along the transect by the Wild Horse batholith (Figure 1-11-1).

As a result of the present study, volcaniclastic rocks of the Nicola Group (eastern belt) are believed to be in direct fault contact with the Chapperon Group. Reconnaissance mapping shows that Nicola volcanic wacke and siltstone, as they are traced eastward from Chapperon Lake (immediately south of the transect near 120° west, Figure 1-11-1), become deformed into recumbent mesoscopic folds. Siltstone develops a prominent cleavage that dips gently west, parallel to the fold axial surfaces. The deformed succession is very similar to unfolded rocks to the west except that it contains minor dark limestone beds. Chapperon Group rocks, mainly mafic and ultramafic schists near the contact with the Nicola Group, exhibit two generations of deformation. Pending more detailed mapping, it is tentatively concluded that the Nicola Group has been thrust eastwards over the Chapperon Group in this vicinity; to the north the thrust zone must cut either above or below the Salmon River unconformity.

MINERAL DEPOSITS

The LITHOPROBE transect passes near three major concentrations of mineral occurrences in and near the Central Nicola horst. As numbered on Figure 1-11-1, these are (1) Swakum Mountain, (2) Nicola Lake and (3) Stump Lake. A fourth locality, Whiteman Creek near Okanagan Lake, unlike the others, is currently the site of a major exploration program. There are important differences of geological setting among these four localities.

SWAKUM MOUNTAIN

The Swakum Mountain occurrences, not visited by the author, were described by Cockfield (1948) and in numerous assessment reports (for example, Kelly, 1984). The area has a history of exploration and small-scale mill testing dating from 1916. Polymetallic (copper, lead, zinc, tungsten, silver and gold) mineralization is found in Nicola Group mafic to intermediate flow and volcaniclastic rocks and limestone; on the south flank of the mountain, dacitic and rhyolitic rocks locally form part of the succession. The Last Chance (Lucky Mike) deposit consists of pyrite, pyrrhotite, chalcopyrite and scheelite, disseminated in a hematite-garnet-epidote skarn that has replaced limestone along its contact with volcanic rocks. Occurrences to the south are veins and replacements lacking scheelite and containing galena, sphalerite and tetrahedrite, with precious metals. The distribution of metals implies zoning, and a positive magnetic anomaly suggests, by analogy with the Guichon Creek batholith to the west, the presence of an intrusive body below surface. Skarn mineralization, similar to Last Chance, also occurs at Rey Lake, 6 kilometres to the north, where it is associated with a small granodiorite intrusion.

NICOLA LAKE

Mineral occurrences near the southwest end of Nicola Lake lie at the northern distribution limit of a large number of prospects, primarily for copper, in volcanic rocks of the Nicola Group. However, the association is primarily copper-molybdenum, with minor gold and silver, within a body of foliated metadiorite (dm, Figure 1-11-2). The principal deposit is the Copperado mine, that has seen underground exploration intermittently since 1949 but no significant production. Quartz veins, broadly synchronous with deformation, carry bornite, chalcopyrite and molybdenite; they are cut by quartz-feldspar porphyry that may relate to the Paleocene granodiorite. The Copperado and several smaller prospects show similarities to porphyry copper-molybdenum deposits in the Guichon Creek batholith (McMillan, 1976). They are within a kilometre of a major extensional, ductile-brittle fault zone that brings relatively undeformed Nicola volcaniclastic rocks against the metadiorite and which appears to connect across Nicola Lake with a fault that separates western belt from central(?) belt facies of the Nicola Group (McMillan, 1981). There are smaller copper occurrences in the hangingwall of the fault. A small separate mass of Nicola Group volcanic rocks on the lake at the south end of the metadiorite contains carbonatized and silicified shear zones with epidote, pyrite and chalcopyrite. Mineralization in both the Nicola rocks and the metadiorite may relate to the regional metamorphism and concurrent deformation displayed within the Central Nicola horst.

STUMP LAKE

North-striking, persistent gold-bearing quartz veins in the Nicola Group south of Stump Lake were actively worked from the late 19th Century to the 1940s (Cockfield, 1948). Although the host rocks were earlier described as primarily volcanic, examination of the property in 1988 reveals that they are a volcaniclastic sedimentary succession consisting mainly of greywacke turbidites with subordinate siltstone and conglomerate containing augite porphyry clasts. The west-dipping succession is broken into several blocks by brittle faults. Vein systems, typically less than a metre in thickness but persistent in some cases for as much as 500 metres along strike and 300 metres down dip (Cockfield, 1948), are surrounded by narrow carbonatized halos; sericitic alteration was observed on the dump of the Enterprise adit. Some of the alteration zones are sheared whereas others show no penetrative deformation; veins and shear zones dip predominantly east at a high angle to bedding. Metallic minerals observed in the veins (Cockfield, 1948) include pyrite, galena, sphalerite, tetrahedrite, chalcopyrite, bornite, scheelite, arsenopyrite, pyrrhotite and native gold. The age of the veins is not directly established. Faults in the host rocks have a similar strike to those mapped by the author east of the

Central Nicola horst at the north end of Nicola Lake, where they separate blocks of distinctly differing primary lithology and degree of penetrative deformation, and appear to be part of the set of Tertiary faults that bounds the horst. Although many small faults are reported in the underground workings at Stump Lake, few were seen to have displacements of more than a metre or so, suggesting that any major faulting either preceded or was coeval with the veins and thus that the veins are of Tertiary age. Alternatively, vein formation may be the result of low-grade regional metamorphism in Mesozoic time. Direct dating of the wallrock alteration would resolve this uncertainty.

WHITEMAN CREEK

Gold prospects immediately west of Okanagan Lake (4, Figure 1-11-1) currently being explored by Huntington Resources Inc. and Corona Corporation (Brett claims), and Brican Resources Ltd. (Gold Star claims), prompted considerable staking activity in the area in 1988. The host rocks are flat-lying basalts and tuffs of presumed Eocene age; vuggy, brecciated gold-quartz veins occupy faults striking north-northwest, dip steeply and are surrounded by clay-silica-pyrite and bleached propylitic alteration halos. Gold is associated with pyrite and minor galena and argentite (Meyers, 1988). Feldspar porphyry dykes, probably related to a nearby Eocene granitic stock (dated at 50 Ma; Church, 1980), have similar attitudes to the veins. Both dykes and stock are also altered, further supporting an Eocene or younger age for the mineralization. Mesozoic (Late Jurassic?) granite that forms the basement to the Eocene volcanic rocks is in steep, probably faulted contact with the lavas along the eastern side of the Brett property; a large alteration zone ("Gossan Zone") in the volcanics is close to this boundary. The epithermal mineralization may have resulted from circulating fluids driven by Eocene magmatic heat; however, the spatial association of the veins with the Okanagan shear zone that was active in Eocene time (Bardoux, 1985; Parrish *et al.*, 1988) indicates the possibility of another energy source. Ductile strain at upper amphibolite grade in the lower plate of the Okanagan shear zone, related geometrically to early Tertiary extension, affects rocks as young as 50 Ma and implies that the hangingwall rocks were juxtaposed against hot underlying gneisses of the Shuswap terrane that may have provided the necessary thermal energy for hydrothermal circulation. Tempelman-Kluit and Parkinson (1986) have called attention to the association of a number of gold prospects with the hangingwall of this major structure.

OTHER MINERAL OCCURRENCES

The western boundary of the Central Nicola horst, near the LITHOPROBE transect, exhibits intense quartz-sericite-pyrite alteration of Nicola Group volcaniclastic(?) rocks where they are exposed in roadcuts on the Coquihalla Highway. Because of limited exposure it is not certain whether this alteration is related to the main boundary fault of the Central Nicola horst or to an earlier structure; however, it is not typical of the nearby Nicola Group at greater distance from the boundary fault. This observation suggests that early Tertiary faults in the area, like those near Okanagan Lake, may be favourable locales for epithermal mineralization.

CONCLUSIONS

The main conclusions arising from the project to date are:

(1) The Central Nicola horst contains at least four distinct plutonic and metaplutonic units as well as regionally metamorphosed and highly strained supracrustal rocks, including siliciclastics that do not correspond to any known facies of the Nicola Group. It preserves a complex history that is not evident in the surrounding Nicola rocks, with a probable time span of at least late Paleozoic to early Tertiary. As such, it constitutes an exhumed part of the crust that underlies the present exposure of the Nicola Group and may represent the roots of the Nicola arc.

(2) The eastern contact of the Nicola Group with underlying, presumably late Paleozoic rocks of the Chapperon Group near the LITHOPROBE transect is an unconformity in at least one locality, but a probable thrust fault elsewhere.

(3) Mineral occurrences near the transect are of several different types and appear to be related to both Mesozoic magmatic and metamorphic processes as well as Tertiary extensional tectonics and volcanism.

LITHOPROBE seismic results, expected early in 1989, should cast more light on the relative importance of the fault systems mapped on surface and, in conjunction with isotopic dating and petrologic studies in progress, provide a clearer image of the deep structure and history of the Intermontane Belt and its associated mineral deposits.

ACKNOWLEDGMENTS

I am indebted to Ken Daughtry of Discovery Consultants, Bill McMillan and Rick Meyers of the British Columbia Ministry of Energy, Mines and Petroleum Resources and Jim Monger of the Geological Survey of Canada for geological information and stimulating discussion in the field. Huntington Resources and Corona Corporation kindly gave their consent to visit their properties. Dick Armstrong (The University of British Columbia) and Randy Parrish (Geological Survey of Canada) provided isotopic age data and Dick Brown, Brad Johnson and Derek Thorkelson, all of Carleton University, contributed information on Tertiary extensional features. Many residents of the area were hospitable, especially Guy Rose and Elmer O'Hanley of Quilchena Cattle Company, Gerard and Lawrence Guichon of Guichon Ranch and Joe Gardner of Douglas Lake Cattle Company. Pip Moore worked hard and long in support of all aspects of the field program, especially in maintaining the computer database.

REFERENCES

Bardoux, M. (1985): The Kelowna Detachment Zone, Okanagan Valley, South-central British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 85-1A, pages 333-339.

Church, B.N. (1980): Geology of the Terrace Mountain Tertiary Outlier, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 37 (revised).

Cockfield, W.E. (1948): Geology and Mineral Deposits of Nicola Map-area, British Columbia, *Geological Survey of Canada*, Memoir 249, 164 pages.

Ewing, T.E. (1980): Paleogene Tectonic Evolution of the Pacific Northwest, *Journal of Geology*, Volume 88, pages 619-638.

——— (1981): Petrology and Geochemistry of the Kamloops Group Volcanics, *Canadian Journal of Earth Sciences*, Volume 18, pages 1478-1491.

Jones, A.G. (1959): Vernon Map-area, British Columbia, *Geological Survey of Canada*, Memoir 296, 168 pages.

Kelly, S.F. (1984): Report on Assessment Work on the Irene and Dam Mineral Claims, Northeast of Merritt, Nicola Mining Division, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 12321.

McMillan, W.J. (1976): Geology and Genesis of the Highland Valley Deposits and the Guichon Batholith, *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 85-104.

——— (1978): Geology of the Guichon Creek Batholith and Highland Valley Porphyry District, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 30.

——— (1981): Nicola Project - Merritt Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 47 (North and South Sheets).

Meyers, R.E. (1988): Brett Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, Part B, pages B15-B22.

Monger, J.W.H. (*in press*): Hope and Ashcroft Map Areas, Southwestern British Columbia, *Geological Survey of Canada*, Open File.

Monger, J.W.H. and McMillan, W.J. (1984): Bedrock Geology of Ashcroft (92I) Map Area, *Geological Survey of Canada*, Open File 980.

Okulitch, A.V. (1979): Lithology, Stratigraphy, Structure and Mineral Occurrences of the Thompson - Shuswap - Okanagan Area, British Columbia, *Geological Survey of Canada*, Open File 637.

Parrish, R.R., Carr, S.D. and Parkinson, D.L.(1988): Eocene Extensional Tectonics and Geochronology of the Southern Omineca Belt, British Columbia and Washington, *Tectonics*, Volume 7, pages 181-212.

Preto, V.A. (1979): Geology of the Nicola Group Between Merritt and Princeton, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 69.

Preto, V.A., Osatenko, M.J., McMillan, W.J. and Armstrong, R.L. (1979): Isotopic Dates and Strontium Isotopic Ratios for Plutonic and Volcanic Rocks in the Quesnel Trough and Nicola Belt, South-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 16, pages 1658-1672.

Read, P.B. and Okulitch, A.V. (1977): The Triassic Unconformity of South-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 14, pages 606-638.

Schau, M.P. (1968): Geology of the Upper Triassic Nicola Group in South-central British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*.

Tempelman-Kluit, D. and Parkinson, D. (1986): Extension Across the Eocene Okanagan Crustal Shear in Southern British Columbia, *Geology*, Volume 14, pages 318-321.

GEOLOGY OF MISSION RIDGE, NEAR LILLOOET, BRITISH COLUMBIA (92I, J)

By Meg Coleman
Carleton University
and Ottawa-Carleton Geoscience Centre

KEYWORDS: Regional mapping, Bridge River terrane, Mission Ridge fault, Yalakom fault, Marshall Creek fault.

INTRODUCTION AND REGIONAL SETTING

The purpose of this study is to determine the geometry and timing of movement on internal and bounding structures of the Bridge River terrane in the vicinity of one segment of the 1988 LITHOPROBE southern Cordilleran transect, near Lillooet, British Columbia (Figure 1-12-1). Specifically, the orientation of the major faults (Yalakom, Marshall Creek and others) is addressed in order to assist in interpreting the seismic reflection data collected in 1988. The tectonic history of rock units at the boundary of the Coast plutonic complex and the Intermontane Belt between 50° and 51° north latitude is highly enigmatic. An already complex history of Mesozoic accretion and probable Eocene extension is obscured by Tertiary strike-slip faulting, involving northward movement of more outboard allochthonous terranes during and/or after accretion.

The Bridge River terrane, composed mainly of Middle Triassic to Middle Jurassic chert, argillite, basalt, minor limestone, alpine-type ultramafic rocks and their metamorphosed equivalents (Roddick and Hutchison, 1973; Monger, 1977; Potter, 1986), lies immediately to the west of the Yalakom fault, a major strike-slip fault (Figure 1-12-1). This terrane has no clear connection to either Terrane I or II of Monger *et al.* (1982). A recent study by Potter (1986) suggests that the Bridge River terrane was formed during the mid-Mesozoic on the western margin of Terrane I, after accretion of Terrane I but prior to accretion of Terrane II.

Near Lillooet, the northwest-trending Yalakom fault separates Jura-Cretaceous Tyaughton basin sediments on the east from the Bridge River Group on the west. The Bridge River Group is deformed by both high-angle and low-angle northwest-trending faults, which are superimposed on an already complex internal structure.

Recent studies in the area include Potter (1983, 1986), which involved detailed mapping of the southern Shulaps Range including the Shulaps ultramafic complex; a detailed structural analysis of fractures within the Lillooet Group adjacent to the Fraser fault by Miller (1988); and fission-track dating of the Mission Ridge pluton by Parrish (1983) which revealed significant rapid Oligo-Miocene uplift. Gold placer operations are currently active along the Yalakom and Bridge rivers.

LITHOLOGY

BRIDGE RIVER GROUP

The Bridge River Group, bounded to the northeast by the Yalakom fault and to the southwest by the low-angle Mission Ridge fault (Figure 1-12-2), is a chaotic mélange of ribbon chert, greenstone, pillow basalt, minor greywacke, limestone olistoliths and narrow serpentinite zones. It has a thickness of 2.5 to 4.5 kilometres in this structural panel (Figure 1-12-3).

Layers of grey radiolarian chert, 1 to 5 centimetres thick, are separated by argillite layers 1 to 10 millimetres thick. Fault-bounded blocks of chert have multiple, randomly oriented slickenside surfaces. These blocks are usually in fault contact with similarly deformed blocks of the previously mentioned lithologies. In the southern Shulaps Range, Potter (1986) found chert in depositional contact with limestone, greenstone and sandstone. Radiolaria from chert found along

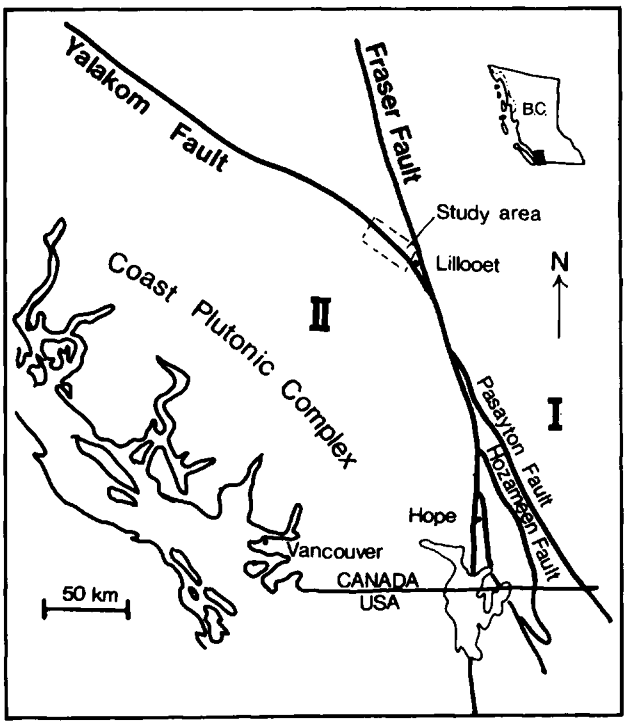


Figure 1-12-1. Map of southwestern British Columbia with study area and major structural features. I and II refer to Terrane I and Terrane II of Monger *et al.*, (1982).

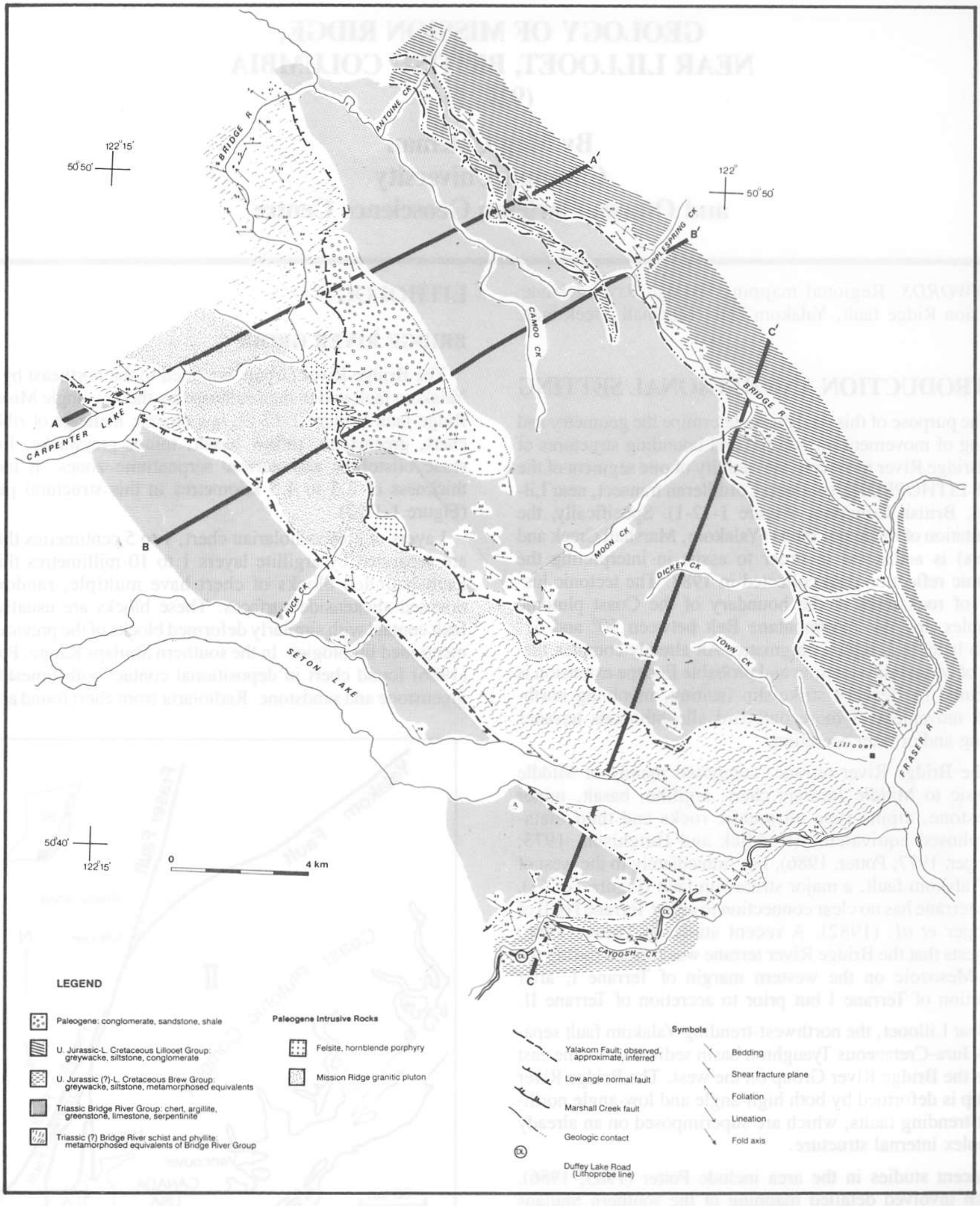


Figure 1-12-2. Geological map of Mission Ridge area. Local relief is more than 2200 metres and accounts for the arcuate trace of some of the major faults.

the Bridge River and Carpenter Lake range from Middle Triassic to Middle Jurassic in age (Potter, 1986; J.W.H. Monger, personal communication, 1988).

Greenstones range from well-preserved pillow basalts to highly sheared and chloritized slickensided blocks. Serpentinized ultramafic rocks occur in discontinuous northwest-trending strands along the Bridge River. Limestone is present as lens-shaped olistoliths as large as 20 metres in diameter, and as 50-metre-thick layers laterally continuous for up to 2 kilometres.

BRIDGE RIVER SCHIST AND PHYLLITE

Metamorphosed equivalents of the Bridge River Group include well-foliated and lineated metachert, phyllite and chlorite schist cut by abundant syntectonic and postdeformational pegmatitic and granitic intrusives (Plates 1-12-1 and 1-12-2). Metamorphic grade is lower greenschist to lower amphibolite facies.

The metacherts are mylonitic, characterized by layers of quartz, 2 to 10 millimetres thick, separated by micaceous pelitic laminations, 1 to 5 millimetres thick. Phyllite contains muscovite, biotite and minor garnet. Chloritized foliated greenstone and greenschist occur in layers 2 to 15 metres thick, and as boudins 2 to 3 metres wide surrounded by metachert and phyllite. Attenuated layers of light grey calcite marble, 1 centimetre to 2 metres thick, occur locally.

LILLOOET GROUP

The Lillooet Group consists of marine siltstones, argillites and conglomerates of volcanic provenance. The Lillooet Group has a minimum thickness of 850 metres with ages based on paleontological data which range from Late Jurassic to Early Cretaceous (Duffell and McTaggart, 1952; Trettin, 1961; Jeletsky, 1971).

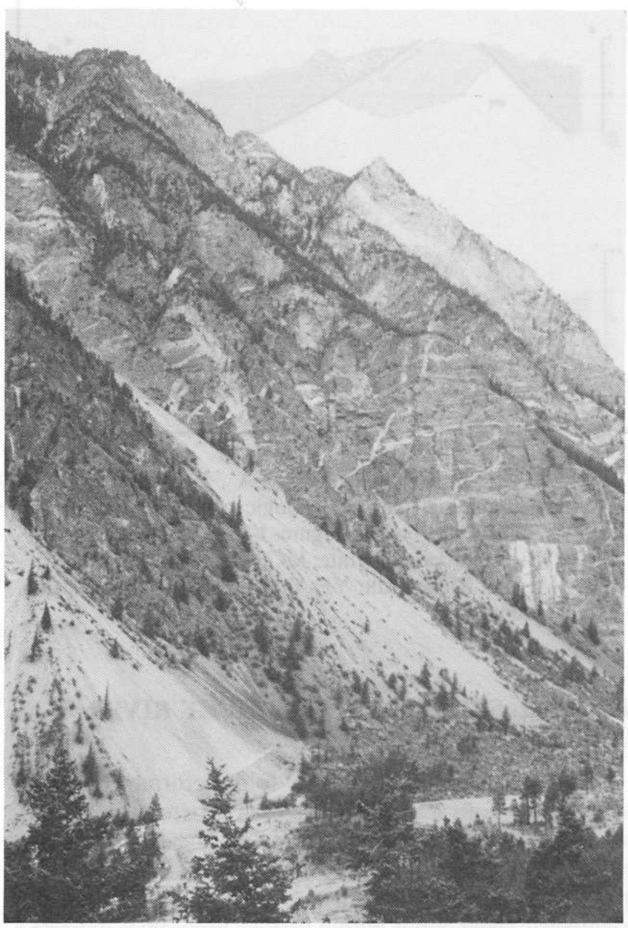


Plate 1-12-1. Bridge River schist and phyllite cut by several syntectonic and postdeformational dykes.

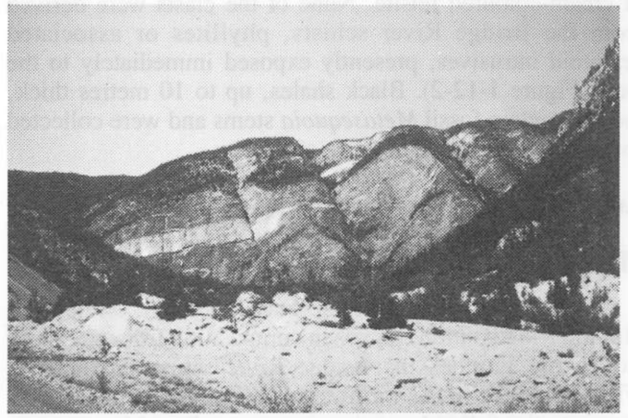


Plate 1-12-2. Foliated late syntectonic granitic dyke in Bridge River schist and phyllite.

In the southeast part of the map area the Lillooet Group consists predominantly of interbedded (1 to 10 centimetres thick) argillite and fine-grained sandstone layers with crossbedding, graded beds and load structures. Beds of coarse-grained greywacke with occasional argillaceous rip-up clasts occur throughout this part of the unit.

Northwest of Applespring Creek, adjacent the Yalakom fault, the Lillooet Group consists predominantly of coarse-grained greywacke with beds of conglomerate. The distinctive conglomerate beds are lenticular, average 10 metres in thickness and 50 metres in length, and are comprised of a limestone matrix and about 75 per cent clasts. The clasts include macrofossil-bearing limestone, granitic rocks and green dacite with feldspar phenocrysts. The clasts are rounded and range from pebble size to cobbles 30 centimetres in diameter. Similar lenses of conglomerate in the Late Triassic Cadwallader Group have been interpreted by Rusmore (1987) as filled channels. Samples of the limestone cobbles were collected for fossil dating. This occurrence of conglomerate is on strike with similar lithologies to the north along the Bridge River described by Leech (1953), but taken together, are in a different geographic area than that of the Cadwallader Group, although they may be correlative.

BREW GROUP

The Early Cretaceous Brew Group is estimated by Duffell and McTaggert (1952) to be at least 2500 metres thick; it includes argillite, quartzite, conglomerate and metamorphic derivatives of these rocks. Within the map area, along the Duffey Lake road, metagreywacke with rip-up argillaceous clasts is recumbently folded. The metagreywacke is of greenschist metamorphic grade and muscovite defines the foliation.

PALEOGENE SEDIMENTS

Overlying the Bridge River Group is a section of well-bedded conglomerate, black shale and coarse-grained sandstone 1500 metres thick. The conglomerate consists of about 70 per cent rounded clasts, up to 15 centimetres in diameter, within a coarse-grained sandy matrix. The clasts are mostly Bridge River Group lithologies with locally abundant clasts of cream-coloured felsite. None of the clasts were derived from the Bridge River schists, phyllites or associated granitoid intrusives, presently exposed immediately to the west (Figure 1-12-2). Black shales, up to 10 metres thick, locally contain fossil *Metasequoia* stems and were collected for palynologic dating.

PALEOGENE INTRUSIVE ROCKS

MISSION RIDGE PLUTON

An elongate, foliated coarse-grained pluton, termed the Mission Ridge pluton, ranges in composition from granite to diorite and intrudes the Bridge River schist and phyllite (Figure 1-12-2). In the northwest quadrant of the map area, it crosscuts the foliation of the country rock and has a weak foliation with the same orientation. The emplacement of the pluton is interpreted to be late synkinematic. Two dykes of similar composition to the Mission Ridge pluton and with the same structural relationship to the Bridge River schist and phyllite, have yielded Eocene preliminary uranium-lead zircon ages (P. van der Hyden, personal communication, 1988).

FELSITE

A leucocratic felsite, in part hornblende phyric, intrudes Paleogene sediments, Bridge River Group, Bridge River schist and phyllite, and the Mission Ridge pluton. It is similar in appearance to the felsite clasts in the Paleogene sediments, although it is not necessarily the source of the clasts.

STRUCTURE

The following section describes major fault boundaries and internal structures of the previously described rock units in an east-to-west sequence (Figure 1-12-2).

YALAKOM FAULT

The north-northwest-trending Yalakom fault separates the Lillooet Group in the eastern hangingwall from the older Bridge River Group in the footwall. Careful field mapping along its trace indicates it dips 40 ± 10 degrees east. It merges with the north-trending Fraser fault near Lillooet and extends at least 250 kilometres to the northwest with an estimated Late Cretaceous/Early Tertiary right-lateral strike-slip displacement of 70 to 190 kilometres (Tipper, 1969; Monger, 1985). Rocks of the Lillooet and Bridge River groups are both brittly deformed at the fault boundary. Within the southeast part of the map area the fault is characterized by narrow zones of rusty weathering, fuchsite-bearing, hematized fault breccia. The exact sense of displacement on the fault is at present uncertain.

INTERNAL STRUCTURE OF THE BRIDGE RIVER GROUP AND PALEOGENE SEDIMENTS

The Paleogene sediments are in probable conformable contact with the underlying, highly disrupted Bridge River Group, although the contact is not well exposed. The Paleogene sediments are folded into a northwest-trending, northwest-plunging syncline which is truncated by the Mission Ridge fault.

MISSION RIDGE FAULT

The Bridge River Group and Paleogene sediments are separated from the underlying Bridge River schist and phyllite and the Mission Ridge pluton by a northeast-dipping low-angle normal fault which steepens to the south (Figure 1-12-2), here termed the Mission Ridge fault. The northwest part of this fault within the map area dips 20 ± 5 degrees and truncates both bedding and broad folds within Paleogene sediments in the hangingwall, as well as foliated footwall rocks (*see* cross-section A-A′ and B-B′, Figure 1-12-3). A felsite, described previously, intrudes both the hangingwall and footwall but is also fractured by the fault and is therefore interpreted to have been emplaced during the last stages of faulting.

To the southeast the fault steepens to a 42 ± 5 degree dip (*see* cross-section C-C′, Figure 1-12-3), where a lower level of the fault zone is exposed; Bridge River Group rocks display a penetrative foliation parallel to the fault plane, particularly in the south.

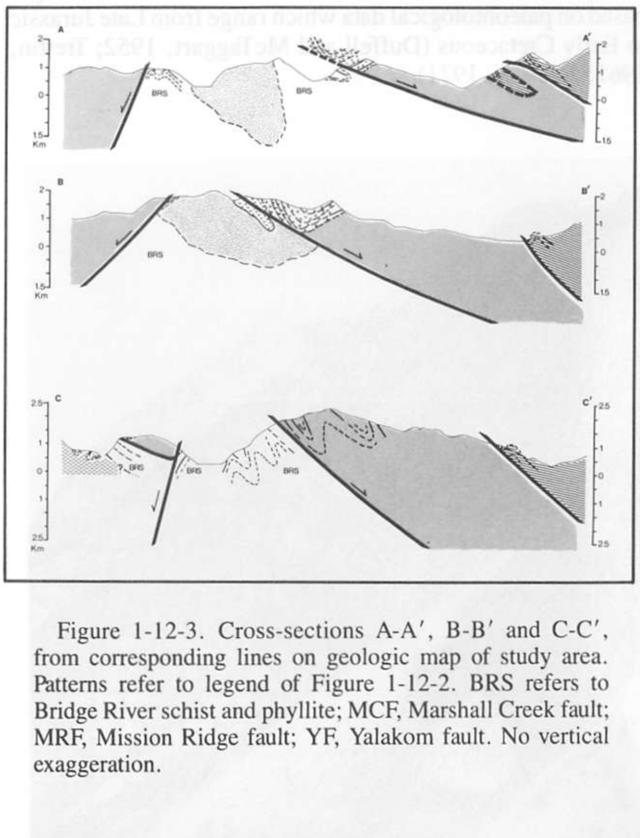


Figure 1-12-3. Cross-sections A-A′, B-B′ and C-C′, from corresponding lines on geologic map of study area. Patterns refer to legend of Figure 1-12-2. BRS refers to Bridge River schist and phyllite; MCF, Marshall Creek fault; MRF, Mission Ridge fault; YF, Yalakom fault. No vertical exaggeration.

INTERNAL STRUCTURE OF BRIDGE RIVER SCHIST AND PHYLLITE

Pervasive foliation and isoclinal folds deformed by asymmetric folds record at least two stages of penetrative deformation, in part accompanied by significant shear strain. Foliation has a consistent northwest strike with shallow northeast dips. Lineation trends northwest with a shallow plunge. Asymmetric shear bands within various lithologies indicate a consistent northwest-over-southeast sense of shear (Plate 1-12-3).

Plate 1-12-3. Shear bands in greenschist of Bridge River schist and phyllite with southeast-directed sense of shear.

MARSHALL CREEK FAULT

The Marshall Creek fault dips 50 to 70 degrees southwest, juxtaposing the Bridge River schists and the lower grade Bridge River Group (Figure 1-12-2).

In the southernmost part of the map area the Marshall Creek fault truncates a low-angle fault. This low-angle fault is similar to the Mission Ridge fault in that it juxtaposes footwall Bridge River schist and phyllite and hangingwall Bridge River Group. The low-angle fault is interpreted to be part of the Mission Ridge fault and restoration of it from cross-section C-C′ (Figure 1-12-3) gives an estimated 3.5-kilometre component of normal displacement on the Marshall Creek fault. This component probably increases to the north. Further to the southeast the Marshall Creek fault juxtaposes the Bridge River schist and phyllite with the Brew Group (Figure 1-12-2).

DISCUSSION AND CONCLUSIONS

The sequence of tectonic events in this area is incompletely understood, but some important relationships have been observed which place important constraints on the geometry, timing and kinematics of the major fault boundaries. Uranium-lead dating of intrusions (in progress) will place tighter limits on ages of faulting, plutonism and ductile strain.

The Mission Ridge fault east of the Mission Ridge pluton truncates southeast-directed mylonitic rocks, probable Eocene intrusions and Paleogene sediments. Assuming a normal geothermal gradient, at least 12 kilometres of Paleogene displacement is necessary to juxtapose upper greenschist facies rocks of the Bridge River schist and phyllite with subgreenschist rocks of the Bridge River Group and Paleogene sediments.

West-verging folds within the Lillooet Group have axial traces parallel to the Yalakom fault and may be related to (in part oblique?) thrusting; however, this folding event has not been definitely linked to faulting. Fifty kilometres northwest of Lillooet, where the Yalakom fault is close to vertical, structures including synthetic and antithetic faults fit a model for dextral movement and transpression (Glover *et al.*, 1988).

The Marshall Creek fault, which displaces the Mission Ridge fault, may extend as much as 150 kilometres northwest from where it is truncated by the Fraser fault near Lillooet, if the correlation of the Marshall Creek fault with the Relay Creek fault (Glover *et al.*, 1988) is valid. Glover *et al.* have estimated 8 kilometres of right-lateral displacement on the Relay Creek fault by restoring truncated units of Late Jurassic Relay Mountain Group. Post-Eocene displacement on the Marshall Creek fault may involve both a strike-slip component and normal movement.

It is evident from relationships within the Bridge River terrane that several episodes of deformation have taken place since the beginning of the Eocene. All are relevant to placing better constraints on the age of major dextral transcurrent movement on the Fraser – Straight Creek fault system. Although each of these episodes may not have involved either major amounts of displacement, or large spans of time, they certainly reveal a complex Tertiary tectonic history. We must first be able to "undo" this more recent deformation in order to clarify older accretionary aspects of the Bridge River terrane.

ACKNOWLEDGMENTS

This project was funded by project 850001 of the Geological Survey of Canada (R. Parrish), a Natural Sciences and Engineering Research Council LITHOPROBE Supporting Geoscience Grant awarded to R. Parrish, and by a research grant from the British Columbia Geological Survey Branch. This paper is LITHOPROBE contribution No. 89. I am especially grateful to Randy Parrish for suggesting the project, providing insightful advice and discussion, and for reviewing this paper. A thorough introduction to the field area and southwest British Columbia geology from Jim Monger is greatly appreciated. Carole Nuttall and Tiny Adamitz are thanked for their enthusiastic field assistance.

REFERENCES

Duffell, S. and McTaggart, K.C. (1952): Ashcroft Map Area, British Columbia, *Geological Survey of Canada*, Memoir 262, 122 pages.

Glover, J.K., Schiarizza, P. and Garver, J.I. (1988): Geology of the Noaxe Creek Map Area (92O/02), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 105-123.

Jeletsky, J.A. (1971): Cretaceous and Jurassic Stratigraphy of some Areas of Southwestern British Columbia, *in* Report of Activities, Part A, *Geological Survey of Canada*, Special Paper 23, pages 125-151.

Leech, G.B. (1953): Geology and Mineral Deposits of the Shulaps Range, Southwestern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 32, 65 pages.

Miller, M.G. (1988): Possible Pre-Cenozoic Left-lateral Slip on the Yalakom Fault, Southwestern British Columbia, *Geology*, Volume 16, pages 584-587.

Monger, J.W.H. (1977): Upper Paleozoic Rocks of the Western Canadian Cordilleran Evolution, *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

——— (1985): Structural Evolution of the Southwestern Intermontane Belt, Ashcroft and Hope Map Areas, British Columbia, *Geological Survey of Canada*, Paper 85-1A, pages 349-348.

Monger, J.W.H., Price, R.A. and Tempelman-Kluit, D.J. (1982): Tectonic Accretion and the Origin of the Two Major Metamorphic and Plutonic Welts in the Canadian Cordillera, *Geology*, Volume 10, pages 70-75.

Parrish, R.R. (1983): Cenozoic Thermal Evolution and Tectonics of the Coast Mountains of British Columbia, 1. Fission Track Dating, Apparent Uplift Rates, and Patterns of Uplift, *Tectonics*, Volume 2, pages 601-631.

Potter, C.J. (1983): Geology of the Bridge River Complex, Southern Shulaps Range, British Columbia: a Record of Mesozoic Convergent Tectonics, Unpublishd Ph.D. Thesis, *University of Washington*, 192 pages.

——— (1986): Origin, Accretion and Postaccretionary Evolution of the Bridge River Terrane, Southwest British Columbia, *Tectonics*, Volume 5, pages 1027-1041.

Roddick, J.A. and Hutchison. W.W. (1973): Pemberton (East Half) Map-area, British Columbia (92J), *Geological Survey of Canada*, Paper 73-17, 21 pages.

Rusmore, M.E. (1987): Geology of the Cadwallader Group and the Intermontane-Insular Superterrane Boundary, Southwestern British Columbia, *Canadian Journal of Earth Sciences*, Volume 24, pages 2279-2291.

Tipper, H.W. (1969): Mesozoic and Cenozoic Geology of Northeast part of Mount Waddington Map Area (92N), Coast District, British Columbia, *Geological Survey of Canada*, Paper 68-33.

Trettin, H.P. (1961): Geology of the Fraser River Valley between Lillooet and Big Bar Creek, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 44, 109 pages.

RESEARCH AND EXPLORATION IN THE BRIDGE RIVER MINING CAMP (92J/15, 16)

By B.N. Church and A.R. Pettipas

KEYWORDS: Regional geology, Bridge River, mineralization, geochemistry, conodonts, geophysics, ammonites, age dating.

INTRODUCTION

The Bridge River mining camp comprises approximately 1500 square kilometres of heavily staked terrain in the Bridge River drainage basin between the Shulaps ultramafic body on the northeast and the Coast Range batholith on the southwest. This area was mapped at 1:20 000 and 1:50 000-scale during the summers of 1986, 1987 and the early part of the 1988 season (Church and MacLean, 1987a; Church *et al.*, 1988). More detailed mapping and mineral studies were completed on the major mining exporation properties (Church, 1986, 1987a, b; Church and MacLean, 1987b; Gaba and Church, 1988; Hanna *et al.*, 1988).

The first contributions to the geology and mineral deposits of the area were by the Geological Survey of Canada, especially the publications of Cairnes (1937, 1943) and more recently Roddick and Hutchison (1973) and Woodsworth (1977). Papers by Joubin (1948), Bacon (1978) and Barr (1980) give an overview of mineralization from the vantage of the mineral exploration industry. The university-based studies of Harrop and Sinclair (1985); Maheux *et al.* (1987); and Leitch *et al.* (1988) provide research data and modern interpretations of the mineralization.

The object of this study is to re-evaluate the mineralization and geology of the Bridge River mining camp in the light of new mining activity in the area. The rationale for the regional mapping completed to date was to fit the numerous mining claims comprising the camp to the geological setting (Church, 1987a; Church *et al.*, 1988). The study updates lithological and structural interpretation of the region providing a framework for further mineral investigations. Control of the mapping is based on approximately 200 traverses and 3000 geological stations scattered across the area.

PHYSIOGRAPHY AND GLACIATION

The Bridge River mining camp covers much of the intervening area between the grey crags and serrated ridges of the Coast Mountains west of the towns of Bralorne and Gold Bridge and the less rugged Chilcotin Ranges north of Carpenter Lake. Elevations diminish from a maximum of 2880 metres at the summit of Mount Truax to the local base level of 650 metres at Carpenter Lake (Figure 1-13-1).

The episodic history of recent uplift and erosion in the region can be gauged in part from the evidence of concordant summits such as viewed locally in the Coast Mountains and the upland surfaces commonly seen in the Chilcotin Ranges. The evidence from buried erosion surfaces is more fragmented and difficult to interpret, nevertheless, the mesa-forming plateau basalts on Mount Noel (dated 18.7 ± 0.7 Ma, this study), at an elevation of about 2400 metres, seem to correlate with the basalts of the Chilcotin Group located 40 kilometres to the north, at roughly the same elevation on Cardtable Mountain and Castle Peak. These outliers are considerably higher in elevation than equivalent lavas exposed to the east on the Interior Plateau, suggesting relative uplift of more than 1500 metres in the Coast Mountains in post-Miocene times.

Near the end of the Pleistocene, the broad Cadwallader valley above the present location of the Pioneer mine was filled with melting ice which drained northwest, depositing much sand and gravel en route to its confluence with the Hurley River. These alluvial deposits were subsequently cut through to bedrock by Cadwallader Creek intercepting its antecedent channels which are now favourable targets for placer exploration.

RESEARCH

New mapping supported by laboratory analyses and research has facilitated interpretation of the structural history of the region.

A significant contribution of the project was to confirm the presence of major units of the Cadwallader Group east of the Eldorado–Taylor basin suture. This north-south lineament, lying roughly between the Eldorado and Taylor Creek basins, was interpreted to be a line of mid-Jurassic docking between the Cadwallader and the "Bridge River" terranes. We now know that significant parts of the Cadwallader lie well within the limits of the so-called Bridge River terrane, suggesting a former broad superposition of the former rocks on the latter. Examples of these outlying Cadwallader rocks are the thick accumulations of Pioneer pillow lavas and Hurley sedimentary beds in the area centred 4 kilometres southwest of Liza Lake, and an area underlain by Hurley conglomerates adjacent to the Shulaps complex 3 kilometres northeast of Liza Lake. Numerous other smaller slices and wedges interpreted to be Cadwallader and younger rocks, containing Late Triassic to Early Jurassic radiolaria (Cordey, 1986) or conodonts, are found throughout the map area, testifying to a complicated paleogeographic and tectonic history.

The sampling of carbonate beds for conodonts has generally confirmed that units assigned to the Cadwallader Group are of Late Triassic age (Table 1-13-1, Figure 1-13-2). Recov-

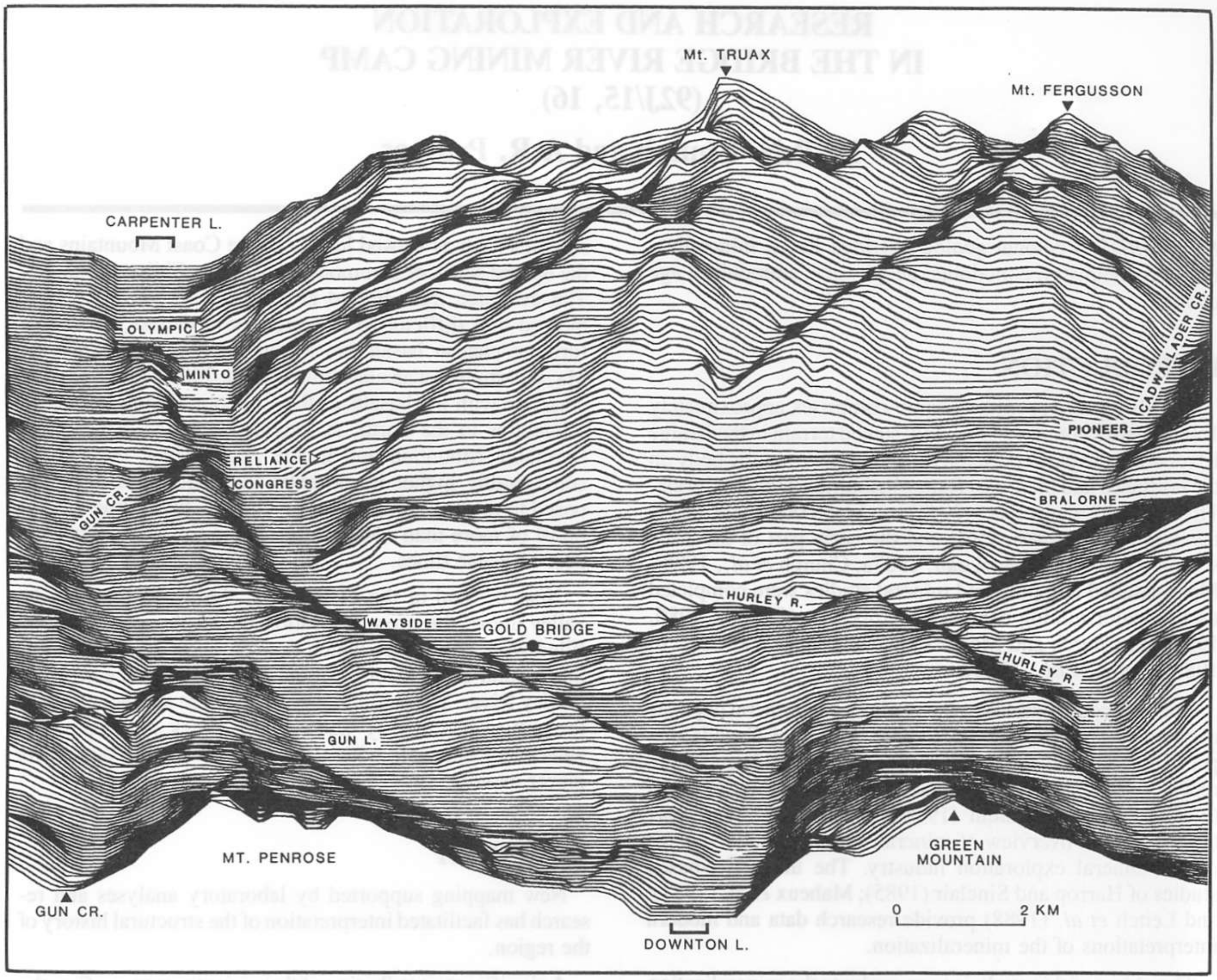


Figure 1-13-1. Panoramic view of the Bridge River mining camp (looking east).

ery of conodonts from rocks mapped as Fergusson Group (Bridge River complex) has been generally negative, these rocks commonly being markedly recrystallized and severely affected by dynamic metamorphism.

The few exceptions to the conodont results are the Late Triassic fauna found in the carbonate lenses intercalated with Fergusson-like ribbon cherts and phyllites near the mouth of Tyaughton Creek and southwest of Marshall Lake (Cameron and Monger, 1971; Table 1-13-1, No. 4, this study) and radiolaria interpreted to be Late Triassic to Early Jurassic in age from several localities along Carpenter Lake (Cordey, 1986). From this evidence it appears that some facies of the Fergusson are younger than similar rocks in the Gold Bridge area cut by the Bralorne intrusions (Permian). Consequently it is believed that part of the Cadwallader and Fergusson groups may have been formed penecontemporaneously – the Cadwallader rocks characterizing the clastics and volcanics of arc-type deposition and the Fergusson rocks a more distal ocean basin environment. The unifying elements in the two groups may be the associated volcanic rocks – the pillow

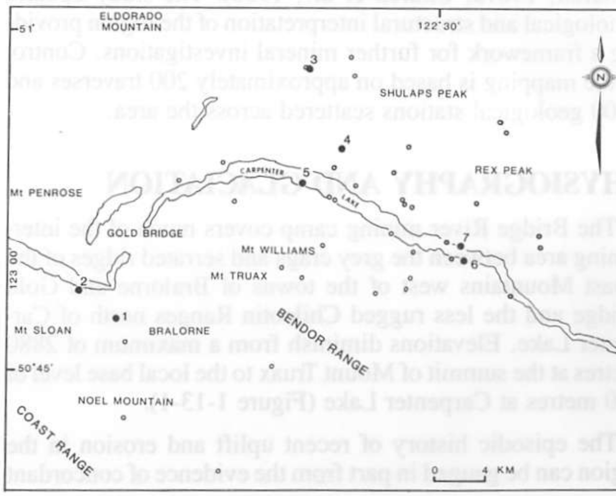


Figure 1-13-2. Conodont sampling stations.

TABLE 1-13-1
NEW CONODONT LOCALITIES

Sample No.	UTM Easting	UTM Northing	Location	Taxa	Age
1	5092	56266	Gwenyth L.	*Epigondolella abneptis* *Neogondolella sp.*	early Norian
2	5062	56289	Downton L.	*Neogondolella navicula*	early Norian
3	5206	56481	Liza L.	*Epigondolella sp.*	Norian
4	5273	56402	Marshall L.	*Epigondolella abneptis* *Neagondolella navicula*	early Norian
5	5374	56315	Carpenter L.	*Paragondolella polygnathiformis*	Late Carnian
6	5244	56374	Carpenter L.	*Neocavitella? sp.* *Paragondolella ex. gr. polygnathiformis*	Carnian
7	5374	56326	Carpenter L.	*Epigondolella? sp.*	Late Triassic

lavas and aquagene breccias of the Pioneer Formation, and the Noel Formation consisting mostly of thinly bedded turbidites. Both formations occur in the lower part of the Cadwallader Group and appear to be either intercalated, intruded or in-faulted into the Fergusson Group.

From Chayes and Velde (1965) it is expected that volcanic rocks from different tectonic settings would show different chemical signatures, that is, that the arc phase of the Pioneer volcanics should be chemically different from the ocean-basin or back-arc phase. However, silicate analyses of fresh-looking pillow lavas and aquagene breccias from a variety of localities indicate simply basaltic composition showing no trends or significant differences in major oxides or titania (Table 1-13-2, Figure 1-13-3).

Leitch and Godwin (1988) have inferred that the Bralorne intrusions (Permian) feed some of the older volcanic rocks, although they could not distinguish these in the Bralorne area. It is possible that some of these missing volcanics are a metamorphic facies of the Fergusson Group such as the amphibolites found with the schists in the Piebiter area and within the phyllites on Mission Ridge in the headwaters of Jones and Bighorn creeks. Figure 1-13-4 shows a clear discrimination between the Bralorne gabbros and the Pioneer basalts on a titania versus felsic index (quartz and orthoclase and albite) plot, the major variable in the index being sodic feldspar (albite). Furthermore, the Bralorne intrusions display a strong anorthositic to mafic cumulate trend (Figure 1-13-5, Table 1-13-3), a feature not shown by the Pioneer volcanics of the Cadwallader Group. Clearly, the Bralorne plutonics (and possibly related Fergusson effusives) are distinctive and seem to fit the ophiolite association: ultramafics, gabbros with soda metasomatism, and cherts.

The Relay Mountain Group is superimposed (unconformable and faulted) on the Permo-Triassic geology adding to the tectonic complexity of the region. The main exposures are near Spruce Lake and in a large downfaulted block of shales and polymictic conglomerate that contains clasts of

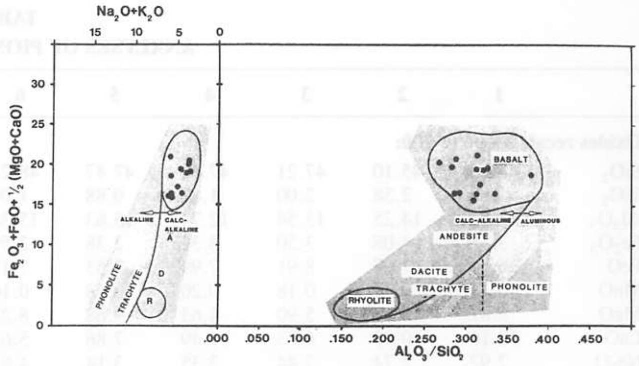


Figure 1-13-3. Variogram showing compositional clustering of pillow lavas and breccias.

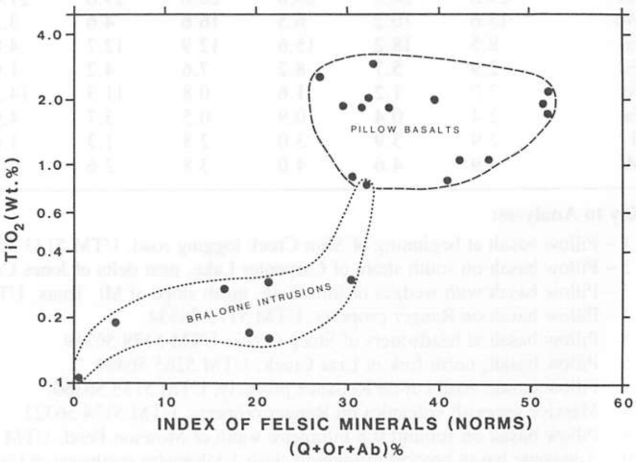


Figure 1-13-4. Compositional range showing discrimination of Pioneer volcanics and Bralorne intrusive rocks.

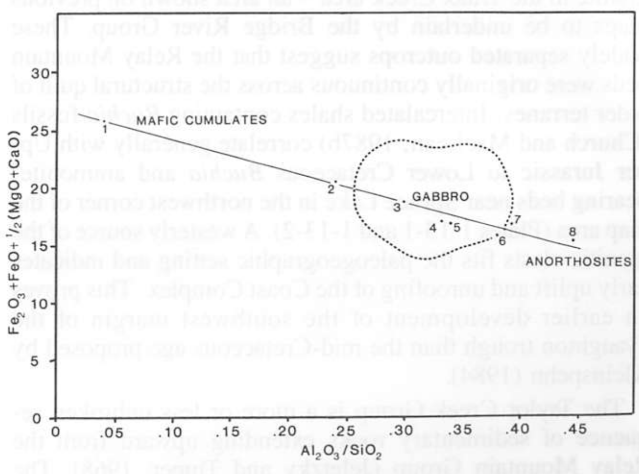


Figure 1-13-5. Cumulate mixing curve for Bralorne intrusions and related plutonic rocks.

TABLE 1-13-2
ANALYSES OF PIONEER VOLCANIC ROCKS

	1	2	3	4	5	6	7	8	9	10	11	12	13
Oxides recalculated to 100:													
SiO_2	44.21	45.10	47.21	47.40	47.47	48.22	48.70	48.92	49.19	49.96	50.32	51.31	52.59
TiO_2	1.88	2.58	2.00	1.82	0.88	1.09	2.20	1.86	2.05	2.99	1.73	1.09	1.96
Al_2O_3	14.02	14.25	13.54	12.74	15.63	15.38	16.41	14.19	15.47	16.13	15.84	14.79	16.42
Fe_2O_3	3.38	4.08	3.50	3.32	2.38	2.59	3.70	3.36	2.70	2.82	3.23	2.59	3.46
FeO	6.81	7.87	8.91	7.99	7.53	7.17	7.94	7.79	6.98	9.57	7.50	6.99	6.55
MnO	0.15	0.17	0.18	0.20	0.18	0.16	0.14	0.15	0.15	0.18	0.13	0.30	0.08
MgO	5.87	6.63	5.90	4.63	9.68	8.24	2.57	7.24	7.87	6.46	4.43	6.10	1.72
CaO	12.16	10.03	6.83	11.49	7.86	5.67	4.84	9.84	11.74	7.72	4.86	6.11	7.65
Na_2O	2.92	2.74	3.44	3.35	3.14	4.61	4.48	3.26	3.35	2.43	4.33	3.94	4.47
K_2O	0.05	0.09	0.85	0.27	0.23	0.29	1.06	0.27	0.50	1.74	1.60	0.36	0.48
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Molecular norms:													
Qz	—	—	—	—	—	—	1.4	—	—	0.6	—	2.7	6.2
Or	0.3	0.6	5.5	1.7	1.4	1.8	6.9	1.6	2.9	10.5	10.1	2.3	3.0
Ab	28.9	26.7	33.8	32.8	29.3	43.5	44.2	30.3	30.3	22.1	41.4	37.7	42.6
Ne	—	—	—	—	—	—	—	—	—	—	—	—	—
An	27.6	28.5	20.8	20.6	29.0	21.4	23.7	24.2	25.6	28.5	20.3	23.1	24.8
Wo	15.6	10.2	6.5	16.6	4.6	3.2	1.1	10.1	13.0	4.2	2.1	3.7	6.2
En	8.5	18.2	15.6	12.9	12.7	4.8	7.8	17.3	6.5	18.1	11.5	18.0	5.0
Fs	2.9	5.7	8.2	7.6	4.2	1.6	7.3	6.2	1.8	8.8	6.6	8.0	5.3
Fo	7.0	1.2	1.6	0.8	11.3	14.3	—	2.6	11.4	—	1.1	—	—
Fa	2.4	0.4	0.9	0.5	3.7	4.9	—	0.9	3.2	—	0.6	—	—
Il	2.9	3.9	3.0	2.8	1.3	1.6	3.4	2.7	2.8	4.2	2.6	1.6	2.9
Mt	3.9	4.6	4.0	3.8	2.6	2.8	4.2	3.6	2.8	3.0	3.6	2.9	3.8

Key to Analyses:

1 – Pillow basalt at beginning of Slim Creek logging road, UTM 5143 56374.
2 – Pillow basalt on south shore of Carpenter Lake, near delta of Jones Creek, UTM 5394 56309.
3 – Pillow basalt with wedges of limestone, north slope of Mt. Truax, UTM 5193 56350.
4 – Pillow basalt on Ranger property, UTM 5173 56334.
5 – Pillow basalt at headwaters of Steep Creek, UTM 5178 56319.
6 – Pillow basalt, north fork of Liza Creek, UTM 5265 56494.
7 – Pillow basalt, road cut on Reliance property, UTM 5155 56360.
8 – Massive greenish volcanics on Ranger property, UTM 5174 56322.
9 – Pillow basalt on summit 0.8 kilometre south of Mowson Pond, UTM 5170 56388.
10 – Aquagene basalt breccia in logging slash 1 kilometre northwest of Gwyneth Lake, UTM 5084 56277.
11 – Pillow basalt at cut on Noaxe logging road, UTM 5189 56480.
12 – Basalt breccia 0.8 kilometre north of Wayside mine, UTM 5119 56368.
13 – Pillow basalt at head of Girl Creek, UTM 5192 56336.

granite in the Truax Creek area – an area shown on previous maps to be underlain by the Bridge River Group. These widely separated outcrops suggest that the Relay Mountain beds were originally continuous across the structural quilt of older terranes. Intercalated shales containing *Buchia* fossils (Church and MacLean, 1987b) correlate generally with Upper Jurassic to Lower Cretaceous *Buchia* and ammonite-bearing beds near Spruce Lake in the northwest corner of the map area (Plates 1-13-1 and 1-13-2). A westerly source of the granitic clasts fits the paleogeographic setting and indicates early uplift and unroofing of the Coast Complex. This proves an earlier development of the southwest margin of the Tyaughton trough than the mid-Cretaceous age proposed by Kleinspehn (1984).

The Taylor Creek Group is a more or less unbroken sequence of sedimentary rocks extending upward from the Relay Mountain Group (Jeletzky and Tipper, 1968). The Taylor Creek Group consists of a broad wedge of mostly coarse polymictic conglomerate (about 1 kilometre thick) exposed in the north part of the map area. The headwall fault of this basin marks the southern limit of the group. The rocks are interpreted to have been deposited in a taphrobasin. Major gravity displacement here is balanced by major uplift in the source are to the southwest. New studies by the authors and Schiarizza *et al.*, and Garver *et al.* (1989, this volume) shed further light on this area, which is underlain by ribbon chert and chlorite-lawsonite-glaucophane blueschists and phyllites, together with sandstones and conglomerate containing clasts from younger formations (Evans and Brown, 1988). The blueschist metamorphism is apparently Permo-Triassic age (Garver *et al.*, 1988). Schiarizza *et al.* propose revision of the stratigraphy and describe overturning and thrusting that was not previously recognized.

STRUCTURAL EVALUATIONS

The results of double derivative filtering of regional magnetic fields for the Bridge River mining camp (Figure 1-13-6) manifest Late Cretaceous to Early Tertiary structures

Plate 1-13-1. *Homolsomites?* from the Relay Mountain Group near Spruce Lake collected by Margaret Hanna and identified by J.W. Haggart, G.S.C. (Early Cretaceous).

Plate 1-13-2. *Buchia pacifica* from the Relay Mountain Group near Spruce Lake collected by Margaret Hanna and identified by T.P. Poulton, G.S.C. (middle Valanginian).

TABLE 1-13-3
ANALYSES OF BRALORNE INTRUSIONS

	1	2	3	4	5	6	7	8
Oxides recalculated to 100:								
SiO_2	53.25	50.82	51.86	50.45	51.15	49.27	49.19	47.71
TiO_2	0.07	0.19	0.82	0.29	0.30	0.27	0.16	0.17
Al_2O_3	2.19	12.37	15.65	16.90	17.34	19.53	18.86	21.89
Fe_2O_3	1.28	1.68	2.30	1.78	1.79	0.92	1.64	1.66
FeO	6.12	3.78	7.13	3.19	5.63	3.92	3.82	2.78
MnO	0.16	0.13	0.19	0.11	0.15	0.10	0.10	0.07
MgO	19.80	10.10	7.64	9.36	10.30	9.67	10.74	8.60
CaO	17.09	20.20	9.76	14.89	9.27	14.26	11.64	13.16
Na_2O	0.04	0.07	3.51	2.32	3.21	1.62	2.11	1.46
K_2O	0.00	0.02	0.15	0.12	0.37	0.44	0.56	1.04
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Molecular norms:								
Qz	—	3.7	—	—	—	—	—	—
Or	—	0.1	0.9	0.7	2.2	2.5	3.3	6.1
Ab	0.4	0.7	31.5	20.6	28.2	14.3	18.6	12.9
An	5.7	33.7	26.6	34.9	31.7	43.8	39.6	49.4
Wo	31.0	27.0	8.8	15.2	5.3	10.2	6.8	6.0
En	51.9	28.1	18.0	16.3	13.2	14.6	13.2	13.6
Fs	8.1	4.6	7.2	2.2	3.4	2.8	2.3	1.7
Fo	1.3	—	2.4	6.9	11.0	8.8	12.0	7.4
Fa	0.2	—	1.0	0.9	2.8	1.7	2.1	0.9
Il	0.1	0.3	1.1	0.4	0.4	0.4	0.2	0.2
Mt	1.3	1.8	2.5	1.9	1.8	0.9	1.9	1.8

Key to Analyses:

1 – Websterite, on north slopes of Mt. Penrose, 0.4 kilometre west of Jewel Creek, UTM 5038 56389.
2 – Mafic gabbro, Wayside mine area, UTM 5122 56364.
3 – Gabbro, Ranger property, UTM 5170 56322.
4 – Gabbro, on side hill 3.2 kilometres west of Shulaps Peak, UTM 5298 56442.
5 – Gabbro, north spur of Mt. Truax, UTM 5170 56324.
6 – Anorthositic gabbro, B.C. Hydro quarry 1 kilometre north of Gold Bridge, UTM 5110 56340.
7 – Anorthositic gabbro, Wayside mine area, UTM 5170 56363.
8 – Anorthosite, Wayside mine area, UTM 5118 56363.

(Church and James, 1988). A northwest-trending "slice fabric" dominates the region. This consists of panels of Cadwallader and Fergusson rocks (and ramped? ultramafic bodies) bounded by *en echelon* transcurrent fractures subparallel to the Yalakom fault. Lithological correlation across these panels seems to preclude major transcurrent dislocation on known faults such as the Cadwallader break and the Marshall Creek lineament. Early Tertiary effusives such as the northwest-elongate Rex Peak–Mission Ridge pluton (45 Ma) were intruded advantageously along the pre-existing fracture system. Subsequent downward rotation along the same fractures has preserved slabs and wedges of Tertiary volcanic rocks from erosion in the Mission Ridge area and on Big Sheep Mountain.

EXPLORATION

Mineralization in the Bridge River mining camp is widely scattered and hosted in a variety of rock types of different ages; no single geological event or process can account for all of the numerous deposits (Figure 1-13-7).

The Bridge River mining district is known mainly as a vein camp and gold producer. A complicated system of fractures is thought to have controlled the ore deposition. The oldest and

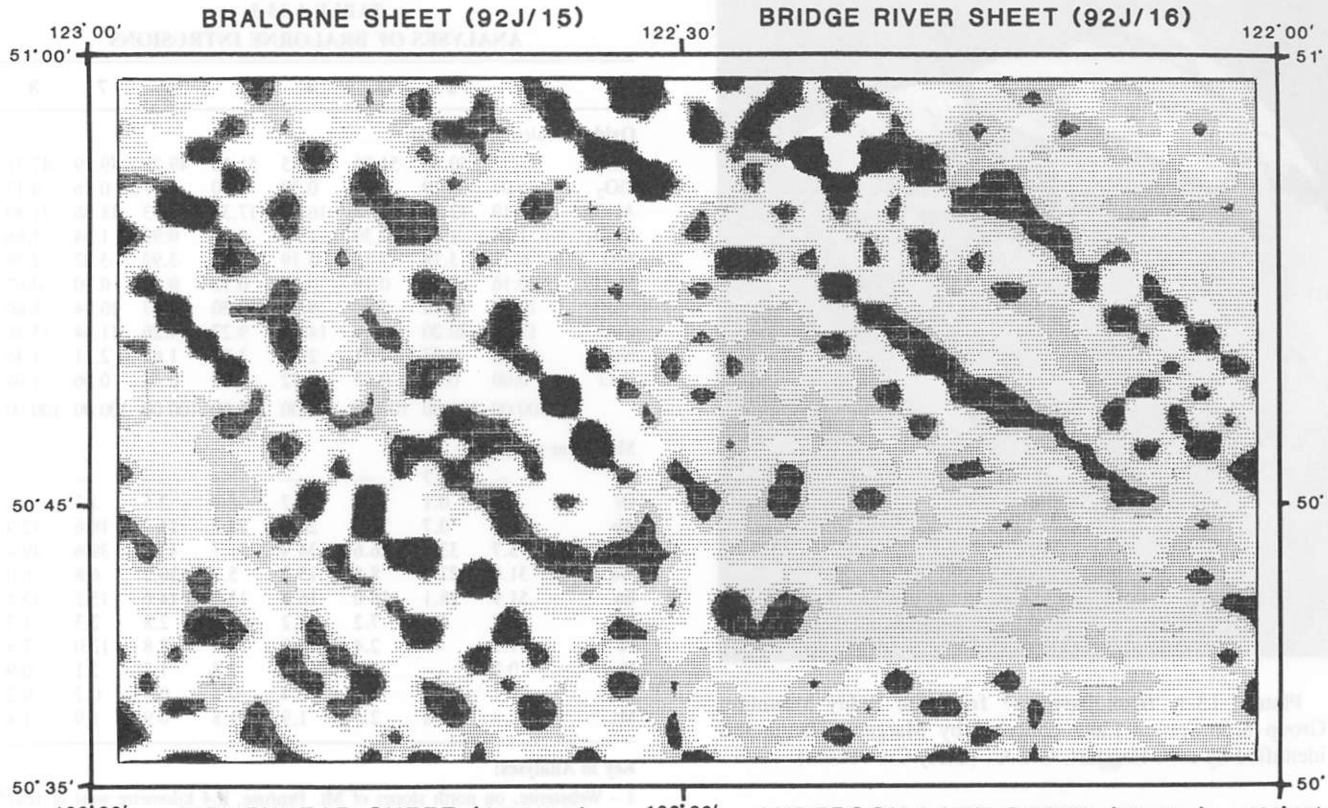


Figure 1-13-6. Double-derivative plot of the total magnetic field based on the G.S.C. regional magnetic Map 8548G – (blank area for values less than 500 /Mi² units, dark grey greater than 500 /Mi² units).

deepest fault zones appear to be the main solution channels and the site of repeated igneous intrusions. For example, the Cadwallader fault zone, along which the principal mines are located, hosts the Bralorne diorite and soda granite, Bendor-related intrusions and a belt of ultramafic rocks.

The source of mineralizing solutions was considered by Cairnes (1937) to be magmatic; a process of differentiation which also produced the soda granite. The Bralorne diorite (Permian) was thought to be the ultimate source and also the prime host rock of the ore fluids because of the location of these bodies on the major fractures and the brittle, fissure-sustaining character of the rocks. A different model was proposed by Gaba and Church (1988); according to this model the Bendor pluton and associated intrusions (63.4 and 64.3±2.3 Ma, this study) are the source of hydrothermal fluids. The age of the Bendor intrusions is within the definite limits for mineralization (91.4 to 43.7 Ma) set by Leitch *et al*. (1988).

According to Woodsworth *et al*. (1977), mineral zoning in the entire camp is the result of a thermal gradient along the eastern margin of the Coast plutonic complex. They have also shown that the younger outlying Tertiary intrusions were involved in the mineralizing process on a more local scale.

The favourable exploration climate in the Bridge River camp reflects the geologic setting and is manifest by the continuing vigorous exploration activity. Evidence of good mineral potential is also indicated by geochemical sampling. The analyses of moss-mat sediments collected from streams in the camp generally yielded good results and anomalous gold values in several samples. The moss from rocks and logs on the banks and beds of streams provides a relatively uniform sampling of silt and minerals. From a total of 112 samples collected during the 1988 field season 15 yield values greater than 100 ppb gold. These are widely scattered across the camp and suggest some new exploration targets (Figure 1-13-8, Table 1-13-4). All samples were collected between June and August 1988 and were subsequently analysed by ACME Laboratories Ltd., Vancouver. The detection limit on all samples is 1 ppb gold. Replication error on samples collected from a location is usually less than x10.

PROPERTY ACTIVITY

The major exploration programs in the camp are by Corona Corporation at the Bralorne mine (MINFILE 092JNE001) and Levon Resources Ltd. on the adjoining Love Oil claims. Other important programs are by Chevron Canada Ltd. on the Wayside property (MINFILE 92JNE030) on the north shore of Carpenter Lake, and Levon Resources Ltd. on the Congress (MINFILE 92JNE029), Minto (MINFILE 92JNE075), and Olypmic (MINFILE 92JNE092) properties to the east. Westmin Resources Limited has initiated a program on the Bristol property (MINFILE 92JNE071) on Tommy Creek 20 kilometres east of Gold Bridge. There is also continuing activity and interest in the Summit property (MINFILE 92JNE035) southwest of Marshall Creek and the Elizabeth-Yalakom property (MINFILE 92OSE012) in the Shulaps area.

The main target of investigation by Corona at Bralorne is the 51B footwall vein. The geological setting of the Bralorne veins has been described by Joubin (1948) and Campbell

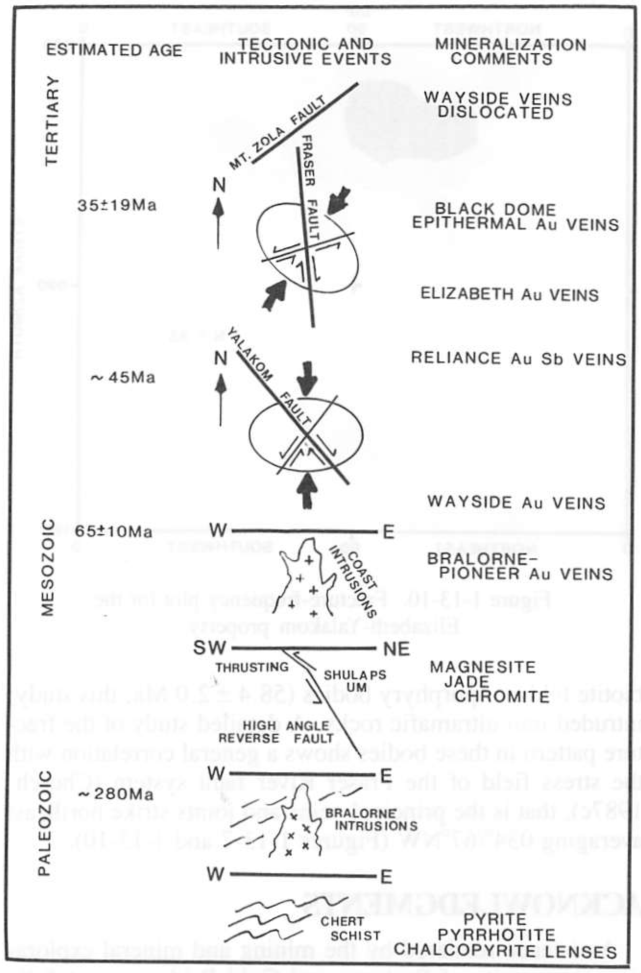


Figure 1-13-7. Some aspects of the structural evolution and mineralization in the Bridge River camp.

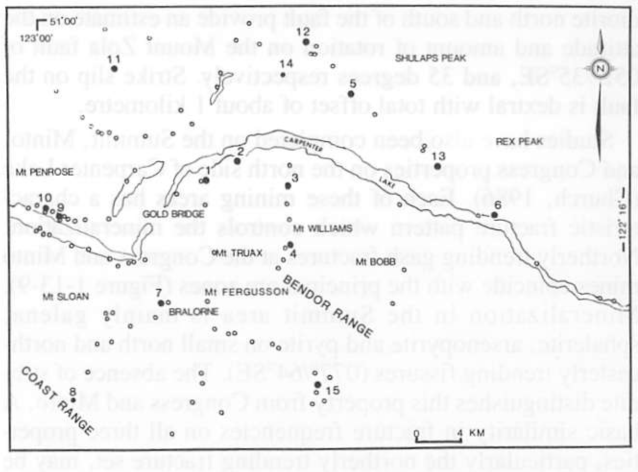


Figure 1-13-8. Moss sampling stations (see Table 1-13-4).

TABLE 1-13-4
GOLD IN MOSS GEOCHEMISTRY

Sample No.	UTM Northing	UTM Easting	Gold ppb	Location Stream
1	5147	56356	212	Steep Cr.
2	5173	56373	164	Girl Cr.
3	5220	56349	592	Unnamed
4	5219	56298	137	Unnamed
5	5274	56432	204	Liza Cr., east
6	5395	56323	592	Jones Cr.
7	5108	56251	913	Carl Cr.
8	5028	56167	245	Unnamed
9	5018	56324	1103	Unnamed
10	5006	56329	1347	Unnamed
11	5067	56455	133	Eldorado Cr.
12	5235	56475	225	Liza Cr., west
13	5350	56368	105	Marshall Cr.
14	5223	56424	165	Tyaughton Cr.
15	5242	56178	274	Cadwallader Cr.

(1975). Over the past several years the 51B vein has been tested by surface drilling (72 holes) and underground drifting on the 400 and 800 levels. This is one of several partially developed veins, the relics of previous mining that are cut off by the Empire fault. Matching the veins across the fault has been an ongoing endeavour. A comparison of fracture patterns across this fault shows a rotation of the principal vein fissures from 118°/45°NE east of the fault to an average attitude of 105°/66°NE west of the fault. This appears to be the result of a small rotation on the fault of about 10 degrees. More research is needed to determine the net slip on the fault.

The new Taylor Cabin discovery by Levon on the Love Oil property has added more interest to the area. The discovery (late 1987) is a quartz vein on the Cosmopolitan Crown-granted claim (latitude 122°47′20″ north, longitude 122°48′40″ west). This is adjacent to the old King workings at the Bralorne mine. The vein is about 1 metre wide and has an attitude of 130°/60°NE. A 3-metre sample across the vein and weathered microdiorite host rock reportedly assayed 60 grams per tonne gold. An arsenopyrite-rich grab sample from the same vein, assayed in the Ministry laboratory, returned gold 332.9 grams per tonne, silver 69 grams per tonne, copper 55 ppm, lead 0.75 per cent, zinc 0.45 per cent, arsenic 2.40 per cent, and antimony 0.11 per cent. Exploration is continuing in the area underlain by the pyritic microdiorite which is well mineralized with quartz veins and stringers. By October 1988 a crosscut was completed intersecting the vein below the regolith.

On the Wayside property, Chevron has completed a two-year program of exploration (21 drill holes) to locate the faulted extension of the Wayside vein and other mineralization. The Wayside mine is near the north end of the "Cadwallader Break" which is an old northerly trending fault system that hosts many igneous intrusions and the principal ore deposits in the camp (Gaba and Church, 1988). The peculiar left-hand movement on the Cadwallader fault appears to be the result of emplacement of the Bendor pluton. It is speculated that lateral forces developed from the rising Bendor intrusion may be responsible for the easterly directed vein sets in the Bralorne-Pioneer area and the northerly oriented veins at Wayside. In the Wayside area, a north-easterly trending fault – known locally as the Mount Zola fault – has displaced a segment of the Bralorne diorite and the Wayside vein. Preliminary results of a fracture study in the diorite north and south of the fault provide an estimate on the attitude and amount of rotation on the Mount Zola fault of 052°/35°SE, and 35 degrees respectively. Strike slip on the fault is dextral with total offset of about 1 kilometre.

Studies have also been completed on the Summit, Minto, and Congress properties on the north side of Carpenter Lake (Church, 1986). Each of these mining areas has a characteristic fracture pattern which controls the mineralization. Northerly trending gash fractures at the Congress and Minto mines coincide with the principal ore zones (Figure 1-13-9). Mineralization in the Summit area is mainly galena, sphalerite, arsenopyrite and pyrite on small north and northeasterly trending fissures (077°/64°SE). The absence of stibnite distinguishes this property from Congress and Minto. A basic similarity in fracture frequencies on all three properties, particularly the northerly trending fracture set, may be related to the stress field associated with the Yalakom fault system.

On the south side of Carpenter Lake the Bristol, Reliance and Olympic properties are the focus of significant exploration programs. These are vein properties where an understanding of the local fracture pattern is important. Each property is geologically unique and in a distinct fracture domain. On the Bristol property mineralization appears to be related to small gash fractures (020°/80°SE) feathering from shears trending 045°/81°SE. The main cross-fracture direction is 107°/78°SW. On the Reliance property there are two principal shear directions, 150°/82°SE and 036°/54°NW; mineralization is mostly related to the latter. Ancillary cross-fractures are 168°/59°NE and 022°/88°NW (Hanna, *et al.*, 1988). On the Olympic property the southeasterly trending fractures (107°/66°NE, 126°/80°SW and 133°/48°SW) are related to dykes, mineralization and shear zones. The principal cross-fracture trend is 022°/60°NW.

The Elizabeth-Yalakom property, in the heart of Shulaps range, has been intermittently developed since 1934 (Gaba *et al.*, 1988). The targets of previous work and current exploration are gold-bearing quartz veins in two adjacent

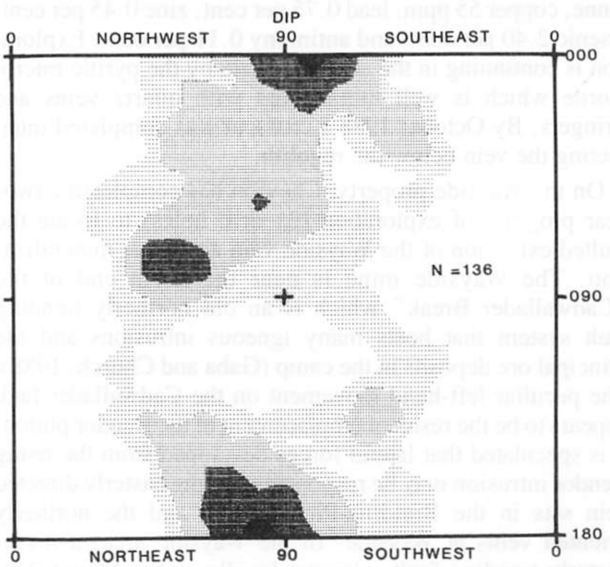


Figure 1-13-9. Fracture-frequency plot for the Congress and Minto properties.

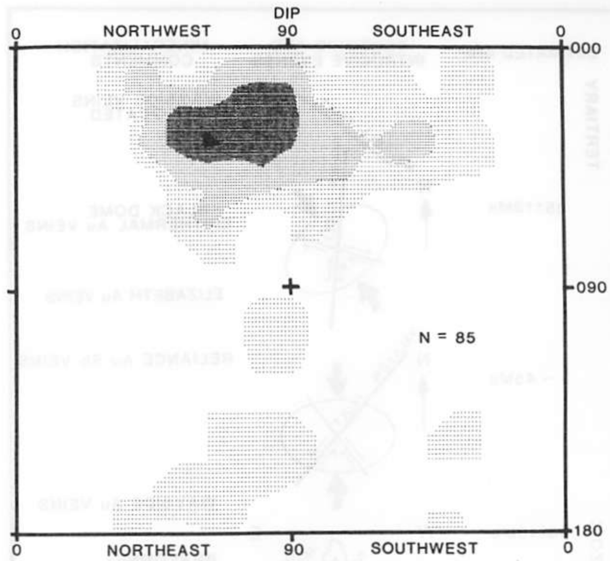


Figure 1-13-10. Fracture-frequency plot for the Elizabeth-Yalakom property.

biotite feldspar porphyry bodies (58.4±2.0 Ma, this study) intruded into ultramafic rocks. A detailed study of the fracture pattern in these bodies shows a general correlation with the stress field of the Fraser River fault system (Church, 1987c), that is the principal veins and joints strike northeast averaging 034°/67°NW (Figures 1-13-7 and 1-13-10).

ACKNOWLEDGMENTS

Assistance rendered by the mining and mineral exploration community of Bralorne and Gold Bridge is gratefully acknowledged. Special thanks are owing Paul Johannes and James Miller Tait of Levon Resources Ltd., Mark Tindall of Corona Corporation, Sandra McAllister of Chevron Canada Resources Ltd., Robert Miller of Westmin Resources Limited, John Tancowney of Anvil Resources Ltd., Frank Whiting and Christopher Sampson (consultants), William Atkinson and Bob Holt of Caribou Chilcotin Helicopters Ltd. and residents of Bralorne, Helen Klassen and Carol and Frank Bethune.

Officers of the Geological Survey of Canada, Terry Poulton, James Haggart, Michael Orchard and James Monger have supplied information on fossils from samples collected during the 1987 and 1988 field seasons.

Technical assistance and advice have been supplied by Ministry colleagues including Paul Ralph (chemical analyses), Paul Matysek (geochemical sampling), Dick Player (lapidary and photography), and contract geologists Robert Gaba and Kim Safton (fieldwork).

REFERENCES

Bacon, W.R. (1978): Lode Gold Deposits in Western Canada, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 71, Number 795, pages 96-104.

Barr, D.A. (1980): Gold in the Canadian Cordillera, *Canadian Institute of Mining and Metallurgy*, Bulletin, June 1980, pages 59-76.

Cairnes, C.E. (1937): Geology and Mineral Deposits of the Bridge River Mining Camp, British Columbia, *Geological Survey of Canada*, Memoir 213, 140 pages.

——— (1943): Geology and Mineral Deposits of Tyaughton Lake Area, British Columbia, *Geological Survey of Canada*, Paper 43-15, 39 pages.

Cameron, B.E.B. and Monger, J.W.H. (1971): Middle Triassic Conodonts from the Fergusson Group, Northeastern Pemberton Map-area, *Geological Survey of Canada*, Report of Activities Part B, November 1970 to March 1971, Pages 94-96.

Campbell, D.D. (1975): Bridge River Gold Camp, *Dolmage, Campbell and Associates 1975 Ltd.*, Private Company Report, 9 pages.

Chayes, F. and Velde, D. (1965): On Distinguishing Basaltic Lavas of Circumoceanic and Ocean-island Type by Means of Discriminent Functions, *American Journal of Science*, Volume 263, pages 206-222.

Church, B.N. (1986): Congress, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia, 1985, pages B10-B14.

——— (1987a): Geology and Mineralization of the Bridge River Mining Camp (92J/15, 92O/2, 92J/10), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 23-29.

——— (1987b): The Pacific Eastern Gold Prospect, Pioneer Extension Property, Lillooet Mining Division (92J/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 31-33.

——— (1987c): Lithogeochemisry of the Gold-silver Veins and Country Rocks in the Blackdome Mine Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia, 1986, pages B40-B49.

Church, B.N., Gaba, R.G., Hanna, M.J. and James, D.A.R. (1988): Geological Reconnaissance in the Bridge River Mining Camp (92J/15,16,10; 92O/02), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 93-100.

Church, B.N. and James, D.A.R. (1988): The Double Derivative Interpretation of Regional Magnetic Fields in the Bridge River Mining Camp, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 101-104.

Church, B.N. and MacLean, M.E. (1987a): Geology of the Gold Bridge Area (92J/15W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-11.

Church, B.N. and MacLean, M.E. (1987b): Geology and Mineralization in the Vicinity of the Mary Mac Mine, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia, 1986, pages B33-B37.

Church, B.N., MacLean, M.E., Gaba, R.G., Hanna, M.J. and James, D.A.R. (1987): Geology of the Bralorne Map-area (92J/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-3.

Cordey, F. (1986): Radiolarian Ages from the Cache Creek and Bridge River Complexes and from Chert Pebbles in Cretaceous Conglomerates, Southwestern British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 86-1A, pages 595-602.

Evans, B.W. and Brown, E.H. (1986): Blueschists and Eclogites, *The Geological Society of America*, Memoir 164, 423 pages.

Gaba, R.G. and Church, B.N. (1988): Exploration in Vicinity of the Wayside Mine, Bridge River Mining Camp, B.C. *Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, pages B35-B44.

Gaba, R.G., Hanna, M.J. and Church, B.N. (1988): The Elizabeth-Yalakom Gold Prospect, Bridge River Mining Camp (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 329-333.

Garver, J.L., Schiarizza, P. and Gaba, R.G. (1989): Stratigraphy and Structure of the Eldorado Mountain Area, Chilcotin Ranges, Southwestern British Columbia (92O/2 and 92J/15), B.C. *Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1988, Paper 1989-1, this volume.

Hanna, M.J., James, D.A.R. and Church, B.N. (1988): The Reliance Gold Prospect, Bridge River Mining Camp (92J/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 325-327.

Harrop, J.C. and Sinclair, A.J. (1985): Bralorne Area – Geological Compilation, Marginal Notes, *The University of British Columbia*, 5 pages.

Joubin, F.R. (1948): Bralorne and Pioneer Mines, Structural Geology of Canadian Ore Deposits, *Canadian Institute of Mining and Metallurgy*, Special Volume, pages 168-177.

Kleinspehn, K.L. (1984): Cretaceous Sedimentation and Tectonics, Tyaughton-Methow Basin, Southwestern British Columbia, *Canadian Journal of Earth Sciences*, Volume 22, pages 154-174.

Leitch, C.H.B. (1988): Isotopic Ages, Wall-rock Chemistry and Fluid Inclusion Data from the Bralorne Gold Vein Deposit (92J/15W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 301-324.

Leitch, C.H.B., Dawson, K.M. and Godwin, C.I. (1988): Late Cretaceous – Early Tertiary Gold Mineralization: A Galena Lead Isotope Study of the Bridge River Mining Camp, Southwestern British Columbia, Canada, *Proceedings of Bicentennial Gold '88*, Melbourne, Australia, May 1988.

Maheux, P.J., Muehlenbachs, K. and Nesbitt, B.E. (1987): Evidence of Highly Evolved Ore Fluids Responsible for Sulfide Associated Gold Mineralization in the Bridge River District, British Columbia, *Geological Association of Canada*, Annual General Meeting, Saskatoon, May 1987, Program with Abstracts 12, page 70.

Roddick, J.A. and Hutchison, W.W. (1973): Pemberton (East Half) Map-area, British Columbia, *Geological Survey of Canada*, Paper 73-17, 21 pages.

Woodsworth, G.J. (1977): Geology of Pemberton (92J) Map-area, *Geological Survey of Canada*, Open File Map 482 (1:250 000).

Woodsworth, G.J., Pearson, D.E. and Sinclair, A.J. (1977): Metal Dispersion Across the Eastern Flank of the Coast Plutonic Complex, South-central British Columbia, *Economic Geology*, Volume 72, pages 170-183.

GEOLOGY AND MINERAL OCCURRENCES OF THE TYAUGHTON CREEK AREA* (92O/2, 92J/15, 16)

By P. Schiarizza and R.G. Gaba, J.K. Glover, Consulting Geologist and J.I. Garver, University of Washington

KEYWORDS: Regional geology, Bridge River complex, Shulaps ultramafic complex, Cadwallader Group, Tyaughton Basin, Taylor Creek Group, blueschist, strike-slip faults, gold veins, stibnite, cinnabar, scheelite.

INTRODUCTION

The Tyaughton Creek map area is centred 185 kilometres north of Vancouver, on the northeastern margin of the Coast Mountains (Figure 1-14-1). It covers about 700 square kilometres of mountainous terrain within the Chilcotin Ranges, north and east of the village of Gold Bridge. Our 1988 mapping program comprises the southeastward extension of the previous two summers' mapping in the Warner Pass (Glover and Schiarizza, 1987; Glover *et al.*, 1987) and Noaxe Creek (Glover *et al.*, 1988a, 1988b) map sheets. It encompasses part of the area covered by reconnaissance geological mapping directed by B.N. Church of this Ministry during mineral deposit studies of the Bridge River mining camp (Church, 1987; Church and MacLean, 1987; Church *et al.*, 1988a, 1988b; Church and Pettipas, 1989, this volume).

This year's program included detailed mapping in the Spruce Lake–Pearson Creek area by J.I. Garver and P.J. Umhoefer as part of their doctoral research at the University of Washington (Garver *et al.*, 1989, this volume). It also incorporated a study of the Shulaps ultramafic complex undertaken by T. Calon of The Memorial University of Newfoundland. Geological mapping and sampling by D.A. Archibald of Queen's University continues a potassium-argon and $^{40}Ar/^{39}Ar$ geochronology study initiated during the 1987 field season; preliminary results of this program are summarized by Archibald *et al.* (1989, this volume).

This is the third year of a 4-year regional mapping project, begun in 1986 and funded by the Canada/British Columbia Mineral Development Agreement. Open File geology and mineral potential maps covering this season's study area will be released in February, 1989.

REGIONAL GEOLOGY

The study area is underlain primarily by Mesozoic sedimentary and volcanic rocks that occur within a structurally complex, northwest-trending belt that flanks the northeastern margin of the Coast plutonic complex (Figure 1-14-1). The area includes several tectonostratigraphic assemblages (Figure 1-14-2) which are described following.

Shulaps Ultramafic Complex: variably serpentinized harzburgite and dunite structurally underlain by serpentinite mélange containing knockers of ultramafic, gabbroic, volcanic and sedimentary rock. It is interpreted by Nagel (1979), Potter (1983, 1986), and T.Calon (personal communication, 1988) as a dismembered ophiolite suite.

Bridge River Complex: imbricated chert, greenstone, gabbro, blueschist, limestone and clastic rocks ranging in age from at least Middle Triassic to Early Jurassic. These rocks, together with the structurally overlying Shulaps ultramafic complex are assigned to the Bridge River terrane by Potter (1983, 1986) and inferred to comprise the remnants of a Mesozoic back-arc basin.

Cadwallader Terrane: greenstone and gradationally overlying Early Triassic sedimentary rocks of the Cadwallader Group, together with Late Triassic clastics and limestone of the Tyaughton Group and overlying Early to Middle Jurassic shale. Trace element geochemistry of Cadwallader greenstones and the composition of Late Triassic clastic sediments suggest derivation from a volcanic arc (Rusmore, 1985, 1987).

Tyaughton Basin: shallow-marine clastic rocks of the Middle Jurassic to Early Cretaceous Relay Mountain Group, and predominantly marine clastics of the mid-Cretaceous Taylor Creek and Jackass Mountain groups. Taylor Creek sediments were in part derived from the adjacent Bridge River complex at the onset of mid-Cretaceous compressional tectonism.

In the Warner Pass map area, weakly deformed Late Cretaceous andesitic volcanics assigned to the Powell Creek volcanics sit above the Taylor Creek Group with pronounced angular unconformity. Late Cretaceous deposits within the Tyaughton Creek area are represented mainly by the coarse, nonmarine Silverquick conglomerate. It overlies the Taylor Creek Group with apparent angular unconformity and passes gradationally upward into andesitic volcanics; these units were subsequently deformed by northerly-directed overturned folds and thrusts.

Mesozoic strata throughout the belt are intruded by Late Cretaceous to Eocene stocks and dykes of felsic to intermediate composition, and are locally unconformably overlain by Eocene volcanic and sedimentary rocks and by Miocene to Pliocene plateau lavas. They are intruded by Late Cretaceous granite to quartz diorite of the Coast plutonic complex along the southwestern margin of the belt.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

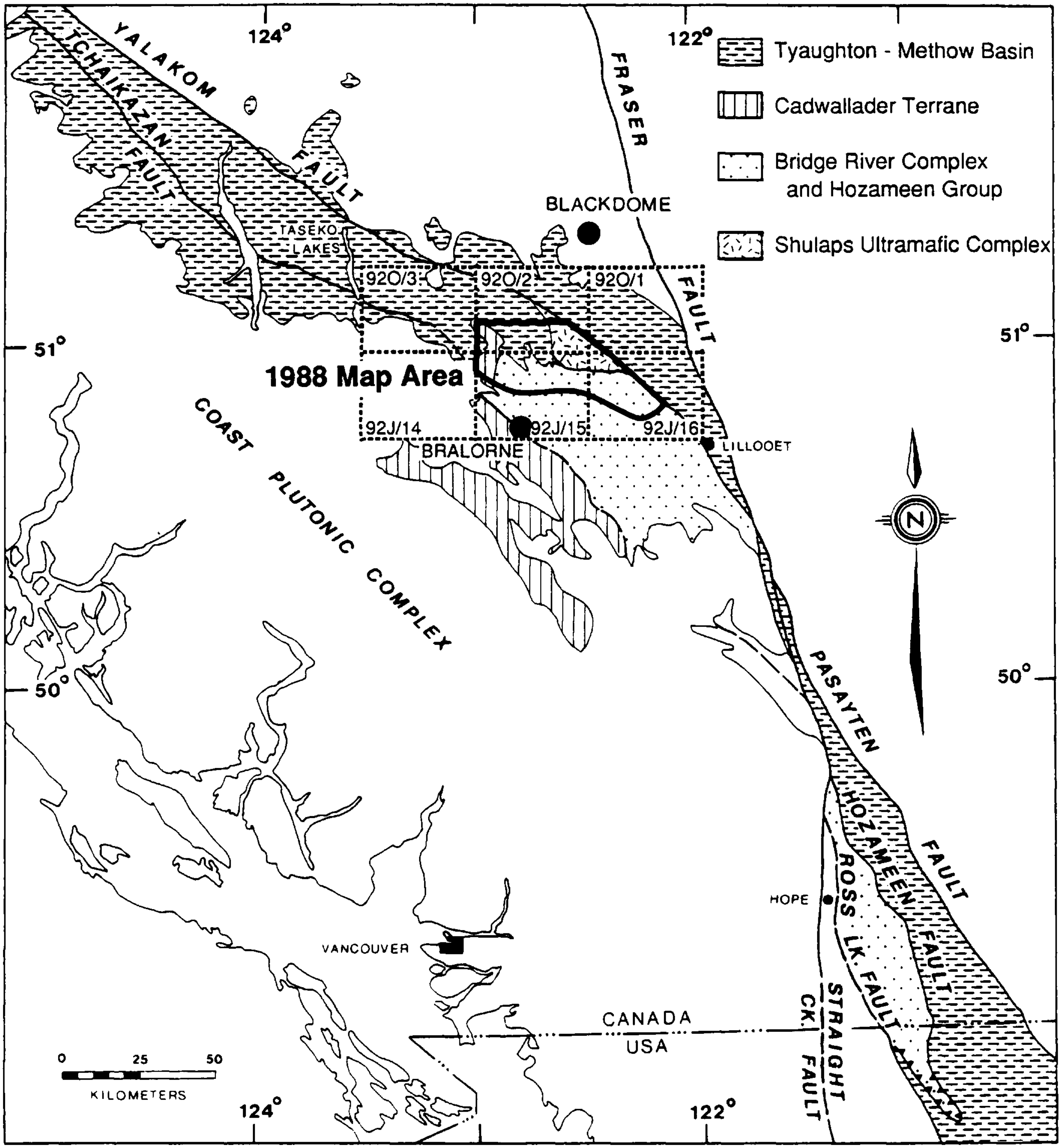


Figure 1-14-1. Location and geological setting, Tyaughton Creek map area.

Mesozoic rocks are offset about 80 kilometres from probable correlatives to the south, where the Hozameen Group and Methow basin correspond to the Bridge River complex and Tyaughton basin respectively. This offset is inferred to be the product of Eocene dextral movement along the north-trending Fraser–Straight Creek fault system (Monger, 1985). Late Cretaceous fragmentation of the belt occurred along northwest-trending dextral strike-slip faults associated with the Yalakom–Hozameen system. This faulting postdated mid-Cretaceous folding and thrusting. Still earlier deformation and metamorphism is recorded locally and may in part be related to the tectonic juxtaposition of the Cadwallader terrane and the Bridge River and Shulaps complexes.

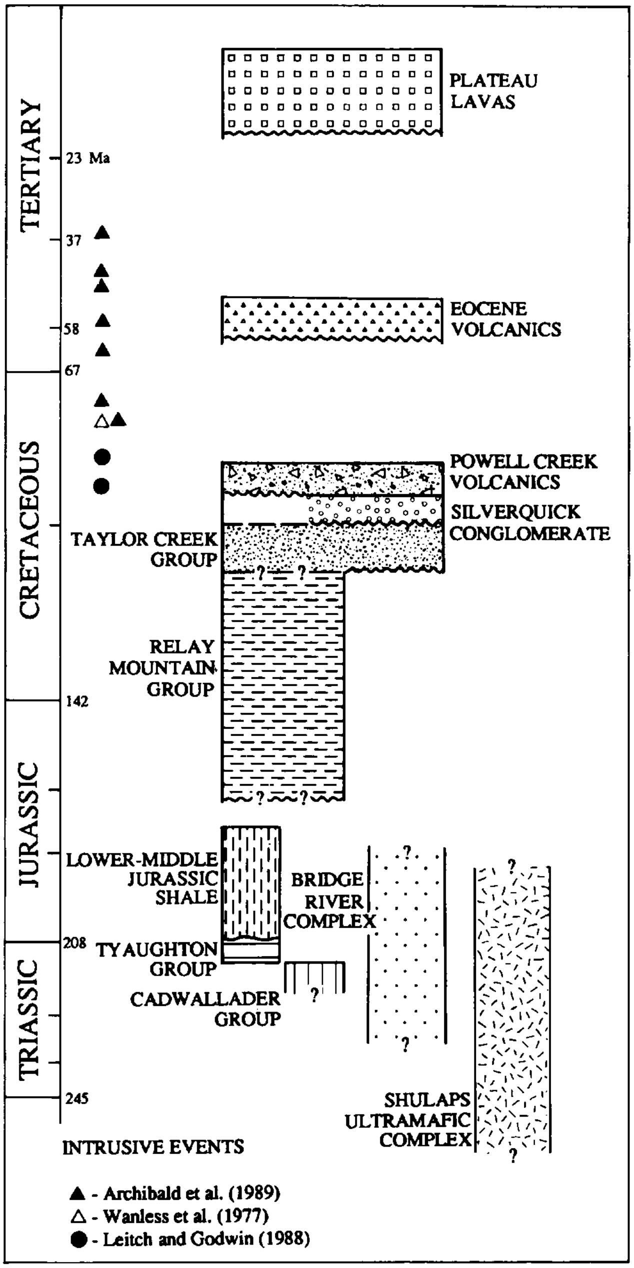


Figure 1-14-2. Tectonostratigraphic assemblages of the Tyaughton Creek map area.

LITHOLOGY

BRIDGE RIVER COMPLEX

The Bridge River complex includes variably metamorphosed and structurally imbricated chert, clastic rocks, limestone, mafic extrusive and intrusive rocks, and serpentinite. It underlies a large portion of the map area between the Shulaps Range and Carpenter Lake (Figure 1-14-3). These rocks were previously assigned to the Bridge River Series by Drysdale (1916) and McCann (1922); to the Bridge River Group by Roddick and Hutchison (1973); and to the Fergusson Series by Cairnes (1937, 1943). They include rocks assigned to the Fergusson Group by Church (1987) and Church *et al.* (1988a, 1988b). In agreement with earlier workers, we also include some greenstone units within the Bridge River complex that Church assigned to the Cadwallader Group. The term "complex" (after Potter, 1983, 1986) is preferred to "Group", because internal structural complexities prohibit measurement of a meaningful type section.

Bridge River rocks within most of the map area comprise prehnite-pumpellyite-grade chert and greenstone, together with lesser amounts of argillite, tuff, limestone, sandstone, conglomerate and gabbro; serpentinite is common along fault zones. Chert is in depositional contact with argillite, greenstone, tuff, limestone and clastic rocks; limestone and greenstone are also in depositional contact. The complex is characterized, however, by a high degree of internal disruption and brittle faulting so that lithologic contacts are commonly faults, and individual lithologic units are traceable for only short distances.

Bridge River chert is generally grey, but also includes red, brown and green varieties. It typically occurs in beds 1 to 10 centimetres thick separated by argillaceous partings, but also occurs as massive pods several metres thick, and as narrow lenses within black argillite. Greenstone is grey-green to chocolate-brown or purplish-brown-weathering metabasalt. It is commonly massive, but also includes pillowed varieties and pillow breccia. It is locally amygdaloidal, and contains rare phenocrysts of plagioclase or altered ferromagnesian minerals. Light grey limestone occurs locally throughout the complex, but is most common in the vicinity of Marshall Ridge. It occurs as thin lenticular beds intercalated in bedded chert; as podiform lenses ranging from a few centimetres to several tens of metres thick within greenstone; and as large olistolith blocks (Potter, 1983) within chert, argillite and coarser clastic rocks. Clastic rocks within the Bridge River complex include chert and volcanic-rich sandstones and chert-pebble conglomerates. These are a relatively minor component locally intercalated with ehert and argillite over intervals ranging up to several tens of metres.

Medium to coarse-grained gabbroic rocks occur locally within the Bridge River complex, where they are typically associated with greenstone. At one locality along the Carpenter Lake road, 9 kilometres west of the east end of the lake, gabbro occurs as a sequence of steeply south-dipping sheeted dykes. Individual dykes typically display only one chilled margin, commonly their southern contact.

A distinctive assemblage of structurally interleaved blueschist, greenschist and metachert with thin limestone beds comprises the Bridge River complex near the headwaters of North Cinnabar Creek where it unconformably underlies the Taylor Creek Group; these rocks are described by Garver *et al.* (1989). This belt has been traced intermittently down to and across Tyaughton Lake for about 15 kilometres to the southeast. Blueschist also occurs within an adjacent fault panel at a single locality along Tyaughton Creek, about 7 kilometres east of Tyaughton Lake.

The Bridge River complex northeast of the Marshall Creek fault is represented mainly by phyllites and schists which were penetratively deformed under predominantly greenschist-facies metamorphic conditions. These rocks are structurally interleaved with serpentinite mélange and talc-serpentine-carbonate schist beneath the upper massive

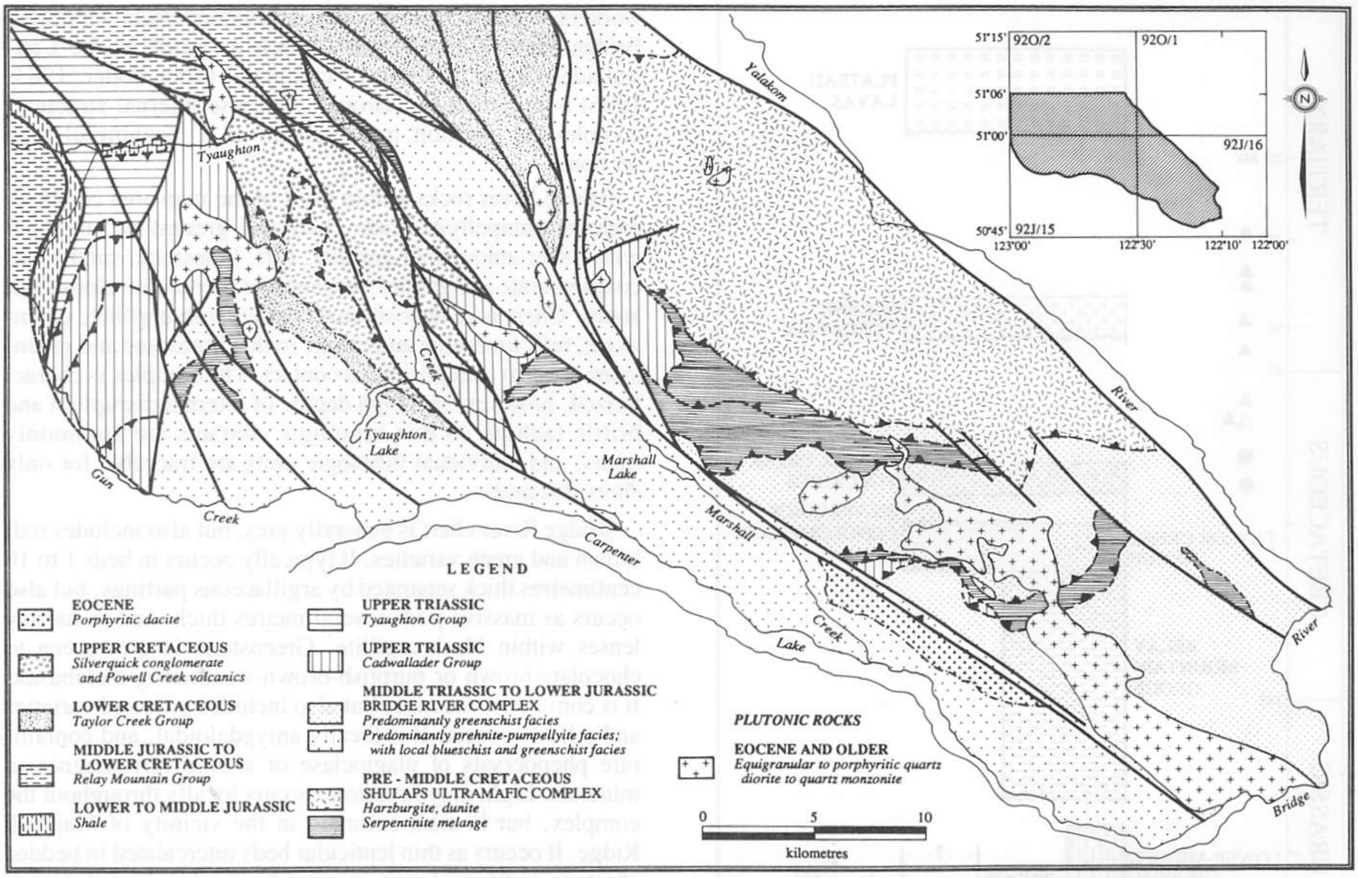


Figure 1-14-3. Generalized geology map, Tyaughton Creek area. Geology east of the Mission Ridge pluton after Potter (1983).

harzburgite unit of the Shulaps ultramafic complex. The most common lithologies are medium to dark grey phyllite, quartz phyllite and biotite-bearing schist derived from argillite and chert, and chloritic schist derived from mafic volcanic rock. These are locally intercalated with crudely foliated phyllosilicate-bearing metasandstone, marble, and chlorite-actinolite-carbonate schists probably derived from impure calcareous sediments. The penetrative cleavage within the phyllites and schists is commonly crenulated. Locally they are structurally imbricated with non-penetratively deformed lithologies similar to those which characterize the Bridge River complex elsewhere within the map area.

The age of the Bridge River complex is presently constrained by Late Triassic conodonts from a limestone pod near the mouth of Tyaughton Creek (Cameron and Monger, 1971), and by Middle Triassic to Early Jurassic radiolarians from twelve localities (seven of them along the Carpenter Lake road within the present map area) between Lillooet and Gold Bridge (Cordey, 1986). To the south correlative Hozameen Group contains Permian to Middle(?) Jurassic strata (R.A. Haugerud, *in* Monger and McMillan, 1984), suggesting that the Bridge River complex may span a wider time range than presently indicated. Preliminary radiometric dates on Bridge River blueschists range from Late Permian to Early Jurassic (Garver *et al.*, 1989); if the older dates are valid they provide evidence of a Paleozoic protolith within the complex. Samples collected during fieldwork are presently being processed for conodonts and radiolaria and may provide further age control.

SHULAPS ULTRAMAFIC COMPLEX

The Shulaps ultramafic complex outcrops in the Shulaps Range and covers the northeastern part of the map area (Figure 1-14-3). It is bounded by the Yalakom fault on the northeast and by Bridge River and Cadwallader Group rocks to the north, west and south. The complex was first studied in detail by Leech (1953), who concluded that it was an intrusive body, emplaced in Late Triassic or Early Jurassic time, and later redistributed, possibly by solid flow, to the west and northwest along fault zones. Later workers (Monger, 1977; Nagel, 1979; Wright *et al.*, 1982) suggested that the Shulaps and Bridge River complexes together constitute a dismembered ophiolite. Potter (1983, 1986) conducted detailed mapping along the southern margin of the complex; he concluded that it had been structurally emplaced while the ultramafic rocks were still hot, and had imparted a dynamothermal metamorphic aureole to underlying Bridge River rocks.

Mapping during the present study was concentrated along the margins of the Shulaps complex, although several traverses were made through the interior of the ultramafic massif. Our mapping was carried out in conjunction with detailed mapping within the complex in the Jim Creek–East Liza Creek area by T. Calon and D. Archibald, who collected samples for radiometric dating.

The Shulaps complex essentially comprises two parts. The structurally highest unit, which makes up the main body of the prominent ultramafic massif, consists of variably serpentinized harzburgite with lesser dunite. The second component consists of serpentinite containing knockers of various rock types, and is termed serpentinite mélange. It sits structurally beneath massive harzburgite along the southwestern margin of the complex, but pinches out within Bridge River rocks to the east. Serpentinite mélange also occurs at a lower structural level, where it is imbricated with Bridge River and Cadwallader Group rocks. It is only locally preserved along the western margin of the complex, where massive harzburgite is juxtaposed against predominantly prehnite-pumpellyite-grade Bridge River rocks across northerly trending faults which may be splays connecting the Marshall Creek and Yalakom fault zones.

Harzburgite within the main mass of the Shulaps complex is locally layered, with layering defined by centimetre-wide bands of orthopyroxenite, and trains of chromite. The layering is interpreted by T. Calon (personal communication, 1988) to be a mantle tectonite fabric. Dunite locally defines layering, but is more common as unoriented pods and lenses, some of which crosscut layering within the harzburgite. Calon suggests that this is indicative of a transitional upper mantle origin.

The upper serpentinite mélange, which locally attains a structural thickness approaching 1000 metres, contains blocks of ultramafic, gabbroic, volcanic and sedimentary rock. The largest knockers, up to hundreds of metres in size, derive from an igneous complex which includes layered ultramafic cumulates, layered gabbro and varitextured gabbro, all cut by swarms of mafic to intermediate dykes. Gabbro at the northwest end of the belt grades into a dyke complex which in turn grades into pillowed volcanic rocks. These volcanics sit structurally above Cadwallader Group rocks, whereas elsewhere in the belt the serpentinite mélange sits above the Bridge River complex.

T. Calon (personal communication, 1988) has noted a crude "knocker stratigraphy" within the serpentinite mélange, such that progressively lower structural levels are dominated by knockers derived from progressively higher structural levels within an ophiolite complex. Sedimentary and volcanic knockers occur from top to bottom of the unit. Most of these comprise Bridge River lithologies, but pebble conglomerates and finer clastic rocks of uncertain origin are also present; some may belong to the Cadwallader Group. The sedimentary and volcanic knockers presumably represent a sampling of the footwall succession across which the Shulaps complex was emplaced.

The structurally lower serpentinite mélange unit was traced from a point 7 kilometres southeast of Marshall Lake, where it is truncated by the Marshall Creek fault, for 10 kilometres to the east, where it is truncated by the Mission Ridge pluton. It apparently continues northeastward from the east margin of the pluton, where it was mapped by Potter (1983) as his "Eastern Imbricate Zone" (Figure 1-14-3). The serpentinite encloses knockers of ultramafic, gabbroic and dioritic rocks similar to those within the upper mélange unit. It is both overlain and underlain by Bridge River rocks, but in two areas is juxtaposed against lenses of Cadwallader Group conglomerates and sandstones along its lower contact. This unit is inferred to be a structural repetition of the upper serpentinite mélange; its occurrence at this lower structural level suggests that emplacement and imbrication of the Shulaps complex was a complex process involving some out-of-sequence thrusting and/or folding.

Serpentinite containing gabbroic, volcanic and sedimentary knockers also occurs 5 kilometres northwest of Marshall Lake and may comprise an offset portion of the Shulaps mélange. Serpentinite containing knockers of mainly Bridge River lithologies occurs within the Bridge River complex south of Eldorado Mountain, close to its contact with the Cadwallader Group (Garver *et al.*, 1989). The intimate association of Cadwallader and Bridge River rocks beneath the Shulaps serpentinite mélange suggests that the Eldorado mélange might be a structural repetition of the same zone. The correlation is consistent with the presence of ultramafic and gabbroic rocks, including the Early Permian Bralorne diorite (Leitch and Godwin, 1988), exposed in close association with both Bridge River and Cadwallader Group rocks south of the Eldorado area (Church *et al.*, 1988a, 1988b).

CADWALLADER GROUP

The Cadwallader Group comprises Upper Triassic sedimentary and volcanic rocks which outcrop in the Eldorado Mountain area, as well as within several fault panels farther to the east. Cairnes (1937, 1943) first used the designations Noel Formation, Pioneer Formation, and Hurley Group for rocks in the Bralorne and Eldorado Mountain areas which had previously been included in the Cadwallader Series of Drysdale (1916, 1917) and McCann (1922). The Noel, Pioneer and Hurley were all assigned formation status by Roddick and Hutchison (1973), and included within the Cadwallader Group. Rusmore (1985, 1987) was the first to study the group in detail. She concluded that the Noel Formation is not a coherent unit and should be abandoned. Her revised stratigraphy, based on sections west of Eldorado Mountain, comprises mafic volcanic rocks of the Pioneer Formation, and conformably overlying siltstone, sandstone and conglomerate of the Hurley Formation; neither the stratigraphic base nor the stratigraphic top of the group was recognized. The Group was assigned a Late Triassic age on the basis of latest Carnian or earliest Norian to middle Norian conodonts collected from the Hurley Formation.

Church (1987) and Church *et al.* (1988a, 1988b) recognize the Pioneer and Hurley formations of Rusmore, but retain the name Noel Formation for black argillite and siltstone locally exposed south of the present study area. They also assign greenstone units to the Pioneer Formation which we, along with previous workers, include within the Bridge River complex. Further confusion as to the status of the Cadwallader Group arises from the fact that volcanic and sedimentary rocks assigned to the group in the Bralorne area are apparently intruded by the Early Permian Bralorne diorite (Leitch and Godwin, 1988).

The divisions of the Cadwallader Group recognized during the present study correspond to those of Rusmore (1985, 1987). The Pioneer Formation consists of green to purplish-weathering, commonly amygdaloidal, pillowed and massive greenstone, and greenstone breccia. The overlying Hurley Formation consists mainly of thin-bedded sandstone and siltstone turbidites, but commonly includes distinctive pebble to cobble conglomerates containing limestone, mafic to felsic volcanic and granitoid clasts. Formational contacts observed by Rusmore east of Eldorado Mountain vary from abrupt to gradational; the latter are marked by a transition zone of intercalated greenstone, bedded tuff, conglomerate, sandstone and minor micritic limestone. A similar gradational contact between the Pioneer and Hurley formations was observed along a northwest-trending ridge 4 kilometres northwest of Liza Lake. The contact between the two formations was not observed elsewhere.

The Cadwallader Group is exposed most extensively in the Eldorado Mountain area, where it occurs as a north-northeast-trending panel separated by faults from the Tyaughton Group to the west and the Bridge River complex to the east. Both Pioneer and Hurley formations also outcrop in Tyaughton Creek canyon, east of Tyaughton Lake, and along a northwest-trending ridge system to the north. In this area the group is juxtaposed against Bridge River complex and Cretaceous rocks across northwesterly trending faults that are splays of the Castle Pass and Relay Creek–Marshall Creek fault systems. The southeastern contact, however, is in part a northwest-dipping shear zone across which the Cadwallader Group apparently sits structurally above a belt of serpentinite mélange.

The Cadwallader Group is also exposed on the northeast side of the Marshall Creek fault where it is juxtaposed against the Shulaps complex and metamorphosed Bridge River rocks. Cadwallader rocks in this area were penetratively deformed under lower greenschist(?) facies metamorphic conditions; fine-grained sediments are typically cleaved and clasts in conglomerate are locally highly flattened. The most extensive exposures occur in the East Liza Creek area, where the Hurley Formation is structurally overlain, across a gently-dipping and locally folded thrust contact, by a pillowed volcanic-dyke-gabbro complex that comprises part of the upper serpentinite mélange. The Hurley Formation also occurs as two lenses structurally beneath the lower serpentinite mélange 10 kilometres southwest of Marshall Lake. These lenses in turn sit structurally above the Bridge River complex.

TYAUGHTON GROUP

The Tyaughton Group, of middle(?) to late Norian age, comprises fluvial to shallow-marine conglomerate, sandstone and limestone. It outcrops in the northwestern corner of the map area, where it occurs within a structurally complex panel on the north and south sides of Tyaughton Creek. The group is subdivided into five distinct units which are described by Glover *et al.* (1988) and Garver *et al.* (1989).

Clastic units within the Tyaughton Group contain mainly intermediate to felsic volcanic detritus. Contacts with the Cadwallader Group are everywhere faults, but the similarity in age and composition suggests that the two groups were originally a coherent sequence, deposited in or near a Late Triassic volcanic arc (Rusmore, 1987).

LOWER TO MIDDLE JURASSIC SHALE

An unnamed unit comprising dark grey calcareous shale together with brown sandstone, siltstone, and minor conglomerate is spatially associated with the Tyaughton Group. It is dated as upper Hettangian to lower Bajocian on the basis of a rich ammonite fauna (Tipper, 1978 and personal communication, 1987), and is inferred to have been deposited disconformably above the Tyaughton Group.

The shale unit outcrops most extensively in the vicinity of Spruce Lake, where it occupies a southeast to south-trending belt along the east side of the Tyaughton Creek fault. It also occurs within a structural window along Tyaughton Creek, and as a northwest-trending fault-bounded sliver within Relay Mountain Group rocks north of the creek, where its extent is too limited to be shown on the geological sketch map (Figure 1-14-3).

RELAY MOUNTAIN GROUP

The Relay Mountain Group comprises Jurassic to Cretaceous shallow-marine strata that are extensively exposed in a northwest-trending belt extending from the northwestern part of the present map area to Big Creek (Glover *et al.*, 1987, 1988b). They are described in detail by Jeletzky and Tipper (1968), who estimated a thickness of 1500 to 2700 metres in sections north of Relay Mountain. The group ranges in age from Callovian (latest Middle Jurassic) to Barremian (Early Cretaceous); detailed subdivisions by Jeletzky and Tipper are based on the rich bivalve and ammonite fauna.

The Relay Mountain Group consists of sandstone, shale and minor conglomerate. Within the map area it crops out in a belt on the west side of the Tyaughton Creek fault, and as several south-tapering fault-bounded wedges that terminate near Tyaughton and Relay creeks.

TAYLOR CREEK GROUP

The Taylor Creek Group, of Albian age, is represented within the study area by the chert-rich Dash conglomerate and conformably overlying shale and micaceous sandstone of the Lizard formation. In the Eldorado Mountain area these rocks sit unconformably above the Bridge River complex and are described by Garver *et al.* (1989). The same units occur as fault slivers along Tyaughton Creek, east and northeast of Eldorado Mountain. They also outcrop extensively in the Big Sheep Mountain area, where they occur within an array of south-tapering fault panels which extend southward from a wide synformal belt exposed between Relay and Lone Valley creeks (Glover *et al.*, 1988a, 1988b; *see* also Figure 1-14-4.)

SILVERQUICK CONGLOMERATE AND POWELL CREEK VOLCANICS

Upper Cretaceous rocks within the Tyaughton Creek area are represented mainly by the Silverquick conglomerate, comprising a lower unit of chert-pebble conglomerates and an overlying unit of interbedded chert-pebble conglomerate, volcanic-pebble to cobble conglomerate and andesitic breccia. These rocks outcrop in several fault panels east of Eldorado Mountain, and are described in more detail by Garver *et al.* (1989). Andesitic breccias and pyroxene-phyric flows of the overlying Powell Creek volcanics occur locally along the west slopes of Tyaughton Creek, due east of Eldorado Mountain. The two units are not separated on the accompanying sketch map (Figure 1-14-3).

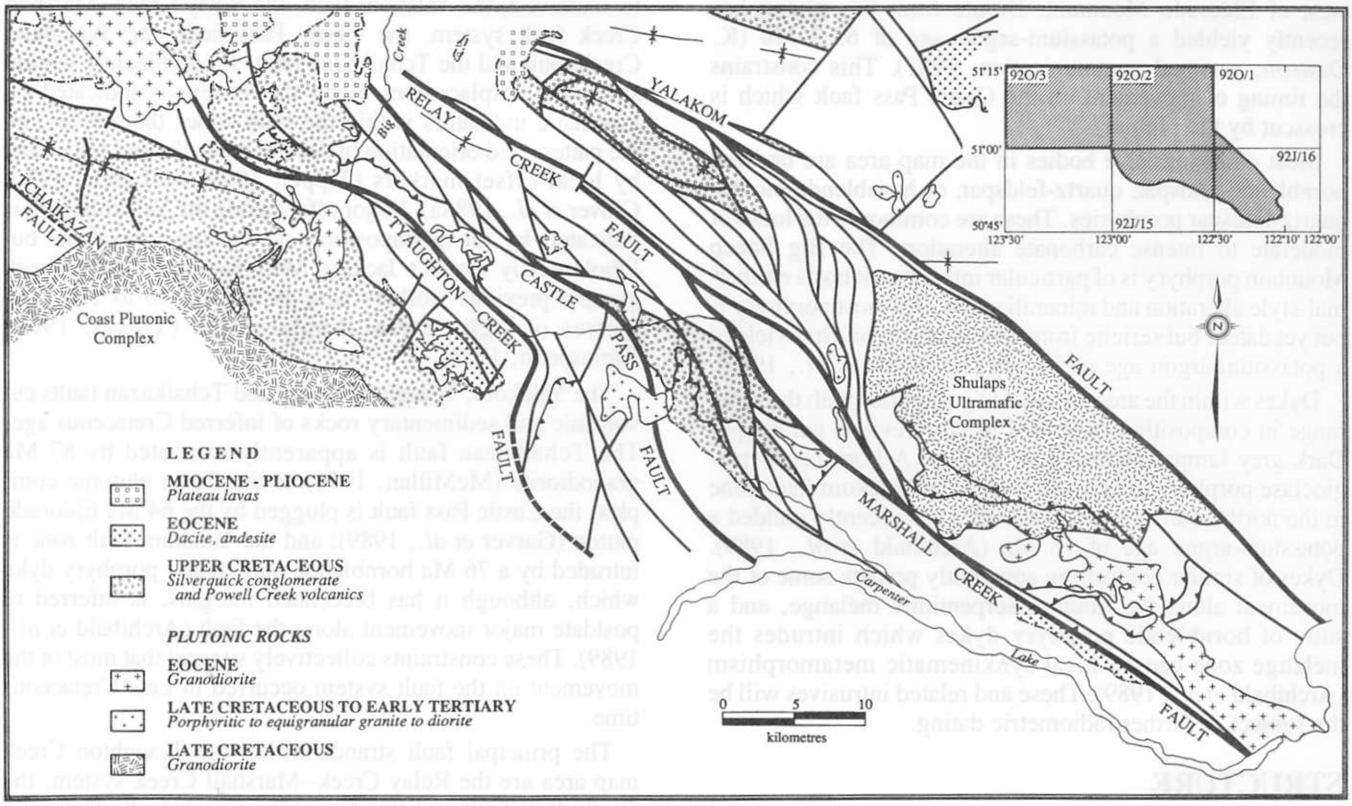


Figure 1-14-4. Major structures of the Taseko–Bridge River area and the distribution of Late Cretaceous and younger rock units.

EOCENE VOLCANIC AND SEDIMENTARY ROCKS

A conspicuous belt of light grey to buff-weathering volcanic flows and breccias outcrops on the slopes northeast of Carpenter Lake, southeast of Hog Creek. The volcanics comprise mainly hornblende, biotite, feldspar and quartz-phyric dacites. They are locally underlain by several tens of metres of conglomerate, sandstone and shale; narrow seams of lignite were reported within the sediments by McCann (1922). The sediments and volcanics dip at shallow to moderate angles northeastward. They sit unconformably above Bridge River rocks to the southwest, and are bounded to the northeast by the Marshall Creek fault. A small patch of similar volcanic rock sits unconformably above the Bridge River complex 2 kilometres north of Liza Lake.

An attempt to date the basal sediments northeast of Carpenter Lake by palynology was unsuccessful; the overlying volcanics were collected for potassium-argon radiometric dating but have not yet been dated. They are provisionally assigned an Eocene age on the basis of their compositional similarity to Eocene rocks elsewhere in the region.

MIOCENE PLATEAU LAVAS

Flat-lying basalt flows (not shown in Figure 1-14-3) cap Castle Peak and several adjacent ridges in the northwestern corner of the map area, where they unconformably overlie rocks of the Tyaughton and Relay Mountain groups. These outliers are erosional remnants of Miocene plateau basalts which cover much of the Chilcotin Plateau to the north (Tipper, 1978).

CRETACEOUS AND TERTIARY INTRUSIVE ROCKS

Intrusive rocks within the Tyaughton Creek area are represented by several mappable plutons and numerous dykes. They are mainly felsic to intermediate in composition, and vary from porphyritic to equigranular in texture. Although few of these rocks are dated within the map area, a similar suite of intrusive rocks to the north and northwest ranges in age from Late Cretaceous to Oligocene (Archibald *et al.*, 1989).

The largest intrusive unit is the Mission Ridge pluton, a markedly elongate body that extends northwesterly from the east end of Carpenter lake for 24 kilometres; it intrudes Bridge River schists and phyllites, as well as both upper and lower serpentinite mélange zones associated with the Shulaps ultramafic complex. The pluton consists mainly of biotite granodiorite in the southeast, but to the northwest passes into predominantly hornblende-biotite-quartz-feldspar porphyry comprising phenocrysts up to several millimetres in size within an aphanitic to fine-grained matrix. Similar porphyry makes up the Hog Creek stock, which intrudes Bridge River schists 1 kilometre west of the north end of the Mission Ridge pluton. Biotite from granodiorite of the Mission Ridge pluton has yielded a potassium-argon age of 44 Ma (Woodsworth, 1977). This date is identical to that recently obtained for two compositionally similar plutons within the Warner Pass map sheet to the northwest (Archibald *et al.*, 1989).

The Eldorado pluton consists of equigranular quartz diorite to granodiorite. It intrudes rocks of the Bridge River complex, the Cadwallader Group and the Taylor Creek Group in the west-central part of the map area, south and west of Eldorado Mountain. Biotite from this pluton has recently yielded a potassium-argon age of 63.7 Ma (K. Dawson, personal communication, 1987). This constrains the timing of movement on the Castle Pass fault which is crosscut by the pluton.

Most other intrusive bodies in the map area are undated hornblende-feldspar, quartz-feldspar, or hornblende-biotite-quartz-feldspar porphyries. These are commonly the locus of moderate to intense carbonate alteration. The Big Sheep Mountain porphyry is of particular interest as it hosts epithermal-style alteration and mineralization. The host porphyry is not yet dated, but sericite from an alteration zone has yielded a potassium-argon age of 27 Ma (Archibald *et al.*, 1989).

Dykes within the area are mainly porphyries with the same range in composition described in the previous paragraph. Dark grey lamprophyres occur locally. A hornblende plagioclase porphyry dyke from within the Yalakom fault zone in the northeastern corner of the area has recently yielded a potassium-argon age of 76 Ma (Archibald *et al.*, 1989). Dykes of similar compsition apparently predate some of the movement along the Shulaps serpentinite mélange, and a suite of hornblende porphyry dykes which intrudes the mélange zone caused local synkinematic metamorphism (Archibald *et al.*, 1989). These and related intrusives will be the subject of further radiometric dating.

STRUCTURE

OVERVIEW

The structure within the map area is dominated by steeply dipping northwest to northerly trending faults which comprise part of a regionally extensive dextral strike-slip system which was active in Late Cretaceous time. Tertiary deformation, probably related to dextral wrench-faulting along the Fraser fault system to the east, is reflected mainly in north to northeast-trending faults, dykes and extensional veins, but also involved predominantly dip-slip movement along earlier-formed northwest-trending structures.

Earlier structural events are recorded within structural blocks separated by major strands of the strike-slip system. Middle Cretaceous compressional deformation is documented in the Taylor Creek Group and younger rocks of the Eldorado Mountain area, where pre-Middle Cretaceous deformation and metamorphism of the underlying Bridge River complex is also recognized. Polyphase folding of the adjacent Cadwallader Group may also reflect mid-Cretaceous and older deformational events. Rocks within the Shulaps block record a complex history of deformation and metamorphism associated with emplacement of the Shulaps ultramafic complex over the Bridge River complex and Cadwallader Group. These events in part predate displacement on the bounding Marshall Creek–Yalakom fault system.

STRIKE-SLIP FAULTS

Figure 1-14-4 shows the main structures within the Warner Pass, Noaxe Creek, Bralorne and Bridge River map areas, as outlined by our past three summers' mapping. The structural pattern is dominated by steep northwest-trending faults inferred to comprise part of a Late Cretaceous dextral strike-slip system. Major through-going faults include, from northeast to southwest; the Yalakom fault, the Relay Creek–Marshall Creek fault system, the Castle Pass fault, the Tyaughton Creek fault and the Tchaikazan fault. Predominantly dextral strike-slip displacement along the system is indicated by kinematie indicators within the fault zones themselves, by the pattern and orientation of subsidiary faults and folds, and by local offset markers (Tipper, 1969; McLaren, 1986; Glover *et al.*, 1988a). Major offset along the Yalakom fault is indicated by the juxtaposition of the age-equivalent, but lithologically distinct Jackass Mountain and Taylor Creek groups; previous workers have postulated 80 to 190 kilometres of right-lateral displacement (Tipper, 1969; Kleinspehn, 1985).

The Yalakom, Tyaughton Creek and Tchaikazan faults cut volcanic and sedimentary rocks of inferred Cretaceous age. The Tchaikazan fault is apparently truncated by 87 Ma granodiorite (McMillan, 1976) of the Coast plutonic complex; the Castle Pass fault is plugged by the 64 Ma Eldorado pluton (Garver *et al.*, 1989); and the Yalakom fault zone is intruded by a 76 Ma hornblende plagioclase porphyry dyke which, although it has brecciated margins, is inferred to postdate major movement along the fault (Archibald *et al.*, 1989). These constraints collectively suggest that most of the movement on the fault system occurred in Late Cretaceous time.

The principal fault strands within the Tyaughton Creek map area are the Relay Creek–Marshall Creek system, the Castle Pass fault and the Tyaughton Creek fault. These are discussed individually in the following paragraphs.

THE RELAY CREEK–MARSHALL CREEK FAULT SYSTEM

The Relay Creek fault extends from Big Creek in the northeastern Warner Pass sheet to the north boundary of the Tyaughton Creek map area as a relatively simple fault which brings steeply dipping, northeast-facing Taylor Creek strata on the northeast against older, generally southwest-facing strata on the southwest. To the south, it bifurcates into two main strands which rejoin near Marshall Lake and continue southeastward as the Marshall Creek fault (Potter, 1983, 1986). These two strands bound a strongly imbricated lozenge of mainly Bridge River rocks, up to 4 kilometres wide, enclosed by younger units.

East of Big Sheep Mountain northerly trending faults which juxtapose the Shulaps complex, Bridge River complex, and Taylor Creek Group are apparently splays off the northern Relay Creek fault strand. These faults merge with the Yalakom system in the Quartz Mountain–Mud Lakes area. The main Relay Creek fault apparently merges with the Yalakom fault in the Big Creek area, 30 kilometres farther to the northwest (Tipper, 1978). The zone between these faults has the form of a large-scale extensional strike-slip duplex, as defined by Woodcock and Fischer (1986). A complex synformal structure defined in 1987 along the southwestern margin of the Yalakom fault, northeast of Relay Creek, may be a negative flower structure within this extensional zone (Figure 1-14-4).

To the southeast the Marshall Creek fault zone (Potter, 1983, 1986) comprises two main fault strands. The northeastern strand separates greenschist facies Bridge River complex, Cadwallader Group and serpentinite mélange on the northeast, from prehnite-pumpellyite-grade Bridge River rocks to the southwest. A parallel fault to the southwest juxtaposes the low-grade Bridge River assemblage against a package of similar Bridge River rocks unconformably overlain by Eocene(?) volcanics. Tertiary motion along this segment is therefore indicated. In the valley of Jones Creek, this Tertiary faulting apparently emplaced Bridge River rocks over the Eocene volcanics along a steep northeast-dipping reverse fault. The two strands apparently merge to the south, where the fault zone may cut the 44 Ma Mission Ridge pluton. Nevertheless, Late Cretaceous movement along the Marshall Creek fault zone is suspected because of its apparent continuation as the Relay Creek and Yalakom faults to the north. The Tertiary movement may represent remobilization of an older fault zone where earlier northwest-trending structures presented a favourable orientation for compressional structures generated during dextral motion along the Fraser fault system (Monger, 1985).

THE CASTLE PASS FAULT

The Castle Pass fault has been traced from the confluence of Graveyard and Big creeks in the Warner Pass map sheet, through the southwestern corner of the Noaxe Creek sheet, to the north shore of Carpenter Lake in the Bralorne sheet. North of the Tyaughton Creek map area it forms the northeastern boundary of the Tyaughton Group. From Tyaughton Creek to the head of Taylor Creek it truncates the Cadwallader Group and the north-northeast-trending fault systems which separate the Cadwallader from the Tyaughton Group on the west and the Bridge River complex to the east. These rocks and structures are juxtaposed against the Taylor Creek Group and Silverquick conglomerate which outcrop east of the Castle Pass fault. Farther south, the Castle Pass fault separates lithologically distinct packages of Bridge River rocks, as described by Garver *et al.* (1989).

The Castle Pass fault is crosscut by the Eldorado pluton south of Eldorado Mountain. Biotite from this pluton has yielded a potassium-argon age of 63.7 Ma (K. Dawson, personal communication, 1987). Movement on the fault must therefore have occurred in the Late Cretaceous, because the fault cuts mid-Cretaceous rocks as well as structures which deform them (Garver *et al.*, 1989).

THE TYAUGHTON CREEK FAULT

This fault extends in a southeasterly direction from Lorna Lake to Tyaughton Creek (Glover *et al.*, 1987, 1988b), then bends to the south through Spruce Lake to Gun Creek, where it separates the Relay Mountain Group from the Lower to Middle Jurasic shale unit to the east. From there it may be continuous with a southeasterly trending system of faults mapped by Church *et al.* (1988b) along Gun Creek. Within the Warner Pass map sheet, offset of an isolated klippe of Tyaughton Group rocks from the main outcrop mass of the group, as well as of an earlier northeast-trending fault, suggests that the Tyaughton Creek fault has been the locus of 8 to 10 kilometres of right-lateral strike-slip movement (Glover *et al.*, 1988a).

The pronounced bend of the Tyaughton Creek fault at Spruce Lake is part of a regional pattern; all faults of the strike-slip system between there and the Yalakom fault display a Z-shaped sygmoidal deflection (Figure 1-14-4). The locus and orientation of this deflection appears to be controlled by the major step in the Marshall Creek system where it bounds the western margin of the Shulaps ultramafic complex and becomes part of the Yalakom system along the southeast margin of the the Relay-Yalakom duplex.

STRUCTURES IN THE ELDORADO MOUNTAIN AREA

The structure of the Eldorado Mountain area is described by Garver *et al.* (1989) and is summarized here. Middle Cretaceous deformation is documented on the east side of the Castle Pass strike-slip fault, where rocks of the Taylor Creek Group and Silverquick conglomerate occur in an overturned panel that formed during northeast-directed folding and associated thrust faulting. The overturned panel, which is cut by the Castle Pass fault, also includes rocks of the Bridge River complex which sit unconformably beneath the Taylor Creek Group. Pre-Middle Cretaceous deformation is indicated by schistosity within Bridge River rocks, which formed under blueschist to greenschist-facies metamorphic conditions. Blueschist, greenschist and prehnite-pumpellyite-grade Bridge River rocks are structurally imbricated beneath the unconformity, and also occur as clasts within the overlying Taylor Creek Group. The imbrication of different metamorphic facies within the Bridge River complex may also have been a pre-Middle Cretaceous event, but may have occurred in conjunction with deposition of the synorogenic Taylor Creek Group.

Polyphase deformation is also documented west of the Castle Pass fault, where Rusmore (1985, 1987) identified two phases of deformation within the Cadwallader Group. The first phase produced upright, northeast-trending folds and associated steep faults; the second phase produced northward-verging folds and thrust faults. The latter event is tentatively correlated with the Middle Cretaceous compressional deformation indicated by the overturned Taylor Creek Group and Silverquick conglomerate east of the Castle Pass fault. The earlier structures are oriented approximately parallel to the systems of faults which bound the Cadwallader Group and separate it from the Bridge River complex to the east and the Tyaughton Group to the west. These structures may be related to pre-Middle-Cretaceous tectonic juxtaposition of the Cadwallader Group and Bridge River complex.

STRUCTURES WITHIN THE MARSHALL RIDGE BLOCK

The Marshall Ridge block comprises Bridge River rocks exposed between the Marshall Creek fault and Carpenter Lake in the southern part of the area, together with imbricated Bridge River, Cadwallader, and Cretaceous rocks along trend to the northwest. Bridge River rocks within this block are predominantly prehnite-pumpellyite grade, and are typically pervaded by outcrop-scale brittle faults and folds. The combined effect of these, and larger scale structures, is to produce a complex array of lenticular blocks which generally prohibits the tracing of individual lithologic units, or even packages of units, for more than a few hundred metres. The structures are highly variable in orientation, but show a preferred northwesterly to northerly trend, parallel to the overall structural grain as defined by the major strands of the Late Cretaceous strike-slip system. This suggests that the fault-induced lenticularity of the Bridge River complex is at least in part a product of Late Cretaceous and younger(?) deformation; this is corroborated by similar complex juxtapositions of lenticular wedges of Cretaceous rocks within the northern part of the Marshall Ridge block. Nevertheless, because this lenticularity characterizes the Bridge River complex throughout the area, even where younger rocks comprise stratigraphically coherent packages, it is probable that in part it records an earlier history of deformation. The presence of blueschists in the Eldorado Mountain block, and at one locality within the Marshall Ridge block, suggests that at least some of this deformation may have occurred within a subduction zone.

The northern part of the Marshall Ridge block is underlain by imbricated Bridge River, Cadwallader and Cretaceous rocks, which occur within a structurally complex zone cut by numerous splays of the Relay Creek–Marshall Creek fault zone, and bounded to the west by a major splay of the Castle Pass fault. The structural imbrication is mainly across steeply-dipping northwest to northerly trending faults which comprise part of the strike-slip system. Gently dipping thrust(?) faults were observed locally and place either Bridge River complex above Cretaceous rocks or Cretaceous rocks above Bridge River complex. These faults are mid-Cretaceous or younger in age; most are thought to be related to the strike-slip faulting, but some may be relicts of the earlier, mid-Cretaceous compressional event.

STRUCTURES WITHIN THE SHULAPS BLOCK

The Shulaps block consists of rocks of the Shulaps ultramafic complex, the Bridge River complex and the Cadwallader Group which are exposed northeast of the Marshall Creek fault and its northerly trending splays east of Big Sheep Mountain. Harzburgite and associated dunite, comprising the main Shulaps massif, sit structurally above serpentinite mélange imbricated with the Bridge River complex and Cadwallader Group.

Rocks within the serpentinite mélange, the Bridge River complex and the Cadwallader Group were penetratively deformed under predominantly greenschist-facies metamorphic conditions. The penetrative fabric commonly observed within metasedimentary and metavolcanic rocks varies from a schistosity to a slaty cleavage. It dips at moderate to high angles to the north or northwest, and is axial planar to east or west-plunging mesoscopic folds. It is locahy crenulated and folded about upright folds which are approximately coaxial with the earlier ones. Mylonite occurs locally along Cadwallader and Bridge River contacts with the mélange, and as small knockers within it. Serpentinite commonly displays a penetrative, steeply north-dipping schistosity cut by discrete, more gently north-dipping slip-surfaces spaced several millimetres to several centimetres apart.

The contacts between major lithologic units within the Shulaps block dip mainly north to northeast, in approximate conformity with foliation, and are inferred to be thrust faults. One of these, the contact between tbe Cadwallader Group and an overlying greenstone-gabbro complex associated with the serpentinite mélange, is exposed north of Marshall Lake. It generally dips gently but is deformed by upright folds; slaty cleavage in the underlying metasediments is axial planar to these folds. The contact itself is marked by a narrow mylonitic zone which is largely obscured by the later slaty cleavage. The contact between Bridge River schists and underlying serpentinite mélange is also folded where it was observed 1 kilometre southwest of Rex Peak. The contact is marked by a mylonitic fabric which appears to grade upward into the schistosity in the overlying schists. It is folded about upright, gently east-plunging, south-verging asymmetric folds; schistosity in talc-serpentine-magnesite schist beneath the contact is axial planar to these folds.

Structures preserved within the Shulaps block record the imbrication and emplacement of the Shulaps ultramafic complex above rocks of the Bridge River complex and Cadwallader Group. Folding of earlier thrust contacts and the presence of polyphase mesoscopic fabrics attest to a complex history of deformation and metamorphism. Synkinematic metamorphism and cleavage development were apparently synchronous with some thrust contacts, but are associated with folds which deform other thrust contacts. Some of the metamorphism, which transformed serpentinite to talc-serpentine-magnesite schists with regenerated olivine porphyroblasts, is of local extent and clearly associated with a suite of intermediate hornblende porphyry intrusives; it is in part synchronous with late folding which deforms an earlier thrust contact and associated penetrative schistosity. Repetition of the serpentinite mélange unit may also be related to relatively late folding and/or thrusting.

The timing of deformation and metamorphism within the Shulaps block is not well constrained. It in part predates displacement on the Marshall Creek fault and associated northerly trending splays, because they separate blocks of contrasting metamorphic grade; these faults were the locus of Tertiary and possibly Late Cretaceus movement. Final cooling after the latest thermal-structural events may be constrained by a preliminary ^{40}Ar-^{39}Ar radiometric date of 73 Ma on hornblende from a metadiabase knocker within the upper serpentinite mélange (Archibald *et al.*, 1989). This event may have been synchronous with strike-slip faulting. The age of the Shulaps complex and its emplacement history are the focus of a radiometric dating program presently in progress.

MINERAL OCCURRENCES

OVERVIEW

The map area straddles the northern part of the Bridge River mining camp, which remains British Colnmbia's foremost historical gold producer. Most of the gold was produced from mesothermal veins south of the present map area, although important production also came from the Minto and Congress mines along the southern boundary of the area. Mineral occurrences within the map area comprise a variety of vein types, most of them auriferous, together with cinnabar disseminations along major strike-slip faults. In addition, disseminated chalcopyrite occurs locally within mafic dykes of the Shulaps ultramafic complex, and jade and magnesite prospects are associated with altered ultramafic rocks within the Shulaps complex and elsewhere.

Many of the mineral occurences in the area show a clear spatial relationship to plutons or dyke swarms. The available data indicate that igneous intrusion and mineralization within the region spanned a considerable time range between the early Late Cretaceous and Oligocene (McMillan, 1976; Woodsworth *et al.*, 1977; Leitch and Godwin, 1988; Archibald *et al.*, 1989). The major strike-slip faults which cut the area also exert an important control on mineralization. In places the faults are older than and/or contemporaneous with mineralization and have acted to localize metal concentrations. Elsewhere, faults may have played a role in juxtaposing mineral occurrences that were apparently deposited at different structural levels.

A regional metal zoning pattern recognized by Woodsworth *et al.* (1977) comprises, from southwest to northeast, overlapping zones of predominantly gold, antimony and mercury mineralization. The map area coincides with the periphery of the gold zone, much of the antimony zone, and all of the mercury zone. This zonation is in part expressed by a general easterly progression from mesothermal to epithermal mineralization within the Bridge River mining camp. It is supported by the trend of decreasing fluid-inclusion homogenization temperatures in vein quartz (Maheux *et al.*, 1987), indicating a general trend toward higher-level metal deposits to the east.

Metal zonations peripheral to individual plutons do not conform with the regional metal distribution of Woodsworth *et al.* (1977), and stand out as general inconsistancies in the proposed regional metal zonation framework. Local juxtaposition of metal deposits representative of different crustal levels and temperature regimes is also inconsistent with this regional zonation. For example: the Apex mercury prospect within the Yalakom fault is adjacent to the Poison Mountain porphyry copper-molybdenum deposit (Glover *et al.*, 1988); the Elizabeth-Yalakom mesothermal vein prospect is juxtaposed with the Big Sheep Mountain epithermal prospect; and the Wayside mine (mesothermal) is juxtaposed with the Howard and Lou prospects (stibnite veins). These inconsistencies reflect some combination of multiple mineralizing events followed by differential uplift across major structures.

Mineral occurrences are classified according to dominant metallic minerals and the textures and structures of metal concentrations. Their locations are plotted in Figure 1-14-5.

PORPHYRY COPPER-MOLYBDENUM

At the Yalakom prospect, minor chalcopyrite and molybdenite occur as disseminations and in quartz veinlets within carbonate and silica-altered granodiorite of the Mission Ridge pluton. This is the only porphyry-type mineralization presently known in the map area. The 44 Ma date from the Mission Ridge pluton indicates that the mineralization is Eocene or younger in age.

LOW-SULPHIDE GOLD-QUARTZ VEINS

Most of the gold produced in the Bridge River mining camp was from quartz veins that contain only a few per cent sulphide minerals. These veins occupy tension fractures or sheared zones within diorite and greenstone at the Bralorne-Pioneer and Wayside mines south of the map area (Church, 1987; Leitch and Godwin, 1988). Vein quartz is milky and contains a variable amount of calcite, ankerite and disseminated metallic minerals. Much of the quartz is ribboned with laminations and stylolitic partings of chlorite-sericite and inclusions of carbonate-sericite-mariposite-altered wallrock. Metallic minerals are mostly pyrite and arsenopyrite, with lesser sphalerite, galena, pyrrhotite, chalcopyrite, tetrahedrite, stibnite, scheelite, marcasite, molybdenite, native gold and gold tellurides. Sulphide concentrations and native gold tend to coincide along ribboned structures, although both are also within vein quartz. The ratio of gold to silver is generally between 4 and 8:1.

Auriferous veins of the Elizabeth-Yalakom prospect are also of this type. The veins occupy north-trending shears in porphyritic quartz diorite within the central part of the Shulaps ultramafic complex. The diorite is crosscut by various aplitic to porphritic dykes; those observed, however, are not spatially coincident with the auriferous veins. The age of the host diorite intrusion is not known, but it postdates the surrounding ultramafic rocks (of unknown age) as shown by the hydrothermally altered contact zone (Gaba *et al.*, 1988).

HIGH-SULPHIDE AURIFEROUS VEINS (PLUTON-ASSOCIATED)

Veins composed dominantly of arsenopyrite and pyrite, with lesser sphalerite, chalcopyrite, jamesonite, pyrrhotite and only minor quartz occupy shears that may be radial extension fractures peripheral to the 64 Ma Eldorado pluton. A local metal zonation about the pluton is represented by the abundance of arsenopyrite in veins closest to the contact (Pearson, Lucky Jem, Northern Lights 1 and 6) and by base metal sulphide and sulphosalt minerals in veins farther from the pluton (Robson, Lucky Strike).

Gold-bearing veins are also locally associated with the 44 Ma Mission Ridge pluton. These are being actively explored at the Spokane prospect, where pyrite, pyrrhotite and chalcopyrite occur within quartz veins cutting both country rock and intrusive phases along the southwestern margin of the pluton.

SKARNS

The Wide West prospect is a pyrrhotite and minor chalcopyrite skarn within limestone of the Bridge River complex along the margin of the Eldorado pluton. Minor gold is associated with the sulphide concentrations.

SCHEELITE-STIBNITE VEINS

The Tungsten King and Tungsten Queen prospects are located along a major strand of the Relay Creek–Marshall Creek fault system. Here, scheelite-stibnite veins occupy branched fractures within pervasively carbonate and silica-altered ultramafic rocks consisting of chalcedonic quartz, ankerite, mariposite and relict serpentinite. The veins are up to 8 centimetres thick and well banded: scheelite is followed inward from vein walls by chalcedonic quartz, coarse crystalline comb-quartz and finally by a central band of stibnite (Stephenson, 1941). There are no obvious alteration selvages

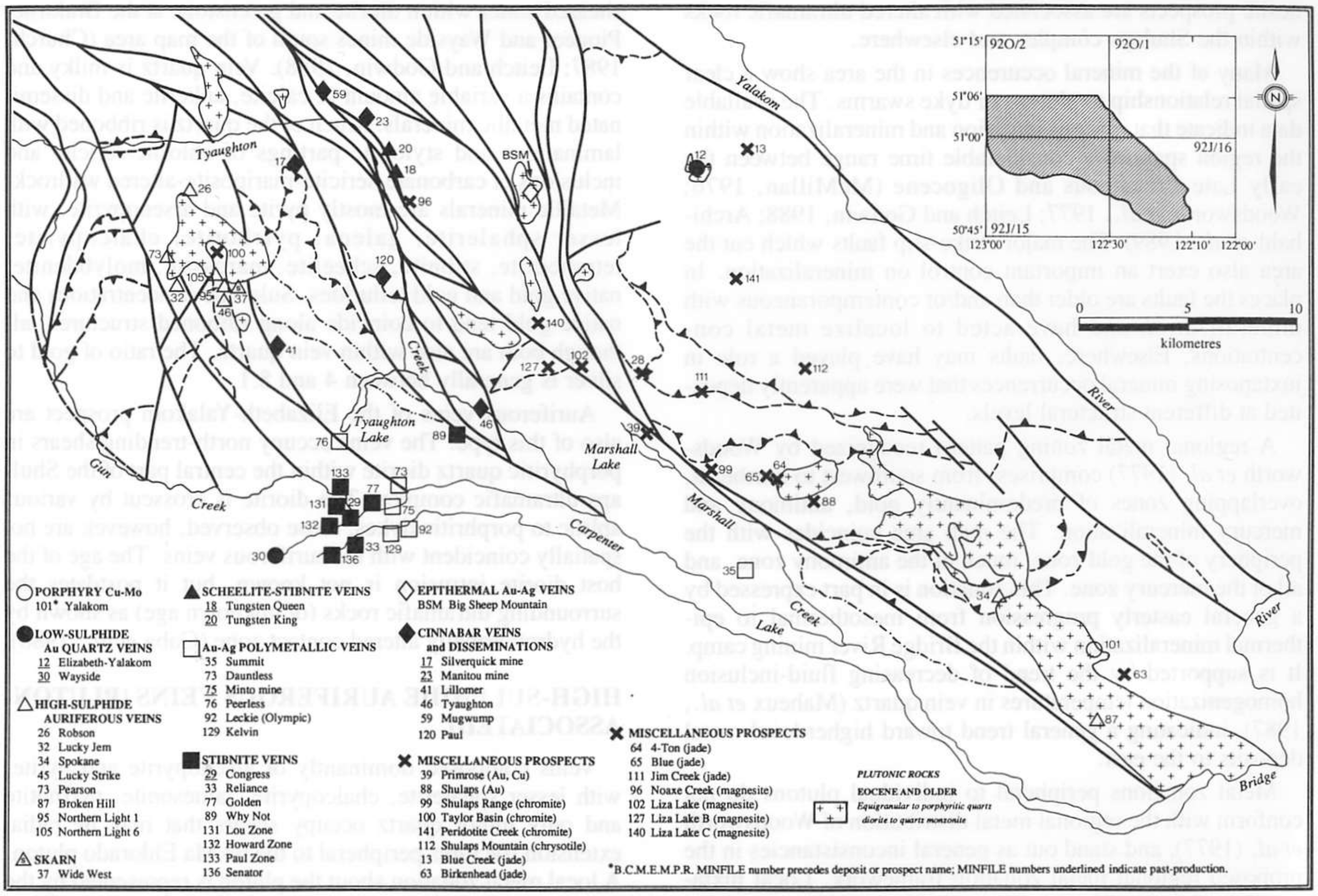


Figure 1-14-5. Mineral occurrences, Tyaughton Creek map area.

along vein margins. Feldspar porphyry dykes parallel the fabric of the altered serpentinite, but are not adjacent to the veins and their participation in mineralization processes is not proven. Diamond drilling on the Tungsten Queen prospect (Sadlier-Brown and Nevin, 1977) sampled scheelite and stibnite concentrations with up to 480 ppb gold within altered ultramafic rocks. These rocks also contain up to 133 ppm arsenic and 17 ppm mercury (Glover *et al.*, 1988b).

Scheelite is typically indicative of a high-temperature hydrothermal environment. The symmetric mineral banding, the comb-textured quartz, and the nature of the branched fractures the veins occupy together suggest a moderate to high-level environment of emplacement. The apparent absence of alteration adjacent to the veins may indicate that metal deposition was coincident with alteration of the serpentinite; the latest and lowest temperature phase (stibnite) occupies the cores to the veins. Cinnabar, reported as minor disseminations in foliated greenstone within 150 metres of scheelite-stibnite veins at the Tungsten Queen prospect (Stephenson, 1941), may be related to a later higher level, lower temperature hydrothermal overprint.

GOLD-SILVER POLYMETALLIC VEINS

Polymetallic veins containing gold and silver occur mainly between Tyaughton and Carpenter lakes, close to the inferred trace of the Castle Pass fault. The Minto vein is by far the largest and the only one to yield economic quantities of metals, namely gold, silver, copper and lead.

The veins occupy shears within foliated greenstone, argillite, chert and serpentinite of the Bridge River complex; they are commonly associated with feldspar porphyry and aplite dykes. Veins contain coarsely crystalline arsenopyrite, pyrite, sphalerite, galena and chalcopyrite together with accessory tetrahedrite, jamesonite, pyrrhotite and bornite. The veins are complex and multiphase; banding is defined by alternating metallic mineral concentrations and quartz-ankerite gangue. Brecciated veins are commonly richer in precious metals. Wallrock alteration is characterized by rare to abundant ankerite and calcite, with lesser sericite, chlorite and mariposite. Gold is closely associated with arsenopyrite; only rarely is gold present as native metal. The ratio of gold to silver is generally between 0.1 and 0.3:1. The close spatial association of veins and dykes suggests a possible genetic relationship. This is probably the case at least for the Minto vein, since it parallels the margin of the "Minto dyke" which is apparently auriferous (J. Miller-Tait, personal communication, 1988).

STIBNITE VEINS

A cluster of stibnite veins cuts Bridge River rocks directly west of the polymetallic veins described in the preceding section. These veins occupy shears within foliated greenstone, and less commonly within sedimentary rocks and gabbro. Feldspar-porphyritic dykes both parallel and crosscut vein structures; dykes range from unaltered to completely altered. Veins consist of quartz, ankerite and stibnite, with lesser pyrite and arsenopyrite. They are discontinuously banded with comb-textured vuggy quartz and are commonly brecciated and discontinuous. Stibnite, pyrite and arsenopyrite are accompanied by sphalerite, tetrahedrite, limonite, marcasite, and cinnabar as irregular and lenticular concentrations that partly replace carbonate-altered wallrock and adjacent dyke rock. Wallrocks are altered for as much as 5 metres away from veins; arsenopyrite and associated gold concentrations are most abundant within these alteration envelopes. The ratio of gold to silver is variable.

Some stibnite veins, such as those at the Congress mine and Golden and Senator prospects, contain an appreciable amount of arsenopyrite and associated gold. Recent discoveries of auriferous stibnite veins are the Howard, Lou and Paul prospects. Veins at the Lou prospect are much like those at the Congress mine. At the Howard and Paul prospects, the veins contain much more arsenopyrite and pyrite. Generally gold is intimately associated with arsenopyrite and metallurgical problems arise in their separation. However, within the upper level drift at the Howard prospect, banded and brecciated, granular, locally vuggy and comb-textured quartz-carbonate veins (with disseminated stibnite and arsenopyrite) locally contain abundant visible gold. Vertical metal zonation is apparent within orebodies at the Congress mine; cinnabar locally accompanies stibnite in the upper levels, whereas with depth, the abundance of pyrite, arsenopyrite and gold increases relative to stibnite (Cairnes, 1937).

EPITHERMAL GOLD-SILVER VEINS

At Big Sheep Mountain gold and silver values are associated with vuggy quartz seams with rare disseminated to massive tetrahedrite, and with limonitic pitch-coated fractures within and adjacent to argillic-altered feldspar and quartz-porphyritic rhyolite that caps a feldspar porphyry pluton (Dawson, 1982). Disseminated pyrite and pyrrhotite are widespread throughout the pluton. Rare amethyst veinlets are reported in altered rhyolite. The limited data regarding the style of mineralization at Big Sheep Mountain suggests a high level or epithermal environment. Epithermal mineralization in the region is best represented by the Blackdome deposit, 35 kilometres to the northeast (Vivian *et al.*, 1987).

CINNABAR VEINS AND DISSEMINATIONS

Cinnabar occurs as thin fracture-coatings and disseminations in sheared Bridge River and Cretaceous rocks along several strands of the Relay Creek and Castle Pass fault systems. At the Mugwump prospect, cinnabar is in calcite-quartz-pyrite veinlets that contain accessory stibnite. Wallrock alteration is characterized by abundant quartz, carbonate and pyrite, and less common hematite, limonite and dickite. Dyke rocks are not spatially associated with cinnabar mineralization.

Cinnabar mineralization at the Mugwump and Manitou showings occurs along a major strand of the Relay Creek fault system. Farther to the southeast, the fault is occupied by lenticular bodies of quartz-ankerite-calcite-mariposite-magnesite-serpentinite rocks which, at the Tungsten Queen and Tungsten King showings, contain scheelite-stibnite veins that locally carry gold values. The association of cinnabar, stibnite, scheelite, and gold with carbonate and silica-altered ultramafic rocks within and adjacent to a major steeply dipping fault is thought to be a near-surface expression of a Mother Lode type gold deposit (Albino, 1988; Musial, 1988). These observations and comparisons suggest that there may be potential for precious metal mineralization along the Relay Creek–Marshall Creek fault system.

SUMMARY

Much of the Tyaughton Creek map area is underlain by partially coeval rocks of the Bridge River complex, the Cadwallader Group, and the Shulaps ultramafic complex. This report documents the lithological characteristics and distribution of these units, and the nature of the structures which separate them. It also describes elements of an important Late Cretaceous fault system which were traced into the area from the north and west, and provides further information on the structural and stratigraphic relationships of mid-Cretaceous rocks within the region. The results of the study are summarized as follows:

(1) The Bridge River complex comprises structurally imbricated chert, greenstone, limestone, clastic rocks, gabbro and serpentinite; it is at least in part Middle Triassic to Early Jurasic in age. Gabbro occurs locally as sheeted dykes, corroborating the oceanic origin suggested by the predominant lithologies. The local importance of clastic rocks, limestone beds and limestone olistoliths suggests derivation from a topographically diverse basin or basins, as was pointed out by Potter (1983, 1986), who suggested a back-arc or marginal ocean basin setting. Most of the complex is at prehnite-pumpellyite metamorphic grade and is characterized by pervasive brittle faulting. Pre-Middle Cretaceous blueschist-facies metamorphism is documented in the Eldorado Mountain area, and suggests that deformation and metamorphism in part occurred in a subduction zone. Predominantly greenschist-facies metamorphism characterises the Bridge River complex where it is structurally imbricated with the Shulaps ultramafic complex.

(2) The Cadwallader Group comprises pillowed and massive greenstone of the Pioneer Formation and overlying conglomerate, sandstone and shale of the Hurley Formation. It is Late Triassic in age and therefore coeval with parts of the Bridge River complex. In the Eldorado Mountain area it is juxtaposed against the Bridge River complex across north-northeast-trending faults that predate the Castle Pass strike-slip fault and may also predate mid-Cretaceous compressional structures. In the Shulaps Range it is penetratively deformed, metamorphosed, and thrust-imbricated with rocks of the Bridge River complex and Shulaps ultramafic complex.

(3) The Shulaps ultramafic complex includes a harzburgite unit with a mantle tectonite fabric, together with structurally underlying serpentinite mélange which contains elements of the ultramafic cummulate to volcanic section

of an ophiolite assemblage. The serpentinite mélange is thrust-imbricated with rocks of the Bridge River complex and Cadwallader Group. Structures preserved within this thrust zone suggest a complex history of deformation and metamorphism that in part predates movement on the bounding Marshall Creek fault zone. Final uplift and cooling, however, may have been coincident with Late Cretaceous strike-slip faulting on the Yalakom–Marshall Creek system.

(4) The tectonic juxtaposition of the Shulaps ultramafic complex, the Bridge River Complex and the Cadwallader Group represents an important event in the accretionary history of the western Cordillera. Several lines of indirect evidence suggest that the initial juxtaposition occurred in Middle Jurassic time (Potter, 1986; Rusmore, 1987; Umhoefer *et al.*, 1988; Rusmore *et al.*, 1988). The preliminary results of our 1988 mapping program provide only a pre-Middle Cretaceous age for this event; dating presently in progress may provide further constraints.

(5) Deposition of the late Early Cretaceous Taylor Creek Group was coincident with the onset of regional compressional tectonism. Clasts within the Taylor Creek Group provide the first evidence of uplift and erosion of the Bridge River complex, while clasts in the overlying Silverquick conglomerate were derived from both the Bridge River complex and Cadwallader Group. Furthermore, the Taylor Creek Group is the oldest unit within the Tyaughton basin documented to sit unconformably above Bridge River basement. This suggests the possibility that thrust imbrication (and accretion?) of the Bridge River and Cadwallader terranes was predominantly a late Early Cretaceous event.

(6) The map area is cut by a northwest-trending system of dextral strike-slip faults that was active in Late Cretaceous time. Northerly trending splays of the Relay Creek–Marshall Creek fault system connect with the Yalakom fault system to define a large-scale extensional duplex structure. This fault system steps across and bounds the northwestern margin of the Shulaps ultramafic complex at its southeastern end. In contrast to the extensional zone to the northwest, the Shulaps complex may have been deformed and uplifted during Late Cretaceous movement on the bounding strike-slip fault systems.

(7) Metallic mineral concentrations are within or adjacent to strike-slip faults or associated structures, and have a close spatial relationship with plutons or dykes. The age of mineralization seems closely tied to igneous activity between Late Cretaceous and Early Tertiary time. The protracted history of mineralization and plutonism combined with differential uplift across faults has led to the juxtaposition of deposits of contrasting structural level and local inconsistencies in the pattern of regional metal zoning documented by Woodsworth *et al.* (1977).

ACKNOWLEDGMENTS

The authors would like to thank Peter Sajgalik, Teresa Lynch, Kim Safton, Paul Umhoefer, Doug Archibald and Tom Calon for their mapping contributions and good company while in the field. We are grateful to C.J. Potter for showing us through parts of the Bridge River complex, and to him, P. Umhoefer and M.E. Rusmore for continuing discussions on the geology and tectonics of the region. Field trips and discussions with B.N. Church, W.J. McMillan, W.R. Smyth, V.A. Preto and G.R. McKillop of this Ministry helped focus our attention on some of the important geological problems in the area. We would also like to thank Bill Atkinson and Bob Holt of Cariboo-Chilcotin Helicopters Ltd. for safe and punctual helicopter service.

REFERENCES

Albino, G.V. (1988): The Pinchi Mercury Belt, Central British Columbia: Near-surface Expression of a Mother Lode-type Mineralized System, *Geological Society of America*, Annual Meeting, Denver, Colorado, Program with Abstracts, Volume 20, Number 7, pages A141-A142.

Archibald, D.A., Glover, J.K. and Schiarizza, P. (1989): Preliminary Report on $^{40}Ar/^{39}Ar$ Geochronology of the Warner Pass, Noaxe Creek and Bridge River Map Areas (92O/3, 92O/2, 92J/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Cairnes, C.E. (1937): Geology and Mineral Deposits of the Bridge River Mining Camp, British Columbia, *Geological Survey of Canada*, Memoir 213, 140 pages.

——— (1943): Geology and Mineral Deposits of Tyaughton Lake Area, British Columbia, *Geological Survey of Canada*, Paper 43-15, 39 pages.

Cameron, B.E.B. and Monger, J.W.H. (1971): Middle Triassic Conodonts from the Fergusson Group, Northeastern Pemberton Map Area, British Columbia, *in* Report of Activities, Part B, *Geological Survey of Canada*, Paper 71-1B, pages 94-96.

Church, B.N. (1987): Geology and Mineralization of the Bridge River Mining Camp (92J/15, 92O/2, 92J/10), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 23-29.

Church, B.N. and MacLean, M.E. (1987): Geology of the Gold Bridge Area (92J/15W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-11.

Church, B.N., Gaba, R.G., Hanna, M.J. and James, D.A.R. (1988a): Geological Reconnaissance in the Bridge River Mining Camp (92J/15, 16,10; 92O/02), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 93-100.

Church, B.N., MacLean, M., Gaba, R.G., Hanna, M.J. and James, D.A. (1988b): Geology of the Bralorne Map Area (92J/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-3.

Church, B.N. and Pettipas, A.R. (1989): Research and Exploration in the Bridge River Mining Camp, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Cordey, F. (1986): Radiolarian Ages from the Cache Creek and Bridge River Complexes and from Chert Pebbles in Cretaceous Conglomerates, Southwestern British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 86-1A, pages 596-602.

Dawson, J.M. (1982): Geological and Geochemical Report on the Big Claims, Lillooet Mining Division, Dupont of Canada Exploration Limited, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 10925.

Drysdale, C.W. (1916): Bridge River Map-area, Lillooet Mining Division, *Geological Survey of Canada*, Summary Report for 1915, pages 75-85.

——— (1917): Bridge River Map-area, Lillooet Mining Division, *Geological Survey of Canada*, Summary Report for 1916, pages 45-53.

Gaba, R.G., Hanna, M.J. and Church, B.N. (1988): The Elizabeth-Yalakom Prospect, Bridge River Mining Camp (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 329-333.

Garver, J.I., Schiarizza, P. and Gaba, R.G. (1989): Stratigraphy and Structure of the Eldorado Mountain Area, Chilcotin Ranges, Southwestern British Columbia (92O/2 and 92J/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Glover J.K. and Schiarizza, P. (1987): Geology and Mineral Potential of the Warner Pass Map Area (92O/3), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 157-169.

Glover, J.K., Schiarizza, P., Umhoefer, P.J. and Garver, J.I. (1987): Geology of the Warner Pass Map Area (92O/3), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-3.

Glover, J.K., Schiarizza, P. and Garver, J.I. (1988a): Geology of the Noaxe Creek Map Area (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 105-123.

Glover, J.K., Schiarizza, P., Garver, J.I., Umhoefer, P.J. and Tipper, H.W. (1988b): Geology and Mineral Potential of the Noaxe Creek Map Area (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-9.

Jeletzky, J.A. and Tipper, H.W. (1968): Upper Jurassic and Cretaceous Rocks of Taseko Lakes Map Area and Their Bearing on the Geological History of Southwestern British Columbia, *Geological Survey of Canada*, Paper 67-54.

Kleinspehn, K.L. (1985): Cretaceous Sedimentation and Tectonics, Tyaughton-Methow Basin, Southwestern British Columbia, *Canadian Journal of Earth Sciences*, Volume 22, pages 154-174.

Leech, G.B. (1953): Geology and Mineral Deposits of the Shulaps Range, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 32, 54 pages.

Leitch, C.H.B. and Godwin, C.I. (1988): Isotopic Ages, Wallrock Chemistry and Fluid Inclusion Data From the Bralorne Gold Vein Deposit (92J/15W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 301- 324.

Maheux, P.J., Muehlenbachs, K. and Nesbitt, B.E. (1987): Evidence of Highly Evolved Ore Fluids Responsible for Sulphide Associated Gold Mineralization in the Bridge River Distriet, B.C., *Geological Association of Canada — Mineralogical Association of Canada*, Annual Meeting, Saskatoon, Saskatchewan, Program with Abstracts, Volume 12, page 70.

McCann, W.S. (1922): Geology and Mineral Deposits of the Bridge River Map Area, British Columbia, *Geological Survey of Canada*, Memoir 130, 115 pages.

McLaren, G.P. (1986): Geology and Mineral Potential of the Chilco–Taseko Lakes Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 265-274.

McMillan, W.J. (1976): Granite Creek Property, (92O/3W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology in British Columbia, 1975, pages 67-84.

Monger, J.W.H. (1977): Upper Paleozoic Rocks of the Western Canadian Cordillera and Their Bearing on Cordilleran Evolution, *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

——— (1985): Structural Evolution of the Southwestern Intermontane Belt, Ashcroft and Hope Map Areas, British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 1985-1A, pages 349-358.

Monger, J.W.H. and McMillan, W.J. (1984): Bedrock Geology of Ashcroft (92I) Map Area, *Geological Survey of Canada*, Open File 980.

Musial, J. (1988): The Mother Lode Belt, *Northern Miner Magazine*, September, 1988, Volume 3, Number 9, pages 21-24.

Nagel, J.J. (1979): The Geology of part of the Shulaps Ultramafite near Jim Creek, Southwestern British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 74 pages.

Potter, C.J. (1983): Geology of the Bridge River Complex, Southern Shulaps Range, British Columbia: A Record of Mesozoic Convergent Tectonics, Unpublished Ph.D. Thesis, *The University of Washington*, 192 pages.

——— (1986): Origin, Accretion and Postaccretionary Evolution of the Bridge River Terrane, Southwest British Columbia, *Tectonics*, Volume 5, Pages 1027-1041.

Roddick, J.A. and Hutchison, W.W. (1973): Pemberton (East Half) Map Area, British Columbia, *Geological Survey of Canada*, Paper 73-17, 21 pages.

Rusmore, M.E. (1985): Geology and Tectonic Significance of the Upper Triassic Cadwallader Group and its Bounding Faults, Southwest British Columbia, Unpublished Ph.D. Thesis, *The University of Washington*, 174 pages.

——— (1987): Geology of the Cadwallader Group and the Intermontane-Insular Superterrane Boundary, Southwestern British Columbia, *Canadian Journal of Earth Sciences*, Volume 24, pages 2279-2291.

Rusmore, M.E., Potter, C.J. and Umhoefer, P.J. (1988): Middle Jurassic Terrane Accretion along the Western Edge of the Intermontane Superterrane, Southwestern British Columbia, *Geology*, Volume 16, pages 891-894.

Sadlier-Brown, T.L. and Nevin, A.E. (1977): A Report on a Diamond-drilling Project on the Wolf and Cub Mineral Claims (Formerly Tungsten Queen), Nuspar Resources Limited, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 6287.

Stephenson, J.S. (1941): Tungsten Deposits of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 10, 103 pages.

Tipper, H.W. (1969): Mesozoic and Cenozoic Geology of the Northeastern Part of Mount Waddington Map Area (92N), Coast District, British Columbia, *Geological Survey of Canada*, Paper 68-33.

——— (1978): Taseko Lakes (92O) Map Area, *Geological Survey of Canada*, Open File 534.

Umhoefer, P.J., Garver, J.I., Glover, J.K. and Schiarizza, P. (1988b): Geology of the Tyaughton Basin, Southern Taseko Lakes Map-area, British Columbia: Part of the Boundary Between the Insular and Intermontane Superterranes, *Geological Society of America*, Abstracts with Programs, Volume 20, number 3, page 238.

Vivian, G., Morton, R.D., Changkakoti, A. and Gray, J. (1987): Blackdome Eocene Epithermal Ag-Au Deposit, British Columbia, Canada–Nature of Ore Fluids, *The Institution of Mining and Metallurgy*, Transactions, Section B, Applied Earth Science, Volume 96, pages B9-B14.

Wanless, R.K., Stevens, R.D., Lachance, G.R. and Delabio, R.N. (1977): Age Determinations and Geological Studies, K-Ar Isotopic Ages, Report 13, *Geological Survey of Canada*, Paper 77-2.

Woodcock, N.H. and Fischer, M. (1986): Strike-slip Duplexes, *Journal of Structural Geology*, Volume 8, pages 725-735.

Woodsworth, G.J. (1977): Pemberton Map Area (92J), *Geological Survey of Canada*, Open File 482.

Woodsworth. G.J., Pearson, D.E. and Sinclair, A.J. (1977): Metal Distribution Across the Eastern Flank of the Coast Plutonic Complex, South-central British Columbia, *Economic Geology*, Volume 72, pages 170-183.

Wright, R.L., Nagel, J.J. and McTaggart, K.C. (1982): Alpine Ultramafic Rocks of Southwestern British Columbia, *Canadian Journal of Earth Sciences*, Volume 19, pages 1156-1173.

STRATIGRAPHY AND STRUCTURE OF THE ELDORADO MOUNTAIN AREA, CHILCOTIN RANGES, SOUTHWESTERN BRITISH COLUMBIA* (92O/2; 92J/15)

By John I. Garver
University of Washington
and
P. Schiarizza and R.G. Gaba

KEYWORDS: Regional geology, stratigraphy, structure, Bridge River complex, Cadwallader Group, Tyaughton Group, Relay Mountain Group, Taylor Creek Group.

INTRODUCTION

The Eldorado Mountain area has been the focus of several recent tectonostratigraphic and structural studies (Rusmore, 1985; Garver, 1987; Garver *et al.*, 1988; Glover *et al.*, 1988a; Umhoefer *et al.*, 1988a, 1988b) in an attempt to better understand the tectonic evolution of various terranes and overlap sequences of this important area situated between the Insular and Intermontane superterranes (Figure 1-15-1). Previous detailed mapping in the Eldorado Creek area by Rusmore (1985), the Taylor Creek area by Garver (unpublished) and the Tyaughton Creek area by Umhoefer *et al.* (1988b) was incorporated in our 1988 mapping program undertaken in conjunction with the Taseko–Bridge River 1:50 000 mapping project (Glover and Schiarizza, 1987; Glover *et al.*, 1987, 1988a, 1988b; Garver *et al.*, 1989; Schiarizza *et al.*, 1989, this volume). Results of the current mapping include the identification of a pervasive Late Cretaceous strike-slip system and evidence for mid-Cretaceous compressional structures. Recognition of these structures has been made possible only through detailed documentation and complete understanding of the regional stratigraphy. The coincidence of precious and base metal concentrations along Cretaceous strike-slip faults suggests spatial and possibly temporal relationships between faults and metal distribution in the Bridge River mining camp.

LITHOLOGY

BRIDGE RIVER COMPLEX

In the Eldorado Mountain area (Figure 1-15-2), the Bridge River complex (Potter, 1983, 1986) is a heterogeneous assemblage of structurally juxtaposed chert and metachert, chert-rich clastic rocks, green volcanic sandstone, greenstone, blueschist and greenschist, and serpentinite. Metamorphic mineral assemblages include quartz-carbonate, prehnite-pumpellyite, epidote-actinolite and lawsonite-crossite. Rapid changes in metamorphic grade within the assemblage are the result of postmetamorphic imbrication and structural repetition. The rock types comprising the Bridge River complex are described below.

CHERT-RICH CLASTIC ROCKS

Interbedded argillite, sandstone, chert-rich conglomerate and bedded chert occur within the Bridge River complex west of the Castle Pass fault (Figure 1-15-2). The conglomerate and sandstone are crudely graded, clast supported, generally poorly sorted and in depositional contact with argillite and bedded chert. These rocks are internally disrupted and stratigraphic trends are unknown. This unit is, however, spatially associated with interbedded black argillite and chert that may be related stratigraphically.

The chert-rich clastic rocks contain clasts and detrital grains of radiolarian-bearing chert and recrystallized chert, fragments of silicic to intermediate volcanic rock, fragments of clastic sedimentary rock, and minor plagioclase. The clastic sedimentary fragments are dominantly fine-grained volcanic arkoses. This unit may represent local reworking of stratigraphically(?) lower parts of the Bridge River complex.

The chert-rich clastic rocks generally have bedding-parallel foliation; thin-bedded layers are commonly isoclinally folded. Although these rocks have a penetrative cleavage, their metamorphic grade is quite low. Metamorphic assemblages, which occur in veins and in the matrix, include carbonate-quartz or smeothe-illite. The age of these rocks is not known.

GREEN VOLCANIC-LITHIC SANDSTONE

Interbedded green volcanic-lithic sandstone and minor mudstone are sparsely distributed in the Bridge River complex. The most extensive exposure is in a fault-bound panel within the Marshall Creek fault system near Liza Lake (Schiarizza *et al.*, 1989, this volume). Smaller isolated exposures occur in the upper Pearson Creek drainage (Figure 1-15-2; Garver *et al.*, 1989). These rocks are typically massive to thin-bedded, green-weathering sandstone with minor interbeds of black mudstone. Internal disruption prohibits stratigraphic analysis. These elastic rocks are commonly imbricated with a greenstone unit.

Detrital grains in the coarse-grained sandstone are dominated by felsic and intermediate volcanic rock fragments,

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

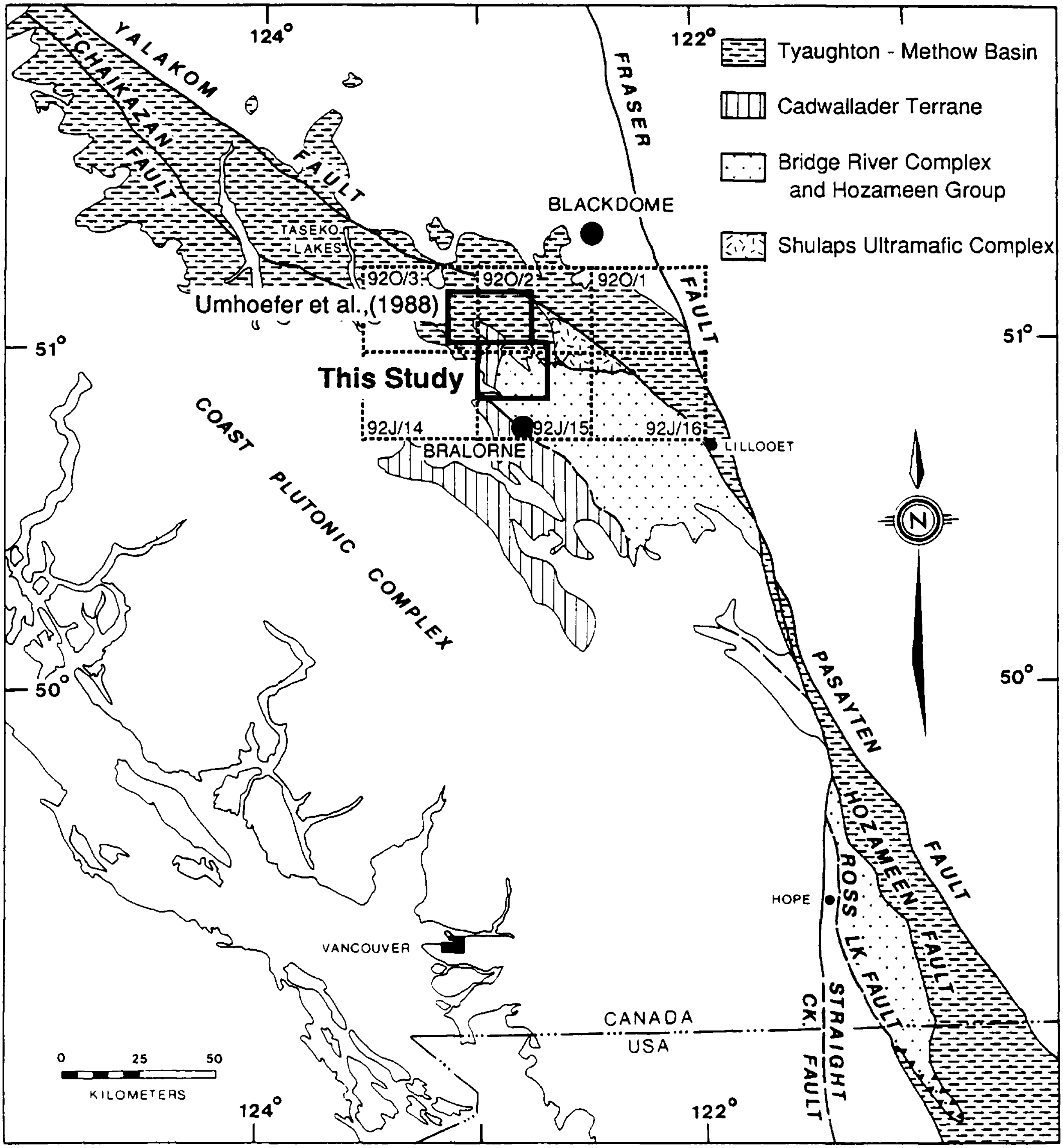


Figure 1-15-1. Location and geologic setting of the map area, showing adjoining mapping projects.

plagioclase and quartz which occurs as unstrained angular fragments; strained, vacuole-rich grains commonly with interlocking plagioclase grains; and quartz tectonites. The variation in the quartz grains suggests that volcanic, plutonic and metamorphic sources supplied detritus to the unit.

The green volcanic sandstone is generally unfoliated and cut by small-scale faults and fractures indicative of pervasive brittle deformation. The metamorphic grade is low; overgrowths and veins include carbonate, prehnite and carbonate, and pumpellyite. The age of this unit is not known.

Chert and Metachert

Bedded chert is a common constituent of the Bridge River complex. Beds of grey, green, black, red and yellow-brown chert, 1 to 10 centimetres thick, are commonly interbedded

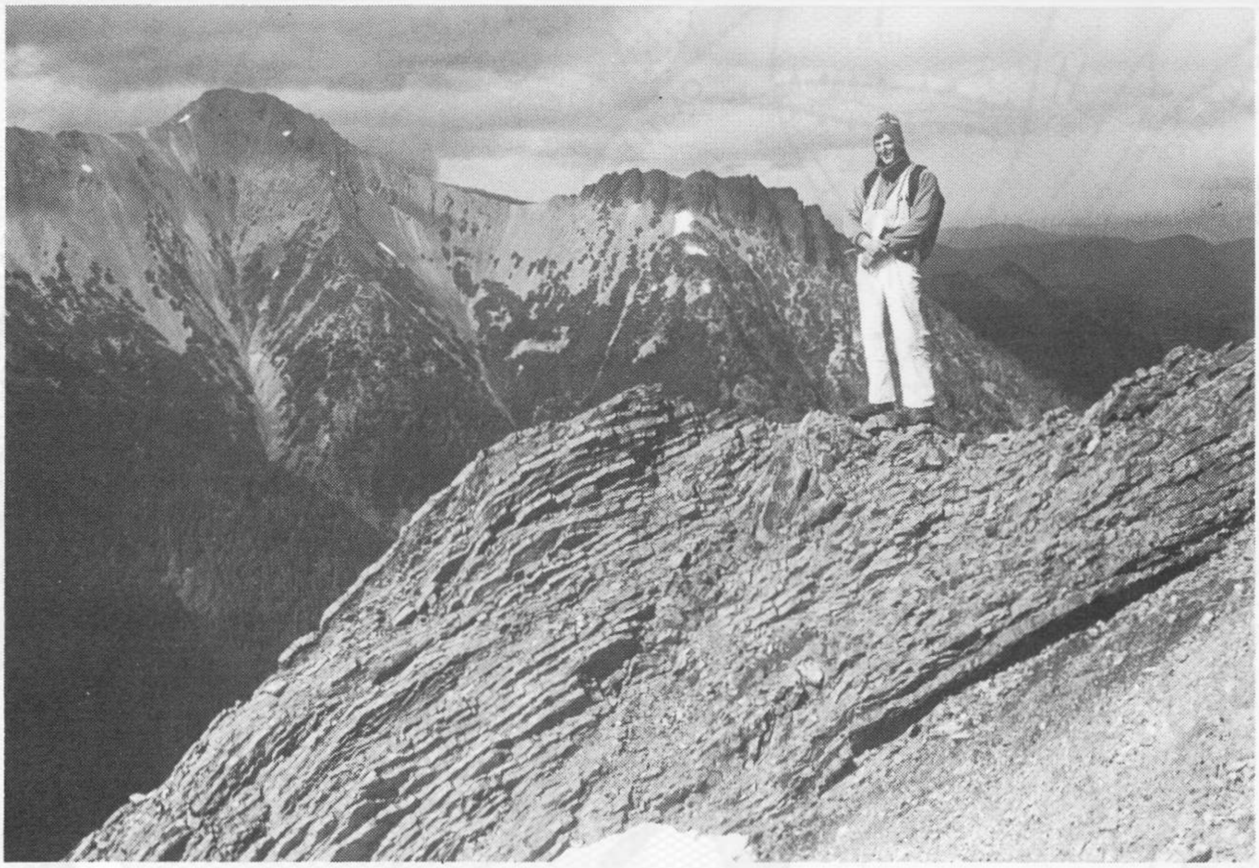


Plate 1-15-1. Gently folded chert of the Bridge River complex that occurs directly below the overturned unconformity of the overlying Dash conglomerate. Photograph is in the Taylor Creek drainage looking to the northeast at the overturned strata of the Silverquick conglomerate.

with minor argillite. Bedded chert is in depositional contact with argillite and sandstone, limestone, and greenstone. Metachert is typically recrystallized, quartz veined and complexly folded. Chert with characteristics transitional between bedded and recrystallized chert is equally abundant.

Chert occurs as relatively undeformed and gently warped panels (Plate 1-15-1) to highly deformed and attenuated beds that are complexly folded. The relative deformation of chert is not homogeneous; no trends have been recognized in the intensity of deformation. The variety of colours, lithologic associations, and structural disposition suggest that cherts of various affinities and ages are juxtaposed in the Bridge River complex. Chert from several localities in the area contains Middle Triassic to Early Jurassic radiolarians (Figure 1-15-3; Potter, 1983; Cordey, 1986).

GREENSTONE

Greenstone is typically massive and weathers greenish brown; pillow structures and breccia textures are commonly preserved in sequences with interbedded chert or limestone. Quartz-carbonate veins and pervasive fracturing are common. Interbedded limestone and chert is rare. Ten samples of greenstone from the Bridge River complex collected further to the east were analysed by Potter (1983) for trace element geochemistry; they plot in the ocean-floor tholeiite to oceanic-island basalt fields of various published discriminant diagrams. The metamorphic grade of the greenstone appears to be variable, but is presently incompletely studied.

TYAUGHTON GROUP

The Tyaughton Group was originally defined by Cairnes (1943) as rocks of Triassic age. Overlying Lower to Middle Jurassic shales were included in the group by Tipper (1978) but in this study are mapped as a separate unit (Figure 1-15-2; as suggested by H.W. Tipper, personal communication, 1987). The Tyaughton Group is best exposed and most thoroughly studied in the Castle Peak area, 10 to 15 kilometres north of the study area (Tozer, 1967; Umhoefer, 1986). Paleontological studies of fauna within the Tyaughton Group (Figure 1-15-3) are principally those of Tozer (1967) and Tipper (1978, and unpublished). The sedimentology and structure of the group is currently under investigation (Umhoefer, 1986; and unpublished).

The Tyaughton Group can be divided into five distinct units. The lower redbeds, which form the base to the group, are about 500 metres thick and contain abundant conglomerate with limestone, volcanic and minor plutonic clasts; some of the conglomerate in the Spruce Lake area contains 95 to 99 per cent limestone clasts (P.J. Umhoefer, personal communication, 1988). The lower redbeds are overlain by light-grey-weathering, massive limestone (30 to 50

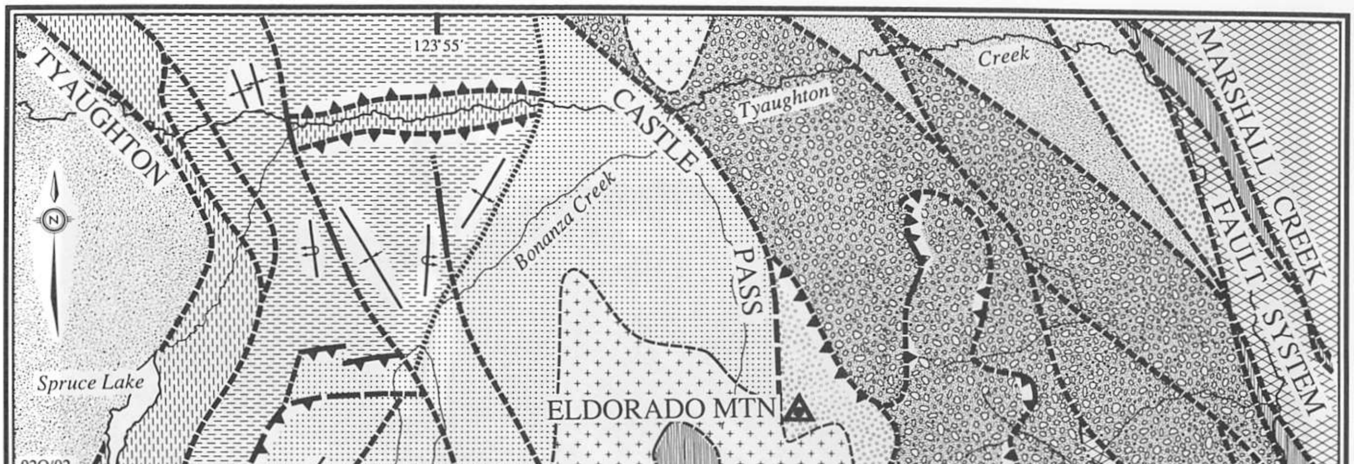


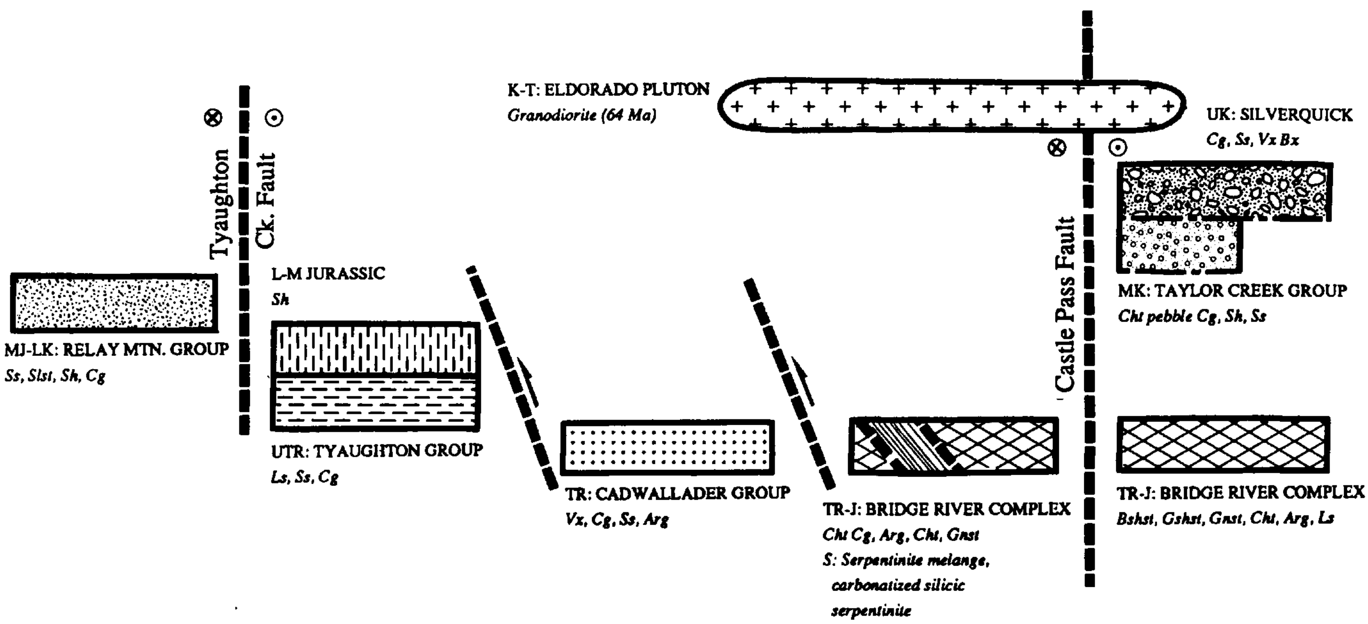
Figure 1-15-2. Geologic map of the Eldorado Mountain area with a tectonostratigraphic legend. Stratigraphic positions and ages of units are detailed in Figure 1-15-3. Lithologic abbreviations: cg = conglomerate, ss = sandstone, slts = siltstone, sh = shale, arg = argillite, ls = limestone, vx = volcanic rocks, bx = breccia, cht = chert, gnst = greenstone, bshst = blueschist, gshst = greenschist; for a complete description of units see text.

metres thick) grading upwards into thin-bedded micritic limestone (less than 15 metres thick), which contains the widely distributed and biostratigraphically significant *Monotis* bivalve. A limestone-cobble conglomerate with quartzose sandstone (less than 20 metres thick) lies, with possible disconformity, above the micritic limestone (Umhoefer, 1986). This conglomerate grades upward into green, cross-stratified sandstone with minor interbedded conglomerate (about 70 metres thick) which is conformably overlain by a brown-weathering siltstone and sandstone unit that contains the distinct and easily recognized bivalve *Cassianella lingulata*. The uppermost unit in the Tyaughton Group is composed of greenish sandstone and volcanic-pebble conglomerate, similar to the lower green-sandstone and conglomerate unit. Most of these units are interpreted to have been deposited in shallow marine to marginal marine conditions with the lower redbeds probably deposited in a fluvial environment (Umhoefer, 1986). The composition of the sediments suggests that they were deposited in an arc-proximal setting, possibly adjacent to the source terrane which supplied detritus to the Cadwallader Group (Rusmore, 1985; Umhoefer, 1986). The Tyaughton Group is probably middle to upper Norian (Figure 1-15-3; Tozer, 1967; Tipper, 1978). Contacts with the Cadwallader Group are faults (Figure 1-15-2), but the closeness of ages and compositional similarity between the Tyaughton and Cadwallader groups suggest they were originally a coherent sequence (Rusmore, 1985).

LOWER TO MIDDLE JURASSIC SHALE

A distinct but unnamed ammonite-bearing calcareous shale unit disconformably overlies the Tyaughton Group. The

TECTONOSTRATIGRAPHIC LEGEND



lower 200 to 300 metres of this unit comprises brown sandstone, siltstone and minor conglomerate which is locally crossbedded. These rocks grade upwards into grey to black, calcareous shale with minor interbedded sandstone which is less than 200 metres thick (Umhoefer *et al.*, 1988b). The shales commonly contain ammonites that indicate an upper Hettangian to lower Bajocian age for the unit (Figure 1-15-3; Tipper, 1978 and personal communication, 1987).

RELAY MOUNTAIN GROUP

The Relay Mountain Group is exposed in the Spruce Lake area (Figure 1-15-2); this is the southernmost occurrence of this widely distributed unit that occurs principally in its type area on Relay Mountain, 10 to 15 kilometres to the north. In the Eldorado Mountain area contacts with the underlying Early to Middle Jurassic shale unit are faulted but elsewhere the contact may be an unconformity (Jeletzky and Tipper, 1968). The Relay Mountain Group, which is 1500 to 2800 metres thick, displays facies changes throughout the area that were recognized on the basis of abundant and well-preserved *Buchia* and *Inoceramus* fossils. Lithologic monotony and subtle facies changes prohibit traditional lithologic mapping of this unit. Workers have used the rich and biostratigraphically distinct fauna as a basis for mapping (Jeletzky and Tipper, 1968; Glover *et al.*, 1987, 1988b; Umhoefer *et al.*, 1988b). The Relay Mountain Group has been divided into eight biostratigraphic subdivisions. Most of the subdivisions show significant facies changes in the region that suggest deposition in a two-sided, northwest-trending basin. Relay Mountain Group rocks in the Spruce Lake area are inferred to represent the southwest margin of this basin.

Blueschist and Greenschist

Structurally interleaved blueschist, greenschist and metachert are exposed to the south and stratigraphically below the unconformity at the base of the Taylor Creek Group in the upper Cinnabar Creek drainage, and as isolated outcrops in the Tyaughton Creek canyon (Figure 1-15-2; *see* Schiarizza *et al.*, 1989, this volume). The largest outcrop belt extends for a strike length of about 4 kilometres.

The blueschist unit is dark blue schistose metabasalt and interlayered, strongly flattened, locally isoclinally folded, blue and grey metachert. A crenulation cleavage is common in outcrop but is not present in blueschist clasts in the overlying basal conglomerate of the middle Albian Taylor Creek Group. The crenulation is therefore probably a post-middle Albian structure. The blueschist assemblage is characterized by fine-grained crossite-actinolite, lawsonite and albite, with or without sphene. Garnet and white mica are locally abundant. The crossite is typically intergrown with actinolite/tremolite in textural equilibrium. Locally, barrositic amphibole forms cores to the crossite/actinolite grains and may represent an early phase of higher temperature metamorphism (A.B. Till, personal communication, 1988).

Strongly foliated greenschist and complexly deformed metachert are spatially associated with blueschist; all occur within the same structural package. Locally, the greenschist has blue amphibole along its foliation. Metachert is present in minor quantities. The metachert is strongly flattened and tightly folded about axial surfaces that are subparallel to bedding.

Blueschist-faeies metamorphism must have predated the middle Albian (*circa* 100 to 105 Ma) because sediments of this age contain clasts of blueschist. Potassium-argon whole-rock dating of three *in situ* blueschist samples yielded ages ranging from 195 to 250 Ma (R.L. Armstrong, personal communication, 1988). More precise age determination of the blueschist is in progress.

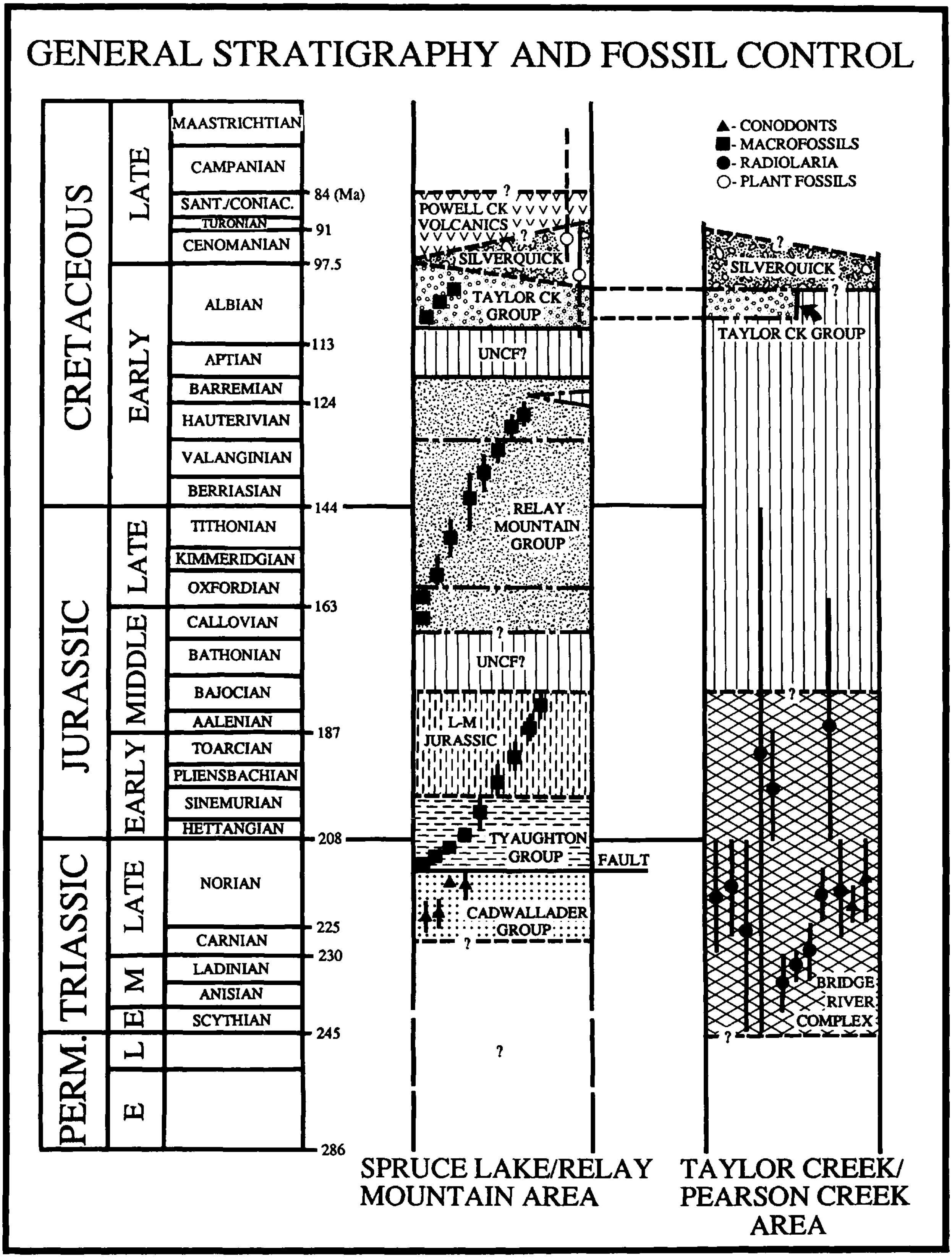


Figure 1-15-3. Stratigraphy and faunal control of the units discussed in the text.

SERPENTINITE MELANGE

A distinct and mappable unit in the Eldorado Creek area is serpentinite with abundant metre to decametre-sized blocks or "knockers" of greenstone, chert, clastic rocks, gabbro and diorite, porphyry and unfoliated ultramafic rocks (Figure 1-15-2). Serpentinite and many of the knockers are foliated. Foliation directions are chaotic, but a crude north to northeast-trending, west-dipping foliation is apparent. Fabric trends are further obscured by later strike-slip faults.

CADWALLADER GROUP

The Cadwallader Group nomenclature has a colorful history which is discussed in detail by Rusmore (1985). Originally named by Drysdale (1916, 1917), later workers have wrestled with both the nomenclature and internal stratigraphy of the group (Roddick and Hutchison, 1973; Rusmore, 1987; Church *et al.*, 1988). In this study, we recognize three principal lithologic units in the Cadwallader Group: basaltic volcanic rocks, conglomerate and coarse-grained bedded sedimentary rocks, and thin-bedded sandstone and argillite. We concur with the subdivisions and relative stratigraphic position of the units outlined in detail by Rusmore (1985, 1987). The following is a brief synopsis of Rusmore's stratigraphic divisions.

Basaltic volcanic rocks are typically pillowed and brecciated and weather green to purple. Rusmore reports the occurrence of minor andesitic and quartz-bearing rhyolitic dykes within this unit. These basaltic volcanic rocks are traditionally referred to as the Pioneer greenstone but correlation with rocks at the type locality has not been proven and remains an outstanding stratigraphic problem in the area.

Transitional rocks include tuffaceous sandstones with interbedded conglomerates that contain clasts of limestone, mafic to intermediate volcanic rocks and quartz-bearing granitic rocks (Plate 1-15-2). This transitional unit is found interbedded with both the stratigraphically lower basalts and the overlying fine-grained sedimentary rocks. Locally, transitional rocks are missing and the fine-grained sedimentary rocks rest directly on the lower volcanic rocks.

Fine-grained sedimentary rocks composed of interlayered thinly bedded sandstone and black argillite are at the stratigraphic top of the Cadwallader Group. These rocks are interpreted to have been deposited as turbidites and are probably correlative with the Hurley Formation of other workers (Roddick and Hutchison, 1973; Church *et al.*, 1988).

Trace-element abundances in the basaltic volcanic rocks suggest an affinity to modern island arc tholeiites (Rusmore, 1985, 1987). The sedimentology and provenance of the overlying sedimentary rocks also suggest proximity to a volcanic arc.

Conodonts from the sedimentary part of the sequence suggest the group is uppermost Carnian or lowest Norian to

Plate 1-15-2. Vertical beds of poorly sorted but well-bedded transitional rocks of the Cadwallader Group above Spruce Lake. Coast Range intrusions are in the background.

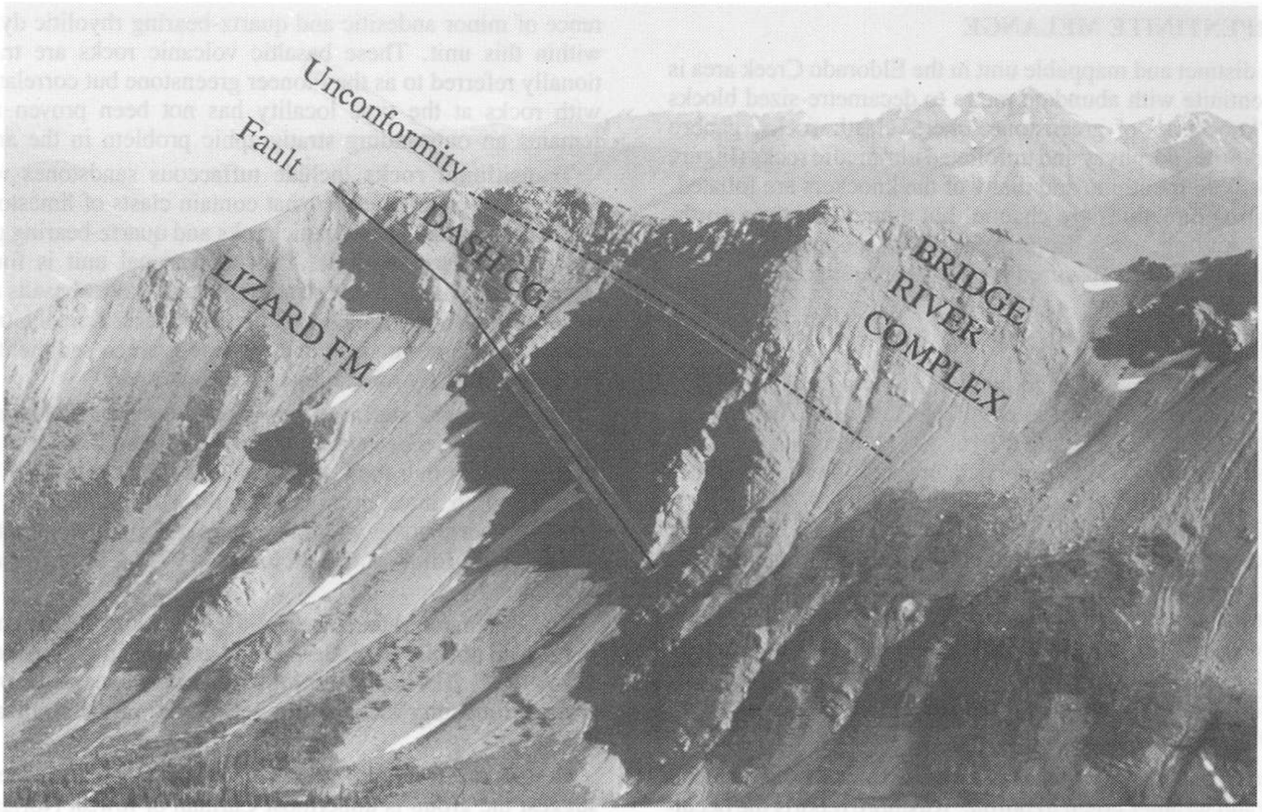


Plate 1-15-3. Overturned unconformity with the middle Albian Dash conglomerate depositionally overlying metachert and blueschist of the Bridge River complex.

upper-middle Norian (Rusmore, 1985; Figure 1-15-3). The uppermost volcanic rocks are interbedded with these dated sediments so must be Late Triassic or older.

In general, the Relay Mountain Group is a sequence of sandstone, shale and minor conglomerate that contains abundant marine bivalves and ammonites, plant fragments and rare sedimentary structures. Volcanic, sedimentary and minor plutonic pebbles are constituents of the conglomerates. A particularly thick section of conglomerate (tens of metres) occurs on the ridge between Slim and Gun creeks (Figure 1-15-2) and has yielded a possible Early Cretaceous *Buchia* (P.J. Umhoefer, personal communication, 1988). Jeletzky and Tipper (1968) note that younger strata of the Relay Mountain Group (Hauterivian) in the Spruce Lake area contain a coarse-grained facies of tuffaceous greywacke most likely deposited in a shallow-marine environment at the southwest basin margin. The Relay Mountain Group contains fossils that indicate an Oxfordian to Hauterivian and possibly Barremian age; all stages (except the Barremian) are represented by at least one biostratigraphic zone.

TAYLOR CREEK GROUP

Cairnes (1937, 1943) originally named the "Taylor Group", but imprecisely defined its stratigraphic elements. Jeletzky and Tipper (1968) modified the name to Taylor Creek Group and restricted its use to what they considered to be marine chert-rich clastic rocks. They estimated a thickness of approximately 3300 metres. Stratigraphically higher nonmarine, chert-pebble conglomerates were named "Kingsvale sediments" and were effectively removed from the Taylor Creek Group. They recognized that these nonmarine conglomerates grade upward into a thick sequence of andesitic volcanic rocks which they named the "Kingsvale volcanics". In the present study the basic subdivisions of Jeletzky and Tipper are retained. However, the stratigraphic interpretation has been refined and names for the upper divisions abandoned in accordance with evidence that the volcanic rocks are not equivalant to the slightly older volcanic rocks near the village of Kingsvale (Thorkelson, 1985; Glover and Schiarizza, 1987; Glover *et al.*, 1988a).

The Taylor Creek Group is informally subdivided into the Dash conglomerate and the Lizard formation, both of which are easily mappable units. The estimated thickness of the Taylor Creek Group exceeds 2800 metres in the centre of the basin (Relay Mountain area to the north), and is approximately 1200 metres in the Eldorado Mountain area.

DASH CONGLOMERATE

The Dash conglomerate is approximately 300 to 500 metres thick and forms the base to the Taylor Creek Group in the Eldorado Mountain area. The basal part of the conglomerate contains a spectacular blueschist, greenstone and chert-pebble to boulder conglomerate that rests unconformably on the Bridge River complex. This unconformity is overturned and is overlain by tens of metres of interbedded conglomerate and red-weathering siltstone (Plates 1-15-3, 1-15-4). In the Relay Mountain area, the Taylor Creek Group probably rests on the Relay Mountain Group (Figure 1-15-3).

Plate 1-15-4. The basal Dash conglomerate containing angular pebbles of greenstone, chert, blueschist (under coin and elsewhere) and greenschist.

The upper 100 to 150 metres of the Dash conglomerate is also dominantly conglomerate and contains ammonites and shallow marine bivalves (Plate 1-15-5). The transition from fluvial to delta to prodeltaic facies represents rapid subsidence within the basin. Paleocurrent indicators are rare but those present suggest transport was toward the west.

As mentioned, the basal conglomerate contains locally derived Bridge River complex detritus. Stratigraphically higher the conglomerate contains chert, bull quartz, volcanic fragments and minor sedimentary and metamorphic fragments. The clastic detritus in the Dash conglomerate is almost exclusively derived from the Bridge River complex.

The age of the Dash conglomerate is well constrained elsewhere in the basin where it is lower to middle Albian based on ammonite fauna (Jeletzky and Tipper, 1968; Garver, unpublished data). The uppermost prodeltaic sediments in the Eldorado Mountain area contain a middle to upper Albian *Inoceramus* species (Jeletzky and Tipper, 1968). The Dash conglomerate in the Eldorado Mountain area is probably correlative to the upper part (middle Albian) of the well-dated Dash conglomerate in the Relay Mountain area.

Lizard Formation

The Dash conglomerate is abruptly, but conformably, overlain by 500 to 600 metres of shale and interbedded thin to medium-bedded sandstone of the Lizard formation. The sandstone is typically graded with complete Bouma sequences. Abundant flute and groove marks suggest paleotransport was to the north-northeast. Volumetrically minor chert-pebble conglomerate and chert-lithic sandstone are locally interbedded with these turbibites.

Plate 1-15-5. Thick-bedded Dash conglomerate. Finer grained intervals contain bivalves and, uncommonly, plant fragments. These beds are interpreted to have been deposited in a fan-delta setting.

The Lizard sandstone is a medium to coarse-grained quartzofeldspathic litharenite with several per cent detrital white mica and lesser biotite. The sedimentary rocks contain plagioclase (28 to 36 per cent), quartz (25 to 35 per cent) and volcanic lithic fragments, which are mostly felsic and intermediate (31 to 48 per cent). The composition of detrital grains suggests that the source area was comprised of tonalitic or dioritic plutonic rocks, intermediate to silicic volcanic rocks, and minor schistose metasedimentary rocks. Although the Dash conglomerate and the Lizard formation together form the Taylor Creek Group, they were derived from distinctly different source terranes.

A possible middle Albian ammonite fossil has been collected from the Lizard formation about 10 kilometres to the west in the Lizard Creek area (Garver, unpublished data). In the Eldorado Mountain area, the basal beds contain middle to upper Albian *Inoceramus* fossils (Jeletzky and Tipper, 1968; Garver, unpublished data). The unconformably(?) overlying Silverquick conglomerate is probably Albian-Cenomanian, but this age is poorly constrained.

SILVERQUICK CONGLOMERATE

The Silverquick conglomerate is divided into two parts. The lower unit is about 1500 metres thick and is almost exclusively composed of chert-pebble conglomerate and minor fine-grained interbeds. The upper unit (of undetermined thickness) contains chert-pebble conglomerate, andesitic breccia and fine-grained interbeds; this unit is referred to as the Powell Creek volcanic transition because it probably passes upward into the Powell Creek volcanics of

Glover *et al.* (1988a). The Silverquick conglomerate is typified by rapid and dramatic changes in thickness and sedimentological characteristics.

Lower Unit

The lower unit comprises numerous fining-upward sequences of 2 to 8-metre-thick, pebble to cobble-conglomerate beds and minor fine-grained intervals. The coarse-grained sedimentary rocks are typically poorly sorted, clast supported and locally have poorly developed horizontal and cross-stratification. Individual sequences within the lower unit typically thin and fine upward into interbedded siltstone and sandstone with minor lenticular pebble-rich beds. The finer grained beds typically contain complete leaf fossil imprints and are locally red or maroon weathering.

Facies of the Silverquick conglomerate are slightly different in the upper and lower plates of a thrust fault mapped east of Eldorado Mountain (Figure 1-15-2). Rocks in the lower plate are generally finer grained and include abundant redbeds, but they have the same clast composition as the rocks in the upper plate. Lower plate rocks possibly rest unconformably on the Bridge River complex in Taylor Creek (Figures 1-15-2, 1-15-3) and in Tyaughton Creek although both exposures are equivocal. Well-exposed upper plate rocks rest with possible low-angle unconformity on the underlying Lizard formation. This possible difference in substrate may attest to basin margin deformation prior to and probably during the deposition of the Silverquick conglomerate.

Pebbles and cobbles in the Silverquick conglomerate include chert (50 per cent), sedimentary rock fragments (20 to 25 per cent), volcanic rock fragments (20 per cent), greenstone and metamorphic rock (5 per cent), and dioritic clasts (less than 5 per cent – percentages based on 17 pebble counts). These rocks have a similar provenance to the Dash conglomerate but the abundance of sedimentary rock fragments (and turquoise-coloured silicic tuff clasts) may be representative of clastic input from erosion of Cadwallader Group rocks. The source area for clasts of chert, greenstone, ultramafic rocks, limestone, and uncommonly, blueschist was undoubtedly the Bridge River complex.

Upper Unit

The lower unit grades upward into interbedded volcanic-clast and chert-rich conglomerate and fine-grained clastic rocks. The volcanic-clast-rich beds are typically 1 to 3 metres thick, and contain very poorly sorted clasts of plagioclase, hornblende and pyroxene-phyric volcanics. Poor sorting, large clast size and the monolithologic nature of these volcanic conglomerates probably represent the onset of intrabasinal volcanism that culminated in the accumulation of 2000 to 3000 metres of Powell Creek volcanic rocks (Glover *et al.*, 1988b).

The age of the Silverquick conglomerate is imprecisely known. It rests with possible unconformity above the middle to upper Albian Lizard formation. In the map area the Silverquick contains nondiagnostic leaf fossils but elsewhere in the Tyaughton Creek region it contains Albian-Cenomanian flora (Jeletzky and Tipper, 1968). The overlying Powell Creek volcanics are intruded by 84.7 to 86.7 ± 2.5 Ma plutons (potassium-argon dates on mica; *see* discussion in Glover and Schiarizza, 1987).

The Taylor Creek Group and the overlying Silverquick conglomerate are representative of syntectonic sedimentation in which rapid basin subsidence, coarse-clastic sedimentation and thick basin fill mark an inferred period of compressional tectonics. Angular unconformable relationships that may represent little or no time gap attest to active deformation during sedimentation. Folding and thrusting have deformed the entire sequence; these structures probably represent continued compressional tectonics following sediment infill of the active sedimentary basin.

IGNEOUS INTRUSIONS

The central part of the map area is occupied by the Eldorado pluton which is an equigranular biotite quartz diorite to granodiorite. The pluton intrudes the Castle Pass fault (discussed below) and therefore provides an important constraint on the timing of motion on this fault. The Eldorado pluton has been dated at 63.7 ± 2.2 Ma (potassium-argon on biotite; K.M. Dawson, personal communication, 1987). Small plugs and dykes of mainly hornblende-feldspar and quartz-feldspar porphyry also occur in the area.

STRUCTURE

STRIKE-SLIP FAULTS

The Eldorado Creek area is cut by numerous high-angle, north to northwest-trending faults which comprise part of a regionally extensive dextral strike-slip fault system. The faults are narrow zones (tens of metres) of brittley deformed rocks that typically contain horizontal to subhorizontal slickensides on fault surfaces; locally, vertical slickensides record the latest movement or simply reflect the complexity of movement along these faults. Fibrous mineral growth orientations and stepped lineations are consistant with the dextral movement indicated by *en echelon* folding and offset of piercing points along the same faults to the north (Glover *et al.*, 1988a). Strike-slip faults cutting the Bridge River complex are commonly marked by strongly foliated serpentinite that has locally undergone a syn to post-faulting carbonate alteration. Serpentinite is uncommon where these faults cut bedded sedimentary rocks unless the Bridge River complex is the immediate basement.

The Tyaughton Creek, Castle Pass and Relay–Marshall Creek fault systems are the principal structures in the Eldorado Mountain area (Figure 1-15-2). Minor subparallel fault strands with tens to hundreds of metres displacement are ubiquitous. Glover *et al.* (1988b) and Umhoefer *et al.* (1988b) have mapped the extensions of these faults to the north. Possible piercing points on the Tyaughton Creek fault suggest that movement may have been in the order of 10 kilometres (Glover *et al.*, 1988a). In the Eldorado Mountain area, strike-slip faults were probably also the loci of minor vertical displacement.

The 64 Ma Eldorado pluton intrudes the Castle Pass fault. The northwestward continuations of other faults in the system (for example, the Tyaughton Creek fault) cut the lower Upper

Cretaceous Battlement Ridge Group (Glover *et al.*, 1988a); movement on this system was during the Late Cretaceous.

MIDDLE CRETACEOUS THRUSTING

In the North Cinnabar and Taylor Creek areas (Figure 1-15-2) a large panel of overturned sedimentary rocks of the Taylor Creek Group (Plate 1-15-3) and the overlying Silverquick conglomerate are in apparent thrust contact with underlying upright rocks of the Silverquick conglomerate. Approximately 3 kilometres of stratigraphic section are overturned; they are interpreted to represent a limb of a large-scale northeast-directed fold that was probably produced during compression and associated thrust faulting. This overturned panel, which includes unconformably underlying blueschist, greenstone and chert of the Bridge River complex, is cut by strike-slip faults. The scale of folding recorded in this overturned panel is an order of magnitude greater than in folds associated with strike-slip faulting in this area. Elsewhere, the Powell Creek volcanics unconformably overlie deformed rocks of the Taylor Creek Group (Glover and Schiarizza, 1987). We infer that thrust faulting was coincident with and immediately following deposition of the nonmarine Silverquick conglomerate. If true, this regionally important intrabasinal compressional event occurred between the late Albian and the Santonian (*circa* 100 to 85 Ma). Northward-verging thrusts and folds are also recognized within the Cadwallader Group (D2 of Rusmore, 1985, 1987). The age of these structures is unknown but they may be contemporaneous with the Middle Cretaceous structures described above; alternatively, they may be later strike-slip related features, as suggested by Rusmore (1985).

NORTHEASTERLY TRENDING STRUCTURES OF UNKNOWN AGE

Upright, northeast-trending folds and steep faults are the earliest structures recognized within the Cadwallader Group (D1 of Rusmore, 1985, 1987). They predate northerly directed folds and thrusts which, as suggested above, may be contemporaneous with Middle Cretaceous compressional structures documented within the Taylor Creek Group and the Silverquick conglomerate. The Cadwallader Group defines a northeasterly trending belt juxtaposed against the Tyaughton Group and the Bridge River complex (Figure 1-15-2).

Along its southeastern margin, the Cadwallader Group is next to the Bridge River complex and associated serpentinite mélange; this poorly defined north-northeasterly trending belt is referred to as the Eldorado fault zone by Rusmore (1985). She suggests that the zone represents an important tectonic boundary between the Bridge River complex and the Cadwallader Group, and notes it is cut by the Bralorne fault zone; this relationship suggests pre-Middle Cretaceous movement. The serpentinite mélange bears some resemblance to fault zones which juxtapose the Shulaps ultramafic complex above the Bridge River complex and Cadwallader Group rocks further to the east (Schiarizza *et al.*, 1989, this volume); these structures may be contemporaneous. The predominant orientation of structures that separate the Cadwallader Group from other rocks and the distribution of units suggests juxtaposition by westerly directed overthrusting.

IMBRICATION OF THE BRIDGE RIVER COMPLEX

Structural relationships within the Bridge River complex are poorly understood. Although it is clear the complex displays much structural repetition, the nature and age(s) of the structures are not well known. Imbricated lithologies are different on either side of the Castle Pass fault. East of the fault, northwest-trending, southwest-dipping lenticular panels of differing metamorphic grade (prehnite to blueschist facies) are imbricated along metre-wide zones of localized strain that are interpreted to be thrust faults. This imbrication preceded deposition of the unconformably overlying Taylor Creek Group (middle Albian) which contains pebbles and boulders from the different panels (Plates 1-15-3, 1-15-4). West of the Castle Pass fault, imbrication has juxtaposed the following assemblages: (1) greenstone with minor limestone; (2) chert; (3) argillite and chert; and (4) argillite, chert-pebble conglomerate and interbedded chert. High-angle fault zones cutting this package commonly contain serpentinite. The metamorphic grade of these rocks is low (prehnite-pumpellyite) and some show no affects of regional metamorphism.

SUMMARY

The Eldorado Mountain area is located in a critical area between sedimentary rocks of the Tyaughton basin to the northwest and the Bridge River oceanic complex to the south and east. This transitional area has provided important information concerning the nature and timing of deformation, lithologic distribution within units, and the sedimentology and provenance of units. The following outlines the most significant findings in the Eldorado Mountain area:

- The Bridge River complex contains lenses of blueschist facies metabasalt and metachert, which may suggest deformation and metamorphism in a subduction zone.
- Blueschist, greenschist and prehnite-pumpellyite facies metamorphic rocks of the Bridge River complex were imbricated following metamorphism and brought to the surface by middle Albian time.
- Basin response to the initial phase of compressional tectonics may be recorded in the synorogenic deposits of the Taylor Creek Group which are lower to middle Albian in age (*circa* 110 to 97 Ma).
- Compressional tectonics, manifested by large-scale folds and thrusting, which probably verged to the northeast, occurred between *circa* 97 and 85 Ma. Inferred synorogenic conglomerates show extreme variation in thickness on a regional scale. This period of deformation corresponds to the timing of mineralization at Bralorne, *circa* 90 Ma (Leitch and Godwin, 1988). Movement on the Bralorne fault zone may have been contemporaneous with deposition of the Silverquick conglomerate.
- Parts of a major strike-slip fault system cut the area. The timing of the major movement was between 64 and about 86 Ma. Stibnite-scheelite-cinnabar mineralization occurs along these faults.

ACKNOWLEDGMENTS

The authors would like to acknowledge important mapping contributions by previous workers in the area. M. McGroder, J. Bourgeois, C.H.B. Leitch, C. Potter, J.K. Glover and M.E. Rusmore influenced our thinking while on field trips during the course of our work. Preliminary potassium-argon dates were provided by R.L. Armstrong. T. Poulton, J. Haggart, A. Sweet and J.A. Jeletzky kindly provided valuable paleontologic assistance. J.K. Glover, M.E. Rusmore and P.J. Umhoefer are sincerely thanked for valuable contributions. This work has been funded principally by the Canada/British Columbia Mineral Development Agreement, with additional support from a National Science Foundation grant (EAR 8617751) to J. Bourgeois of the University of Washington.

REFERENCES

Cairnes, C.E. (1937): Geology and Mineral Deposits of the Bridge River Mining Camp, British Columbia, *Geological Survey of Canada*, Memoir 213, 140 pages.

——— (1943): Geology and Mineral Deposits of Tyaughton Lake Area, British Columbia, *Geological Survey of Canada*, Paper 43-15, 39 pages.

Church, B.N., Gaba, R.G., Hanna, M.J. and James, D.A.R. (1988): Geological Reconnaissance in the Bridge River Mining Camp (92J/15, 16, 10; 92O/02), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 93-100.

Cordey, F. (1986): Radiolarian Ages from the Cache Creek and Bridge River Complexes and from Chert Pebbles in Cretaceous Conglomerates, Southwestern British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 86-1A, pages 596-602.

Drysdale, C.W. (1916): Bridge River Map-area, Lillooet Mining Division, *Geological Survey of Canada*, Summary Report, 1915, pages 75-85.

——— (1917): Bridge River Map-area, Lillooet Mining Division, *Geological Survey of Canada*, Summary Report, 1916, pages 45-54.

Garver, J.I. (1987): Provenance and Petrofacies of the Albian Taylor Creek Group, Tyaughton Basin, South-central British Columbia, *Geological Society of America*, Abstracts with Programs, Volume 19, Number 7, page 672.

Garver, J.I., McGroder, M.F., Umhoefer, P.J. and Bourgeois, J. (1988): Pre- to Syn-collisional Sedimentation in the Jura-Cretaceous Methow-Tyaughton Basin, Northern Washington, Southern British Columbia, *Geological Society of America*, Abstracts with Programs, Volume 20, Number 7, page A274.

Garver, J.I., Umhoefer, P.J., Rusmore, M. and Schiarizza, P. (1989): Geology of the Eldorado Mountain Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1989-3.

Glover, J.K. and Schiarizza, P. (1987): Geology and Mlueral Potential of the Warner Pass Map Area (92O/03), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 157-169.

Glover, J.K., Schiarizza, P. and Garver, J.I. (1988a): Geology of the Noaxe Creek Map Area (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 105-123.

Glover, J.K., Schiarizza, P., Garver, J.I. and Umhoefer, P.J. (1988b): Geology of the Noaxe Creek Map Area (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-9A.

Glover, J.K., Schiarizza, P., Umhoefer, P.J. and Garver, J.I. (1987): Geology of the Warner Pass Map Area (92O/3), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-3A.

Jeletzky, J.A. and Tipper, H.W. (1968): Upper Jurassic and Cretaceous Rocks of Teseko Lakes Map Area and their Bearing on the Geological History of Southwestern British Columbia, *Geological Survey of Canada*, Paper 67-54.

Leitch, C.H.B. and Godwin, C.I. (1988): Isotopic Ages, Wallrock Chemistry and Fluid Inclusion Data from the Bralorne Gold Vein Deposit (92J/15W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 301-324.

Potter, C.J. (1983): Geology of the Bridge River Complex, Southern Shulaps Range, British Columbia: A Record of Mesozoic Convergent Tectonics, Unpublished Ph.D. Thesis, *University of Washington*, 192 pages.

——— (1986): Origin, Accretion and Postaccretionary Evolution of the Bridge River Terrane, Southwest British Columbia, *Tectonics*, Volume 5, pages 1027-1041.

Roddick, J.A. and Hutchison, W.W. (1973): Pemberton (East Half) Map Area, British Columbia, *Geological Survey of Canada*, Paper 73-17, 21 pages.

Rusmore, M.E. (1985): Geology and Tectonic Significance of the Upper Triassic Cadwallader Group and its Bounding Faults, Southwest British Columbia, Unpublished Ph.D. Thesis, *University of Washington*, 174 pages.

Schiarizza, P., Garver, J.I. and Gaba, R.G. (1989): Stratigraphy and Structure of the Eldorado Mountain Area, Chilcotin Ranges, Southwestern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, This Volume.

Thorkelson, D.J. (1985): Geology of the Mid-Cretaceous Volcanic Units near Kingsvale, Southwestern British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 85-1b, pages 333-339.

Tipper, H.W. (1978): Taseko Lakes (92O) Map-area, *Geological Survey of Canada*, Open File 534.

Tozer, E.T. (1967): A Standard for Triassic Time, *Geological Survey of Canada*, Bulletin 156, 103 pages.

Umhoefer, P.J. (1986): The Upper Triassic to Lower Jurassic Tyaughton Group of Southwestern British Columbia: Depositional History and Paleogeography, *Geological Society of America*, Abstracts with Programs, Volume 18, Number 2, page 194.

Umhoefer, P.J., Garver, J.I., Glover, J.K. and Schiarizza, P. (1988a): Geology of the Tyaughton Basin, Southern Taseko Lakes Map-area, British Columbia: Part of the Boundary between the Insular and Intermontane Superterranes, *Geological Society of America*, Abstracts with Programs, Volume 20, Number 3, page 238.

Umhoefer, P.J., Garver, J.I. and Tipper, H.W. (1988b): Geology of the Relay Mountain Area (92O/2, 92O/3), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-16.

NOTES

PRELIMINARY REPORT ON $^{40}Ar/^{39}Ar$ GEOCHRONOLOGY OF THE WARNER PASS, NOAXE CREEK AND BRIDGE RIVER MAP AREAS*
(92O/3, 2; 92J/16)

By D.A. Archibald, Queen's University
J.K. Glover, Consulting Geologist
and
P. Schiarizza

KEYWORDS: Geochronology, argon-argon dating, Warner Pass, Noaxe Creek, Bridge River, Cretaceous, Tertiary, structure, ophiolite.

INTRODUCTION

The Warner Pass, Noaxe Creek and Bridge River map areas lie approximately 200 kilometres north of Vancouver on the eastern margin of the Coast Mountains. These areas have been the focus of recent detailed geological mapping to provide a better understanding of the geology and mineral potential. The isotopic dating project, using $^{40}Ar/^{39}Ar$ geochronology, is being carried out in cooperation with project geologists and scientists from the Geological Survey of Canada (Pacific Geoscience Centre) and is directed toward establishing the age of magmatic, tectonic and mineralizing events in these and adjoining areas. Few radiometric ages have been reported and $^{40}Ar/^{39}Ar$ dating has not been applied to problems in this part of British Columbia. This report presents the first such results for 15 samples collected during the 1987 field season and includes 18 total-fusion dates and two age spectra.

GEOLOGY

The regional and detailed geology are summarized in Glover *et al.* (1988) and Glover and Schiarizza (1987). The area is underlain by Mesozoic sedimentary and volcanic rocks that lie within a northwest-trending, structurally complex zone along the western margin of the Intermontane Belt, east of the Coast plutonic complex (Figure 1-16-1). These rocks comprise several fault-bounded tectonostratigraphic packages that record episodic tectonism. This study focuses on the Late Cretaceous and Tertiary events which include:

1. Deposition of the nonmarine Silverquick conglomerate and overlying continental andesitic volcanics of the Powell Creek formation, (informal; Glover *et al.*, 1988). This occurred during and after major compressional tectonics, documented by thrusting and folding of mid-Cretaceous strata in the Tyaughton-Methow basin (Garver *et al.*, 1988). Biostratigraphic control is poor in these Late Cretaceous rocks but hornblende-phyric volcanic rocks offer the opportunity for potassium-argon radiometric dating.
2. Northwest-trending dextral wrench faulting involving a total displacement of probably several hundred kilometres, distributed across a broad brittle to semi-brittle shear zone. The timing of movement along individual faults within this zone is poorly constrained but several of these structures are truncated by granitoid plutons or contain alteration minerals suitable for radiometric dating. In several cases the plutons are spatially associated with mineralization, some of which has gold potential.
3. Eocene volcanism and associated extensional faulting probably related to dextral displacement along the Fraser–Straight Creek fault system (Monger, 1985; Glover *et al.*, 1988).
4. Several episodes of plutonism, with available dates ranging from mid-Cretaceous to mid-Eocene. Min-

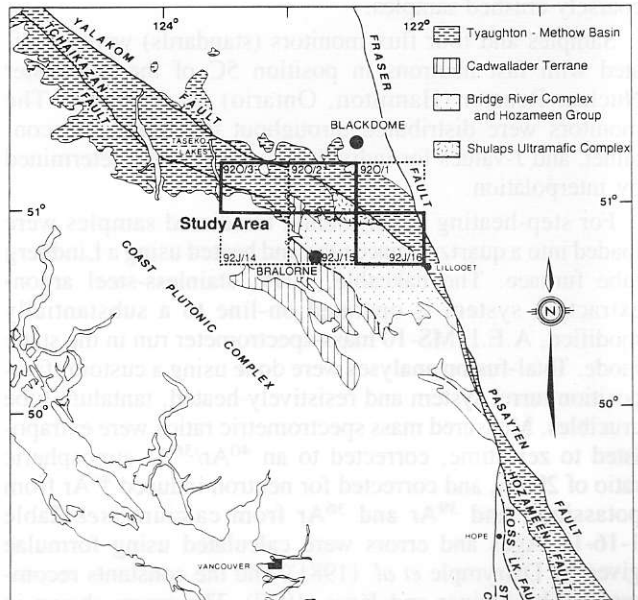


Figure 1-16-1. Location and geological setting, Warner Pass (92O/3), Noaxe Creek (92O/2) and Bridge River (92J/16) map areas.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

eral deposits within the region show a definite spatial relationship to areas of intrusive activity.

SAMPLING AND $^{40}Ar/^{39}Ar$ ANALYTICAL METHODS

Samples were collected from 25 sites. These were selected to provide a temporal framework for the magmatic, tectonic and mineralizing events in the area. Two samples of hornblende-phyric andesite flows, near the base of the Powell Creek formation, were collected in an attempt to bracket the age of the unconformity at the base of this unit and to assess the thermal history of these rocks which are being studied paleomagnetically by P.J. Wynne (Pacific Geoscience Centre). These rocks also host the Taylor-Windfall gold deposit and a sample of alteration from this deposit was obtained for dating. One of the four intrusive units mapped by Glover and Schiarizza (1987) is chlorite-epidote-altered hornblende plagioclase porphyry which may be related to this episode of mineralization. Samples of this and the other three intrusive units and related alteration material are the basis of this report.

With the exception of the andesitic flows and very fine-grained alteration material, most samples yielded high-purity mineral separates. These were prepared using heavy organic liquids and a Frantz magnetic separator. The volcanic rocks are altered and minerals are intergrown to such an extent that pure separates could not be obtained. It was, however, possible to split the sample into several density/magnetic fractions to concentrate the potassium-bearing minerals. Sericite in alteration material was concentrated by hand-picking from coarsely crushed samples.

Samples and four flux monitors (standards) were irradiated with fast neutrons in position 5C of the McMaster Nuclear Reactor (Hamilton, Ontario) for 25 hours. The monitors were distributed throughout the irradiation container, and J-values for individual samples were determined by interpolation.

For step-heating experiments, irradiated samples were loaded into a quartz furnace tube and heated using a Lindberg tube furnace. The bakeable, UHV, stainless-steel argon-extraction system is operated on-line to a substantially modified, A.E.I. MS-10 mass-spectrometer run in the static mode. Total-fusion analyses were done using a custom, five-position turret system and resistively-heated, tantalum-tube crucibles. Measured mass spectrometric ratios were extrapolated to zero-time, corrected to an $^{40}Ar/^{36}Ar$ atmospheric ratio of 295.5, and corrected for neutron induced ^{40}Ar from potassium, and ^{39}Ar and ^{36}Ar from calcium (*see* Table 1-16-1). Ages and errors were calculated using formulae given by Dalrymple *et al.* (1981), and the constants recommended by Steiger and Jäger (1977). The errors shown in Tables 1-16-1 and 1-16-2 represent the analytical precision at 2-sigma assuming that the error in J-value is zero.

PRESENTATION AND DISCUSSION OF THE DATA

The isotopic data for eighteen $^{40}Ar/^{39}Ar$ total-fusion determinations on fifteen samples are presented in Table 1-16-1; $^{40}Ar/^{39}Ar$ step-heating data for three mineral separates (including one additional rock sample) are listed in Table 1-16-2. The ages and locations of the samples are plotted in Figure 1-16-2; two of the $^{40}Ar/^{39}Ar$ age spectra are shown in the inset.

POWELL CREEK VOLCANICS

Gently warped and tilted continental volcanic rocks of the Powell Creek formation lie with marked angular unconformity on mid-Cretaceous (Albian) and older strata within the Warner Pass map area (Glover and Schiarizza, 1987). Similar volcanic rocks sit gradationally above the nonmarine Silverquick conglomerate in the southern Noaxe Creek area. There, the Silverquick conglomerate and Powell Creek volcanics are separated from underlying Albian strata by an

TABLE 1-16-1
$^{40}Ar/^{39}Ar$ TOTAL-FUSION DATA FOR WARNER PASS AND NOAXE CREEK AREAS

Sample#	Min. (1)	$^{40}Ar/^{39}Ar$ (1)	$^{36}Ar/^{39}Ar$ (1,2)	$^{37}Ar/^{39}Ar$	Vol. $^{39}Ar_K$ $\times 10^{-7}$ cm^{3}NTP (3)	%^{40}Ar rad. (5)	Date $\pm 2\sigma$ Ma
TL-87-17	Maf.	56.910	0.1841	140.600	0.0144	22.90	148.8 ± 14.1
TL-87-17	F.P.	10.435	0.0121	6.355	0.2020	70.20	77.6 ± 1.5
TL-87-17	WR	6.842	0.0059	0.581	0.9887	74.60	54.4 ± 0.3
TL-87-13a	Maf.	21.970	0.0067	127.100	0.0204	52.60	131.0 ± 7.4
TL-87-4	Hb	11.362	0.0144	8.647	0.2080	68.10	82.1 ± 2.0
TL-87-4	Bi	8.606	0.0061	0.046	1.7620	78.80	71.8 ± 0.6
DH-87-163.3	Aln.	8.244	0.0042	0.011	6.1280	84.60	73.7 ± 0.5
TL-87-11	Hb	15.690	0.0320	11.690	0.0926	45.20	75.6 ± 2.8
TL-87-14	A.P.	9.062	0.0095	2.139	0.2680	70.30	67.6 ± 0.6
TL-87-6	Hb	12.150	0.0239	13.080	0.1080	49.80	64.7 ± 2.1
TL-87-1	Hb	7.495	0.0087	6.132	0.1645	71.50	57.2 ± 1.4
TL-87-8	Hb	7.671	0.0108	7.245	0.1547	65.30	53.5 ± 0.8
TL-87-8	Bi	6.577	0.0072	0.235	1.0650	67.70	47.4 ± 0.5
TL-87-20	Bi	5.356	0.0042	0.071	1.2250	76.80	43.9 ± 0.6
TL-87-7	Bi	5.504	0.0048	0.027	1.7910	74.20	43.5 ± 0.3
TL-87-16	Hb	10.412	0.0274	12.340	0.1460	30.90	34.7 ± 1.9
TL-87-12	Ser.	3.279	0.0024	0.013	2.9810	77.90	27.3 ± 0.2
J = 5.892x10-3							

Abbreviations: Maf. = mafic concentrate obtained by heavy liquids and Frantz magnetic separator; F.P. = fresh plagioclase; A.P. = altered (sericitized) plagioclase; WR = whole-rock; Ser. = sericite ± quartz; Aln. = alunite, nearly pure; Bi = biotite separate; Hb = hornblende separate.

(1) True ratios corrected for fractionation and discrimination $^{40}Ar/^{36}Ar$ atmos. = 295.5
Ratios are not corrected for system blank, Ar, but:
Vol. of blank ^{40}Ar: 500°C<T<1050°C, 1 × 10-8 cc STP
at T = 500°C and T>1050°C, 2.2 × 10-8 cc STP.
Vol. of blank ^{36}Ar: 500°C<T<1050°C, 3 × 10-12 cc STP.
at T − 500°C and T>1050°C, 7.4 × 10-12.
$^{40}Ar/^{36}Ar$ blank = 297.

(2) $^{37}Ar/^{39}Ar$ is corrected for the decay of ^{37}Ar during and after irradiation λ37 = 1.975 × 10-2 days-1).

(3) Volume of ^{39}Ar determined using the equilibration peak height and mass spectrometer sensitivity.

(4) Isotope production ratios for the McMaster Reactor (Masliwec, 1981):
(40/39) K = 0.0156
(36/39) Ca = 0.390169
(37/39) Ca = 1536.1

(5) Ages calculated using the constants recommended by Steiger and Jäger (1977). Errors represent the analytical precision only (i.e., error in J-values = 0).
Flux monitor used: DA-83-48-BB biotite (97.5 Ma) referenced to mmHb-1 hornblende and LP-6 biotite.

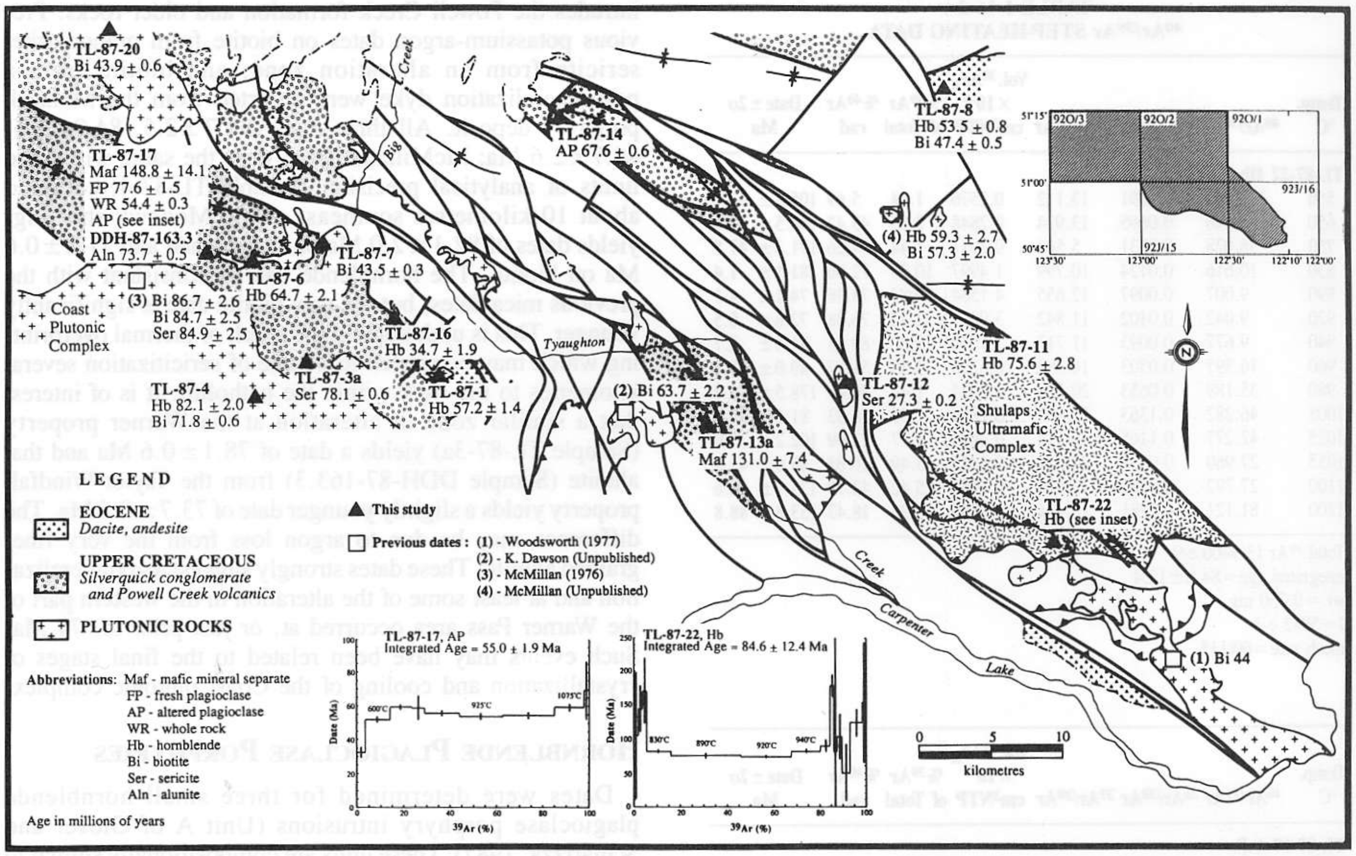


Figure 1-16-2. Distribution of Late Cretaceous and Tertiary rocks in Warner Pass, Noaxe Creek and Bridge River map areas.

apparent unconformity, but have themselves been involved in overturned folding and thrusting (Garver *et al.*, 1989, this volume). Thus, these rocks were deposited during and after an important phase of compressional tectonism that affected mid-Cretaceous and older strata.

Two samples of hornblende-phyric andesite, both from near the base of the Powell Creek formation, were dated. One (TL-87-17) is from the central part of the Warner Pass sheet, and the other (TL-87-13a) is from the southern Noaxe sheet. As the samples are chlorite-epidote altered no pure mineral separates could be obtained. The dates for the whole-rock, "fresh" plagioclase, and the mafic fraction are 54.4 ± 0.8, 78 ± 2 and 149 ± 14 Ma, respectively for TL-87-17; the integrated age of the "altered" plagioclase from this sample which was step-heated (*see below*) is 55 ± 2 Ma. The mafic fraction from TL-87-13a yields a date of 131 ± 7 Ma. These dates are highly discordant and suggest that both samples have suffered some degree of argon or potassium loss or redistribution. As both sample sites are within 2 kilometres of younger plutons and contain abundant fine-grained alteration minerals, this is not unexpected.

As shown in Table 1-16-1, the mafic fractions of these two samples are characterized by high $^{37}Ar/^{39}Ar$ ratios, proportional to the Ca:K ratio; these are typical of calcic pyroxene and this phase clearly exceeds amphibole in this fraction. Pyroxene commonly contains excess argon and it is probable that the apparent dates (greater than the stratigraphic age) for these fractions are a reflection of this. As discussed below $^{40}Ar/^{39}Ar$ step-heating may permit useful ages to be determined from these partial separates.

The concordance of the dates for the whole-rock and the "altered" plagioclase for TL-87-17 suggests that the bulk of the potassium is now bound in the fine-grained sericite that has replaced some, but not all, of the smaller plagioclase laths in this sample. The age spectrum is plotted in Figure 1-16-2. The $^{37}Ar/^{39}Ar$ ratios and the volumes of ^{39}Ar (Table 1-16-2) indicate this sample is a two-phase system. The argon released in the initial, low-temperature step yields a date of 32 Ma and subsequent dates increase to 60 Ma before decreasing to a minimum of 54 Ma (925 and 1000°C steps). The maximum date from the first pulse of ^{39}Ar released may correlate with release from fine-grained sericite whereas the higher temperature plateau (for 41 per cent of the ^{39}Ar released) may be related to the smaller plagioclase phenocrysts. The "fresh" plagioclase appears to be a product of the larger phenocrysts (typically 2 by 5 millimetres) which have not been as altered. Thus, the 78 Ma date for the "fresh plagioclase" is not likely to be a reliable age of extrusion and may be the result of mixing of the much younger sericite and a primary plagioclase; or overprinting of primary plagioclase during younger thermal events. Additional $^{40}Ar/^{39}Ar$ step-heating will help resolve this problem.

COAST PLUTONIC COMPLEX

Granodiorite of the Coast plutonic complex underlies the southwest corner of the Warner Pass map area, where it

TABLE 1-16-2
$^{40}Ar/^{39}Ar$ STEP-HEATING DATA

Temp. °C	$^{40}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	Vol. $^{39}Ar_K$ $\times 10^{-9}$ cm^{3}NTP	%^{39}Ar of Total	%^{40}Ar rad	Date ± 2σ Ma
TL-87-22 Hb							
550	177.290	0.5691	13.112	0.2576	1.84	5.69	105.3± 92.9
650	30.846	0.0605	13.924	0.2848	2.05	45.42	144.5± 34.1
750	38.028	0.0731	5.561	0.2011	1.44	44.26	171.3± 47.5
830	10.616	0.0124	10.799	1.4997	10.75	72.96	81.1± 1.4
890	9.007	0.0097	12.655	4.1584	29.83	78.36	74.1± 4.1
920	9.042	0.0102	11.842	3.0841	22.12	76.48	72.6± 0.5
940	9.677	0.0093	11.713	1.7570	12.60	80.33	81.4± 2.7
960	16.391	0.0303	14.393	0.6256	4.49	51.92	89.0± 8.5
980	35.189	0.0653	20.529	0.2024	1.44	49.49	178.5± 15.4
1005	46.282	0.1363	23.903	0.1884	1.35	16.83	81.6±185.9
1025	42.277	0.1165	25.114	0.2486	1.77	22.99	102.2± 33.0
1055	27.969	0.0839	20.031	0.4875	3.49	16.63	49.6± 41.3
1100	27.792	0.0582	17.524	0.7561	5.42	42.79	123.9± 20.6
1200	81.121	0.2281	16.494	0.1896	1.36	18.43	153.8± 88.8

Total ^{39}Ar 13.9400 e-9
integrated age = 84.6 ± 12.4
wt. = 0.250 mg
J = 5982 e-3
mesh size = 60/115

Temp. °C	$^{40}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	Vol. $^{39}Ar_K$ $\times 10^{-9}$ cm^{3}NTP	%^{39}Ar of Total	%^{40}Ar rad	Date ± 2σ Ma
TL-87-17 A.P.							
500	15.868	0.0436	0.434	3.2300	4.02	18.45	32.1± 3.4
600	7.686	0.0095	0.703	8.1300	10.11	63.69	52.1± 0.4
700	7.500	0.0065	0.600	7.9120	9.84	74.46	59.5± 1.7
775	7.396	0.0062	0.384	4.1190	5.12	75.06	58.9± 7.1
850	6.232	0.0033	0.174	12.1210	15.08	84.10	55.7± 1.3
925	5.998	0.0031	0.152	14.9600	18.60	84.39	53.9± 1.1
1000	6.259	0.0030	0.196	18.1120	22.53	81.36	54.1± 1.0
1075	10.716	0.0174	0.399	10.0280	12.47	53.48	59.3± 1.7
1200	26.956	0.0694	1.275	1.7807	2.21	25.30	69.3±17.0

Total ^{39}Ar 80.0390 e-9
integrated age = 55.0 ± 1.9
wt. = 0.120 g
J = 5.9820 e-3
mesh size = 80/170

Temp. °C	$^{40}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	Vol. $^{39}Ar_K$ $\times 10^{-9}$ cm^{3}NTP	%^{39}Ar of Total	%^{40}Ar rad	Date ± 2σ Ma
TL-87-14 Maf.							
<800	Lost						
1000	17.721	0.0324	0.476	5.6512		46.01	86.1±10.3
1200	94.522	0.2762	2.607	1.3965		13.85	136.3±37.4

Total ^{39}Ar —
integrated age —
wt. = 0.120 g
J = 5.920 e-3
mesh size = 60/120

(*See* footnotes and abbreviations in Table 1-16-1.)

intrudes the Powell Creek formation and older rocks. Previous potassium-argon dates on biotite from granodiorite; sericite from an alteration zone; and biotite from a postmineralization dyke were reported from the Mohawk porphyry deposit. All three ages (84.7±2.5, 84.9±2.5, 86.7±2.6 Ma; McMillan, 1976) were the same within the limits of analytical precision. Sample TL-87-4, collected about 10 kilometres southeast of the Mohawk showing, yields dates of 82.1±2.0 Ma on hornblende and 71.8±0.6 Ma on biotite. The hornblende date is consistent with the previous mica dates, but the new biotite date is significantly younger. This is undoubtedly the result of thermal overprinting which may be related to a zone of sericitization several kilometres to the west within the batholith. It is of interest that a similar zone of alteration at the Warner property (Sample TL-87-3a) yields a date of 78.1±0.6 Ma and that alunite (Sample DDH-87-163.3) from the Taylor-Windfall property yields a slightly younger date of 73.7±0.5 Ma. The difference may be due to argon loss from the very fine-grained alunite. These dates strongly suggest that mineralization and at least some of the alteration in the western part of the Warner Pass area occurred at, or just prior to, 74 Ma. Such events may have been related to the final stages of crystallization and cooling of the Coast plutonic complex.

Hornblende Plagioclase Porphyries

Dates were determined for three small hornblende plagioclase porphyry intrusions (Unit A of Glover and Schiarizza, 1987). These units are compositionally similar to the andesitic volcanics of the Powell Creek formation and two of the three are spatially associated with these volcanics. Like the enclosing volcanics, the porphyries are chlorite-epidote altered. The oldest reliable date, 75.6±2.8 Ma on hornblende from sample TL-87-11, is from a narrow dyke that can be traced for 1500 metres within the Yalakom fault zone, in the southeastern Noaxe sheet. Although the dyke margins are sheared, this date is interpreted as an upper limit for major strike-slip movement along the Yalakom fault.

Hornblende from the Dorrie Peak stock (Sample TL-86-6) yielded a date of 64.7±2.1 Ma. This date is concordant, within analytical error, with the 63.7 Ma date obtained by K. Dawson (personal communication, 1987) for the Eldorado pluton to the southeast; it is consistent with part of this suite being younger than the Coast plutonic complex and Early Paleocene in age.

The North Relay porphyry is associated with a zone of intense alteration, some of which is gold-bearing. The pluton is itself very altered and the sericitized plagioclase (Sample TL-87-14) yielded a date of 67.6±0.6 Ma. This area is remote from other plutons and the date may provide a good estimate of the time of alteration and mineralization in this zone. An attempt to step-heat a small mafic separate from this sample was largely unsuccessful (in part, the result of severe carbonate alteration). However, the fraction of the gas released between 800 and 1000°C (Table 1-16-2) yielded a date of 86±10 Ma. This date has a large analytical uncertainty, but it may indicate that the hornblende plagioclase porphyries in this zone are of a different age than elsewhere. The 86 Ma date is consistent with the inferred Late Cretaceous age for the Powell Creek volcanics. Samples of less-altered rock were collected in 1988 for additional $^{40}Ar/^{39}Ar$ step-heating experiments.

Hornblende-Plagioclase-Biotite-Quartz Porphyries

Small stocks of this composition (Unit C of Glover and Schiarizza, 1987), occur within restricted areas of andesitic to rhyolitic volcanics. The volcanic rocks unconformably overlie Upper Cretaceous units and have been correlated with Eocene strata elsewhere in the region. The Mount Sheba stock, which intrudes these volcanics in the southeastern Warner Pass map area, yields a date of 57.2 ± 1.4 Ma on hornblende (Sample TL-87-1). The Red Mountain porphyry intrudes similar volcanics in the northeastern corner of the Noaxe Creek map area. Hornblende and biotite from a sample of this porphyry (Sample TL-87-8) yield discordant dates of 53.5 ± 0.8 and 47.4 ± 0.5 Ma, respectively. The spread in the dates may be caused by excess argon in the hornblende or argon loss from the biotite. The first is possible as both samples contain small mafic, hornblende-bearing xenoliths. A Paleocene age for this suite, however, is also possible as potassium-argon dating of intrusion, potassic alteration and mineralization at the Poison Mountain porphyry copper deposit, 10 kilometres southwest of Red Mountain, has yielded concordant biotite and hornblende dates of about 58 Ma (Glover *et al.*, 1988). Although a Tertiary age for these plutons is not in doubt, $^{40}Ar/^{39}Ar$ step-heating is required to explain the discordant dates and define their ages precisely.

Beece Creek and Lorna Lake Stocks

Equigranular monzogranite (Unit D of Glover and Schiarizza, 1987), occurs as two relatively large plutons in the Warner Pass map area; these comprise the Beece Creek pluton in the northwest corner of the sheet and the Lorna Lake stock at the head of Big Creek. Biotite from both stocks is very fresh and in each case has yielded dates of about 44 Ma (Samples TL-87-7 at 43.5 ± 0.3 and TL-87-20 at 43.9 ± 0.6). These dates suggest a Middle Eocene age for these bodies. The Beece Creek pluton is one of the largest stocks east of the Coast plutonic complex. Although no mineral showings are associated with it in the Warner Pass map area, it is cut by small quartz-tourmaline-epidote veins and stockwork, and may be genetically related to extensive chlorite-epidote alteration peripheral to it. The Lorna Lake stock was apparently emplaced along a north-northeast-trending normal fault which occupies the Big Creek valley. It has a narrow chlorite-epidote alteration envelope and minor associated chalcopyrite-molybdenite mineralization.

The 44 Ma dates from the Beece Creek and Lorna Lake plutons are identical to the 44 Ma date obtained by Woodsworth (1977, potassium-argon on biotite), from the compositionally similar Mission Ridge pluton, which outcrops in the Bridge River area to the southeast (Schiarizza *et al.*, 1989, this volume).

Lizard Stock and Big Sheep Mountain Alteration

The two youngest dates obtained so far, are from the Lizard stock in the Warner Pass area and from a sericitic alteration zone on Big Sheep Mountain in the Noaxe Creek area. The Lizard stock is a small (less than 500 metres diameter) body of very fine-grained hornblende porphyry which was emplaced across the Chita Creek fault and an unmineralized, rusty carbonate alteration zone in Powell Creek volcanics and older rocks. The hornblende from the Lizard stock (Sample TL-87-16) yields a date of 34.7 ± 1.9 Ma. This provides an upper limit (Oligocene) for faulting and alteration events in the western part of the area.

The sericitic alteration zone on Big Sheep Mountain, which was developed in a highly silicified hornblende porphyry, has attracted interest for its gold potential. A sericite-rich sample (TL-87-12) yielded a date of 27.3 ± 0.2 Ma. As the host porphyry is not yet dated, it is difficult to assess the significance of this date. Samples of less-altered host rock and several other dykes in the area were collected for dating in 1988.

Amphibolite at the Base of the Shulaps Ultramafic Complex

In preparation for 1988 field work in the Bridge River and Bralorne map areas (92J/16 and 92J/15, respectively), a reconnaissance was made of the south side of the Shulaps ultramafic complex in an area previously mapped by Potter (1983). The upper Hog Creek area is underlain by Potter's "imbricate zone", consisting of sheared serpentinite that contains "knockers" of a wide variety of igneous lithologies, ranging in composition from ultramafic to intermediate, as well as a variety of sedimentary rocks, some of which appear to correlate with those of the Bridge River complex. The sample selected for dating is a medium-grained, massive to coarsely brecciated, equigranular amphibolite that occurs as a knocker within the imbricate zone. This rock-type differs from the foliated to lineated amphibolite which Potter viewed as part of the basal metamorphic aureole of the Shulaps ultramafic complex; it is most likely part of the sheeted to brecciated, mafic dyke complex of an ophiolite succession. As the metamorphism may have been a sea-floor process, it was hoped that dating the amphibole in this sample would provide the age of the Shulaps complex. However, mapping in 1988 by T. Calon (Memorial University of Newfoundland) and the authors reveals that this zone has had a more complex thermal history than previously thought.

The $^{40}Ar/^{39}Ar$ age spectrum for the amphibole separate (Sample TL-87-22) is shown in Figure 1-16-2 and the analytical data are listed in Table 1-16-2. Overall, the spectrum has a U-shaped form characteristic of minerals that contain excess argon. The bottom of the "U" corresponds to the main pulse of ^{39}Ar release (over 70 per cent) from the amphibole. Steps in this segment of the age spectrum are characterized by similar $^{37}Ar/^{39}Ar$ ratios (proportional to the Ca:K ratio). The dates for the higher temperature steps are derived from a phase with a higher $^{37}Ar/^{39}Ar$ ratio and with a much lower potassium content. The amphibole in this sample is actinolitic and appears somewhat fibrous in thin section; this may account for the relatively low temperature of the release of the bulk of the ^{39}Ar. Thus, although the integrated date is 84.6 ± 12 Ma, the minimum date, 72.6 ± 0.5 Ma, is taken as the best estimate of the age for this sample.

To interpret this date it is necessary to consider the geology of, and the thermal processes that were active in, the imbricate zone. Detailed mapping of the serpentinite mélange beneath the Shulaps ultramafic complex has revealed the presence of synkinematic dykes of mafic to intermediate composition. Locally the dykes reacted with the serpentinite to form rodingite and, near larger bodies, to regenerate olivine in the serpentinite (T. Calon, personal communication, 1988). The temperature within this part of the mélange was probably *circa* 500°C and would be sufficiently high to thermally overprint or recrystallize amphibole. It is probable that any pre-existing amphibole, such as was dated, would record a secondary metamorphic age. Thus, we interpret the 73 Ma date as indicating the time of cooling of the mélange following this magmatic event. This may mark the uplift and final emplacement of the Shulaps ultramafic complex. Late Cretaceous movement is supported by the fact that undeformed hornblende plagioclase porphyry cuts penetratively deformed metasedimentary knockers within the mélange, but does not extend into the serpentinite. This particular porphyry is characterized by acicular hornblende phenocrysts and is very similar to the dyke within the Yalakom fault zone which yielded a date of 75.6 ± 2.8 Ma (Sample TL-87-11). More samples were collected of this and other amphibole-bearing rocks from this zone in 1988, to better define the thermal history of the Shulaps complex.

CONCLUSIONS

There are several preliminary conclusions that have a bearing on the timing of magmatism, mineralization and tectonism in this region:

1. Andesitic volcanics of the Powell Creek formation, are intruded by 87 to 82 Ma granodiorite of the Coast plutonic complex and must therefore be Santonian or older in age. Mineralization and alteration within these volcanics along the margins of the Coast plutonic complex may have occurred between 74 and 78 Ma, during the final stages of crystallization of the complex.
2. Hornblende plagioclase porphyries (Unit A of Glover and Schiarizza, 1987), may be of several different ages; intrusive events at 86, 76 and 65 Ma are suspected, but not proven.
3. Hornblende-plagioclase-biotite-quartz porphyries (Unit C of Glover and Schiarizza, 1987), may be Paleocene (57 Ma) or Middle Eocene (47 Ma) or both.
4. Dates of 44 Ma for the Beece Creek pluton and Lorna Lake stock are concordant with a previously published age for the Mission Ridge pluton, thus confirming an important magmatic event during Middle Eocene time.
5. Oligocene dates from a small hornblende porphyry stock and a distant sericitic alteration zone may indicate the presence of magmatic and hydrothermal events of this age.
6. A 76 Ma hornblende plagioclase porphyry dyke within the Yalakom fault zone is interpreted to postdate major strike-slip movement along the fault. This compares with dates of 85 to 87 Ma on granodiorite which truncates the Tchaikazan fault, and a 64 Ma date (K. Dawson, personal communication, 1987), on the Eldorado pluton which truncates the Castle Pass fault. The three faults are part of an important dextral strike-slip system which cuts the early Late Cretaceous Powell Creek formation and older rocks; movement must therefore have been during the Late Cretaceous.
7. The final stage in the emplacement of the Shulaps ultramafic complex may also have occurred in the Late Cretaceous, between 76 and 73 Ma. This does not rule out, however, an earlier history of deformation within and adjacent to the complex.

ACKNOWLEDGMENTS

The authors would like to thank T. Calon of the Memorial University of Newfoundland for imparting to them some of his expertise on ophiolites while in the field in 1988. R. Lane of Westmin Resources Limited is thanked for supplying the drill core for the alunite sample. The project is funded mainly by the Canada/British Columbia Mineral Development Agreement. The senior author acknowledges the financial support of Energy, Mines and Resources Canada and the interest of P.J. Wynne (Pacific Geoscience Centre) in this research. The Geochronology Laboratory at Queen's University is supported by a Natural Sciences and Engineering Research Council operating grant to E. Farrar.

REFERENCES

Dalrymple, G.B., Alexander, Jr., E.C., Lanphere, M.A. and Kraker, G.P. (1981): Irradiation of Samples for $^{40}Ar/^{39}Ar$ Dating Using the Geological Survey TRIGA Reactor, *U.S. Geological Survey*, Professional Paper 1176, 55 pages.

Garver, J.I., Umhoefer, P.J., Mohrig, D., McGroder, M.F., and Bourgeois, J. (1988): Upper Jurassic and Cretaceous Sedimentation in the Methow-Tyaughton Basin: Northern Washington and Southern British Columbia, in Sedimentary Basins of the Canadian Cordillera, *Geological Association of Canada Symposium*, Victoria, B.C., March 25, 1988, Program and Abstracts, pages 10-11.

Garver, J.I., Schiarizza, P., and Gaba, R.G. (1989): Stratigraphy and Structure of the Eldorado Mountain Area, Chilcotin Ranges, Southwestern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, this volume.

Glover, J.K., and Schiarizza, P. (1987): Geology and Mineral Potential of the Warner Pass Map Sheet (92O/3), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 157-169.

Glover, J.K., Schiarizza, P., and Garver, J.I. (1988): Geology of the Noaxe Creek Map Area (92O/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 105-123.

Masliwec, A. (1981): The Direct Dating of Ore Minerals, Unpublished M.Sc. Thesis, *University of Toronto*.

McMillan, W.J. (1976): Granite Creek Property (92O/3W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology in British Columbia, 1975, pages 67-84.

Monger, J.W.H. (1985): Structural Evolution of the Southwestern Intermontane Belt, Ashcroft and Hope Map Areas, British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 85-1A, pages 349-358.

Potter, C.J. (1983): Geology of the Bridge River Complex, Southern Shulaps Range, British Columbia: A Record of Mesozoic Convergent Tectonics, Unpublished Ph.D. Thesis, *University of Washington*, 192 pages.

Schiarizza, P., Gaba, R.G., Glover, J.K. and Garver, J.I. (1989): Geology and Mineral Occurrences of the Tyaughton Creek Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, this volume.

Steiger, R.H. and Jäger, E. (1977): Subcommission on Geochronology: Convention on the Use of Decay Constants in Geo and Cosmochronology, *Earth and Planetary Science Letters*, Volume 36, pages 359-362.

Woodsworth, G.I. (1977): Pemberton Map-area (92J), Scale 1:250 000, *Geological Survey of Canada*, Open File Map 482.

NOTES

GEOLOGY AND MINERAL OCCURRENCES IN THE VICINITY OF TASEKO LAKES* (92O/3, 4, 5, 6)

By G.P. McLaren and J.N. Rouse

KEYWORDS: Regional geology, Taseko Lakes, Tyaughton trough, geochemistry, precious metals, vein deposits, porphyry, copper-molybdenum.

INTRODUCTION

Previous 1:50 000-scale mapping by the Geological Survey Branch in map sheets 92O/03 (Glover and Schiarizza, 1987) and 92O/04,05 (McLaren, 1986a) left a strip of unevaluated rocks centered on the Taseko Lakes – Lord River drainage system. During the 1988 field season approximately one month was spent in this area conducting geological mapping, lithogeochemical sampling and stream sediment sampling to complement the previous work. Figure 1-17-1 shows the location and geologic setting of the field area and areas of previous mapping.

Approximately 200 square kilometres were surveyed in this project. Stream sediment samples were collected from 39 locations to complement the geochemical surveys previously conducted west of Taseko Lakes (McLaren, 1986b, 1987b). Forty-one selected rock chip samples were collected from areas of mineralization or zones of alteration related to mineralizing processes. All of these data will be released as an Open File early in 1989.

REGIONAL GEOLOGY

The regional geology has previously been mapped by Tipper (1978) and the faunal stratigraphy discussed by Jeletzky and Tipper (1968). This work was refined by Glover and Schiarriza (1987), Glover *et al.* (1988) and McLaren (1986a, 1987a). The region is underlain by Middle Jurassic to Upper Cretaceous strata that accumulated within the Tyaughton trough. The coarse clastic sediments that dominate the axial regions of the trough interfinger with volcanic lithologies in the Taseko to Chilko lakes area. A number of significant northwest-trending faults, with both strike-slip and compressional movements, transect the region. Intrusive rocks of the Coast plutonic complex truncate the stratified rocks on the south and southwest.

Mineral occurrences are well documented throughout the region; primary exploration targets in the area have been precious metal vein deposits and porphyry copper-molybdenum deposits.

LOCAL GEOLOGY

Figure 1-17-2 outlines the general geology of the Taseko Lakes area. Work conducted in 1988 was concentrated in a zone varying from 5 to 10 kilometres wide surrounding Taseko Lakes. The figure incorporates previously published work of Glover and Schiarizza and of McLaren on the east and west respectively.

The area is underlain by Lower and Upper Cretaceous strata that have been intruded by a variety of stocks and dykes. Two large faults, the Tchaikazan and Chita Creek faults, cut across the area on a northwesterly trend. Lower Cretaceous strata south of the Tchaikazan fault comprise intimately interbedded volcanic, volcanic epiclastic and clastic sedimentary rocks. Rocks immediately north of this fault are Late Cretaceous in age. North of the Chita Creek fault, Lower Cretaceous strata comprise interbedded clastic sediments that are unconformably overlain by Upper Cretaceous volcanics and sediments. Only lithologies mapped during the 1988 fieldwork are described here; descriptions of other units shown on Figure 1-17-2 are provided by previous workers.

STRATIGRAPHY

UNIT LK_{tc}

Unit LK_{tc} comprises rocks that are correlative with late-Lower Cretaceous Taylor Creek Group lithologies. Two distinct Tyaughton trough depositional environments are represented. To the southwest interbedded volcanics and sediments (Unit LK_{tcv}) formed in a volcanic island arc environment on the southwest flank of the trough while to the northeast clastic sediments (Unit LK_{tcs}) are more typical of the axial regions of the trough.

Lower Cretaceous volcanics comprise intermediate to felsic pyroclastics and flows. Feldspar crystal and lapilli tuffs and lithic fragmental tuffs predominate and are well exposed on the ridge west of Lord River. These are dark green to pale grey, massive to well-layered units. Dacitic to rhyolitic horizons, often containing disseminated pyrite, are common. Thinly laminated black argillite, quartzose siltstone and sandstone are intimately interbedded with the tuffs and may also contain sufficient pyrite to produce local limonitic horizons. Quartz veins with drusy cavities and pyritic boxwork textures cut both the volcanics and sediments.

In the northeastern corner of the area a few outcrops of chert-pebble conglomerate, sandstone, siltstone and minor interbedded tuff (Unit LK_{tcs}) were noted in creek valleys. The coarser sediments tend to be well bedded but poorly sorted. Although chert pebbles dominate, both sedimentary and volcanic lithic clasts are present. Interbedded tuffs are intermediate to felsic in composition and appear to increase in volume toward the northern boundary of the map area. These lithologies are identified as part of the Dash con-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

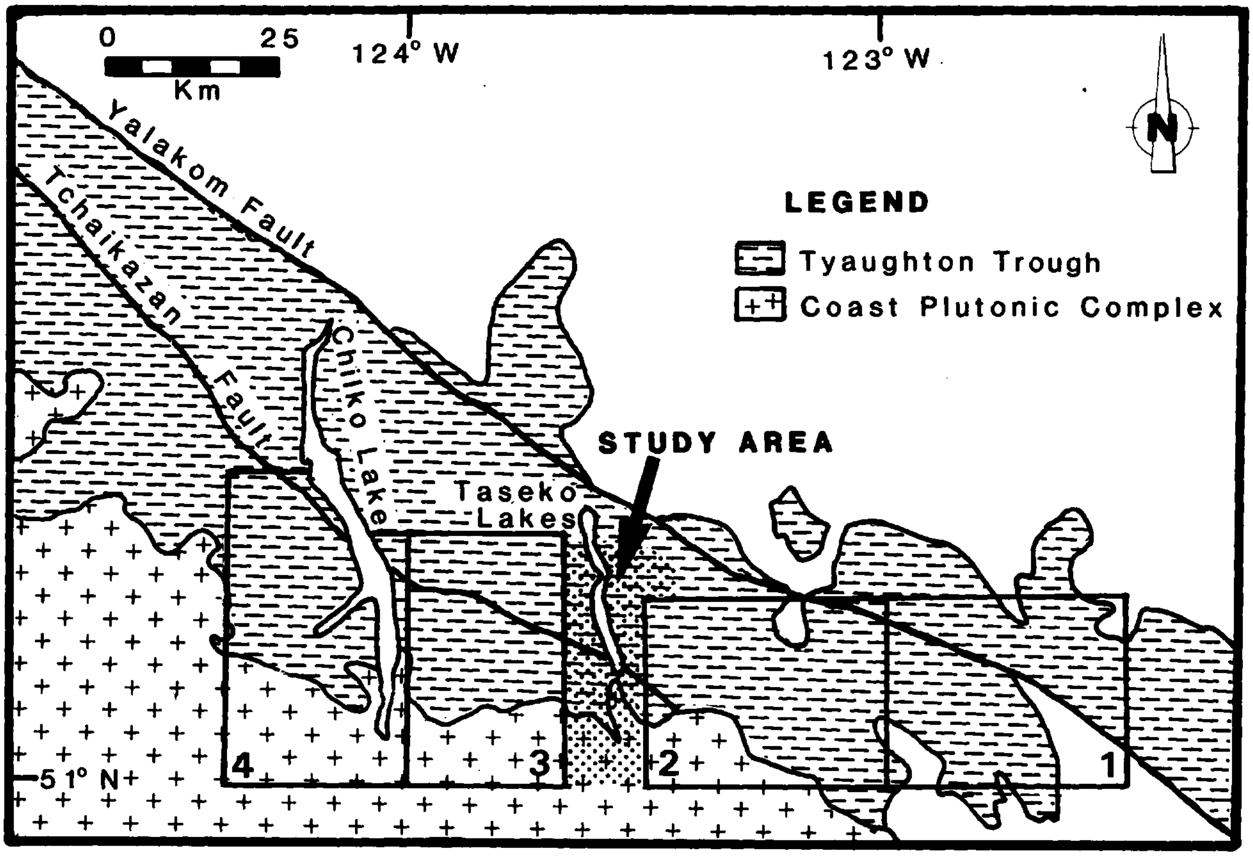


Figure 1-17-1: Location and geological setting of the Taseko Lakes area. Previous 1:50 000 mapping shown as: 1 – Glover *et al.* (1988), 2 – Glover and Schiarizza (1987), 3 – McLaren (1986), 4 – McLaren (1987).

glomerate (Schiarizza and Garver, personal communication, 1988) which is unconformably overlain by Upper Cretaceous rocks in this area (Glover *et al.*, 1988).

UNIT UK_{sq}

This unit is dominated by poorly sorted chert-pebble conglomerate that is interbedded with quartz-rich sandstones, argillites and minor volcanic flows. Pebble to cobble-sized clasts in the conglomerates are primarily chert or quartz, however up to 25 per cent may be volcanic or other sedimentary lithologies. Quartz-rich sandstone interbeds, often with sparsely distributed pebbles, are common. Crossbedding, scours and grading occur locally in the sandstones. Finer grained argillaceous sediments regularly contain woody fossil debris and leaf imprints. Sandstones often become brown weathering, calcareous and contain limy concretions. These rocks are well exposed on the shore of Lower Taseko Lake and on the ridges near the Chita porphyry copper-molybdenum occurrence. The sediments are locally hornfelsed adjacent to the Chita intrusive.

The contact with the overlying volcanics was observed in one location east of the Chita porphyry. It is conformable and displays a limited amount of erosional scouring by the volcanics. This unit is equivalent to the Upper Cretaceous Silverquick Formation (Schiarizza and Garver, personal communication, 1988) mapped in the Taseko River valley (Glover and Schiarizza, 1987) and is probably equivalent to the Upper Cretaceous sedimentary unit mapped west of Taseko Lakes (McLaren, 1986a).

UNIT UK_{pc}

Overlying the Upper Cretaceous clastic sediments is a thick succession of massive volcanic breccias, agglomerates and tuffs intercalated with minor basic flows. The pyroclastic rocks are generally poorly sorted and are comprised of hornblende-feldspar porphyry fragments set in a feldspar crystal to volcanic epiclastic matrix. Angular volcanic lithic fragments and rounded boulders range up to 2 metres in size. More recessive rocks have a distinct layering of finer grained tuffs; locally these are maroon and contain disseminated hematite. Hornblende-porphyritic flows are not extensive but locally form resistant ridges.

These volcanics are conformably overlain by a bedded unit of Upper Cretaceous andesitic lahars and epiclastic sediments outcropping on a ridge crest east of Upper Taseko Lake. This upper unit was not mapped in this project.

INTRUSIVE ROCKS

UNIT A — HORNBLENDE DIORITE

A small plug of hornblende diorite occurs on a steep ridge north of Taseko Mountain. Much of this intrusive is inaccessible, however it is significant as it is likely responsible for the numerous gossan zones and mineralization in the area. Limonitic talus of this material is medium grained and hornblende-phyric with moderate to strong epidote and chlorite alteration. The surrounding volcanics are fractured, extensively pyritized, and locally, strongly silicified.

UNIT B — COAST PLUTONIC COMPLEX

Granodiorite and quartz diorite of the Coast plutonic complex intrude Cretaceous sediments and volcanics across the southern margin of the map area. Biotite and hornblende, with variable chlorite and epidote alteration, are accessory minerals. The rocks are generally massive and often jointed. Foliations are developed locally in the Lord River valley where a faulted lobe of this unit extends well north of the general trend of the intrusive contact. Strong carbonate alteration was noted along one of the prominent faults in this area.

UNIT C — FELSITES

A number of white-weathering intrusive stocks were previously mapped west of Taseko Lakes (McLaren, 1986a; Tipper, 1978). These medium to fine-grained feldspar and biotite-feldspar porphyries often show argillic or carbonate alteration. One of these intrusions outcrops near the narrows between the Taseko Lakes and another on the ridge crest west of the south end of Upper Taseko Lake.

UNIT D — PLAGIOCLASE HORNBLENDE PORPHYRY

North of Chita Creek an elongate body of feldspar porphyry, extending over 5 kilometres in length and up to 1.3 kilometres in width, intrudes the clastic sediments of Unit UK_{sq}. The intrusive is characterized by coarse euhedral plagioclase phenocrysts that are often zoned and range up to 2 centimetres in size. Smaller hornblende phenocrysts are common and euhedral biotite or quartz crystals may be present locally. The grey to green matrix is a medium to fine-grained composite of feldspar, quartz and mafic minerals. This intrusive varies from relatively fresh through a general argillic alteration to pervasive and intense carbonate and argillic alteration. The highly altered zones include narrow sections of multiple veining and variable silicification. This intense alteration extends into the surrounding sediments, particularly at the southern end of the porphyry where it forms prominent red cliffs. The main porphyry stock has a very irregular shape and a number of small satellite bodies crop out peripheral to it, particularly to the east and southeast. A large sill of this unit caps a low ridge of Unit LK_{tcs} in the northeastern corner of the map area. Other isolated feldspar porphyry outcrops between here and the main body are also suspected to be remnants of a sill.

A few isolated outcrops of intrusive hornblende porphyry were noted peripheral to the main feldspar porphyry body. They lack the distinctive large plagioclase phenocrysts and have a finer grained equigranular matrix.

UNIT E — BEECE CREEK PLUTON

The Beece Creek pluton in the northeastern corner of the map area comprises a fine to medium-grained quartz monzonite to granodiorite. Epidote is a common accessory mineral and weak chlorite and sericite alteration are present. The surrounding volcanics and sediments are strongly hornfelsed.

DYKES

Numerous quartz-eye felsite dykes cut virtually all rock types in the Taseko Mountain to Chita porphyry area. These distinctive rocks form white to buff-weathering outcrops that produce flaggy talus. Contorted flow laminae are common. Larger, more massive bodies of this rock occur adjacent to Unit D. Elsewhere narrow diabase and lamprophyre dykes are present.

STRUCTURE

The structure of the area is dominated by the northwest-trending Tchaikazan and Chita Creek faults. There are numerous subsidiary splays and other subparallel structures. Northeasterly trending faults with apparently little displacement are relatively young structures. No significant folding was seen in the area mapped.

The Tchaikazan fault has previously been traced westwards through the Chilko Lake area (McLaren, 1986a, 1987a) and beyond to the Tatlayoko Lake area where more than 30 kilometres of dextral transcurrent movement has been suggested (Tipper, 1969). Considerable compressional movement is evident on a parallel structure between Taseko and Chilko lakes. Near Taseko Lakes the fault is poorly exposed as it follows topographic depressions, however in the Taseko River valley to the east, prominent orange-weathering alteration zones highlight the trend of the fault. Here a broad zone of pervasive carbonate alteration with localized zones of brecciation and moderate to intense silicification is remarkably similar to alteration in this fault zone along the west shore of Chilko Lake. Geochemical anomalies in the Taseko valley are also similar to those determined to the west. No sense of movement can be confidently assigned to the fault in the study area.

The location of the Tchaikazan fault to the southeast is somewhat problematical due to sparse outcrop and alteration along the contact of the Coast plutonic complex. Carbonate alteration zones trending south of Taseko River across Amazon Creek suggest the fault extension is truncated by the Coast intrusives. The altered volcanic rocks south of the fault are attributed to Unit LK_{tcv} since the Tchaikazan fault separates Lower and Upper Cretaceous lithologies west of Taseko Lakes. Felsic volcanic rocks west of Amazon Creek support this hypothesis as they are known to occur commonly in unit LK_{tcv} but not in unit UK_{pc}. Movements on the Tchaikazan fault in this area are then constrained to older than Middle to Late Cretaceous by biotite potassium-argon radiometric dates (84.7 to 86.7 ± 2.5 million years) obtained from granodiorite near Granite Creek (McMillan, 1976).

The Chita Creek fault also follows topographic lows and does not outcrop in the map area. Mapping to the east has indicated both vertical and transcurrent movements on this fault (Glover *et al.*, 1988). An extension of the fault has been mapped well to the west of Taseko Lakes, cutting Upper Cretaceous rocks.

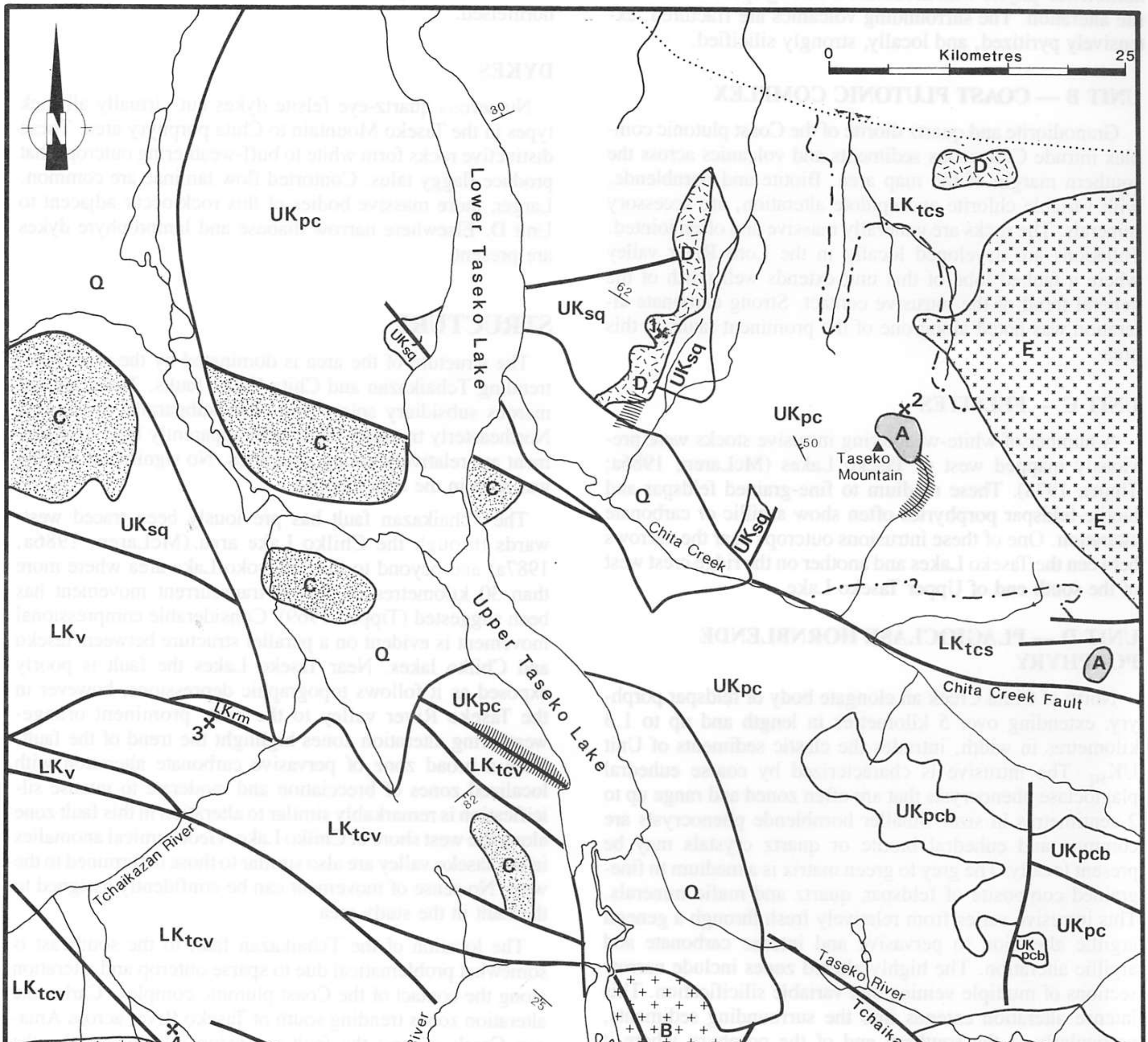


Figure 1-17-2: Geology and mineral occurrences of the Taseko Lakes area.

LEGEND FOR FIGURE 1-17-2

STRATIFIED ROCKS

Quaternary

Q	Alluvium, till

Upper Cretaceous

UK_{pbc}	Powell Creek Formation: bedded laharic andesitic breccia and epiclastic sediments.
UK_{pc}	Powell Creek Formation: andesitic breccia, lapilli tuff, crystal tuff and ash tuff; minor andesitic to basaltic flows.
UK_{sq}	Silverquick Formation: pebble to cobble polymict conglomerates, sandstones and argillite; minor andesitic flows.

Lower Cretaceous

LK_{tcv}	Taylor Creek Group: rhyolitic to basaltic tuffs and flows; black argillite, siltstone, sandstone.
LK_{tcs}	Taylor Creek Group: argillite, siltstone, sandstone; minor tuffs.
LK_{rm}	Relay Mountain Group: black argillite, siltstone, sandstone, minor andesitic tuffs and flows.
LK_v	Purple andesitic pyroclastics and breccias, minor flows.

Intrusive Rocks

A Hornblende diorite

B Coast plutonic complex: granodiorite, quartz diorite

C Felsites: feldspar and biotite-feldspar porphyry

D Plagioclase hornblende porphyry

E Beece Creek pluton: quartz monzonite to granodiorite

×	Mineral occurrences.
	Areas of anomalous stream sediment geochemistry.

Name	MINFILE Number	Type	Commodities
1. Chita Mountain	092O 049	Porphyry	Co, Mo
2. Taseko Mountain	—	Vein	Au, As, Cu, Zn
3. Charlie	092O 043	Vein	Au, Ag
4. Twin Creek	—	Vein	As
5. Pellaire	092O 045	Vein	Au, Ag
6. Mohawk	092O 001	Porphyry	Cu, Mo, Au, Ag
7. Spokane	092O 004	Porphyry	Cu, Ag, Au
8. Rowbottom	092O 025	Porphyry	Cu, Mo
9. Empress	092O 033	Porphyry	Cu, Au

GEOCHEMISTRY

Approximately 25 stream sediment samples were collected from the current map area in the course of Regional Geochemical Survey 3-1979. Analyses of these samples show a sporadic distribution of elevated levels of copper, molybdenum, arsenic and mercury. The 39 sites sampled in 1988 served to confirm the geochemical patterns determined in the regional geochemical survey and highlighted some further anomalies. These data, to be released as an Open File map at 1:50 000 scale, are summarized in the following paragraphs. The small data population precludes any meaningful calculation of anomalous thresholds; anomalous values have been estimated based on levels determined from previous stream sediment surveys in the Taseko – Chilko Lakes area (McLaren, 1986b, 1987b). Areas of anomalous stream sediment results are indicated on Figure 1-17-2.

Samples collected from streams draining Unit UK_{pc} returned uniformly low values, except from areas of known mineral occurrences. Unit LK_{tcv} however, produced several anomalous levels of copper and zinc, and scattered samples with elevated levels of molybdenum, lead and arsenic. Most of these anomalies occur in the limonitic felsic volcanic and sedimentary sequence west of Lord River.

Streams draining the Chita porphyry copper-molybdenum occurrence carry sediments anomalous in copper and zinc and with elevated nickel, cobalt, manganese, lead and gold values. A single sample anomalous in arsenic, copper and zinc was obtained from a creek east of Taseko Mountain draining a limonite-stained diorite intrusive. Arsenic anomalies were detected in streams draining the Tchaikazan fault zone on the west side of Upper Taseko Lake, confirming data determined in the regional geochemical survey.

MINERAL OCCURRENCES

Known mineral occurrences in the region are primarily precious metal vein deposits (epithermal or mesothermal) and porphyry copper-molybdenum (± gold) deposits (Figure 1-17-2). The only deposit with recorded production in the vicinity, the Taylor-Windfall occurrence (MINFILE 092O 028) 10 kilometres east of the study area in the Taseko River valley, appears to have developed in a setting transitional between a porphyry and epithermal environment. A number of mineral showings south of Taseko River near the contact of the Coast plutonic complex have also been explored for both porphyry copper-molybdenum and precious metal mineralization. The Fish Lake porphyry copper-gold occurrence (MINFILE 092O 041, 042) lies 15 kilometres north of the map area.

There are two significant mineral occurrences within the mapped area, the Chita porphyry (MINFILE 092O 049) and the Taseko Mountain gold-bearing sulphide veins. Minor mineralization hosted in favourable geologic environments is present in two other areas.

The Chita (Banner) porphyry copper-molybdenum occurrence has been explored intermittently since the early 1960s. A prominent red mound overlooking the Chita Creek valley comprises intense carbonate and argillic alteration with disseminated pyrrhotite and pyrite in Units A and UK_{sq}. These rocks are extensively fractured and cut by quartz veins that carry minor chalcopyrite, molybdenite and pyrite. Localized breccia zones and intensely silicified zones host the best chalcopyrite and molybdenite mineralization. The largest breccia zone, approximately 40 metres long and with an undetermined width, is composed of angular fragments of hornfelsed sediments and volcanics in a siliceous matrix; quartz veins cut both the matrix and fragments. Sulphide minerals occur interstitial to the fragments as streaks and large clots, along fracture planes, and within the quartz veins. Local intensely silicified zones in the feldspar porphyry also contain copper and molybdenum mineralization.

A previous soil geochemical survey over this property (Assessment Report 8893) confirmed a large copper and molybdenum anomaly adjacent to the main mineralized zone, but also indicated anomalous levels of copper, molybdenum, arsenic and gold over a broad area downslope to the west. Rock-chip sampling in this project was concentrated in this peripheral veined and carbonate-altered zone.

Disseminated and stockwork sulphide mineralization occurs on a very steep ridge northeast of Taseko Mountain. This mineralization, originally discovered through follow-up of stream sediment geochemical anomalies, was briefly explored in 1982 and yielded highly anomalous values in gold, silver, copper, zinc and arsenic in rock and soil samples (Assessment Report 10674). A diorite stock intruding volcanic rocks of Unit UK_{pc} has produced extensive limonitic hornfels zones, however the area of greatest interest is relatively inaccessible due to the steep terrain. Intermittent limonitic alteration is visible for over 1 kilometre of cliff exposure. Intensely silicified boulders in the moraines immediately below the north side of this ridge contain sulphide veins up to 5 centimetres wide carrying arsenopyrite, sphalerite, chalcopyrite and pyrite. Analyses of 35 rock samples, from both outcrop and moraines, have been previously reported from this property. Gold and silver values range from below the detection limit to 7.3 grams per tonne and 58.0 grams per tonne respectively; copper and zinc analyses include results in excess of 1 per cent.

The Tchaikazan fault zone contains anomalous levels of mercury, arsenic and gold in rock and stream sediment samples from the Taseko River valley and west of Taseko Lake. The structural setting, associated limonitic alteration zones, and proximity to an intrusive heat source combine to provide a highly favourable environment for epithermal precious metal mineralization.

Anomalous stream sediment geochemistry derived from the sequence of gossanous felsic volcanics and sediments west of Lord River presents another zone of relatively unexplored potential. This zone lies 3 kilometres east of the Pellaire gold occurrence (MINFILE 092O 045) where gold-bearing quartz veins cut a lobe of granodiorite intruding the volcanic-sediment sequence. Pyritic quartz veins were noted cutting the rocks west of Lord River.

SUMMARY

This project has provided stratigraphic continuity of Lower to Upper Cretaceous lithologies across the Taseko Lakes area and has complemented the stream sediment geochemical and lithogeochemical database previously acquired for map sheets 92O/4 and 92O/5. Metallogenic environments characteristic of other parts of the Tyaughton trough are present in the study area.

Exploration completed to date on the Taseko Mountain gold-bearing sulphide veins has been limited by the steep terrain, however the extent of the limonitic zones and the high levels of precious metals indicated in the talus samples indicate a more thorough evaluation is warranted. The potential for epithermal vein mineralization in the altered segments of the Tchaikazan fault zone also has not been fully evaluated.

Porphyry copper-molybdenum mineralization at the Chita occurrence is not sufficiently extensive, as outlined by previous exploration, to suggest a large deposit is present. However the sizeable alteration zone peripheral to the intrusive has a moderate potential for precious metal mineral occurrences.

ACKNOWLEDGMENTS

An informative field trip and discussions with P. Schiarizza and J. Garver of the British Columbia Ministry of Energy, Mines and Petroleum Resources provided us with a more thorough understanding of Tyaughton trough lithologies and history. The field assistance of H. Letient and J. Grilo is appreciated. Mr. John Gates of Pemberton Helicopter Services provided experienced and congenial helicopter support.

REFERENCES

British Columbia Ministry of Energy, Mines and Petroleum Resources, (1979): Regional Geochemical Survey, Taseko Lakes Map Area (92O), B.C. RGS 3.

Glover, J.K. and Schiarizza, P. (1987): Geology and Mineral Potential of the Warner Pass Map Sheet (92O/3); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 157-169.

Glover, J.K., Schiarizza, P. and Garver, J.I. (1988): Geology of the Noaxe Creek Map Area (92O/02); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 105-123.

Jeletzky, J.A. and Tipper, H.W. (1968): Upper Jurassic and Cretaceous Rocks of Taseko Lakes Map Area and their Bearing on the Geological History of Southwestern British Columbia; *Geological Survey of Canada*, Paper 67-54.

McLaren, G.P. (1986a): Geology and Mineral Potential of the Chilko – Taseko Lakes Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1985, Paper 1986-1, pages 265-274.

——— (1986b): Stream Sediment Geochemistry of the Chilko – Taseko Lakes Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1986-6 (15 maps plus notes).

——— (1987a): Geology and Mineral Potential of the Chilko Lake Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 231-243.

——— (1987b): Geochemistry West of Chilko Lake, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-14 (17 maps plus notes).

McMillan, W.J. (1976): Granite Creek Property 92O/3W; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology in British Colombia, pages 66-84.

Tipper, H.W. (1969): Mesozoic and Cenozoic Geology of the Northeast Part of Mount Waddington Map Area (92N), Coast District, British Columbia; *Geological Survey of Canada*, Paper 68-33.

Tipper, H.W. (1978): Taseko Lakes Map Area (92O); *Geological Survey of Canada*, Open File 534.

QUESNEL MINERAL BELT: SUMMARY OF THE GEOLOGY OF THE BEAVER CREEK – HORSEFLY RIVER MAP AREA*

By André Panteleyev and Kirk D. Hancock

KEYWORDS: Regional geology, Quesnel terrane, Horsefly, Quesnel Lake, volcanic arc, placer gold, porphyry copper-gold, propylitic alteration, Tertiary basins.

INTRODUCTION

The Quesnel project, a regional mapping program at 1:50 000 scale, was begun in 1986, funded by the Canada/British Columbia Mineral Development Agreement. It is primarily intended to study the geological setting and economic potential for gold and copper-gold deposits in the Triassic-Jurassic Quesnel island arc volcanic rocks and their flanking and underlying clastic rocks. The map area is within the southern part of the Quesnel terrane (Tipper *et al.*, 1981) in the region previously known as the Quesnel trough (Figure 1-18-1). The regional geology has been described by Campbell (1978) and Struik (1986). Results of recent Ministry mapping and other work are summarized by Panteleyev (1987, 1988), Bloodgood (1987, 1988), and Bailey (1988).

This report summarizes mapping in the Beaver Creek (93A/5) and Horsefly River (93A/6) map-areas (*see* Figure 1-18-2) and concludes three seasons of fieldwork. A 1:50 000 Open File geology map is in preparation and will be followed by a publication in the Ministry's Paper series. Other project-generated discussions of nearby map-areas are those of Bailey and Lu (1989, this volume) and Bloodgood (1989, in preparation).

Outcrop in the map area is relatively scarce. Bedrock is exposed mainly where the generally shallow overburden has been disrupted by industrial activity, most commonly logging and road building. Frequently outcrop can be found along ridge crests, and less commonly, in some of the more deeply incised creek gulleys and at the southeast end (the up-ice or stoss side) of some glacial ridges.

Geological interpretation of the sparse outcrop data is difficult due to the similarity of the predominantly pyroxene-phyric lithologies and abundant block faulting. However, a few distinctive breccia units and flows containing analcite phenocrysts or feldspar laths provide readily identifiable marker units. Considerable assistance in map interpretation is provided by federal/provincial 1:63 360 (1 inch to 1 mile) aeromagnetic maps 5239G (93A/6) and 1532G (93A/5).

LITHOLOGIC MAP UNITS

Mafic volcanic rocks of calcalkaline to alkaline affinity are the dominant rock type. The stratigraphic succession consists mainly of pyroxene-phyric basaltic flows, flow breccia, debris flow or lahar deposits and locally derived epiclastic rocks. Within this sequence there are at least two basalt units containing relict olivine and/or analcite crystals. These mafic rocks overly and interfinger with a basal sequence of basaltic-source sandstone and siltstone and are overlain, in turn, by more felsic polylithic alkalic volcanic-clast breccia and the upper unit of amygdaloidal analcite-bearing olivine basalt flows. Locally, remnants of Tertiary lacustrine deposits, crystal ash flows and subaerial flows of intermediate composition overlie the mafic rocks. Miocene plateau basalts overlap the southwestern and southern parts of the map area along Beaver Creek and Horsefly River. The western boundary of the volcanic belt is a fault contact with calcareous and graphitic sediments of the Paleozoic Cache Creek Group.

The map units used are compatible with subdivisions first established by Bailey (1976, 1978) and used in more recent reports by Bailey and Panteleyev. The stratigraphy outlined by Morton (1976) in the central and eastern parts of the map area has been completely revised.

The following map units represent a sequence that is approximately 5 kilometres thick as shown in Figure 1-18-2.

Unit 1: Dark brown and grey mafic volcaniclastic sandstone and siltstone, minor cherty beds and rare calcareous siltstone. Generally a thinly bedded sequence containing turbidite units; locally contains moderately thick beds or

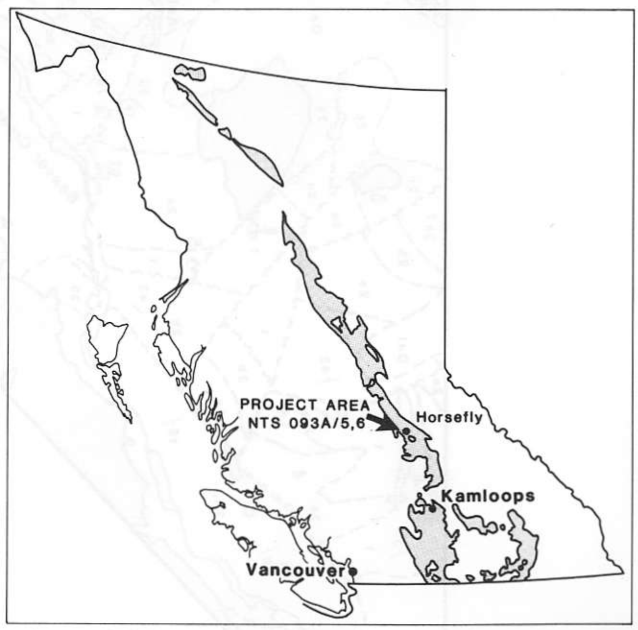


Figure 1-18-1. Location of Quesnel mineral belt project area within the Quesnel terrane.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

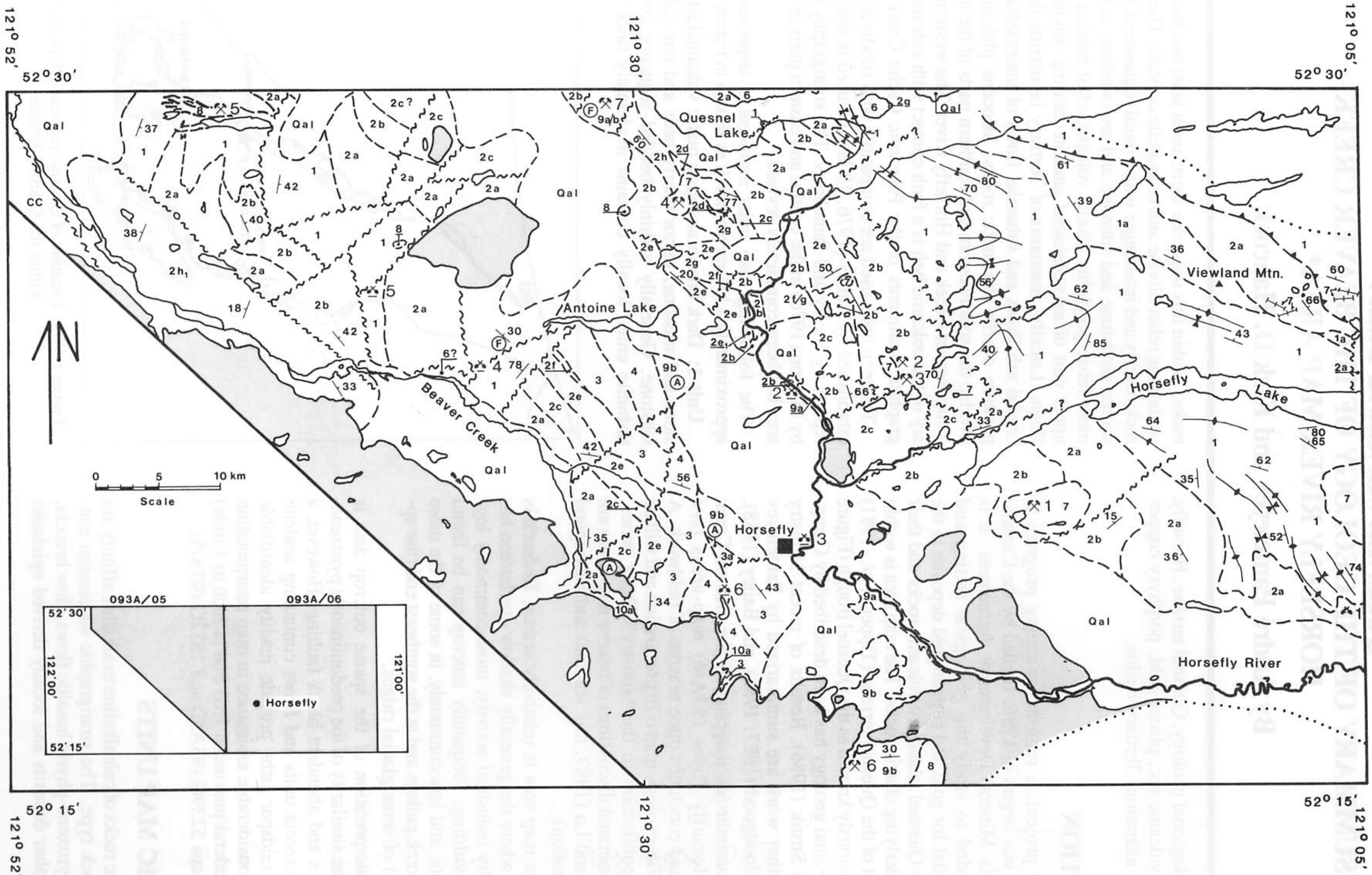


Figure 1-18-2. Geology of the central Quesnel terrane in the Horsefly area.

LEGEND

QUATERNARY
PLEISTOCENE AND RECENT

Qal Glacial and fluvial deposits; alluvium

TERTIARY
MIOCENE

10 Grey to black plateau basalt (alkali olivine basalt); 10A - basal white-quartz cobble conglomerate and gravel, fluvial channel deposits

EOCENE

9b Grey, pale mauve, buff plagioclase crystal ash tuff; pale grey, flaggy, biotite latite and andesite

9a Grey, cream to buff, pale yellow lacustrine sandstone, siltstone, minor conglomerate

JURASSIC
LATE JURASSIC (?) POSSIBLY CRETACEOUS

6 Polylithic cobble conglomerate, shale, sandstone; in part red beds

SINEMURIAN

4 Maroon and grey vesicular, zeolitized, amygdaloidal alkali olivine pyroxene-phyric basalt, contains analcite

3 Maroon and grey polylithic breccias; clasts of mafic and intermediate composition including latite, monzonite and other feldspathic rocks; locally feldspathic sandstone, limestone lenses and limestone matrix breccia

TRIASSIC
NORIAN (?) OR YOUNGER

2h Sandstone, siltstone, calcareous siltstone - flaggy thinly bedded. $2H_1$ - also contains sandstone, limestone, some tuffaceous beds, conglomerate with abundant chert and limestooe clasts and pyroxene hornblende basalt breccia

NORIAN

2g Feldspar-lath, pyroxene-phyric basalt; locally breccia with limestone matrix; locally felsic breccia

2f Dark grey to brown, fetid mafic sandstone and siltstone, calcareous siltstone, limestone breccia

2e Analcite-bearing purple, dark brown and green-grey alkali basalt, locally feldspathic; minor crystal lithic ash tuff; $2E_1$ - sparse pyroxene-phyric to aphanitic basalt - intrusive plug ?

2d Pyroxene basalt breccia, tuff; pyroxene-rich wacke

2c Polylithic, grey-green and purple mafic breccia, debris flow or lahar, minor volcanic-source conglomerate, pyroxene-rich greywacke, minor feldspathic clasts

2b Dark green, maroon and grey pyroxene-phyric basalt breccia, lithic lapilli and ash tuff, mafic wacke. Includes some flows and pyroxene-phyric plagioclase microlite-bearing basalt

2a Green and dark grey pyroxene-phyric alkali olivine basalt and alkali basalt flows, pillow lava and pillow breccia; locally breccia and vesicular amygdaloidal flows with lenses of mafic wacke, limestone or limestone clast-bearing basalt breccia

CARNIAN AND (?) YOUNGER

1 Grey to dark brown siltstone and sandstone, volcaniclastic towards top of unit, rare thin chert beds and limestone lenses. Locally interfingers with unit 2A. 1A - conglomerate, sandstone, minor pyroxene basalt breccia. Locally contains hornblende monzonite and latite clasts in breccia

PALEOZOIC

CC Cache Creek Group - flaggy, fetid limestone, graphitic argillite and siltstone

8 Grey, medium-grained hornblende quartz diorite and granodiorite, locally leucocratic

7 Grey and pink fine to medium-grained diorite, monzodiorite, syenodiorite, monzonite and syenite, hornblende porphyry dykes; locally pyroxenite, hornblendite

SYMBOLS

Map unit contact
Fault-mapped and inferred
-thrust
Fold axis
Bedding attitude
Dykes of granitic rocks
Limit of mapping
Potassium-Argon sample site
Fossil sample site

Mineral prospects

Lemon Lake	Cu,Au	1
Kwun Lake	Cu,Au	2
Beekeeper	Au,Hg,Cu	3
Shiko Lake	Cu,Au	4
Gavin Lake	Cu,Mo	5
Megabuck	Cu,Au	6
Vuggy quartz-calcite veinlet epithermal occurrence	Au	7

Historic placer workings

Black Creek (active)	1
Hobson's Hydraulic mine	2
Ward's Horsefly mine	3
Antoine Creek	4
Choate (west) Creek	5
China Cabin Creek	6

lenses of pebble-bearing wacke and conglomerate derived predominantly from pyroxene basalt and containing limestone and shale chips.

Unit 1A: A subunit restricted to an eruptive centre and coarse clastic wedge in the Viewland Mountain area. Conglomerate and sandstone in the northwest, pyroclastic breccia and autobrecciated flows and/or small intrusions in the southeast, forming Viewland Mountain. The unit forms a northward-thickening coarse clastic wedge or slope-base debris flow/fanglomerate deposit. Predominantly pyroxene basalt clasts, but polylithic with some feldspathic rocks and hornblende-bearing latite or monzonite debris. This unit represents the first, more evolved and differentiated alkalic eruptive cycle in the overall basaltic succession.

Unit 2A: Dark green olivine-bearing, pyroxene-phyric basalt flows, flow breccia, pillow lava and pillow breccia. Locally extensively chloritized with abundant calcite veinlets. Some flows contain granular aggregates and skeletal cumulophyric grains of analcite. In the upper part of the unit flows are commonly vesicular and extensively zeolitized. Zeolites present are laumontite, thompsonite and scolecite. Rocks of this unit are present as members in the uppermost part of Units 1 and 1A where they commonly form pillow basalt flows or domes and pillow breccia units. In some places, especially in the northwest to the north of Beaver Creek, there is extensive interfingering of Units 1 and 2A. Locally the unit contains abundant small lenses of mafic wacke containing limestone clasts.

Unit 2B: Dark green and purple, medium to coarse pyroxene-phyric basalt breccia and flows. Lithic lapilli ash tuffs and mafic wacke are commonly interbedded with flow units and breccias. Some members contain fine to medium-grained plagioclase laths.

Unit 2C: Grey, grey-green, purple to maroon polylithic mafic breccia; in large part derived from lahar or debris flow deposits. Contains some feldspathic, monzonitic clasts. Reworked conglomeratic deposits occur locally.

Unit 2D: Pyroxene basalt, breccia, tuff; pyroxene-rich wacke.

Unit 2E: Grey-green and dark purple to purplish brown analcite-bearing pyroxene-phyric basalt flows and flow breccia. This unit is characterized by fine to very coarse-grained, white, buff or salmon-pink euhedral analcite phenocrysts and coarse-grained pyroxene. Locally, plagioclase laths are also present; elsewhere pyroxene dominates and analcite is rare or absent. Some basal units contain analcite crystal ash and lapilli tuffs. **$2E_1$**: Dark green to grey-green, aphanitic to very fine-grained basalt, with sparse pyroxene phenocrysts forms a small body unique to the map area, possibly an intrusive plug or neck.

Unit 2F: Dark grey to brown sandstone and siltstone derived from mafic volcanics. Silty limestones or calcareous siltstones are common. The rocks are fetid and contain fine sulphide grains. A benthonic bivalve assemblage is relatively common.

Unit 2G: Grey, feldspar-pyroxene-phyric basalt flows and flow breccia. Autobrecciated flow tops and margins have a crystalline limestone matrix. Limestone lenses commonly contain volcanic clasts and pyroxene grains as well as crinoid columns, coral and fragments of bivalves. At the Shiko Lake prospect this unit contains two lenses of felsic to intermediate polylithic breccia that might be in part intrusive or are extrusive precursors of the Shiko stock.

Unit 2H: Fine-grained sandstone, siltstone, and calcareous siltstone; contains carbonaceous wood debris and fragments of ammonites, bivalves, corals and gastropods. **$2H_1$**: Thinly bedded, fine-grained sediments. The unit contains limestone, tuffaceous beds, conglomerate with chert and limestone clasts and locally polymictic breccia and flow breccia of pyroxene hornblende basalt.

Unit 3: Breccia; maroon, purple, lavender and grey polylithic breccias containing mafic and felsic clasts. Felsic clasts are alkali-feldspathic latite or monzonite species. Locally slumping has produced reworked breccia and lithic tuff beds, some with calcareous matrix or limestone matrix breccia. **3A**: Hornblende-phyric andesite flows; platey and moderately zeolitized.

Unit 4: Dark grey, grey-green to maroon pyroxene-phyric basalt flows and flow breccia. Locally contains fine-grained analcite; generally zeolitized and amygdaloidal.

Unit 5: This unit is not recognized in the map area. It occurs further to the north along the Quesnel River where it has been described by Bailey (1988).

Unit 6: Conglomerate with clast-supported cobbles of chert, limestone, siltstone, sandstone and rare greenstone. The santly matrix contains ferruginous carbonate cement that commonly weathers rusty orange. Conglomerate and sandstone of similar composition, but strongly oxidized to form red beds, occurs along Beaver Creek and is shown on Figure 1-18-2 as Unit 6?

Unit 7: Diorite and monzonite intrusions; plutons, stocks and dykes. Grey to pink, medium-grained equigranular to porphyritic rocks; coarse-grained hornblende porphyry and very coarse poikilitic syenite occur as dykes and small plugs. Locally mafic phases of pyroxenite and hornblendite are developed within stocks or along their contacts.

Unit 8: Grey fine-grained quartz diorite to medium-grained granodiorite; dykes may be leucocratic. Commonly weathers rusty coloured.

Unit 9: Pale grey to buff and yellow, thin-bedded and varved lacustrine siltstone and sandstone with floral debris and rare fish imprints. The unit contains some tuffaceous beds and locally has a basal polymictic cobble conglomerate.

Unit 9B: Grey to pale violet plagioclase crystal ash tuff. Breccia is present in the north; platey, strongly epidotized, massive to thin-bedded, dust and ash tuff or epiclastic deposits in the south. A weak compaction or flow foliation is evident in ash flows as well as a pervasive deuteric alteration that produces chloritization and hematite alteration of mafic minerals.

Unit 10: Plateau basalt. Dark grey to black alkali olivine basalt flows approximately 80 metres in thickness. The base of the flows occurs at an approximate elevation of 880 metres.

Unit 10A: River channel gravel deposits underlying plateau basalt flows. The gravels contain abundant white quartz detritus; locally calcite-cemented conglomerate marks the basal contact.

TABLE 1-18-1
POTASSIUM-ARGON DATA, BEAVER CREEK – HORSEFLY RIVER

Sample Number	Location (UTM)	Lithology	Material Analysed	% K	Ar^{40*} 10^{-10} (moles/gm)	$\frac{Ar^{40*}}{\text{Total } Ar^{40}}$	Apparent Age (Ma)
87AP-3/1-4	603440E, 5799080N	Unit 9B	biotite	7.250±0.020	6.662	93.2	52.2±1.8
87AP-6/3-16	605670E, 5799080N	Unit 3A	hornblende	0.642±0.240	2.181	97.2	186±0.5
87AP-18/8-44	601710E, 5797170N	Unit 10	whole rock	0.722±0.008	0.1838	33.4	14.6±0.5

The units described above comprise the Quesnel belt. They are in fault contact with Unit CC, Cache Creek graphitic shales and calcareous siltstone. All bedrock units are covered extensively by glacial and fluvioglacial deposits and alluvium (Qal). Thick valley fill in the upper reaches of the Horsefly River, between Horsefly village and Antoine Creek and to the northwest, and along Beaver Creek, mark the main Pleistocene meltwater channelways. Elsewhere a relatively thin but persistant veneer of glacial deposits and alluvium covers the gently rolling terrain. The most common ice-movement direction is 305 degrees.

AGE OF MAP UNITS

The age of the volcanic arc rocks and underlying sediments ranges from Middle Triassic to Early Jurassic (Campbell, 1978; Struik, 1986). Bailey (1988) and Panteleyev (1988) have summarized faunal evidence for a Norian to possibly Late Hettangian age for Unit 2. Conodonts have been described by Dr. Michael Orchard, Geological Survey of Canada, from one of the 15 samples collected from the map area by the writer. The sample from Unit 1, 1.5 kilometres to the west-southwest of Antoine Lake, contains the conodont taxa *Epigondonella* cf. *E. abneptis* Huckriede and *Neogondonella* species. This confirms a Late Triassic, probably early Norian age for the limestone clasts in this conglomerate member.

Radiometric data from diorite-monzonite plutons intruding Unit 2 rocks range from 186 to 201 Ma (Panteleyev, 1987 and 1988). A new potassium-argon date of 186 Ma (Table 1-18-1) confirms the Early Jurassic age of Unit 3A volcanic rocks, but suggests that they may be younger than the "probably Sinemurian" age considered by Bailey (1988) for Units 3 and 4.

Tertiary rocks have been dated both radiometrically and by palynomorphs. Bedded lacustrine sediments of Unit 9A/B along Hazeltine Creek near Quesnel Lake have been shown by palynomorphs to be equivalent to the Middle Eocene rocks (Panteleyev, 1987) of Unit 9A. Dr. Glen Rouse of The University of British Columbia has identified diagnostic 48 to 52 Ma palynomorphs from Unit 9A/B as shown in Table 1-18-2. The crystal ash tuffs and conglomerates of Unit 9B overlie these Middle Eocene sediments. The biotite latite platey lavas of Unit 9B have been dated to be Middle Eocene, 52.2±1.8 Ma (Table 1-18-1). Debris of this unit is contained in the basal conglomerate of Unit 9A.

A whole-rock radiometric sample of alkali olivine basalt of Unit 10 gives a Middle Miocene date of 14.6±0.5 Ma. (Table 1-18-1). These flows overly the extensive white-quartz-cobble-bearing gravel channels of Unit 10A. The channels are developed within and follow the distribution of the Middle Eocene lacustrine sediments of Unit 9A. This dating confirms the wisdom of the ancient placer miners who regarded the white-quartz channels to be Miocene and considered them to be the sources of some of the younger reworked placers of glacial and postglacial origin.

STRUCTURE

The major regional structures in the area are a northwesterly trending, extensively block-faulted syncline in the volcanic axis of the Quesnel belt and a broad anticlinal structure in sedimentary rocks of Unit 1 in the northeast corner of the map area. The basal sedimentary rocks of Unit 1 crop out in the eastern and western parts of the area mapped and, together with the intervening 15 to 20-kilometre-wide volcanic arc deposits of Units 2 to 4, define a broad structural depression, truly a "Quesnel Trough". Superimposed on the northwesterly trending Triassic-Jurassic volcanic belt is a north-northwesterly trending depression, probably a series of connected grabens, filled by Middle Eocene sediments, subaerial volcanics and isolated remnants of a once-continuous thin cover of Miocene plateau basalts. The Middle to Late Tertiary depression is now extensively infilled by glacial and fluvioglacial deposits.

Folding is most evident in sedimentary units, especially at deeper structural levels, as described by Bloodgood (1987). The sedimentary rocks of Unit 1 north and south of Horsefly Lake display open, upright asymmetrical folds with steep

TABLE 1-18-2
LIST OF PALYNOMORPHS FROM SAMPLE 87AP 32/4-99

angiosperm pollen
- *Rhoipites retipillatus*
- *Pistillipollenites mcgregori*
- *Carpinpites ancipites*
- *Quercus shiabensis*
- *Araliaceoipollenites granulatus*

conifer pollen
- *pinus haploxylon* type
- *P. diploxylon* type
- *Picea grandivescipites*
- *Tsuga phyllites*
- *Keteleeria* sp.

fungal spores
- *Granatisporites cotalus*
- *Rhizophagites cerasiformis*
- Fungal hypha – type C of Norris

algal cyst
- *Lejeunia hyalina*

southwest limbs and moderately dipping northeast limbs. In the more thinly bedded successions, folds may be tight to isoclinal. There is no widespread penetrative deformation evident; in places an axial planar spaced cleavage is developed. A second phase of broad, open folding or large-scale warping about northeasterly-trending axes is superimposed on the major folds. It modifies the overall northwesterly trending fold pattern. The overlying volcanic rocks display little or no folding. They form thick, poorly stratified panels that are tilted and rotated by numerous block faults.

Faults dissect the area mapped along two dominant trends – northwesterly and northeasterly. The former are the older set, probably Middle to Late Jurassic in age and related to the first period of major compressive, subduction-related deformation. Many have been reactivated, possibly during the second phase of northeasterly faulting. It is likely that many of the map unit boundaries shown in Figure 1-18-2 as lithologic contacts are faulted. The only thrust fault or steepened reverse fault noted is between Horsefly and Quesnel Lakes to the north of Viewland Mountain. There the folds in Unit 1 verge southwesterly and the rocks are thrust onto rocks of Units 1A and 2A.

A long-lived, reactivated fault zone along Beaver Creek forms the southwestern and western map boundary. It marks the contact between Mesozoic volcanic and Cache Creek rocks along what is most probably a right-lateral fault of major regional extent. Later reactivation, probably related to Tertiary extentional tectonism, emplaced younger volcanic units ($2H_1$ and 6?) into the resulting graben – now marked by the Beaver Valley. This structural zone was again reactivated in the Late Tertiary with uplift of the north side. This uplift formed a highland buttress against which the Miocene plateau basalt was deposited. The basalt now forms a "rim rock" wall along almost the entire length of lower Beaver Creek.

The youngest faults also trend northwesterly and northeasterly, and are possibly reactivated older structures. They control the distribution of the inliers of Teriary flows and ash flows of Unit 9B (Figure 1-18-2). The distribution of Middle Eocene rocks outlines a north to northwesterly trending, broad, shallow basin or series of interconnected basins along the upper Horsefly River – Antoine Creek axis. This zone remained a depression during much of the Tertiary and was the site of sedimentation in a shallow lake followed by deposition of volcanic rocks in locally developed grabens. The area remained as a (fault-bounded?) depression into the Late Tertiary when it was flooded by Miocene basalt flows.

MINERALIZATION

No lode metal deposits have been worked in the area nor are economic reserves known to be present in any of the gold or copper-gold prospects. However, in 1859 the Horsefly area was the scene of some of the first placer gold mining in the Cariboo (Holland, 1950). Significant gold (over 465 kilograms recorded) was won from underground and hydraulic workings at the Hobson's Horsefly and Ward's mines near the village of Horsefly (Figure 1-18-2). Placer activity has been recorded in a number of other areas including Antoine, Beaver (Lake), Black, China Cabin and Moffat creeks. In addition, some small-scale, unrecorded mining has been done by local residents on Parminter and 'West' (Choate-Teasdale) creeks, both tributaries to Beaver Creek. Black Creek is the only active placer mine in the area.

Lode sources of the placer gold remain unknown. Much, possibly all, of the gold was originally transported within the Miocene white-quartz channelways of Unit 10A. Most deposits, such as Black and Antoine creeks, represent reworked placers in which gold is reconcentrated in Pleistocene fluvioglacial channelways which have cut into or through the Miocene gravels. These placers are similar in age to other deposits in the Cariboo district. They are related to pre or post-Wisconsin glacial gravels, generally 59 000 Y.B.P. in age or younger (Eyles and Kocsis, 1988; Clague, 1987). In contrast, gold at the Hobson mine and possibly some other Horsefly River deposits was recovered directly from the calcite-cemented basal part of the Miocene gravels.

The source of the white quartz pebbles and cobbles and the associated gold has long been speculated to be metamorphic terranes, possibly in the Eureka Peak – Crooked Lake – Horsefly River headwaters to the southeast (93A/7) or even further east. A metasedimentary, high-grade metamorphic source is consistent with samples of panned or sluiced concentrates taken from most of the placer creeks and two road cuts in the Miocene gravels. The samples are remarkably consistent. The heavy concentrates are notably lacking in black sand but contain abundant ruby-red garnet and kyanite as well as rare zircon, scheelite and pseudobrookite in addition to relatively common epidote, pyroxene, hornblende and biotite. The light fraction contains abundant white mica as well as quartz and feldspar. Contrary to the suggestions in Geological Fieldwork, 1987 (Panteleyev, 1988) based on older Ministry reports, Antoine and Beaver Creek samples are similar to the other placer pan-samples and do not appear to be derived from a different source.

Exploration for lode gold and copper-gold deposits has concentrated on intrusion-related alteration zones within and peripheral to the Early Jurassic alkalic intrusions at Lemon, Shiko and Kwun lakes. Exploration targets are auriferous porphyry copper mineralization similar to the Cariboo-Bell deposit (Hodgson *et al.*, 1976) and gold in propylitic alteration zones in basalts such as at the QR deposit (Fox *et al.*, 1987; Melling and Watkinson, 1988).

Younger porphyry-style mineralization is found in the Cretaceous(?) copper-molybdenum-bearing Gavin Lake granodiorite stock and in Eocene rocks at the Megabuck prospect, 8 kilometres south of Horsefly. At Megabuck, a quartz stockwork zone contains chalcopyrite, pyrite, magnetite and epidote. Elsewhere on the property the extensively epidotized rocks are sericitized and cut by veinlets and small breccia bodies with quartz, black tourmaline and pyrite. The Eocene age of the Megabuck host rocks is established by geologic mapping and lithologic correlation with identical, dated rocks of Unit 9B to the north. The mineralization cannot be related to the nearby Early Jurassic Takomkane batholith nor Cretaceous quartz monzonites like those of the Boss Mountain stock to the south (Soregaroli and Nelson, 1976). Similar quartz-carbonate veinlets and stockworks occur in Eocene rocks of Unit 9A/B along Hazeltine and Edney creeks near the northern edge of the map area (Occurrence 7, Figure 1-18-2).

Elsewhere in the area mapped, there are widespread indications of hydrothermal activity in fault and fracture zones. However, the presence of olivine as remnant, partially replaced grains in basalts and the pristine, unaltered nature of pyroxene and analcite crystals in many of the volcanic units, attests to the lack of pervasive alteration in most of the volcanic succession. Similarily, the conodont alteration index (CAI) of 2 to 3 (M. Orchard, personal communication, 1988) indicates the relatively low thermal maturation conditions in sedimentary rocks of Unit 1 near Antoine Lake. Also, palynomorphs from the vicinity of quartz-carbonate veinlets in lacustrine sediments of Unit 9A (Occurrence 7, Figure 1-18-2) have an estimated maximum temperature of about 200°C based on thermal maturation (G. Rouse, personal communication, 1988).

The evidence therefore, based on geological mapping, petrography and alteration assemblages suggests that thermal conditions capable of supporting any significant hydrothermal activity are restricted to the Jurassic and Cretaceous(?) intrusive centres and Eocene grabens containing volcanic deposits. Elsewhere alteration, mainly zeolite, calcite, quartz, chlorite and epidote in fracture zones, faults and some of the permeable pyroclastic units, indicates some potential for low-temperature gold and possibly mercury deposits.

ACKNOWLEDGMENTS

The authors thank Mr. Lyle Shunter for conducting a tour of the Black Creek placer workings and for providing access through his property. During this and previous field seasons, Doctors Howard Tipper and Michael Orchard, Geological Survey of Canada, have provided prompt fossil identifications and discussions that greatly assisted geological interpretation and further mapping. Dr. Glen Rouse, The University of British Columbia, provided rapid, authoritative palynological results. Susan and Bill Hall, Horsefly residents, provided amiable accommodation at the Birch Bay Resort but more significantly, volunteered invaluable information about access roads, outcrop locations, history, culture and mining lore of the region.

REFERENCES

Bailey, D.G. (1976): Geology of the Morehead Lake Area, Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 20 with Notes.

——— (1978): The Geology of the Morehead Lake Area, South-central British Columbia, Unpublished Ph.D. Thesis, *Queens University*, 198 pages.

——— (1988): Geology of the Eastern Quesnel Belt (93A/12), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 147-153.

Bloodgood, M.A. (1987): Geology of the Triassic Black Phyllite in the Eureka Peak Area, Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 135-142.

——— (1988): Geology of the Quesnel Terrane in the Spanish Lake Area, Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 139-145.

——— (1989): Geology of the Eureka Peak and Spanish Lake Areas, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-2, in preparation.

Campbell, R.B., (1978): Quesnel Lake 93A Map-area, *Geological Survey of Canada*, Open File Map 574.

Clague, John J. (1987): A Placer Gold Exploration Target in the Cariboo District, British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 1987-1A, pages 177-180.

Eyles, N. and Kocsis, S.P., (1988): Gold Placers in Pleistocene Glacial Deposits; Barkerville, British Columbia, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 81, pages 71-79.

Fox, P.E., Cameron, R.S. and Hoffman, S.J. (1987): Geology and Soil Geochemistry of the Quesnel River Deposit, *in* GEOEXPO '86, Proceedings, *Associaton of Exploration Geochemists*, Vancouver, May, 1986, pages 61-71.

Hodgson, C.J., Bailes, R.J. and Verzosa, R.S. (1976): Cariboo-Bell, *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 388-396.

Holland, Stuart S. (1950): Placer Gold Production in British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 28, 89 pages.

Melling, D.R. and Watkinson, D.H. (1988): Alteration of Fragmental Basaltic Rocks: Quesnel River Gold Deposit, Central British Columbia (93A/12W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 335-347.

Morton, R.L. (1976): Alkalic Volcanism and Copper Deposits of the Horsefly Area, Central British Columbia, Unpublished Ph.D. Thesis, *Carleton University*, 196 pages.

Panteleyev, A. (1987): Quesnel Gold Belt – Alkalic Volcanic Terrrane Between Horsefly and Quesnel Lakes, 93A/6, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 126-133.

——— (1988): Quesnel Mineral Belt – The Central Volcanic Axis Between Horsefly and Quesnel Lakes, 93A/5E, 6W, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 131-137.

Soregeroli, A.E. and Nelson, W.I. (1976): Boss Mountain, *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 432-443.

Struik, L.C. (1986): Imbricated Terranes of the Cariboo Gold Belt with Correlations and Implications for Tectonics in Southeastern British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, Number 8, pages 1047-1061.

Tipper, H.W., Woodsworth, J.G. and Gabrielse, H. (1981): Tectonic Assemblage Map of the Canadian Cordillera, *Geological Survey of Canada*, Map 1505A.

GEOLOGY OF THE CENTRAL QUESNEL BELT, SWIFT RIVER, SOUTH-CENTRAL BRITISH COLUMBIA (93B/16, 93A/12, 93G/1)

By D.G. Bailey
Bailey Geological Consultants (Canada) Ltd.

KEYWORDS: Regional geology, economic geology, Barkerville terrane, Swift River, stratigraphy, Upper Triassic, Lower Jurassic, alkalic plutons, porphyry copper.

INTRODUCTION

In 1988 regional mapping of the central Quesnel belt (the Quesnel Project; Panteleyev, 1987, 1988; Bailey, 1988; Bloodgood, 1988) continued in the Horsefly area (Panteleyev and Hancock, 1989, this volume) and in the Swift River area, north of the Quesnel River (Figure 1-19-1). In the latter area the Mesozoic stratigraphy was mapped to north of the Quesnel-Barkerville Highway (Figure 1-19-2) where the volcanic element of the stratigraphy lenses out. Upper Triassic pelitic and psammitic sedimentary rocks, equivalent to Bloodgood's (1988) Units 5 to 7 which underlie the Mesozoic volcanic rocks, continue to the north.

The area described in this report includes most of map sheet 93B/16, the northern part of 93A/12 and the south-eastern part of 93G/1 and extends northward from the Hydraulic area mapped in 1987 (Bailey, 1988). The west-central part of the map area is partly compiled from detailed mapping in the Cantin Creek area by Lu (1989, this volume).

In the Swift River area Mesozoic outcrop is extremely sparse and geological interpretation relies to a large extent on the stratigraphic relationships determined in the Hydraulic area to the south and the aeromagnetic patterns of the various rock units. Nevertheless, the pattern of outcrop distribution is consistent with the geology of both the Hydraulic (Bailey, 1988) and Horsefly (Panteleyev, 1988) areas; volcanic rocks exhibit a regional synformal structure with local modifications. Intermediate to felsic volcanic rocks occupy the central part of the synform and mafic rocks are exposed on the limbs. The basal sedimentary rocks are more asymmetrically distributed with finer grained varieties more common to the east ("phyllites" of Struik, 1983, and Bloodgood, 1988) than in the west where psammite rather than pelite predominates. No attempt has been made to subdivide the basal sedimentary rocks (Unit 1) in the Swift River map area.

Mapping was carried out by pace-and-compass traversing, at intervals determined by the nature of the terrain and the relative abundance of outcrop interpreted from aerial photographs. Several all-weather roads and numerous logging roads and trails provide good access to most parts of the area.

STRATIGRAPHY

SEDIMENTARY AND VOLCANIC ROCKS

In general the stratigraphic succession in the Swift River area is the same as in the Hydraulic area. The lowermost rocks comprise Upper Triassic sandstone, siltstone and minor claystone with intercalated beds of mafic tuff and breccia. These volcanic beds occur throughout the sedimentary succession but become more common towards the top. Overlying the sedimentary rocks are basaltic volcanic rocks, also of Late Triassic age (probably Norian); the top of the volcanic suite is marked by a thin discontinuous limestone unit, the uppermost Triassic unit in the Mesozoic sedimentary-volcanic succession.

The Triassic stratigraphy is overlain by volcanic tuffs and breccias characterized by varying abundances of felsic material. These Lower Jurassic rocks are confined to the central volcanic axis of the belt. Middle Jurassic strata mapped in the Hydraulic area are interpreted to extend into the Swift River area, east of Maud Lake (Figure 1-19-2).

Tertiary rocks in the Swift River area are represented by Miocene plateau basalt, and sedimentary and volcanic rocks of possible Eocene age. A veneer of Pleistocene glacial and glaciofluvial deposits covers much of the area and, although probably thin, effectively masks underlying rocks.

Mapping conventions for the Triassic and Jurassic units in the Swift River area are the same for the Hydraulic area to the south, thus pyroxene basalt of Subunit 2A in the Hydraulic area is equivalent to Subunit 2A in this study. However, due

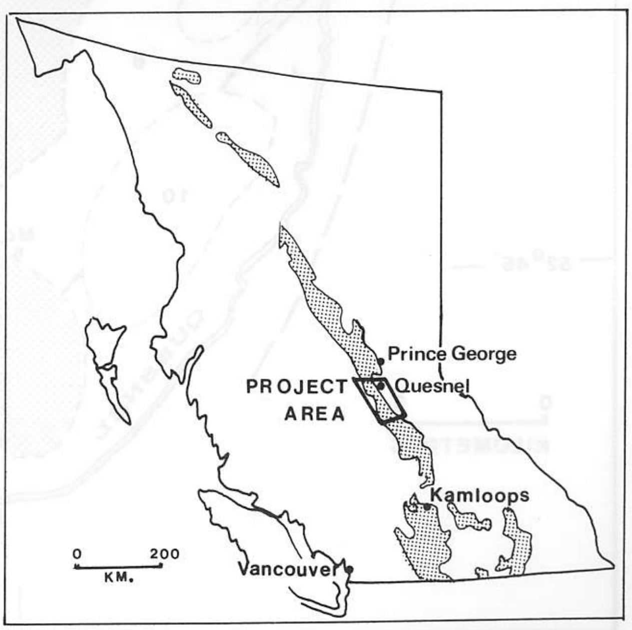


Figure 1-19-1. Location map, Swift River area. Quesnel belt and related Mesozoic volcano-sedimentary rocks shown stippled.

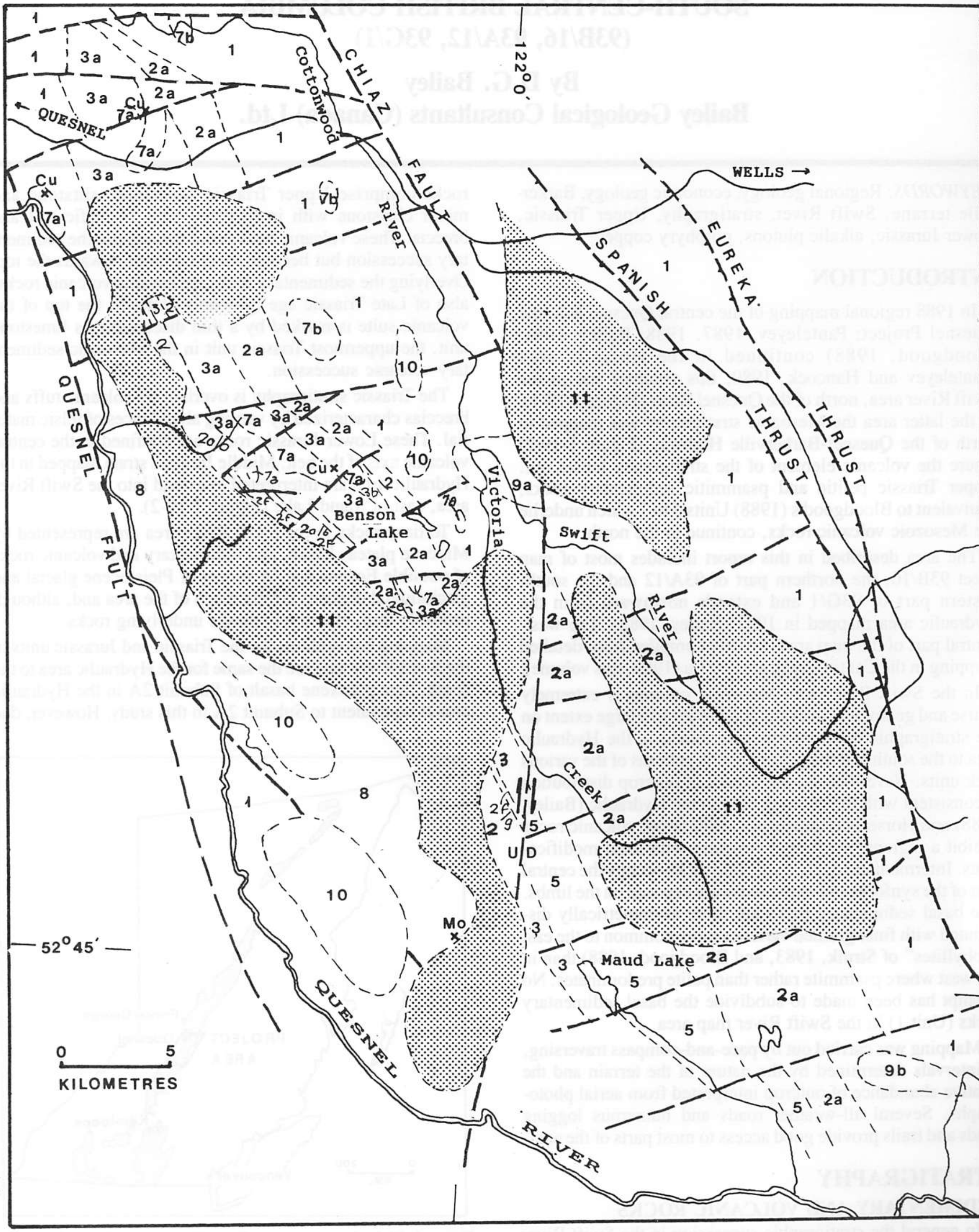


Figure 1-19-2. Geology of the Swift River area.

LEGEND

SEDIMENTARY AND VOLCANIC ROCKS

PLEISTOCENE

- **11** Glacial, fluvioglacial gravel and sand

MIOCENE

- **10** Alkali olivine plateau basalt

EOCENE

- **9b** Light grey latite tuff, tuff-breccia and autobreccia
- **9a** Light grey sandstone and mudstone

CRETACEOUS

JURASSIC

PLIENSBACHIAN

- **5** Dark to medium grey interbedded sandstone and siltstone

SINEMURIAN

- **3b** Reddish grey to maroon monolithic latite tuff and breccia
- **3a** Maroon polylithic breccia with feldspathic clasts

TRIASSIC

NORIAN

- **2g** Massive grey limestone and calcareous sandstone
- **2f** Interbedded mafic siltstone and sandstone
- **2e** Analcite-bearing maroon and grey basalt
- **2b** Maroon alkali basalt breccia
- **2a** Green and grey alkali and alkali olivine basalt

CARNIAN

- **1** Dark grey and green siltstone, sandstone, mafic tuff; minor conglomerate

INTRUSIVE ROCKS

- **8** Medium to coarse - grained granodiorite and quartz monzonite
- **7b** Pink and grey megacrystic syenite; minor hornblende gabbro and diorite
- **7a** Pink and grey, medium to fine-grained syenite, monzonite and diorite

SYMBOLS

- - - - Geological contact (inferred)

— — Fault (inferred)

× Mineral occurrence

Cu Copper

Mo Molybdenum

to the lack of Mesozoic exposures, the same degree of rock-type definition has not been achieved in the Swift River area and some distinct subunits such as 2C and 2D of Hydraulic have therefore been included within Subunit 2A.

Unit 1

This unit consists mainly of sedimentary rocks which, on the basis of conodonts collected from limestones to the southeast (Bloodgood, 1988) and macrofossils identified in the western part of the Hydraulic area (Bailey, 1988), is mainly of Upper Triassic age with perhaps some Middle Triassic (Anisian) strata at the base. The unit is dominated by dark grey to medium grey pelite with grey to green-grey interbeds of psammite. Graded bedding, scour-and-fill structures and trough crossbedding are commonly seen in areas of abundant outcrop such as along the banks of the Swift and Cottonwood rivers and, with few exceptions, indicate the unit is right way up.

Psammitic beds with a large basaltic tuff component, generally recognized by a green coloration, are common in the almost continuous outcrop along the Swift River gorge in the central part of the map area. Conglomerate beds in this area also contain volcanic debris in the form of pyroxene basalt clasts and tuffaceous partings in the matrix. Basaltic breccia deposits occur elsewhere within the sedimentary rocks of Unit 1. With two exceptions these deposits are too limited in extent to represent on a 1:50 000-scale map although they do appear to occur throughout the sedimentary sequence.

Light grey and orange rhyolite sills or dykes also outcrop in the Swift River gorge, cutting the sedimentary bedding at very shallow angles. Triassic-Jurassic rocks containing modal quartz are rare within the central Quesnel belt although rhyolite dykes have been recognized in outcrops along the Quesnel River to the west of the Hydraulic area and siliceous tuffs occur within Unit 1 sediments on Spanish Mountain (Bloodgood, 1988). The significance of these dykes and tuffs with respect to the evolution of the central Quesnel belt is not yet fully understood.

In places finer grained sediments of Unit 1 are calcareous, occurring as impure silty limestone and micritic siltstone. Limestones, such as those described by Bloodgood (1988) to the southeast, have not been recognized within Unit 1 in the Swift River area.

Unit 2

This unit represents the lowermost wholly volcanic unit in the Swift River area and is equivalent to Unit 2 in the Hydraulic (Bailey, 1988) and Horsefly (Panteleyev, 1988) areas. It consists of green and grey pyroxene basalt, pyroxene hornblende basalt and pyroxene olivine basalt (2A), usually in the form of monolithologic tuff breccias, pillow lavas, pillow breccias and autobrecciated flows. Overlying these rocks are maroon basaltic breccias of both polylithologic and monolithologic compositions (2B) representing shallow water or subaerial equivalents of the underlying green and grey basalt. Towards the top of the basaltic sequence is porphyritic analcite-bearing pyroxene basalt (2E), equivalent to that described by Bailey (1978) near Mount Polley in the Hydraulic area.

Thin maroon sandstone beds occur discontinuously at or near the top of the maroon basaltic breccia, along the strike of the volcanic belt in the Swift River area. Although included in Subunit 2F of Bailey (1988) because of its stratigraphic position, this unit may not have the same composition as Subunit 2F in the Hydraulic area. The top of the basaltic section is marked by a thin, light grey limestone unit (2G) which, however, only appears to occur on the western contact with overlying rocks of Unit 3.

Unit 2 is considered to be entirely of Late Triassic age (Norian) on the basis of fossil evidence in the Hydraulic area (Bailey, 1988). No fossils have been identified in these rocks in the Swift River area.

Unit 3

Whereas Unit 2 is mainly basaltic in composition, Unit 3 is characterized by felsic rocks as well as basaltic debris derived from the underlying unit. In the Swift River area Unit 3 comprises polylithologic breccias (3A) and minor amounts of monolithologic breccia of Subunit 3B.

Subunit 3B represents the direct products of felsic volcanism while the much more voluminous Subunit 3A is considered to have resulted from laharic activity along the flanks of volcanic edifices. Subunit 3A contains material from all underlying rock types together with clasts of syenite, monzonite, monzodiorite and diorite, and extrusive equivalents of these rock types. Without exception, Unit 3 is distributed along the axis of the Swift River area volcanic belt.

Based on paleontological evidence in the Hydraulic area (Bailey, 1988) the age of Unit 3 is probably Sinemurian (Early Jurassic), indicating a possible depositional hiatus of several million years between Unit 2 and Unit 3.

Unit 5

Unit 5 has a similar composition to Unit 1 consisting of dark to medium grey, commonly pyritic, psammite and pelite. Although unfossiliferous, the outcrop distribution suggests these rocks are equivalent to similar sedimentary rocks which outcrop to the southeast, along the Quesnel River near Likely. The contact of Unit 5 with underlying rocks of Unit 2 is either an unconformity or a fault.

The presence of *Arieticeras* sp. collected from Unit 5 in the Likely area (R.B. Campbell, personal communication, 1976) indicates these rocks are of Pliensbachian age. Unit 4, a maroon analcite-bearing basaltic unit stratigraphically lower than Unit 5 in the Hydraulic area, is absent in the Swift River area.

Unit 9

A sequence of light grey mudstones and sandstones (9A), which Struik (1987) considered to be of Eocene age, crops out along part of the Swift River and Victoria Creek. Lithologically these rocks are similar to sedimentary rocks exposed along the Horsefly River (Panteleyev, 1988) from which Middle Eocene fish fossils have been obtained (Wilson, 1977a, 1977b). Along Victoria Creek these strata dip gently east, in contrast to the steeply dipping underlying Mesozoic sedimentary rocks.

A succession of latite tuff, polylithologic and monolithologic breccias mainly of latitic composition, and minor autobrecciated latite flows (9B) is exposed near Kangaroo Creek in the southeastern part of the map area. These rocks overlie sedimentary rocks of Unit 1 and are spatially unrelated to felsic volcanic rocks of Unit 3. Although it is conceivable they represent a separate Sinemurian (Unit 3) volcanic centre, the writer considers it more likely they are equivalent to biotite-bearing Eocene volcanic rocks described by Panteleyev (1988) in the Horsefly area. However, biotite is absent in volcanic rocks in the Kangaroo Creek area; in this respect they are more similar to latitic rocks of Unit 3.

Unit 10

This unit consists of olivine basalt flows, remnants of plateau basalt which covered much of the Quesnel region during Miocene time. In the Swift River area flow-top breccias and columnar jointing are well developed in Unit 10 which provides a subhorizontal capping to hills in the central and southwestern parts of the area.

Unit 11

This unit comprises the unconsolidated deposits of Pleistocene glacial and fluvioglacial processes and covers much of the map area. Although commonly consisting of a thin veneer of till, these deposits have attained thicknesses of greater than 150 metres in incised river valleys such as that of the Quesnel River. Direction of transport of these deposits was commonly between about 300 and 310 degrees.

INTRUSIVE ROCKS

Unit 7

Unit 7, comprising stocks of syenite, monzonite and diorite, is subdivided into two subunits. Subunit 7A consists of generally fine-grained, nonporphyritic grey monzonite, diorite and pink syenite which have intruded the Triassic-Jurassic volcanic stratigraphy. Almost all of these stocks have associated pyrite-chalcopyrite mineralization with attendant propylitic alteration halos. Subunit 7B consists mainly of stocks of a distinctive grey porphyritic syenite with very large (up to 10 centimetres in length) feldspar phenocrysts; these rocks are only seen intruding sedimentary rocks of Unit 1.

A stock of Subunit 7B, in which porphyritic syenite has been intruded by diorite and later by coarse-grained hornblende pyroxene gabbro, outcrops along the Cottonwood River. In places the mafic rocks are intensely chloritized although the syenite has remained relatively unaltered.

The age of Subunit 7A is considered to range from late Early Jurassic to Middle Jurassic on the basis of stratigraphic evidence and radiometric dates from similar plutons to the south. However, whether Subunit 7B is the same age is not known at this time. Hornblende from gabbro of the Cottonwood River stock has been collected for radiometric dating but results are not yet available.

Unit 8

A large granodiorite and quartz monzonite pluton extends along the southwestern corner of the Swift River area and into the Hydraulic map area (Bailey, 1988). It is similar in composition to Cretaceous plutons elsewhere in the region and is also assumed to be Cretaceous.

STRUCTURE AND METAMORPHISM

The structural geology of the Swift River area is similar to that of the Hydraulic area to the south (Bailey, 1988) and is related to collision of Quesnellia with the Omineca crystalline belt to the east and to a later period of crustal extension. The accretion of Quesnellia onto the Mesozoic North American margin is only recorded in the easternmost rocks of Unit 1 in the Swift River area. Here northwest-striking folds (F_1), with an accompanying well-developed axial planar fabric, have been refolded about northeast-striking axes (F_2). Although F_2 folding does not appear to have been accompanied by penetrative deformation, an S_2 crenulation cleavage is commonly associated with F_2 folds. This style of deformation is similar to that described by Bloodgood (1988) in the Spanish Lake area.

Deformation of the easternmost rocks of Unit 1 has resulted in the formation of phyllite in fine-grained carbonaceous sediments. The occasional development of chlorite along foliation planes suggests greenschist facies of regional metamorphism has been attained in this area.

The contact of Unit 1 sedimentary rocks with the older crystalline rocks of the Omineca Belt is marked by the Eureka thrust (Struik, 1983). Rocks in the footwall of the thrust comprise metasedimentary rocks of the Barkerville terrane.

Struik has mapped a second thrust fault, the Spanish thrust, within Unit 1 metasedimentary rocks. The location of these thrusts, compiled from Struik (1987), is shown in Figure 1-19-2.

Northeasterly striking faults are inferred throughout the Swift River area, cutting the Mesozoic stratigraphy. Although none of these faults has been directly observed, their presence is suggested by aeromagnetic patterns and outcrop distribution. It is not clear whether they cut the thrust faults which bound the eastern part of the central Quesnel belt. Bloodgood (1988) has mapped northeasterly striking faults within the Barkerville terrane of the Spanish Lake area but there is little evidence for offset of the Eureka thrust itself.

Northeasterly striking faults are interpreted to cut late Lower Jurassic to Middle Jurassic rocks but not rocks interpreted to be Cretaceous and younger. In contrast, northerly to northwesterly striking faults in the Swift River area, named here the Quesnel and Chiaz faults, have cut rocks assumed to be of Cretaceous age but not Miocene plateau basalt. The Chiaz fault cuts obliquely through the volcanic axis of the central Quesnel belt in the Swift River area with minimum dextral displacement of about 4 kilometres. The distribution of outcrops of Triassic basalt on either side of the fault suggests 5 kilometres of relative uplift on the west side of the fault. The trace of the Chiaz fault zone, which is exposed in the Swift River valley, is well displayed on the regional aeromagnetic map.

Metamorphism of Mesozoic rocks in the Swift River area is typical of the zeolite facies of regional metamorphism. Contact metamorphic effects have occurred around several plutons, with the development of biotite hornfels where stocks have intruded sedimentary rocks of Unit 1. Where stocks have intruded volcanic rocks contact metamorphic effects are not obvious, perhaps because these rocks were less reactive or because contact metamorphic effects have been obliterated by later metasomatic overprinting.

MINERALIZATION

The porphyry copper potential of the central Quesnel belt has long been realized and most of the larger Jurassic alkaline stocks have been explored. The Cariboo Bell deposits in the Polley stock of the Hydraulic area (Bailey, 1988) are by far the largest porphyry copper deposits discovered to date, but almost all stocks within felsic rocks of Unit 3 have associated copper mineralization.

In the Swift River area copper mineralization is known in stocks south of Benson Lake, at Cantin Creek and at Mouse Mountain in the northern part of the map area (Figure 1-19-2). Copper is invariably chalcopyrite with minor bornite and occasional chalcocite. Pyrite is always present, both with chalcopyrite and as a pyritic-propylitic halo around zones of copper mineralization. Magnetite is also ubiquitous and magnetic patterns are important indicators of the presence of stocks in overburden-covered areas.

Copper deposits associated with alkaline felsic stocks are commonly enriched in gold relative to porphyry deposits in calcalkaline intrusions. The QR deposit in the Hydraulic area (Bailey, 1988) comprises gold-bearing pyrite mineralization with associated chalcopyrite within a zone of intensely propylitized basaltic breccia marginal to an alkaline felsic stock. The reactive nature of the rocks was probably caused by the presence of abundant carbonate in marine sediments in which the basaltic breccias were deposited, and also by post-depositional carbonate metasomatism. Given the very poor exposure in the Swift River area and the fact that most drilling has been within the felsic stocks themselves, there is potential for new discoveries similar to the QR deposits which are more related to exoskarns than to porphyry systems.

In addition to copper mineralization associated with alkaline felsic stocks intruding felsic volcanic terrain, minor pyrite-chalcopyrite mineralization occurs in a small stock which has intruded sedimentary rocks east of Benson Lake. The general lack of sulphide mineralization around stocks of Subunit 7B may perhaps be attributed to depth of intrusion, a factor in the formation of hydrothermal systems. The lack of suitable source rocks may also be a contributing factor.

Minor molybdenite mineralization was discovered in granodiorite of Unit 8 during exploration of this stock in the early 1970s.

ACKNOWLEDGMENTS

Giovanni Pagliuso is thanked for his enthusiastic and uncomplaining assistance during the mapping program. Maps supplied by Dr. Peter Fox of Fox Geological Consultants Ltd. were of great help in locating outcrops in heavily wooded and till-covered terrain and were much appreciated.

REFERENCES

Bailey, D.G. (1978): The Geology of the Morehead Lake Area, South-central British Columbia, Unpublished Ph.D. Thesis, *Queen's University*, 198 pages.

——— (1988): Geology of the Central Quesnel Belt, Hydraulic, South-central British Columbia (93A/12), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 147-153.

Bloodgood, M.A. (1988): Geology of the Quesnel Terrane in the Spanish Lake Area, Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 139-145.

Lu, J. (1989): Geology of the Cantin Creek Area, Quesnel River (93B/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, This Volume.

Panteleyev, A. (1987): Quesnel Gold Belt–Alkalic Volcanic Terrane between Horsefly and Quesnel Lakes, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 126-133.

——— (1988): Quesnel Mineral Belt–the Central Volcanic Axis between Horsefly and Quesnel Lakes (93A/05E, 06W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 131-137.

Panteleyev, A. and Hancock, K.D. (1989): Quesnel Mineral Belt–Summary of the Geology of the Beaver Creek–Horsefly River Map Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1988, This Volume.

Struik, L.C. (1983): Bedrock Geology of Spanish Lake (93A/11) and Parts of Adjoining Map Areas, Central British Columbia, *Geological Survey of Canada*, Open File Map 920.

——— (1987): Bedrock Geology, Swift River, *Geological Survey of Canada*, Open File Map 858.

Wilson, M.V.H. (1977a): Paleoecology of Eocene Lacustrine Varves at Horsefly, British Columbia, *Canadian Journal of Earth Sciences*, Volume 14, pages 953-962.

——— (1977b): Middle Eocene Freshwater Fishes from British Columbia, *Royal Ontario Museum*, Life Sciences Contributions, Volume 113, pages 1-61.

GEOLOGY OF THE CANTIN CREEK AREA QUESNEL RIVER (93B/16)

By J. Lu; Visiting Scholar, Ministry of Metallurgical Industry, Hefei Peoples' Republic of China

KEYWORDS: Regional geology, Quesnel belt, Cantin Creek, stratigraphy, lithogeochemistry, alteration, gold.

INTRODUCTION

The Cantin Creek map area lies in the south-central part of the Quesnel belt, about 33 kilometres south of Quesnel and 55 kilometres northwest of Likely (Figure 1-20-1). It covers an area of approximately 100 square kilometres between latitudes 52°53′ and 53°00′ north and longitudes 122°22′ to 122°08′ west. The area was studied as part of a 4-year mapping project, the goal of which is to interpret the geological setting and evaluate the gold and copper resource potential along the central volcanic-intrusive axis of the Quesnel belt, (Bloodgood, 1987, 1988; Bailey, 1988; Panteleyev, 1988).

The Quesnel belt, previously known as the Quesnel trough, consists of Upper Triassic and Lower Jurassic basic to intermediate volcanic and volcaniclastic rocks, as well as coeval alkalic intrusions. The belt is bounded to the east by the Precambrian to Lower Paleozoic Snowshoe Group and to the west by the Permo-Carboniferous Cache Creek Group (Figure 1-20-2).

PREVIOUS WORK

The first geological investigation of the Quesnel belt dates back to 1887 when G.M. Dawson recognized Triassic volcanic rocks near Kamloops. Extensive regional mapping and local, detailed research were carried out only after the 1940s. In the 1970s, Fox (1975), Lefebure, Morton, Barr *et al.*, Hodgson *et al.*, (all 1976), Bailey (1978) and Preto (1979) described the alkaline nature of the plutonic and volcanic rocks of the region.

Early mining activity in the area was limited to placer gold operations. From the late 1960s, exploration for porphyry copper and copper-gold deposits and, more recently, mesothermal and epithermal gold-bearing systems has occurred. The discovery of several deposits, including the QR gold deposit (Fox *et al.*, 1986), is a direct result of these efforts.

LITHOLOGY

Due to the general sparseness of outcrop, fault offsets, and the limited size of the map area, correlation of map units is difficult. Fortunately there are two seemingly continuous horizons of volcanic wackes and one horizon of maroon basalt flows that may be used as markers. The sequence established here (Figure 1-20-3) is compatible with those of previous workers in the Quesnel belt. In this study Unit 1 is equivalent to Unit 1 of Bailey (1988) and Panteleyev (1988). Similarly Units 2 to 5 correspond to Bailey's Units 2A to 2H, and Unit 6 is part of his Unit 3. The instrusive Units 7, 8 and 9 are similar to those described by Bailey and Panteleyev, except that Unit 7 in the Cantin Creek area contains alkalic, mafic cumulate material as well as diorite and monzonite.

Unit 1 – Argillite: Dark grey to black, thinly bedded, locally with thin layers of fine-grained, pink to pale grey feldspathic wacke. The unit is exposed in the northwest part of the map area and as xenoliths within an intrusion of megacrystic quartzose syenite porphyry (Unit 9). The stratigraphic thickness is unknown due to the intrusion of the porphyry.

Unit 2 – Basalt Flows: Dark green, porphyritic with phenocrysts 2 millimetres in average diameter consisting of 3 per cent feldspar, 8 per cent pyroxene and minor olivine. The matrix is altered and contains carbonate and chlorite. The base of the unit is not exposed and the thickness is not known.

Unit 3 – Pyroxene-bearing Wacke: Maroon, coarse-grained; subrounded grains; locally well bedded otherwise massive, consisting of 15 per cent feldspar, 15 per cent

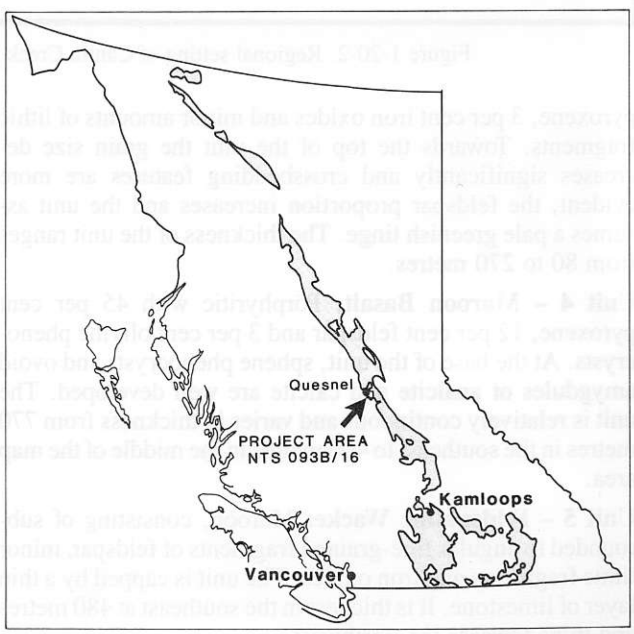


Figure 1-20-1. Location of Cantin Creek map-area in Quesnel terrane.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

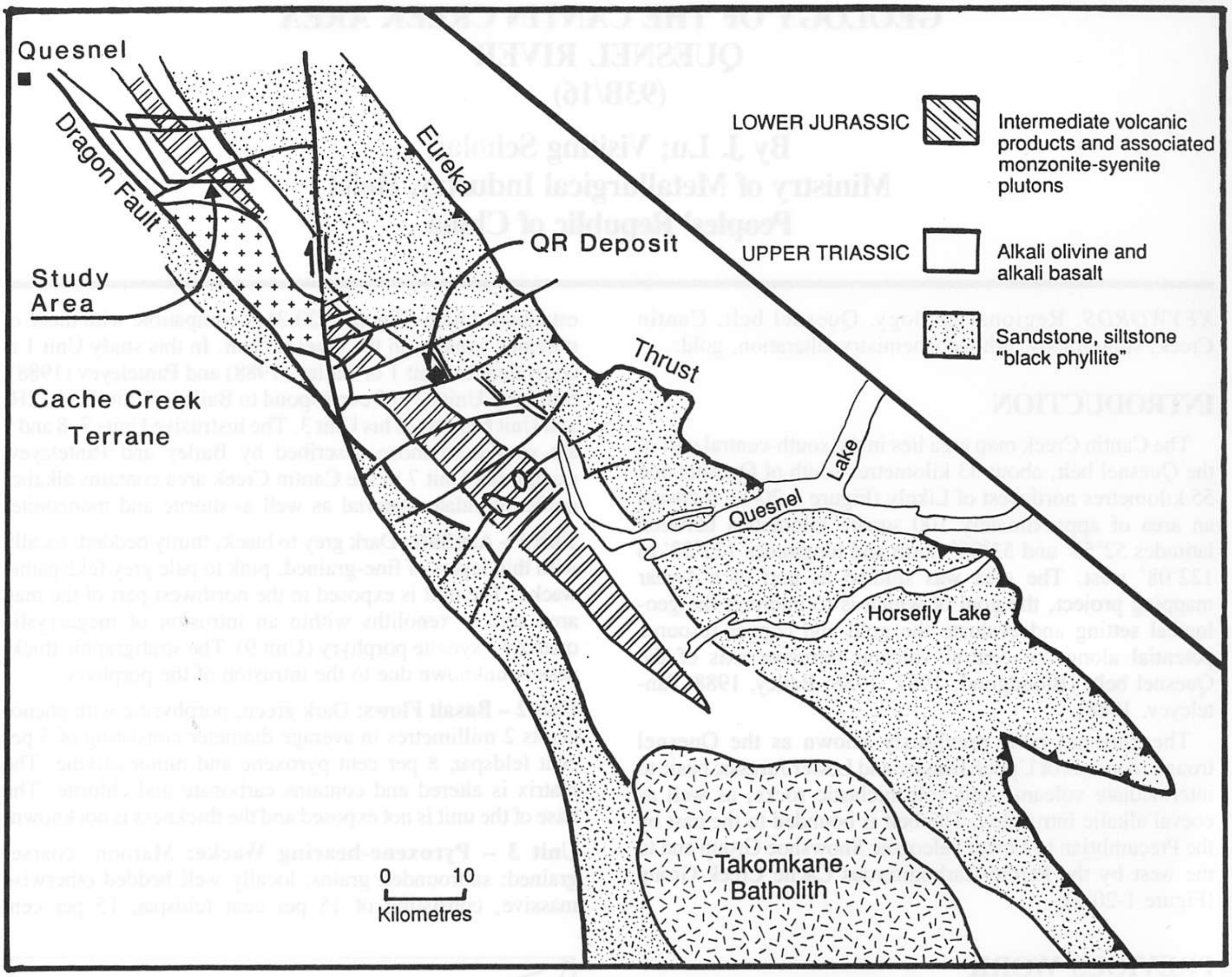


Figure 1-20-2. Regional setting of Cantin Creek map-area in Quesnel belt, (93A, B) (after Bailey, 1988).

pyroxene, 3 per cent iron oxides and minor amounts of lithic fragments. Towards the top of the unit the grain size decreases significantly and crossbedding features are more evident, the feldspar proportion increases and the unit assumes a pale greenish tinge. The thickness of the unit ranges from 80 to 270 metres.

Unit 4 – Maroon Basalt: Porphyritic with 45 per cent pyroxene, 12 per cent feldspar and 3 per cent olivine phenocrysts. At the base of the unit, sphene phenocrysts and ovoid amygdules of analcite and calcite are well developed. The unit is relatively continuous and varies in thickness from 770 metres in the southeast to 400 metres in the middle of the map area.

Unit 5 – Feldspathic Wacke: Maroon, consisting of subrounded to angular fine-grained fragments of feldspar, minor lithic fragments and iron oxides. The unit is capped by a thin layer of limestone. It is thickest in the southeast at 480 metres and thins towards the northwest.

Unit 6 – Polylithic Breccia and Feldspathic Tuffs: Breccias with feldspathic and heterolithic clasts from underlying tuffaceous rocks are dark green to maroon, consisting of 70 to 80 per cent feldspar, 10 to 20 per cent pyroxene, minor olivine and other minerals. In the southeast of the map area, breccias are most common. The thickness of the unit is not well defined. The section is 700 to 1300 metres thick but probably has some structural thickening.

Unit 7 – Pyroxenite, Gabbro, Diorite, Monzonite and Minor Syenite: This unit intrudes Unit 6. The mafic rocks are green due to extensive chloritization. Where sampled they contain 50 per cent phenocrysts consisting of 35 per cent pyroxene, 10 per cent feldspar, and 5 per cent olivine. The matrix composition is optically indeterminable due to alteration. The map unit is poorly exposed and is mainly defined by diamond drilling.

Unit 8 – Syenite to Quartz-Syenite Porphyry: Pink to greyish white when weathered, with 30 to 60 per cent potassium feldspar phenocrysts and megacrysts that are 20 by 2 millimetres on average and occassionally reach 12 by 2 centimetres in size. The matrix is fine grained and consists of feldspar, amphibole and quartz. Within the stock are xenoliths of diorite consisting of 70 per cent feldspar, 15 to 20 per cent amphibole and minor amounts of other minerals.

TABLE 1-20-1

MAJOR OXIDE AND MINOR ELEMENT ANALYSIS, CANTIN CREEK; SAMPLES PLOTTED ON FIGURES 1-00-4 AND 1-00-5 SHOWN WITH AN ASTERISK

Rec. No.	Field Label	Unit	Description	Rb	Sr	Y	Zr	Nb	Mo	U	Th	Cr	Ni	Ba	Ti	V	Au	Ag	Cu	Pb	Zn	Hg	As	Sb	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	$NSiO_2$
1	C1-9	8	Syenite Porphyry	86	1091	10	100	2	1	3	0	18	11	1936	1247	67	20	0.0	3	15	38	0	4.3	0.0	65.54	0.21	17.33	2.07	0.08	0.62	2.02	5.91	5.66	0.07	0.33	69.89
2	C2-3	8	Syenite Porphyry	90	995	21	121	4	4	9	1	36	14	1271	3733	217	30	0.0	69	12	0	33	1.1	0.0	57.08	0.60	16.27	6.81	0.14	2.66	5.69	4.06	5.25	0.31	1.24	61.17
3	C3-3	6	Altered Basalt (Vein?)	40	1885	22	173	2	2	9	23	305	162	7289	8135	219	20	0.0	58	20	90	560	1.7	2.8	47.79	1.31	14.34	9.25	0.14	6.52	6.34	2.72	2.92	1.02	6.22	54.05
4	C3-4	7	Basaltic Porphyry?	41	839	12	42	0	0	0	10	203	42	458	4272	297	20	0.0	85	6	82	15	29.7	0.6	47.05	0.66	12.24	11.37	0.21	7.97	13.21	2.45	1.67	0.46	2.20	49.44
5	C3-10	6	Basaltic Tuff	55	325	23	106	3	4	0	11	6	1	1762	3955	117	0	0.0	4	25	19	0	3.3	0.5	54.73	0.66	16.88	7.60	0.12	2.92	3.44	5.35	3.94	0.31	3.91	59.68
6	C4-2C	6	Basaltic Breccia	75	435	19	66	0	0	0	5	9	6	1714	4905	228	0	0.0	7	6	46	0	29.7	0.6	47.55	0.80	17.01	9.54	0.14	3.06	6.68	4.53	3.25	0.23	6.70	53.24
7	C4-10	5	Basalt (Vein?)	64	994	15	65	0	0	7	4	207	49	864	4316	285	0	0.0	8	14	105	10	10.5	1.8	46.64	0.68	11.59	10.64	0.18	8.59	9.16	2.07	3.83	0.76	4.92	52.08
8	C4-12B	5	Basalt (Vein?)	31	1147	15	62	1	1	7	0	74	24	655	4844	297	30	0.0	13	8	105	0	14.1	0.6	47.14	0.78	13.72	11.36	0.20	6.23	9.25	4.65	1.29	0.70	3.34	50.01
9	C5-2	6	Altered Basalt	45	1280	30	329	86	5	0	8	186	165	480	19482	212	20	0.0	51	5	153	0	12.1	0.0	42.42	3.06	11.28	14.53	0.21	8.73	9.83	3.72	2.09	1.11	1.70	45.23
10	C6-2C	4	Maroon Basalt	77	536	16	60	6	2	4	0	228	55	987	4307	221	20	0.0	90	9	89	0	1.1	0.0	47.20	0.68	12.03	10.80	0.20	8.13	9.24	2.97	3.26	0.75	4.05	51.73
11	C6-3A	4	Maroon Basalt	58	574	18	63	3	0	2	3	590	102	619	3716	172	20	0.0	19	14	80	0	12.1	0.8	43.32	0.58	12.97	8.71	0.16	5.24	8.32	2.48	4.08	0.45	13.11	52.97
12	C7-3	4	Maroon Basalt	75	1482	14	57	0	1	11	0	110	25	1042	4057	243	0	0.0	168	10	97	48	28.4	0.0	47.36	0.62	13.45	10.56	0.21	5.71	10.05	2.41	3.96	0.53	3.73	52.41
13	C8-3	9	Granite	30	621	10	147	0	8	3	7	10	5	2358	1241	26	0	0.0	4	16	18	0	13.4	0.0	68.11	0.21	16.00	1.42	0.03	0.44	1.15	6.61	3.34	0.07	1.27	72.48
14	C8-6	9	Granite	95	1017	11	130	0	0	9	6	38	18	1614	1827	44	0	0.0	2	27	30	0	0.0	0.0	67.01	0.31	15.71	2.28	0.05	1.01	2.09	5.21	3.42	0.10	1.66	71.54
15	C8-7C	3	Volcanic Pyroxene-bearing Wacke	25	543	20	70	2	0	1	0	14	13	86	5515	312	0	0.0	110	8	93	0	0.0	3.4	47.95	0.89	15.04	10.70	0.20	4.42	7.83	3.96	1.55	0.37	6.16	52.70
16	C8-7K	9	Granite Porphyry	26	575	15	122	0	8	3	7	47	14	1956	2541	69	0	0.0	11	16	63	10	14.4	1.1	63.87	0.44	15.67	3.60	0.06	2.11	3.18	5.35	1.19	0.17	4.07	67.75
17	C10-1C	3	Volcanic Pyroxene-bearing Wacke	23	367	19	60	4	2	0	4	140	21	2027	5025	1122	0	0.0	246	4	87	0	0.0	0.0	49.25	0.84	15.15	9.32	0.18	5.07	6.06	4.96	2.00	0.30	6.15	54.22
18	C10-3A	4	Maroon Basalt	35	1985	20	127	1	2	13	0	376	221	5952	7153	182	40	0.0	62	16	24	60	12.5	5.3	45.68	1.16	12.96	7.88	0.13	7.50	6.99	2.84	1.52	0.58	10.98	53.65
19	C10-3B	8	Syenite Porphyry	26	581	3	77	0	11	0	0	12	8	1657	831	14	20	0.0	15	15	83	76	8.2	6.0	68.42	0.15	16.99	0.99	0.02	0.50	1.48	6.30	1.52	0.03	2.65	72.13
20	C10-3D	3	Volcanic Pyroxene-bearing Wacke	46	592	16	51	0	1	0	0	23	14	754	5476	299	30	0.0	89	4	60	11	3.0	3.0	47.50	0.86	18.23	9.68	0.17	4.52	11.00	1.95	2.17	0.26	3.18	50.58
21	C11-9	4	Maroon Basalt	70	483	16	56	2	1	4	0	213	82	2286	4182	276	40	0.0	123	9	95	12	5.0	0.0	46.52	0.64	13.36	10.72	0.17	7.24	10.73	0.99	4.28	0.44	3.37	51.48
22	C11-11	4	Maroon Basalt	77	336	13	38	0	0	0	0	346	82	1374	4182	258	0	0.0	510	8	75	17	11.8	0.0	46.49	0.76	11.59	12.59	0.21	8.35	10.69	1.51	3.59	0.26	3.36	50.43
23	C11-19	6	Basaltic Tuff	45	609	25	97	3	0	3	0	9	6	1951	4925	188	0	0.0	22	8	77	0	13.1	0.9	51.58	0.80	17.86	9.25	0.16	3.26	6.12	4.58	2.47	0.27	2.78	55.10
24	C12-6	8	Syenite Porphyry	58	731	22	82	2	2	4	0	15	10	1779	3186	130	0	0.0	38	28	94	19	22.2	1.2	58.99	0.53	17.12	6.95	0.19	2.71	3.49	4.54	2.49	0.24	2.71	62.41
25	C13-7	2	Basalt	47	968	20	73	0	3	4	0	52	16	932	6006	315	0	0.0	54	6	133	0	6.0	2.5	47.73	0.97	15.27	11.25	0.20	5.09	8.56	3.68	2.28	0.32	3.38	51.46
26	G3-3	8	Syenite(?)	67	280	12	63	4	3	0	10	60	26	1571	2028	150	50	0.0	30	15	47	82	11.5	1.1	57.82	0.33	14.65	6.56	0.11	4.21	4.65	4.33	5.48	0.19	1.46	62.40
27	G3-4	7	Pyroxenite	11	71	6	19	4	0	0	0	2112	877	25	1872	119	20	0.0	13	0	78	38	0.0	0.0	42.01	0.31	2.36	12.42	0.22	25.80	10.28	0.00	0.02	0.01	6.55	44.98
28	G5-2	6	Basaltic Breccia	78	428	16	79	2	3	0	7	37	25	1792	3316	241	30	0.0	66	12	23	26	20.6	1.9	52.15	0.54	16.11	8.63	0.11	3.47	4.48	4.88	4.84	0.30	3.09	57.71
29	G7-3	7	Pyroxenite	11	174	7	22	5	0	0	0	1041	343	27	2546	174	30	0.0	11	0	55	28	1.7	0.0	46.21	0.37	3.36	9.97	0.19	17.44	17.74	0.22	0.01	0.02	2.05	48.39
30	G8-1	7	Basaltic Porphyry	65	530	16	47	0	2	6	0	195	63	2338	3926	254	20	0.0	221	5	76	16	13.8	0.0	49.74	0.61	12.99	10.30	0.16	6.35	9.84	2.04	3.78	0.30	2.59	54.05
31	G8-3	6	Basaltic Tuff(?)	29	645	20	80	2	2	3	11	12	8	611	3772	164	0	0.0	15	7	46	20	22.9	1.7	53.52	0.63	17.99	7.82	0.15	3.39	5.30	5.77	1.69	0.16	2.58	56.59
32	G8-4	7	Basaltic Porphyry	48	294	16	48	0	2	0	7	174	52	1279	4502	299	20	0.0	295	8	98	2000	19.3	0.8	47.09	0.76	12.10	11.70	0.20	6.76	9.41	3.36	2.56	0.48	2.82	51.53

Note: Values below the analytical detection limit are listed as zero.

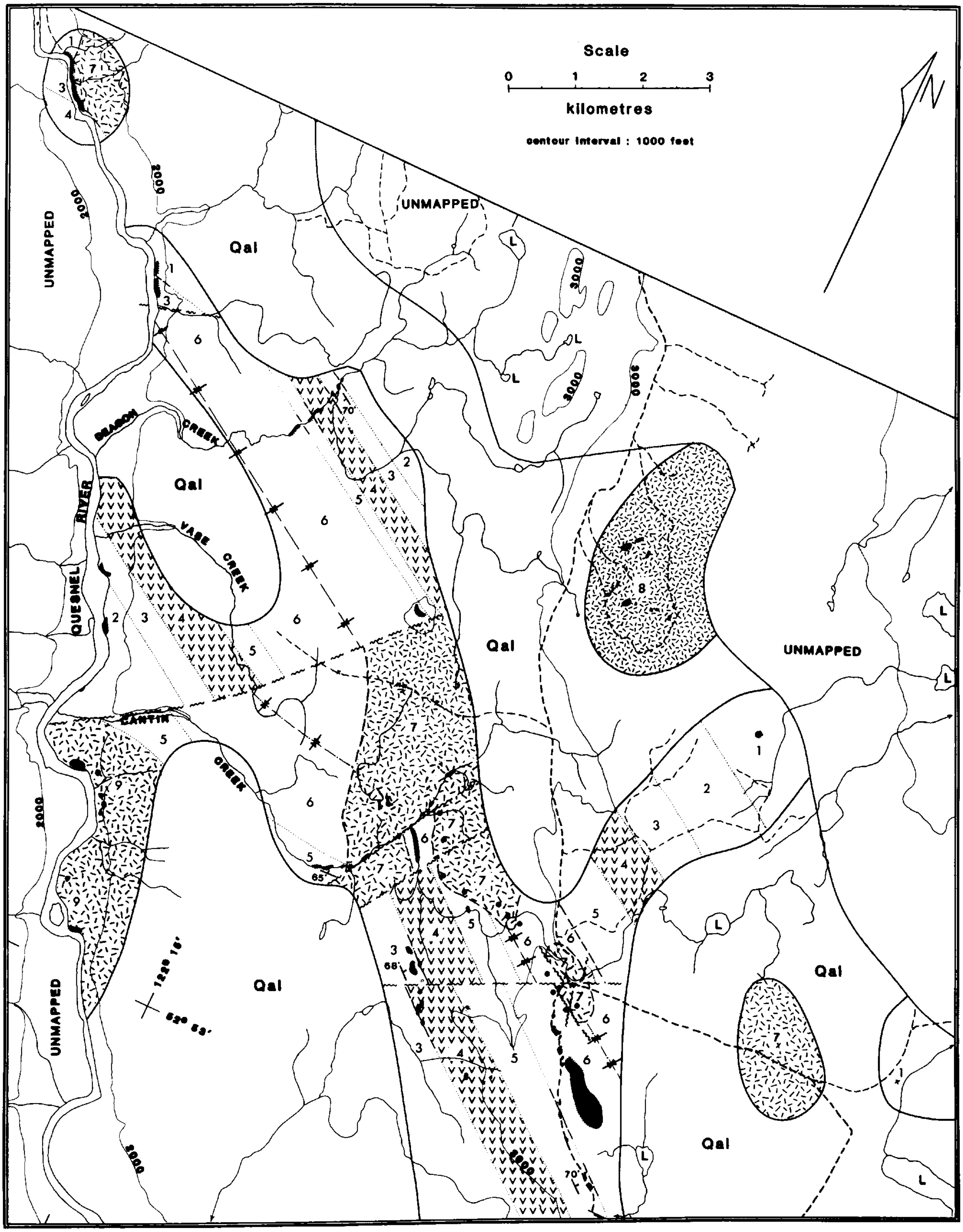
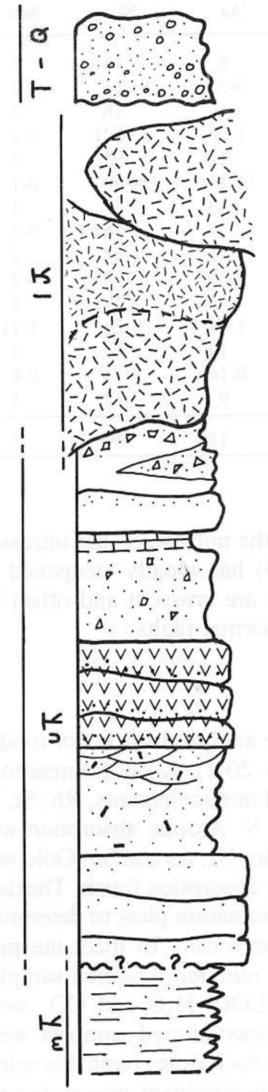
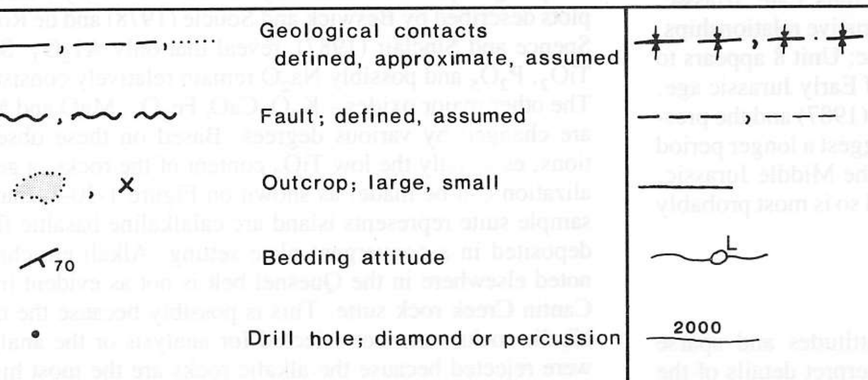


Figure 1-20-3a. Cantin Creek Study Area.

AGE / STRATIGRAPHIC COLUMN	UNIT #	NAME	DESCRIPTION
	Qal	Alluvium	Unconsolidated till and overburden, sand to cobble size, poorly sorted
	9	Granodiorite	Grey, medium-grained, biotite-bearing, locally carbonate-altered
	8	Quartz Syenite, Syenite Porphyry	Pink to pale grey and chalk-white, medium to coarse-grained, locally megacrystic
	7	Gabbro, Pyroxenite, Diorite, Monzonite, Syenite	Differentiated diorite to monzonite stock; mafic cumulate and syenite, in part
	6	Polylithic breccias, feldspathic tuffs	Breccia with heterolithic clasts; feldspathic clasts and tuffs common, contains basaltic detrius
	5	Feldspathic wacke	Maroon feldspathic wacke, overlain by a thin limestone member
	4	Maroon Basalt flows	Maroon flows, massive, containing pyroxene and feldspar phenocrysts
	3	Pyroxene - bearing Wacke	Maroon crystal - lithic wacke, abundant pyroxene and feldspar grains
	2	Basalt flows	Dark green flows, massive, fine-grained, containing small feldspar and pyroxene phenocrysts
	1	Argillite and Siltstone	Dark grey to black, thinly bedded, locally thin beds of feldspathic wacke



Geological contacts defined, approximate, assumed	Synform; approximate, assumed
Fault; defined, assumed	Roads; primary, secondary
Outcrop; large, small	Limit of mapping
Bedding attitude	Streams and lakes
Drill hole; diamond or percussion	Contours: elevation in feet

Figure 1-20-3b. Legend for Figure 1-20-3a.

TABLE 1-20-2
MINOR ELEMENT ANALYSIS – RANGE AND MEAN VALUE ACCORDING TO MAP UNITS.

Map Unit	No of Samples	Au	Ag	Cu	Pb	Zn	Hg	Sb	As	Ni	Mo
		(Minor elements in ppm; Au and Hg in ppb)									
2	1 mean	0	0	54	6	133	0	2.5	6	16	3
3	3 range	0-30	0	89-246	4-8	60-93	0-11	3-3.4	0-3	13.21	0-2
	mean	10	0	148	5	80	4	2.1	1	16	1
4	6 range	0-40	0	19-510	8-16	24-97	0-60	0-5.3	1-28	25-221	0-2
	mean	20	0	162	11	77	23	1	12	95	1
5	2 range	0-30	0	8-13	8-14	105	0-10	0.6-1.8	11-14	24-49	0-1
		15	0	11	11	105	5	1.2	13	37	1
6	7 range	0-30	0	4-66	5-25	19-153	0-560	0-2.8	2-30	1-165	0-5
	mean	10	0	32	12	65	87	1.2	15	53	2
7	5 range	20-30	0	11-295	0-8	55-98	15-2000	0-0.8	0-30	42-827	0-2
	mean	22	0	125	4	78	419	0.3	13	275	1
8	5 range	0-50	0	3-69	12-28	0-94	0-82	0-6	1-22	8-26	1-11
	mean	24	0	31	17	52	42	2	10	14	4
9	3 range	0	0	2-11	16-27	18-63	0-10	0-1.1	0-14	5-18	0-8
	mean	0	0	6	20	37	3	0.4	9	12	5
All Units	32 mean	15	0	79	11	71	96	1.2	11	80	2

Note: Values below the analytical detection limit are shown as zero.

Late-stage syenite dykes, consisting of 80 per cent potassium feldspar, 10 per cent amphibole and 5 per cent quartz cut the stock. Veins of granular white quartz are found throughout the stock and crosscut all phases of the unit.

Unit 9 – Granite Stock: White to greyish white with a porphyritic texture. It is composed of 60 to 70 per cent potassium feldspar, 15 to 20 per cent quartz, 5 to 7 per cent biotite, and 5 to 10 per cent sodium feldspar. Locally the rock has been intensely carbonatized.

STRATIGRAPHY

The age of the map units has been determined by lithologic correlation as no fossil control has been established in the map area.

The age of Unit 1, which is equivalent to Bailey's (1988) Unit 1, has been determined elsewhere (Struik, 1986) to range from Middle Triassic to Late Triassic, mainly on the basis of conodont dating. Units 2 through 5 are stratigraphic equivalents to Bailey's Unit 2 and are thus Late Triassic, probably Norian in age. According to intrusive relationships, Units 6 and 7 are probably Early Jurrasic; Unit 8 appears to be similar to other dated alkalic stocks of Early Jurassic age. However, radiometric data of Panteleyev (1987) and the presence of much hydrothermal alteration suggest a longer period of intrusive activity, possibly well into the Middle Jurassic. Unit 9 is equivalent to Bailey's Unit 9 and so is most probably Cretaceous in age.

STRUCTURAL GEOLOGY

Due to the variability of bedding attitudes and sparse outcrop distribution, it is difficult to interpret details of the regional structure. Based on the established stratigraphic column, the map area is probably underlain by a tight syncline. The southwest limb is relatively well preserved in the southeast and central parts of the map area and trends approximately 130° with dips of 60° to 70° northeast. In the central area, the strata are offset by a fault and are tightly folded and locally overturned. The northeast limb trends approximately 120° and dips 70° southwest. In the northwest, the intrusion of the granite porphyry (Unit 9) has locally steepened or overturned the strata. The strata are crosscut and offset by northeast to northerly trending normal faults.

PETROCHEMISTRY

Thirty-two rock samples were analyzed for major oxides and minor elements (*see* Table 1-20-1). X-ray flourescence was used for all major oxides and minor elements, Rb, Sr, Y, Zr, Nb, U, Th, Cr, Ba, Ti, and V. Atomic absorption was used to determine Ag, Cu, Zn, Mo, Ni, As and Sn. Gold was analyzed by fire assay and atomic absorption finish. The data were plotted on a series of discrimination plots to determine the geochemical character of the rocks. To meet the prerequisites of certain diagrams, a number of altered samples with elevated loss on ignition (LOI), H_2O and CO_2 were screened out. Fourteen of the least-altered samples were chosen to be representative of the rock suite. Even this select sample group, when tested by discriminant major-element plots described by Beswick and Soucie (1978) and de Rosen-Spence and Sinclair (1987), reveal that only Al_2O_3, SiO_2, TiO_2, P_2O_5 and possibly Na_2O remain relatively consistent. The other major oxides – K_2O, CaO, Fe_2O_3, MgO and MnO are changed by various degrees. Based on these observations, especially the low TiO_2 content of the rocks, a generalization can be made, as shown on Figure 1-20-4, that the sample suite represents island arc calalkaline basaltic flows deposited in a convergent plate setting. Alkali enrichment noted elsewhere in the Quesnel belt is not as evident in the Cantin Creek rock suite. This is possibly because the more alkalic rocks were not selected for analysis or the analyses were rejected because the alkalic rocks are the most highly altered.

Minor element discriminant plots based on immobile elements are considered to be less affected by alteration. Various plots, some of which are shown on Figure 1-20-5, indicate a volcanic-arc environment of basaltic character. However, the minor element plots are not capable of further resolving whether the magma suites are alkaline or sub-

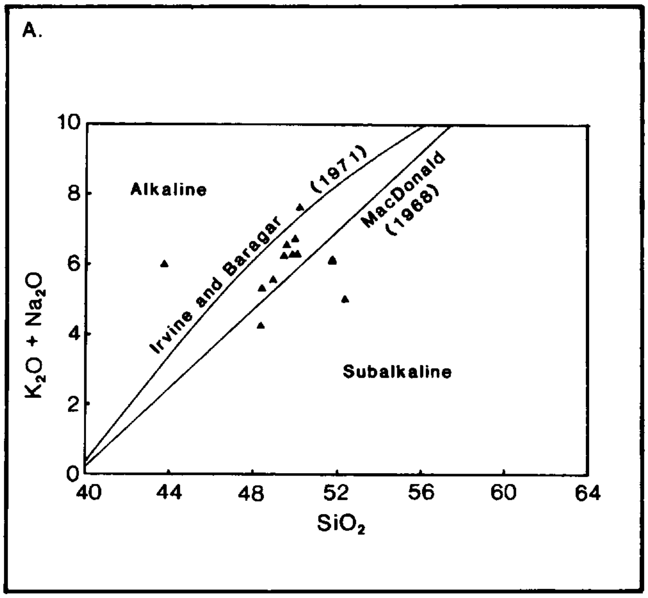


Figure 1-20-4a. Alkalinic-subalkalic divisions according to Irvine and Baragar (1971) and MacDonald (1968).

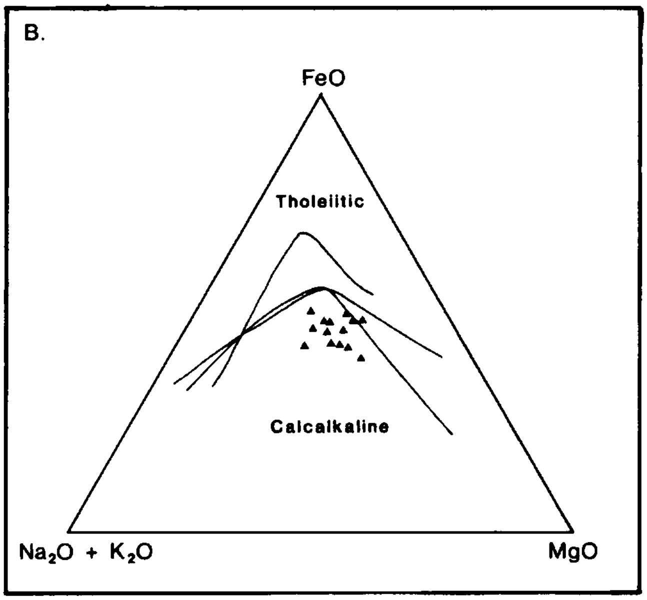


Figure 1-20-4b. AFM diagram after Irvine and Baragar (1971) and MacDonald and Katsura (1964) showing calcalkaline nature of Cantin Creek rocks.

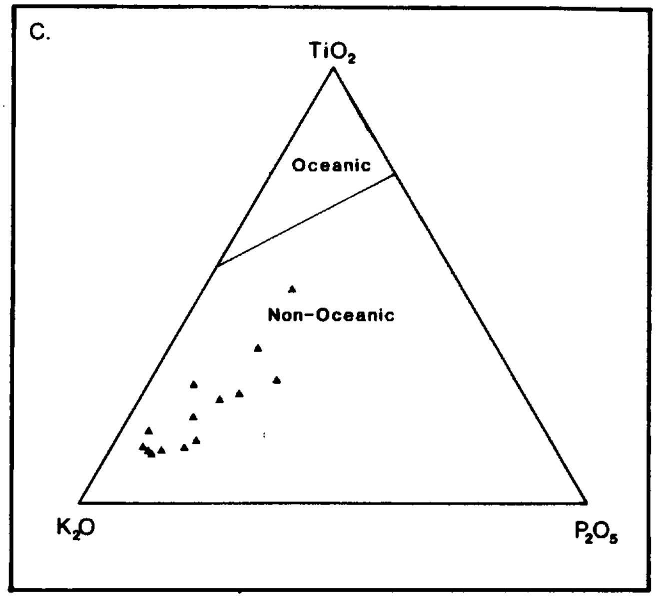


Figure 1-20-4c. TiO_2-K_2O-P_2O_5 plot after Pearce *et al.* (1975) showing the low TiO_2 and potassic nature of the non-oceanic rocks.

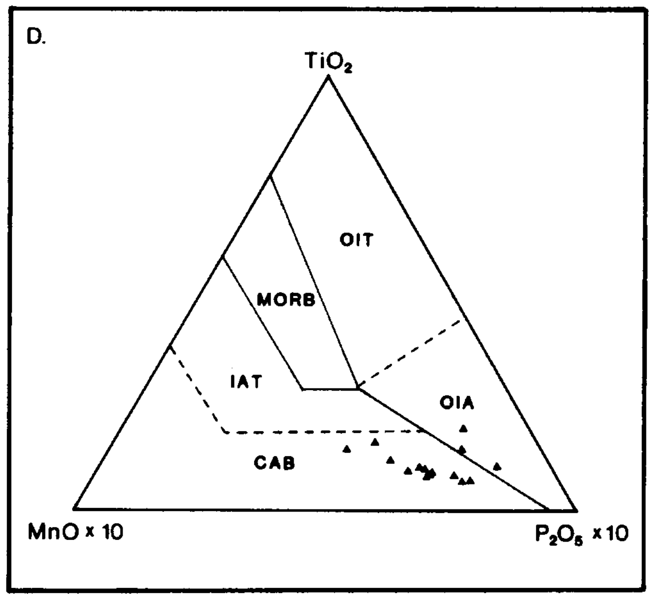


Figure 1-20-4d. Tectonic setting discrimination according to Mullen, (1983) showing calkalkaline (CAB) to ocean island (alkaline) basalt (OIA) character. IAT = island arc (low K) tholeiite, OIT = ocean island tholeiite; MORB = mid-ocean ridge basalt.

alkaline (tholeiitic) in affinity. These indeterminable minor element data are consistent with other analyses from pyroxene-bearing basalts that were deposited during early Quesnel arc volcanism (Bloodgood, 1987; Morton, 1976; Bailey, 1978).

ALTERATION AND MINERALIZATION

At least five related types of relatively low-temperature hydrothermal alteration or burial metamorphism have been identified at Cantin Creek: carbonatization, chloritization, epidotization, pyritization and zeolitization. All types are found as pervasive alteration and in some veins. Carbonatization is most common throughout the map area and is not confined to any specific map unit. Chloritization is also common, but is best developed in Units 5 and 6. Epidote alteration is confined to Unit 6 and pyritization to Unit 5. Zeolite alteration is essentially restricted to the vesicles of flow rocks. Units 5 and 6 are the most pervasively altered, seemingly because of their high porosity.

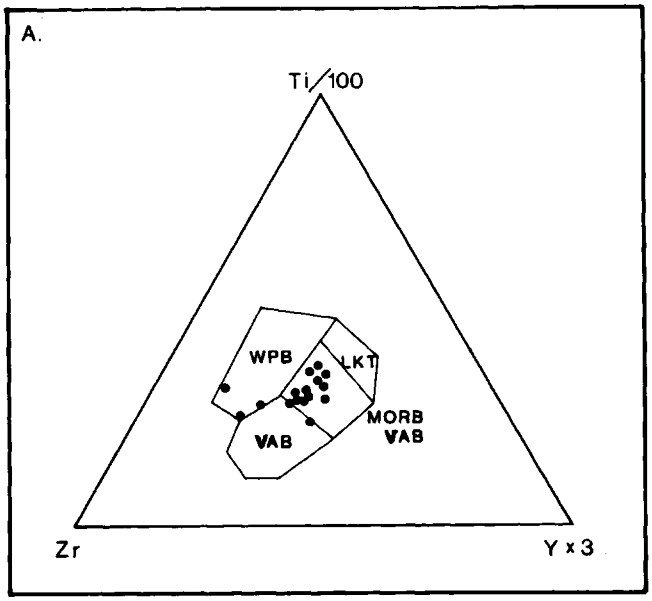


Figure 1-20-5a. Discriminant minor element tectonic setting plot after Pearce and Cann (1973). VAB = volcanic arc basalt; WPB = within plate basalt.

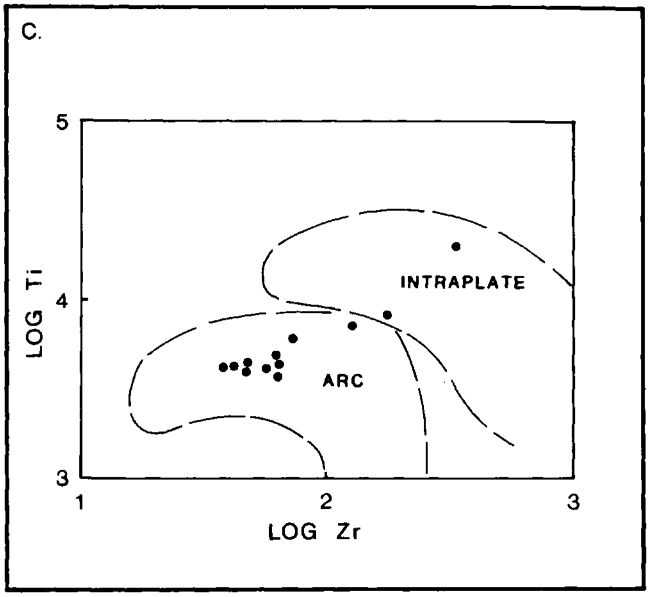


Figure 1-20-5c. Minor element discriminant plots after Pearce (1982).

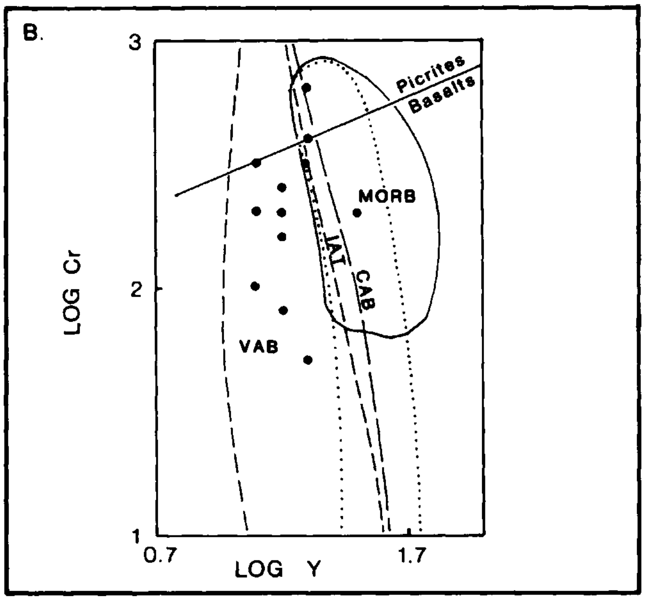


Figure 1-20-5b. Minor element discriminant plots after Pearce (1982).

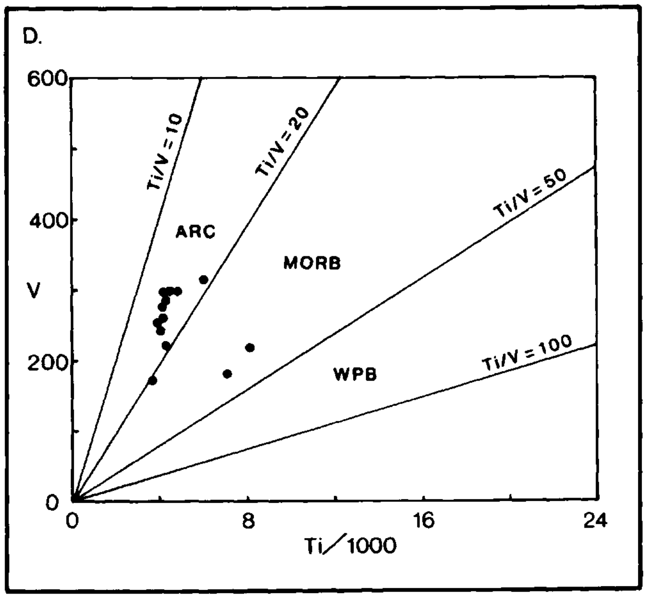


Figure 1-20-5d. Ti-V discriminant plot after Shervais (1982) distinguishing tectonic settings.

A series of 21 rock samples were analyzed for gold and related elements (Au, Ag, Cu, Pb, Zn, Hg, Sn, Mo, Ni; *see* Table 1-20-2) in order to study the relationship between alteraton and mineralization. Statistical analysis shows there is no clear association between any specific rock unit and gold enrichment. Furthermore, there is no apparent correlation between alteration type and gold. However, comparing Cantin Creek to the Horsefly area (Morton, 1976) and the Nicola Group (Preto, 1979), the data are significantly different. In the Horsefly area, the maximum nickel, copper and zinc values are 128; 198; and 125 ppm; in the Cantin Creek area these values are much higher at 877; 510; and 187 ppm respectively. In Nicola rocks, the mean values of nickel for flow rocks, tuffs and intrusive rocks are approximately 17; 10; and 6 ppm; for copper, 77; 56; and 45 ppm; for zinc, 93; 89; and 76 ppm; and for lead, 12; 10; and 6 ppm. In contrast, the mean values for the same rocks in the Cantin Creek area are: nickel, 95; 53; and 114 ppm; copper, 162; 32; and 61 ppm; zinc, 77; 65; and 59 ppm; and lead, 11; 12; and 13 ppm. These values clearly indicate that the copper and nickel content in Cantin Creek rocks is greater than that of Nicola Group rocks in general. These data demonstrate the basic nature of the basal Quesnel volcanic units and their pyroxene-rich erosional products compared to the more differentiated Nicola sucessions. Gold, silver and related-element data from the map area cannot be compared with other areas in the

Quesnel belt due to the limited data available. However, with mercury values up to 2 ppm, mean gold values of 15 ppb and up to 50 ppb, the potential for significant gold concentrations in the area is indicated.

ACKNOWLEDGMENTS

I would like to acknowledge Dr. Andre Panteleyev and Kirk Hancock for advice and assistance in preparing this report. Mike Fournier is thanked for his able assistance in the field. I am also grateful to Joanne Nelson and Don MacIntyre who assisted me with the microscope and microcomputer work. Special thanks are due to Dr. Peter Fox of Fox Geological Consultants Ltd., who provided property information and permitted sampling of drill core from the Cantin Creek site. Dr. D.G. Bailey's critical review of earlier mauscripts has greatly improved the clarity of this report.

REFERENCES

Bailey, D.G. (1978): Geology of the Morehead Lake Area, South-central British Columbia, Unpublished Ph.D. Thesis, *Queens University*, 198 pages.

——— (1988): Geology of the Central Quesnel Belt, Hydraulic, South-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 147-153.

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A., (1976): The Alkaline Suite Porphyry Deposits: a Summary *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute Mining and Metallurgy,* Special Volume 15, pages 359-367.

Beswick, A.E. and Soucie, G. (1978): A Correction Procedure for Metasomatism in an Archean Greenstone Belt, *Precambrian Research*, Volume 6, pages 235-248.

Bloodgood, M.A. (1987): Geology of the Triassic Black Phyllite in the Eureka Peak Area, South-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 135-142.

——— (1988): Geology of the Quesnel Terrane in the Spanish Lake Area, Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 139-145.

de Rosen-Spence, A. and Sinclair, A.J. (1987): Classification of the Cretaceous Volcanic Sequences of British Columbia and Yukon, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1 pages 419-427.

Fox, P.E. (1975): Alkaline Rocks and Related Mineral Deposits of the Quesnel Trough, B.C. *Geological Association of Canada*, Cordilleran Section, Program and Abstracts, February 1975, page 12.

Fox, P.E., Cameron, R.S. and Hoffman, S.J. (1986): Geology and Soil Geochemistry of the Quesnel River Gold Deposit, British Columbia, *in* GEOEXPO 86, Proceedings, *Association of Exploration Geochemists*, Vancouver, May 1986, pages 61-71.

Hodgson, C.J., Bailes, R.J. and Verzosa, R.S. (1976): Cariboo-Bell, *in* Porphyry Deposits in the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 388-396.

Irvine, T.N. and Baragar, W.R.A. (1971): A Guide to the Chemical Classification of the Common Volcanic Rocks, *Canadian Journal of Earth Sciences*, Volume 8, pages 523-547.

Lefebure, D.V. (1976): Geology of the Nicola Group in the Fairweather Hills, British Columbia, Unpublished M.Sc. Thesis, *Queen's University*, 178 pages.

MacDonald, G.A. (1968): Composition and Origin of Hawaiian Lavas, *Geological Society of America*, Memoir 116, pages 477-522.

MacDonald, G.A. and Katsura, T. (1964): Chemical Composition of Hawaiian Lavas, *Journal of Petrology,* Volume 5, pages 82-133.

Morton, R.L. (1976): Alkalic Volcanism and Copper Deposits of the Horsefly Area, Central British Columbia, Unpublished Ph.D. Thesis, *Carleton University*, 196 pages.

Mullen E.D., (1983): $MnO_2/TiO_2/P_2O_5$: A Minor Element Discriminant for Basaltic Rocks of Oceanic Environments and its Implications for Petrogenesis; *Earth and Planetary Science Letters*, Volume 62, pages 53-62.

Panteleyev, A. (1987): Quesnel Gold Belt – Alkalic Volcanic Terrane Between Quesnel and Horsefly Lakes, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 125-133.

——— (1988): Quesnel Mineral Belt – The Central Volcanic Axis Between Horsefly and Quesnel Lakes, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 131-137.

Pearce, J.A. (1982): Trace Element Characteristics of Lavas From Destructive Plate Boundaries. *in* Andesites, Thorpe, R.S., Editor, *John Wiley & Sons*, New York, pages 525-548.

Pearce T.H., Gorman B.E. and Birkett T.C., (1975): The TiO_2-K_2O-P_2O_5 Diagram: a Method of Discriminating Between Oceanic and Non-oceanic Basalts; *Earth and Planetary Science Letters*, Volume 24, pages 419-426.

Preto, V.A. (1979): Geology of the Nicola Group between Meritt and Princeton, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 69, 90 pages.

Shervais J.W., (1982): Ti-V Plots and the Petrogenesis of Modern and Ophiolitic Lavas, *Earth and Planetary Science Letters*, Volume 59, pages 101-118.

Struik, L.C. (1986): Imbricated Terranes of the Cariboo Gold Belt with Correlations and Implications for Tectonics in Southeastern British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, Number 8, pages 1047-1061.

NOTES

GEOLOGY AND MINERAL OCCURRENCES IN NORTH NEWCOMBE LAKE MAP SHEET* (93E/14)

By L.J. Diakow and J. Drobe

KEYWORDS: Regional geology, Newcombe Lake, Nechako Plateau, Telkwa Formation, Bulkley intrusions, Kasalka, Nanika intrusions, Cretaceous volcanics, porphyry copper-molybdenum, quartz veins.

INTRODUCTION

The 1988 Whitesail project extends published 1:50 000 regional mapping in the Sibola Range (MacIntyre, 1985) further to the north (Figure 2-21-1). This report describes the dominant features of mappable lithologic units and documents the geological setting of mineral prospects in the map area.

The mapping complements previous work in the Whitesail Reach and Chikamin Mountain map sheets (Diakow and Mihalynuk, 1987; Diakow and Koyanagi, 1988). The aim of the Whitesail project is to update and refine present Mesozoic and Cenozoic stratigraphic nomenclature, and to resolve the genesis and mineralization controls of the principal mineral deposit types. The project area includes the 1:50 000-scale map sheets 93E/6, 10, 11E, 13 and 14 (Figure 1-21-1) and the project will conclude in 1989 with the completion of mapping in the Nanika Lake map area (NTS 93E/13).

STRATIGRAPHY

The Lower Jurassic Telkwa Formation of the Hazelton Group is the oldest volcanic succession exposed io the map area. Younger volcanic rocks, tentatively assigned to the Cretaceous Skeena and Kasalka groups, appear to rest unconformably on the Telkwa Formation. Sedimentary strata of the Middle Jurassic Smithers Formation or Lower Cretaceous Skeena Group are absent from the map area, with the exception of few scattered outcrops between Newcombe and Twinkle lakes. Stocks of diorite, granodiorite and monzonite cut and locally alter the oldest stratified rocks at Tableland Mountain and Smoke Mountain. Hypabyssal dykes and plugs, which have mineralogical and textural similarities to spatially associated Cretaceous volcanic rocks, occur north of Nadina Lake and southwest of Smoke Mountain. The distribution of stratified and intrusive rock units is shown in Figure 1-21-2.

LOWER JURASSIC

HAZELTON GROUP — TELKWA FORMATION

The Telkwa Formation is made up primarily of fragmental deposits and less voluminous lava flows. These rocks form well-layered exposures east of Kidprice Lake, on the plateau of Tableland Mountain, and on the north and west slopes of Smoke Mountain; they also underlie the intervening area. Elsewhere, they outcrop sporadically over the topographically low terrain north and south of Nadina Lake.

Alternating thick beds of dark maroon and green lapilli tuff are characteristic and diagnostic of the Telkwa Formation. The pyroclasts are typically lapilli size; blocks are uncommon with the exception of rare, intercalated lapilli-block tuff layers. The preponderance of dark-hued maroon and green fragments that have aphanitic textures is a widespread and definitive feature in the lapilli tuff beds. In contrast, apihyrie and flow-laminated rhyolitic fragments are areally extensive in lapilli tuffs exposed between Tableland Mountain and Newcombe Lake, and in outcrops of the Telkwa Formatioo north and south of Nadina Lake. Coarse to fine ash tuff and crystal-ash tuff comprise internally laminated beds intercalated and graded with coarser fragmental deposits. Accretionary lapilli occur in ash tuff layers throughout the Telkwa succession. Mafic phenocrysts are not preserved, whereas quartz phenocrysts, about 1 millimetre in diameter, are sparsely distributed in many tuffs.

Dark green and maroon lava flows generally form thin layers within the lapilli tuffs but a composite succession of flows, about 200 metres thick, is exposed on the lower part of the ridge east of Kidprice Lake. Aphyric flows, the most common variety, usually have a transitional contact with amygdaloidal flows. The latter have quartz-calcite-epidote-chlorite amygdules that are randomly distributed or, less frequently, arranged in trains that define igneous layering. Aphyric flows are fine grained and in places contain subvitreous pyroxene phenocrysts. Flow members in a section exposed immediately north of Kidprice Lake weather to a dense rock with subtle protruding laminae several millimetres thick. This feature, and the fresh appearance of these rocks, can be easily confused with the weathered surface of some Upper Cretaceous flows southwest of Smoke Mountain. Epidote accompanies quartz in irregular clots and lines fractures in the aphyric flows.

Rocks of dacitic to rhyolitic composition are spatially associated with Telkwa tuffaceous rocks, particularly those west of Newcombe Lake containing rhyolitic fragments. The morphology of exposures varies from lenticular and concordant, with interlayered lapilli tuff, to dome like. The rhyolite flows commonly have laminations and spherulitic textures.

The Telkwa Formation in the Newcombe Lake area resembles well-layered volcanic rocks south of Coles Lake, at Core Mountain and north of Chikamin Mountain in the Chikamin Mountain map area (Diakow and Koyanagi, 1988). The principal difference between these correlative successions is that lava flows of basaltic and rhyolitic composition appear to be more voluminous in the Newcombe Lake area where they

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

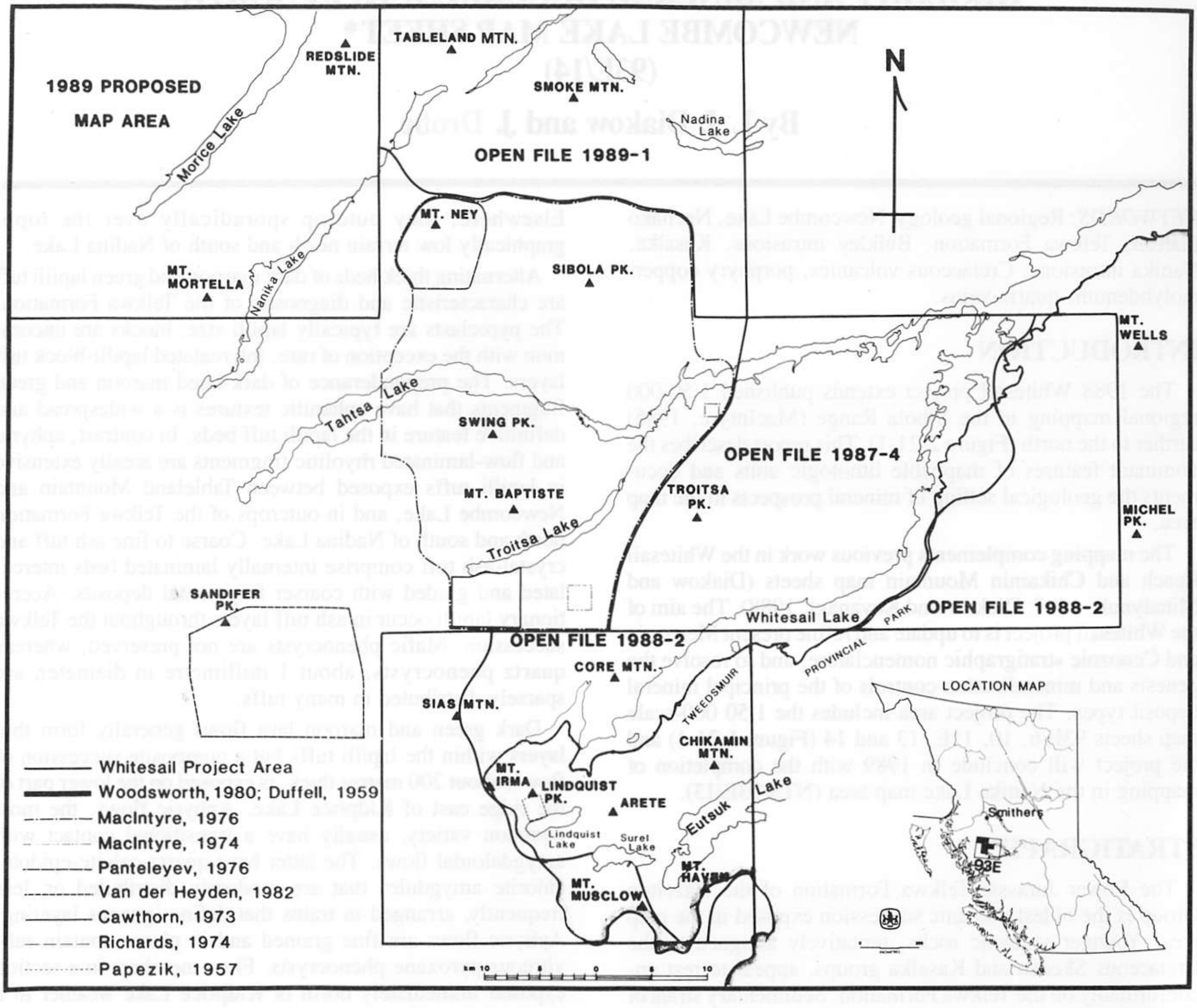


Figure 1-21-1. Location of Whitesail project.

are associated with fragmental rocks characterized by felsic pryoclasts. These felsic rocks are probably related to small eruptions from domes.

Lower Cretaceous

A succession of lava flows of undetermined thickness crops out on prominent ridges immediately north of Nadina Lake and south of Smoke Mountain. The lower contact is not exposed but is thought to be an unconformity with the Telkwa Formation.

The lava flows range from dark green to maroon in colour and diagnostically contain 30 to 40 per cent slender plagioclase laths between 1 and 3 millimetres long. Pyroxene phenocrysts are ubiquitous as subvitreous crystals that rarely exceed 2 millimetres in diameter. Felty and amygdaloidal textures predominate in these rocks. The spheroidal shape of chlorite and calcite amygdules, between 2 and 5 millimetres in diameter, distinguishes these rocks from Telkwa Formation flows of intermediate composition that typically have an aphyric texture and contain larger, more irregular-shaped amygdules.

Pillow lavas, about 50 metres thick, overlie amygdaloidal and fine-grained porphyritic flows on the first prominent knob southwest of Smoke Mountain. They dominate the upper portion of a stratigraphic succession which changes downward to aphyric lavas resting directly upon about 20 metres of green and black mudstone and siltstone. These sediments are interpreted as a localized sedimentary member within the Upper Jurassic Ashman Formation, however, this correlation cannot be confirmed because fossils have not been found and the lower contact is not exposed.

The fine-grained porphyritic and amygdaloidal flows resemble a succession of basaltic flows in the Tahtsa Lake area which MacIntyre (1976) mapped as the lower volcanic division of the Skeena Group. These volcanic rocks are conformably overlain by marine sediments of the Skeena Group, which locally contain Albian fauna (Duffell, 1959). In the present study area, sedimentary rocks correlated with Skeena

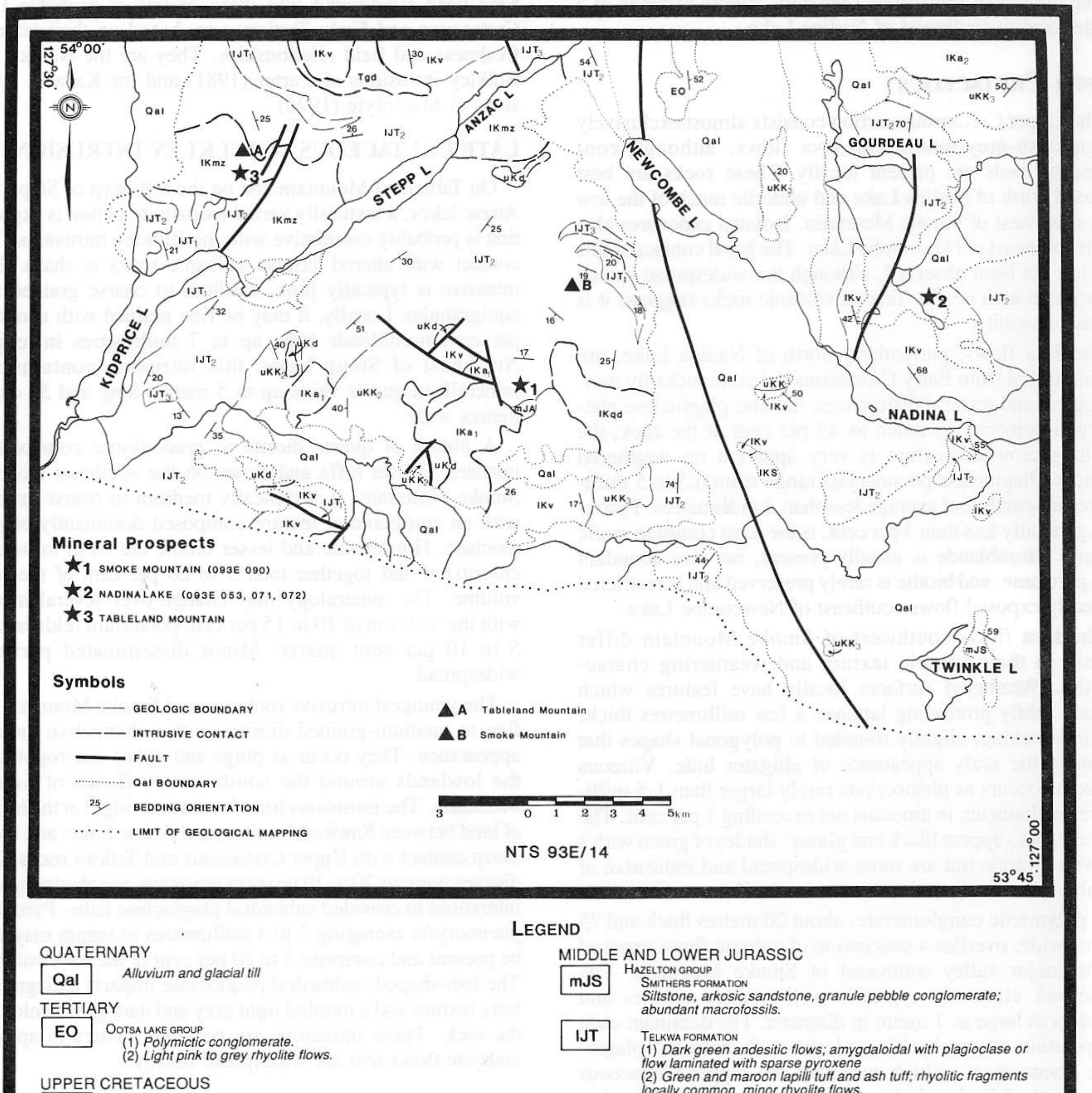


Figure 1-21-2. Geology of North Newcombe Lake map sheet (NTS 93E/14).

Group consist of micaceous sandstone rubble exposed at a single locality southwest of Nadina Lake.

Upper Cretaceous

The Upper Cretaceous section consists almost exclusively of greenish-grey-weathering lava flows, although conglomerate beds are present locally. These rocks are best exposed north of Nadina Lake and underlie much of the low area southwest of Smoke Mountain. Isolated exposures also occur southeast of Newcombe Lake. The basal contact of this unit has not been observed, although the widespread spatial association with nearby Telkwa volcanic rocks suggests it is an unconformity.

The lava flows, particularly north of Nadina Lake, are distinguished from Early Cretaceous volcanic rocks by mineralogical and textural differences. Tabular plagioclase phenocrysts comprise as much as 45 per cent of the rock; the resulting crowded texture is very apparent on weathered surfaces. Plagioclase phenocrysts range from 0.5 to 5 millimetres in length, but average less than 2 millimetres. Pyroxene, generally less than 3 per cent, is the most common mafic mineral. Hornblende is usually present, but less abundant than pyroxene, and biotite is rarely preserved and is restricted to poorly exposed flows southeast of Newcombe Lake.

The lava flows southwest of Smoke Mountain differ mainly in their aphyric texture and weathering characteristics. Weathered surfaces locally have features which include subtly protruding laminae a few millimetres thick, and interlocking, slightly rounded to polygonal shapes that resemble the scaly appearance of alligator hide. Vitreous pyroxene occurs as phenocrysts rarely larger than 1.5 millimetres in diameter, in amounts not exceeding 1 per cent. The freshest rocks appear black and glassy; shades of green with a mauve to purple tint are more widespread and indicative of variable weathering and oxidation in the flows.

A polymictic conglomerate, about 20 metres thick and 75 metres wide, overlies a succession of aphyric flows exposed in the major valley southwest of Smoke Mountain. The framework clasts are typically well-rounded cobbles and boulders as large as 1 metre in diameter. The dominant clast composition is porphyritic andesite with crowded plagioclase phenocrysts, which resemble the Upper Cretaceous flows north of Nadina Lake. Also present are clasts of aphyric andesite and granodiorite. Several widely separated exposures of pebble conglomerate west of Smoke Mountain appear to occur at a similar stratigraphic level. Collectively, these conglomerates probably reflect a period of local uplift and fluvial transport of detritus eroded mainly from Upper Cretaceous rocks.

The aphyric and crowded porphyritic andesite flows diagnostic of this map unit are correlated with a succession of latite-andesite flows near the base of the Kasalka Group at Swing Peak (MacIntyte, 1976). A very fresh specimen of aphyric rock was collected southwest of Smoke Mountain for potassium-argon dating.

INTRUSIVE ROCKS

Jurassic and Cretaceous volcanic rocks are intruded by small irregular stocks, sills and numerous dykes. Intrusions have been subdivided into three groups of probable Late Cretaceous and Early Tertiary age, based on their texture, freshness and field relationships. They are the Nanika and Bulkley intrusions of Carter (1981) and the Kasalka intrusions of MacIntyre (1976).

LATE CRETACEOUS — BULKLEY INTRUSIONS

On Tableland Mountain and on the hills east of Stepp and Anzac lakes, a texturally varied monzonite pluton is exposed that is probably correlative with the Bulkley intrusions. The contact with altered Telkwa volcanic rocks is sharp. This intrusive is typically pink, medium to coarse grained and equigranular. Locally, it may be fine grained with about 15 per cent hornblende laths up to 7 millimetres in length. Northeast of Stepp Lake, this intrusion contains unmineralized quartz veins up to 5 metres long and 50 centimetres wide.

A pluton of quartz diorite to granodiorite composition intrudes Telkwa tuffs and flows on the southeast slope of Smoke Mountain. It is typically medium to coarse grained with an equigranular texture composed dominantly of plagioclase. Hornblende and lesser biotite are fresh to weakly chloritized and together total 5 to 20 per cent of the rock volume. The mineralogy may change over several metres with the addition of 10 to 15 per cent potassium feldspar and 5 to 10 per cent quartz. Minor disseminated pyrite is widespread.

The youngest intrusive rocks around Smoke Mountain are fine to medium-grained diorites with a distinctive mottled appearance. They occur as plugs and dykes outcropping in the lowlands around the southwestern flanks of Smoke Mountain. The intrusions form knobs and ridges at the height of land between Smoke Mountain and Anzac Lake, and are in sharp contact with Upper Cretaceous and Telkwa rocks. The diorites contain 20 to 30 per cent pyroxene as anhedral grains interstitial to crowded subhedral plagioclase laths. Pyroxene phenocrysts averaging 2 to 4 millimetres in length may also be present and comprise 5 to 20 per cent of the rock volume. The lath-shaped, subhedral plagioclase imparts a diagnostic felty texture and a mottled light grey and dark green colour to the rock. These intrusions are possible feeders to aphyric andesite flows that are widespread nearby.

LATE CRETACEOUS — KASALKA INTRUSIONS

Kasalka intrusions, as defined by MacIntyre (1976) in the Tahtsa Lake area, have porphyritic textures and compositions similar to the volcanic rocks of the Kasalka Group. In the Newcombe Lake area several small stocks and dykes are exposed north of Nadina Lake and south of Smoke Mountain, where upper Cretaceous volcanic rocks are best preserved. The intrusive contacts are generally sharp, but in places the intrusions grade imperceptibly into lava flows.

These plutons contain a diagnostic phenocryst assemblage of plagioclase, hornblende and, in places, biotite, set in a greyish green aphanitic matrix. A typical pluton, north of Nadina Lake, consists of 30 to 40 per cent plagioclase phenocrysts between 4 and 10 millimetres in diameter. These rocks differ in texture from the small stock south of Smoke Mountain, where plagioclase rarely exceeds 4 millimetres in diameter and comprises as much as 45 per cent of the rock volume, resulting in a diagnostic crowded porphyritic texture. Hornblende prisms, commonly 3 to 5 millimetres long, are ubiquitous, locally comprising as much as 7 per cent of the rock volume, but averaging less than 3 per cent. Biotite is found as subvitreous and partially chloritized grains, generally in amounts of 1 to 2 volume per cent and mainly in dykes spatially associated with the small stocks near Nadina Lake.

The Kasalka intrusions have textural features that suggest crystallization of andesitic magma at a high crustal level. The similar mineralogy and texture of nearby Upper Cretaceous flows suggest a genetic relationship. The age of these intrusive rocks is inferred from a potassium-argon date of 85 Ma (Diakow, unpublished data, 1987) from a biotite-hornblende-plagioclase porphyritic andesite stock in the western part of the Whitesail Reach map area (NTS 93E/10). *En echelon*, northwest-trending dykes identical to this rock occur on west Tahtsa Reach and probably correlate with those outcropping near Nadina Lake.

EARLY TERTIARY — NANIKA INTRUSIONS

A columnar-jointed sill of biotite-phyric coarse-grained granodiorite outcrops on a dip slope on the northeast flank of Tableland Mountain. Vitreous biotite books up to 3 millimetres across comprise as much as 20 per cent of the rock. This sill was intruded along the contact between Telkwa lapilli tuffs and Lower Cretaceous andesite flows, and is probably Tertiary in age.

STRUCTURE

Steeply inclined faults which trend northwest and northeast are the principal structural elements in the Newcombe Lake area. The absence of stratigraphic markers inhibits mapping the trace of significant through-going faults, particularly in large areas underlain by a single rock unit. This results in a map pattern of unconnected fault segments.

Fault displacements are clearly recognized where bedded Lower Cretaceous rocks are in contact with the Telkwa Formation on the southwest side of Smoke Mountain and in offsets of the intrusive contact on Tableland Mountain. Elsewhere, inferred faults, mainly within the Telkwa Formation volcanic rocks near Kidprice Lake, are thought to be minor structures.

The absence of Middle Jurassic Smithers Formation and Lower Cretaceous Skeena Group sedimentary successions above Telkwa volcanic rocks throughout most of the map area is difficult to explain, as thick accumulations of these sediments are widely exposed immediately to the south in the Sibola Range. The restriction of sedimentary rocks to the low terrain between Twinkle and Newcombe lakes may be related to block faulting, however, no major faults have been mapped.

MINERAL OCCURRENCES

Porphyry copper-molybdenum mineralization associated with granitic intrusions is the principal type of mineral occurrence found in the map area. Quartz veins and veinlets, sparsely mineralized with pyrite, locally cut Lower Jurassic volcanic rocks.

PORPHYRY COPPER-MOLYBDENUM

Porphyry-style mineral occurrences in the study area form part of a north-trending belt of porphyry deposits associated with Late Cretaceous Bulkley intrusions and Eocene Nanika intrusions in west-central British Columbia (Carter, 1981). The geological setting of deposits in the vicinity of Tahtsa Lake and the Sibola Range has been described by MacIntyre (1985).

Porphyry copper mineralization is associated with intrusions north of Nadina Lake and at Smoke Mountain. Both areas were extensively explored between 1968 and 1974.

NADINA LAKE AREA

Several small granitic stocks intrude and alter Lower Jurassic Telkwa and Cretaceous volcanic rocks in the hilly region north of Nadina Lake. The intrusions and surrounding tuffs and andesites are well mineralized with disseminated pyrite, typically comprising 1 to 3 per cent of the rock volume, but ranging up to 5 per cent. Chalcopyrite and molybdenite, in amounts usually less than 1 per cent, are assocated with the pyritic rocks. The sulphides also fill narrow fractures and line sporadic quartz gash veins which are less than 2 metres long and 20 centimetres wide. Pyritic alteration zones centred over the intrusions result in strong induced polarization and magnetic anomalies which have been used to guide exploration.

SMOKE MOUNTAIN AREA

A Late Cretaceous quartz diorite intrusion that outcrops on the southern flank of Smoke Mountain contains 1 to 3 per cent pyrite, 0.5 to 1 per cent chalcopyrite, and traces of molybdenite and bornite mineralization as disseminations and fracture coatings. Sulphide mineralization is spotty, with highly fractured, calcite-rich exposures showing the most sulphides. Elsewhere, the rock is fresh with only a trace of disseminated pyrite that extends into nearby altered Telkwa volcanic rocks.

A well-mineralized zone is exposed by a creek draining the southern flank of Smoke Mountain. It has eroded highly fractured and gossanous shaly sediments with sparse intercalated sandstone beds. The shales contain 5 to 10 per cent disseminated pyrite and veins of massive pyrite 3 metres long and up to 20 centimetres wide. Traces of chalcopyrite, bornite and malachite are associated with calcite veining and fracture coatings. This mineralized zone can be traced for about 200 metres along the creek and 30 metres up slope. The sediments are tentatively correlated with the Ashman Formation.

QUARTZ VEINS

Quartz veinlets and short, narrow veins cut Lower Jurassic rhyolitic flows and pyroclastic rocks immediately north of Anzac Lake. The veins trend easterly and dip steeply. Veins typically consist of white drusy quartz, rarely exceed a few centimetres in width, and are traceable along strike for less than 10 metres. They occur mainly as discrete *en echelon* veinlets with variable spacing but, in places, form zones of anastomosing veins over widths of up to a metre. The veins are generally barren of sulphides and the lack of wallrock alteration suggests they have little economic potential.

Several quartz veins are exposed on a series of knobs and ridges northeast of Stepp Lake. One group of veins cuts fine-grained andesite, another is within a quartz monzonite intrusive. The fine-grained flow-laminated andesite hosts four or more quartz veins that average 10 to 30 centimetres wide and 1 to 3 metres long. The quartz is coarsely crystalline and comb textured with much open space. Hematite imparts a gossanous look to the veins, but no sulphides are visible. West of this occurrence, five or more subparallel quartz veins, again averaging 10 to 30 centimetres wide and 1 to 3 metres long, cut coarse-grained unaltered monzonite outcropping on a west-facing dip slope. The quartz is milky and massive, or clear, coarsely crystalline and comb textured. Hematite is common and gives the veins a rusty colour. Many smaller, barren quartz veins are evenly distributed across the outcrop.

On Tableland Mountain, near the eastern margin of the plateau, an outcrop of strongly fractured purple lapilli tuffs is cut by quartz veins with a northerly trend, parallel to the fractures. The veins are gossanous due to hematite but contain only thin selvages weakly mineralized with pyrite and very minor malachite. The host rock is gossanous within about a metre of the veins.

CONCLUSIONS

Regional mapping in Newcombe Lake map area reveals the following:

1. The Lower Telkwa Formation, representing the lowest stratigraphic level exposed, consists mainly of well-bedded pyroclastic rocks interlayered locally with thick flows of basaltic to rhyolitic composition. These rocks are generally unconformably overlain by two similar successions of porphyritic andesite flows of probable Early and Late Cretaceous age. In adjacent areas, the interval represented by this non-erosional unconformity is normally occupied by marine sedimentary rocks of the Middle Jurassic Smithers Formation.

   The distribution of stratified Cretaceous rocks suggests deposition on an uplifted and irregular paleosurface underlain by Telkwa volcanic rocks. Uplift is assumed to be the result of block faulting, although major through-going faults have not been recognized.

2. Porphyry copper-molybdenum mineralization is associated with plutons tentatively correlated with the Late Cretaceous Bulkley intrusions and Eocene Nanika intrusions.

   Quartz veins occurring in narrow, discontinuous zones, with no associated wallrock alteration, contain sporadic pyrite and lesser chalcopyrite.

ACKNOWLEDGMENTS

Pat Bartier and Mark Leir provided capable field assistance. This work has benefitted from informative discussions during several field trips to outlying areas with Dr. D.G. MacIntyre. Joe Gardeau at Nadina Lake Lodge is given special thanks for his generous hospitality.

REFERENCES

Carter, N.C. (1981): Porphyry Copper and Molybdenum Deposits, West-central British Columbia, *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Bulletin 64, 150 pages.

Cawthorn, N.G. (1973): Geology and Petrology of the Troitsa Property, Whitesail Lake Map-area, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*.

Diakow, L.J. and Koyanagi, V. (1988): Stratigraphy and Mineral Occurrences of Chikamin Mountain and Whitesail Reach Map Areas, *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 155-168.

Diakow, L.J. and Mihalynuk, M. (1987): Geology of the Whitesail Reach and Troitsa Lake Map Areas, *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 171-179.

Duffell, S. (1959): Whitesail Lake Map-area, British Columbia, *Geological Survey of Canada*, Memoir 299, 119 pages.

MacIntyre, D.G. (1974): Zonation of Alteration and Metallic Mineral Assemblages, Coles Creek Copper Prospect, West-central British Columbia, Unpublished M.Sc. Thesis, *University of Western Ontario*.

——— (1976): Evolution of Upper Cretaceous Volcanic and Plutonic Centres and Associated Porphyry Copper Occurrences, Tahtsa Lake Area, British Columbia, Unpublished Ph.D. Thesis, *University of Western Ontario*, 149 pages.

——— (1985): Geology and Mineral Deposits of the Tahtsa Lake District, West-central British Columbia, *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Bulletin 75, 82 pages.

Panteleyev, A. (1976): Berg Porphyry Copper-molybdenum Deposit, Unpublished Ph.D. Thesis, *The University of British Columbia*, 235 pages.

Papezik, V.S. (1957): Geology of the Deer Horn Prospect, Omineca Mining Division, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*.

Richards, G.G. (1974): Geology of the Ox Lake Cu-Mo Porphyry Deposit, Unpublished M.Sc. Thesis, *The University of British Columbia*.

van der Heyden, P. (1982): Tectonic and Stratigraphic Relations between the Coast Plutonic Complex and Intermontane Belt, West-central Whitesail Lake Map Area, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 172 pages.

Woodsworth, G.J. (1980): Geology of Whitesail Lake (93E) Map-area, *Geological Survey of Canada*, Open File Map 708.

PALYNOLOGY OF SUBSURFACE CENOZOIC SEDIMENTS AND PYROCLASTIC ROCKS SOUTHWEST OF VANDERHOOF, BRITISH COLUMBIA*
(93F/10, 16)

By G.E. Rouse and W.H. Mathews
The University of British Columbia

KEYWORDS: Tertiary stratigraphy, palynology, Nechako Plateau, Eocene volcanics, Fraser Bend Formation, Australian Creek Formation, hydrocarbon source beds.

INTRODUCTION

The Nechako Plateau of central British Columbia is an area of rolling topography with bedrock outcrops generally confined to some of the river banks and to the upper and steeper slopes of hills. The road from Vanderhoof to the Kenney Dam 75 kilometres to the southwest, for example, is within sight of bedrock outcrops only at Mount Greer, midway along its length and at the Kenney Dam itself (Figure 1-22-1). Exposed bedrock is, moreover, almost exclusively Mesozoic to Eocene plutonic and volcanic rocks. Two notable departures from the dominance of crystalline rocks were revealed by drilling in a vain search for uranium by E. & B. Explorations Ltd. (now owned by Imperial Metals Corporation) in 1978 on its EN and GY claims.

RESULTS

Graphic logs for both drill holes are shown in Figure 1-22-2. In both, the uppermost rocks are Middle Eocene volcanics lying on younger Tertiary sediments. Hole EN-1 bottomed in volcanic rocks which have a potassium-argon date of 42.7 Ma, that is, Middle Eocene (for analytical data on the potassium-argon determinations *see* Rouse and Mathews, 1988).

Sediment samples were collected and processed for palynological recovery at the intervals indicated in Figure 1-22-2. Recovery varied from good to poor. Surprisingly, the palynoassemblages from 17 to about 140 metres in EN-1 correlate with Miocene assemblages reported to the east at Quesnel, in the Fraser Bend Formation, by Rouse and Mathews (1979), and equivalents to the south on Gang Ranch by Mathews and Rouse (1984). The main Miocene palynomorphs are shown on Plate 1-22-1. These have been grouped in three zones in

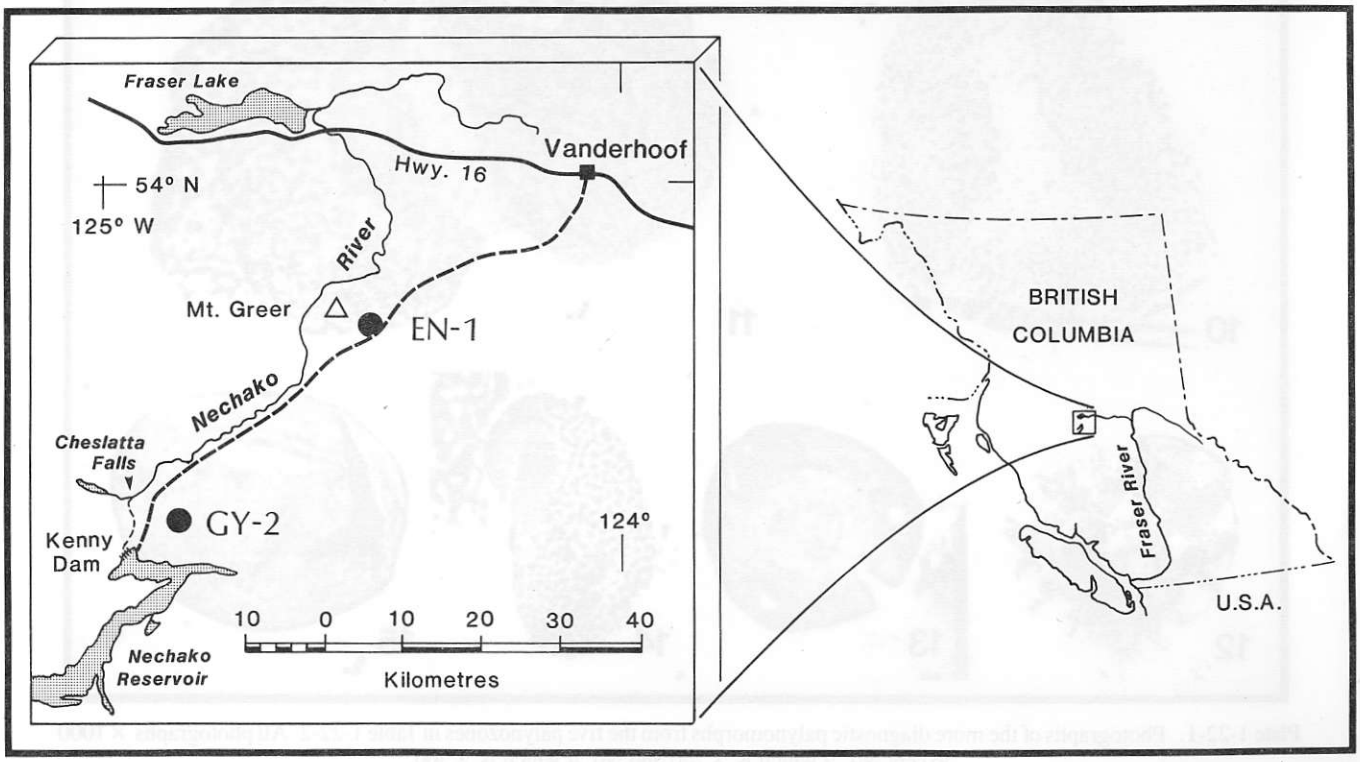


Figure 1-22-1. Location of the study area in central British Columbia, and location of drill holes EN-1 and GY-2 with respect to the main road between Vanderhoof and the Kenney Dam.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

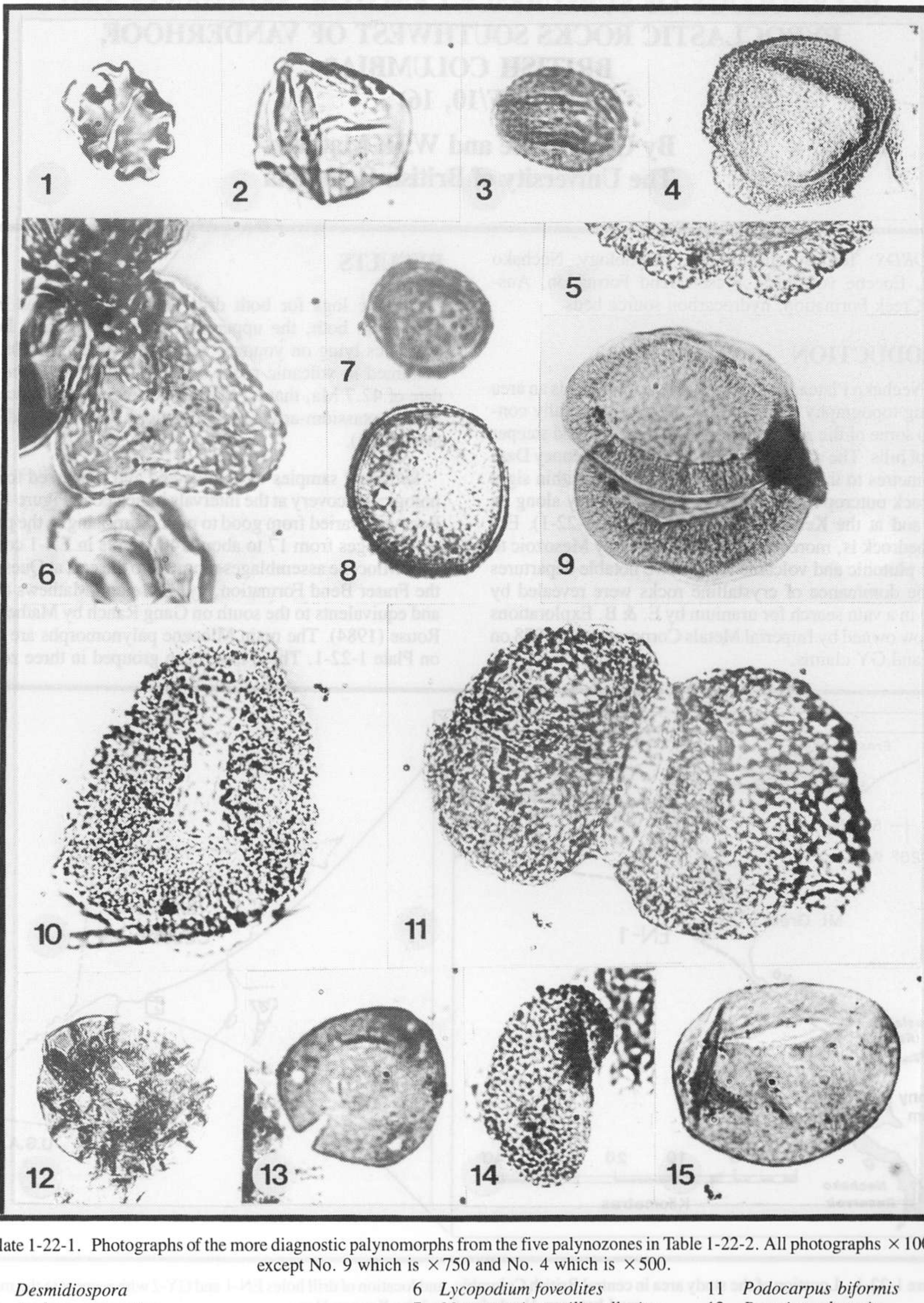


Plate 1-22-1. Photographs of the more diagnostic palynomorphs from the five palynozones in Table 1-22-2. All photographs × 1000 except No. 9 which is × 750 and No. 4 which is × 500.

1	*Desmidiospora*	6	*Lycopodium foveolites*	11	*Podocarpus biformis*
2	*Juglans periporites*	7	*Metasequoia papillapollenites*	12	*Pesavis tagluensis*
3	*Quercoidites microhenricii*	8	*Monulcipollenites confossus*	13	*Carya veripites*
4	*Tsuga igniculus*	9	*Cedrus perialata*	14	*Arecipites columellus*
5	magnification of part of the outer wall of No 4	10	*Tsuga heterophyllites*	15	*Laevigatosporites kloster*

TABLE 1-22-1
PALYNOZONATION OF THE MIOCENE AND OLIGOCENE SEDIMENTS FROM DRILL HOLES EN-1 (MIOCENE AND OLIGOCENE) AND GY-2 (ALL OLIGOCENE). THE NUMBERS FOLLOWING THE PALYNOMORPH NAMES REFER TO THE SPECIES ILLUSTRATED IN PLATE 1-22-1

MIOCENE	Zone 1 17–32 m	*Desmidiospora sp.* (1) *Juglans periporites* (2) *Quercoidites microhenricii* (3) *Tsuga igniculus* (4)
	Zone 2 48-63 m	*Lycopodium foveolites* (6)
	Zone 3 68-140 m	*Metasequoia papillapollenites* (7) *Monulcipollenites confossus* (8) *Cedrus perialata* (9)
OLIGOCENE	Zone 4 149-178 m	*Tsuga heterophyllites* (10) *Podocarpus biformis* (11)
	Zone 5 180-283 m	*Pesavis tagluensis* (12) *Carya veripites* (13) *Arecipites columellus* (14) *Laevigatosporites kloster* (15)

TABLE 1-22-2
XRF MAJOR-ELEMENT ANALYSES OF VOLCANIC ROCKS FROM EN-1 AND GY-2 DRILL CORE

Depth (m)	SiO_2	Al_2O_3	Fe_2O_3*	FeO*	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5
					EN-1					
Surface	59.22	15.02	2.24	6.09	5.48	3.14	4.23	3.33	1.42	0.01
17	54.27	16.09	3.62	6.61	7.78	2.55	4.94	1.47	2.12	0.37
288	52.48	15.27	3.38	6.48	7.03	6.51	4.82	1.60	1.88	0.43
					GY-2					
133	58.06	15.68	2.76	5.88	6.09	2.92	4.79	1.81	1.25	0.31

* Fe_2O_3 and FeO adjusted during normalization according to Irvine and Baragar (1971). Results expressed in weight %, normalized to 100%.

TABLE 1-22-3
RANDOM REFLECTANCES OF SIX SAMPLES OF VITRINITE FROM DRILL HOLE EN-1

Depth (m)	% Ro_{ran}
17*	0.26 ± 0.05
22	0.20 ± 0.02
149	0.44 ± 0.07
239	0.47 ± 0.05
249	0.56 ± 0.05
291+	4.26 ± 0.57

* vitrinite squeezed into fractures (faults?) in lava.
\+ vitrinite under lavas, evidently baked.

Table 1-22-2, in case future drilling programs may reveal similar zones for correlation.

The palyno-assemblages in EN-1, from about 140 metres to the contact with the basal lavas, correlate with those from the Oligocene Australian Creek Formation reported from the Quesnel region by Rouse and Mathews (1979). The assemblage in GY-2, from the upper volcanics to the bottom of the hole, also correlates with the Australian Creek assemblages. The palynomorphs illustrated in Plate 1-22-1 are some of the more diagnostic of the overall Oligocene assemblage. These have been grouped into two zones in Table 1-22-2.

The contact of the Miocene and Oligocene palyno-assemblages in EN-1 is marked by a sharp lithologic change, from white tuffaceous siltstone in the Miocene to coal in the top of the Oligocene, and brown carbonaceous siltstones and coal seams and stringers in much of the lower sections of the Oligocene.

Volcanic rocks in the core (Figure 1-22-2) include both lava flows and breccias of andesitic to basaltic composition. Major-element analyses of four samples are given in Table 1-22-1. The sedimentary units are for the most part tuffaceous; pale grey to white lapilli and bentonitic alteration are common.

There is also a sharp change in vitrinite reflectance values from the Miocene to Oligocene (Figure 1-22-2; Table 1-22-3). This is probably a result of greater time and depth of burial for the Oligocene sediments.

SIGNIFICANCE

The most significant feature of this study is that Middle Eocene volcanics overlie about 250 metres of younger Tertiary sediments. One explanation is that the Eocene volcanics, which outcrop quite close to both drill holes, were thrust over the Miocene sediments in EN-1, and on Oligocene sediments in GY-2. However, a thrust surface was not recognizable in either hole, nor are the beds markedly disturbed.

A second explanation is that slabs of Middle Eocene rocks from surrounding hills broke off sometime after sediment deposition and slid downwards to form the volcanic caps.

That this development was fairly regional is suggested by the report by Kathryn Andrew (1988) of Middle Eocene strata on top of Miocene sediments in the Capoose Lake area, some 75 kilometres to the southwest of EN-1.

Another significant feature is that middle to late Tertiary basins, some of them deep, appear to be numerous below the mid-Eocene volcanic cover. This setting has high potential for hydrocarbon source beds, and suggests that gravity and seismic exploration are warranted to search for such basinal deposits.

ACKNOWLEDGMENTS

We wish to thank Imperial Metals Corporation for access to the cores, and for copies of drill-hole logs. Our appreciation also goes to our colleague Dr. R.M. Bustin for the determination of vitrinite reflectances. We also acknowledge the work done and information on the Capoose Lake properties provided by Kathryn Andrew and Dr. Colin Godwin, and to Dr. Colin Spence of Lornex Mining Corporation Limited for providing additional samples and information on the Capoose Lake sediments. Many thanks are due to Katherine Lesack for a superb job of organization, photography, and production of the final manuscript. We are indebted to the British Columbia Ministry of Energy, Mines and Petroleum Resources which has made this project possible by means of a research grant.

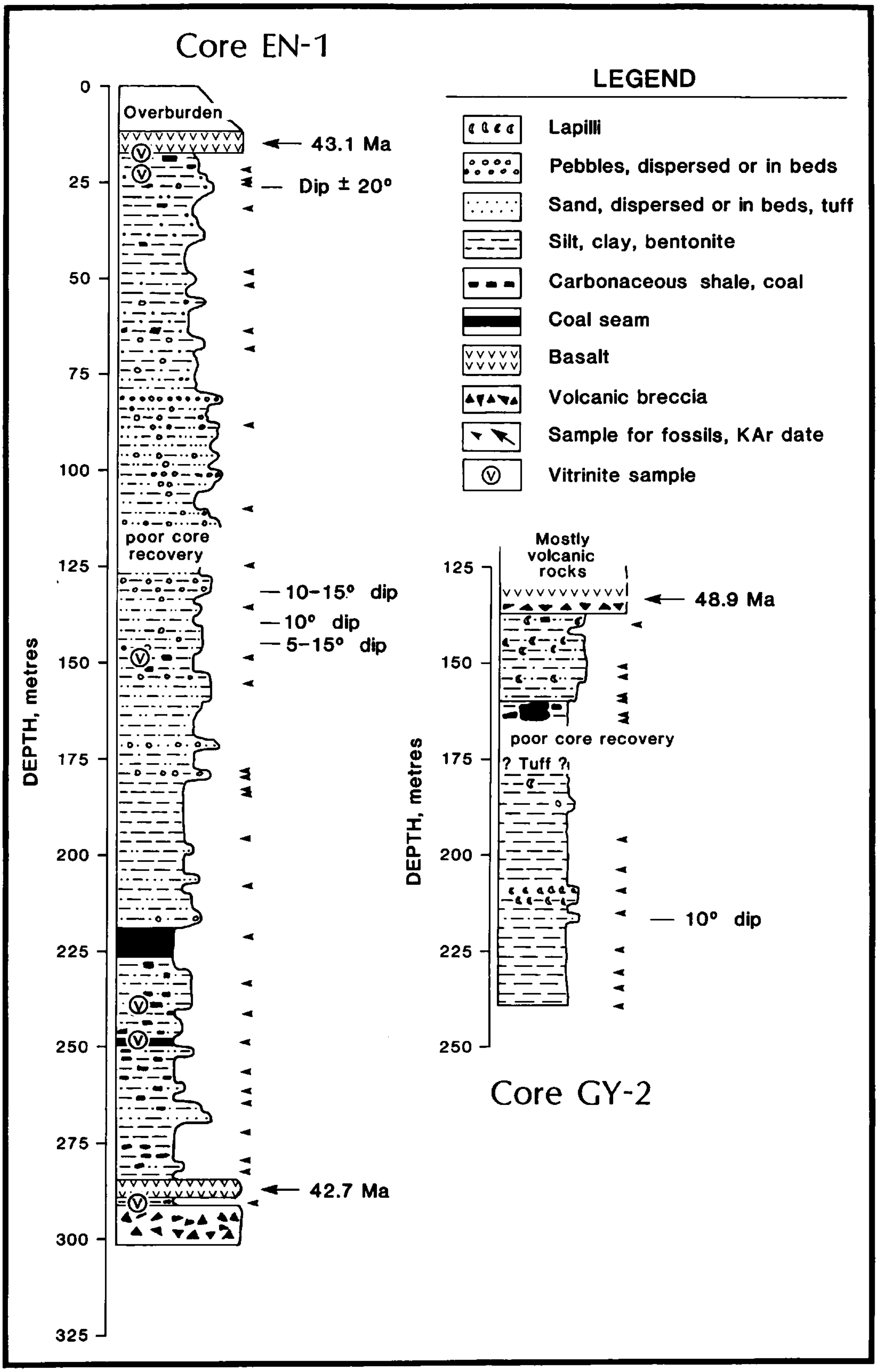


Figure 1-22-2. Graphic logs for drill holes EN-1 and GY-2, showing K-Ar dates, location of samples for palynology and for vitrinite reflectance. Lithology in part from company drill logs, in part by present authors.

REFERENCES

Andrew, K.P.E. (1988): Geology and Genesis of the Wolf Precious Metal Epithermal Prospect and the Capoose Base and Precious Metal Porphyry-style Prospect, Capoose Lake Area, Central British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 334 pages.

Irvine, T.N. and Baragar, W.R.A. (1971): A Guide to the Chemical Classification of the Common Volcanic Rocks, *Canadian Journal of Earth Sciences*, Volume 8, pages 523-548.

Mathews, W.H. and Rouse G.E. (1984): The Gang Ranch–Big Bar Area: Stratigraphy, Geochronology, and Palynology of the Tertiary Beds and their Relationship to the Fraser Fault, *Canadian Journal of Earth Sciences*, Volume 21, Number 10, pages 1132-1144.

Rouse, G.E. and Mathews, W.H. (1979): Tertiary Geology and Palynology of the Quesnel Area, British Columbia, Bulletin, *Canadian Petroleum Geology*, Volume 27, pages 418-445.

——— (1988): Palynology and Geochronology of Eocene Beds from Cheslatta Falls and Nazko Areas, Central British Columbia, *Canadian Journal of Earth Sciences*, Volume 25, pages 1268-1276.

NOTES

JURASSIC STRATIGRAPHIC RELATIONSHIPS IN THE BABINE AND TELKWA RANGES (93L/10, 11, 14, 15)

By D.G. MacIntyre, P. Desjardins and P. Tercier

KEYWORDS: Jurassic stratigraphy, Hazelton Group, Telkwa Formation, Nilkitkwa Formation, Smithers Formation, Ashman Formation, Trout Creek assemblage, Babine Range, Telkwa Range, structure, tectonic history.

INTRODUCTION

This report discusses preliminary observations on Jurassic volcanic stratigraphy in the Babine and Telkwa ranges. These observations are based on 1:50 000 mapping conducted as part of the Babine and Telkwa projects (Figure 1-23-1).

The Babine project began in 1984 with 1:10 000 mapping of the Dome Mountain gold camp (MacIntyre, 1985). In 1986 and 1987 the remaining part of the Babine Range, including most of the Driftwood Creek (93L/15) and Quick (93L/10) map sheets, was mapped at 1:50 000 scale (MacIntyre *et al.*, 1987; MacIntyre and Desjardins, 1988).

The Telkwa project is an enhancement to the Babine project. The objective is to extend previous mapping westward to cover important mineral camps in the Telkwa Range. Parts of the Smithers (93L/14) and Telkwa River (93L/11) map sheets (Figure 1-23-1) were previously mapped by R.V. Kirkham and J.Koo (1984). Mapping in 1988 was concentrated in areas not covered by this earlier work, thus providing complete 1:50 000 coverage of the two map sheets. In 1989 mapping will extend southward into the Thautil River map sheet (93L/6).

An important part of the Telkwa project is the recompilation and publication at 1:20 000 scale of detailed mapping by R.V. Kirkham on Hudson Bay Mountain. This work, which has not been previously published, was completed between 1963 and 1968 while Dr. Kirkham was in the employ of the British Columbia Department of Mines. Dr. Kirkham also did regional mapping in the Bulkley Valley and Telkwa River areas during this period and his data have been incorporated into this report.

REGIONAL GEOLOGIC SETTING

West-central British Columbia is part of the Stikine terrane. This terrane, which is believed to have travelled north from low paleolatitudes in Late Cretaceous or Early Tertiary time, includes: submarine calcalkaline to alkaline volcanic island arc rocks of the Late Triassic Takla Group; subaerial to submarine calcalkaline volcanic, volcaniclastic and sedimentary rocks of the Early to Middle Jurassic Hazelton Group; Late Jurassic and Early Cretaceous successor basin sedimentary rocks of the Bowser Lake, Skeena and Sustut groups; and Late Cretaceous to Tertiary calcalkaline continental volcanic arc rocks of the Kasalka, Ootsa Lake and Goosly Lake groups. The younger volcanic rocks occur sporadically throughout the area, mainly in subsided fault blocks and grabens that may be the remains of cauldron subsidence complexes.

Potassium-argon isotopic dating has defined three major magmatic events. These are the Late Triassic to Early Jurassic Topley intrusions, the Middle to Late Cretaceous Bulkley intrusions and the Eocene Babine intrusions (Carter, 1981). Mineral deposits in the area are associated with emplacement of these intrusions. The most economically important exploration targets are porphyry copper and molybdenum deposits and mesothermal and epithermal precious metal veins. A few small massive sulphide occurrences have also been discovered.

TECTONIC HISTORY

The tectonic history of the area is divisible into three distinct regimes. From Early to Middle Jurassic time an extensive calcalkaline island arc evolved, with a possible back-arc basin located to the east. This was followed from late Middle Jurassic to Early Cretaceous time by development of the Bowser and Nechako successor basins. Thick deposits of molasse derived from an uplifted Skeena Arch and Omineca crystalline belt accumulated within these basins. A major plate collision in Middle Cretaceous time resulted in uplift of the Coast Range and extensive folding of rocks to the east. Debris was shed eastward across the area from the rising metamorphic-plutonic complex and this was

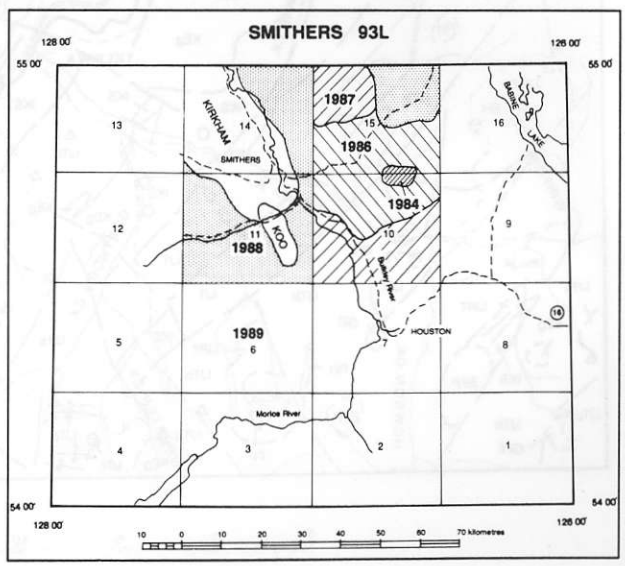


Figure 1-23-1. Location of the 1988 project area.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

followed by the growth of a north-trending Andean-type volcanic arc in Middle to Late Cretaceous time. A transtensional tectonic regime in Late Cretaceous to Early Tertiary time produced the basin-and-range geomorphology that controls the current map pattern of the area. The latest tectonic event appears to be northeast shearing and tilting of fault blocks to the southeast (MacIntyre and Desjardins, 1988). This shearing has offset northwest-trending grabens that developed in Late Cretaceous to Early Tertiary time.

GEOLOGY OF THE STUDY AREA

The geology of the study area, as determined by fieldwork conducted from 1986 to 1988, is shown in Figure 1-23-2. Relationships between the different map units in the Telkwa and Babine ranges are shown diagrammatically in Figure 1-23-3. Table 1-23-1 lists the major stratigraphic and tectonic elements of the Stikine terrane as summarized by Richards (1988). This report will deal mainly with the Jurassic stratigraphy of the Babine and Telkwa ranges.

The Telkwa and Babine ranges consist of a series of uplifted and tilted fault blocks containing rocks ranging from early Jurassic to Tertiary in age. In general the fault blocks are tilted toward the Bulkley valley graben which separates the two ranges. Rocks of Cretaceous and Tertiary age are preserved within the graben. The graben is offset by several major northeast-trending shear zones of probable Tertiary age.

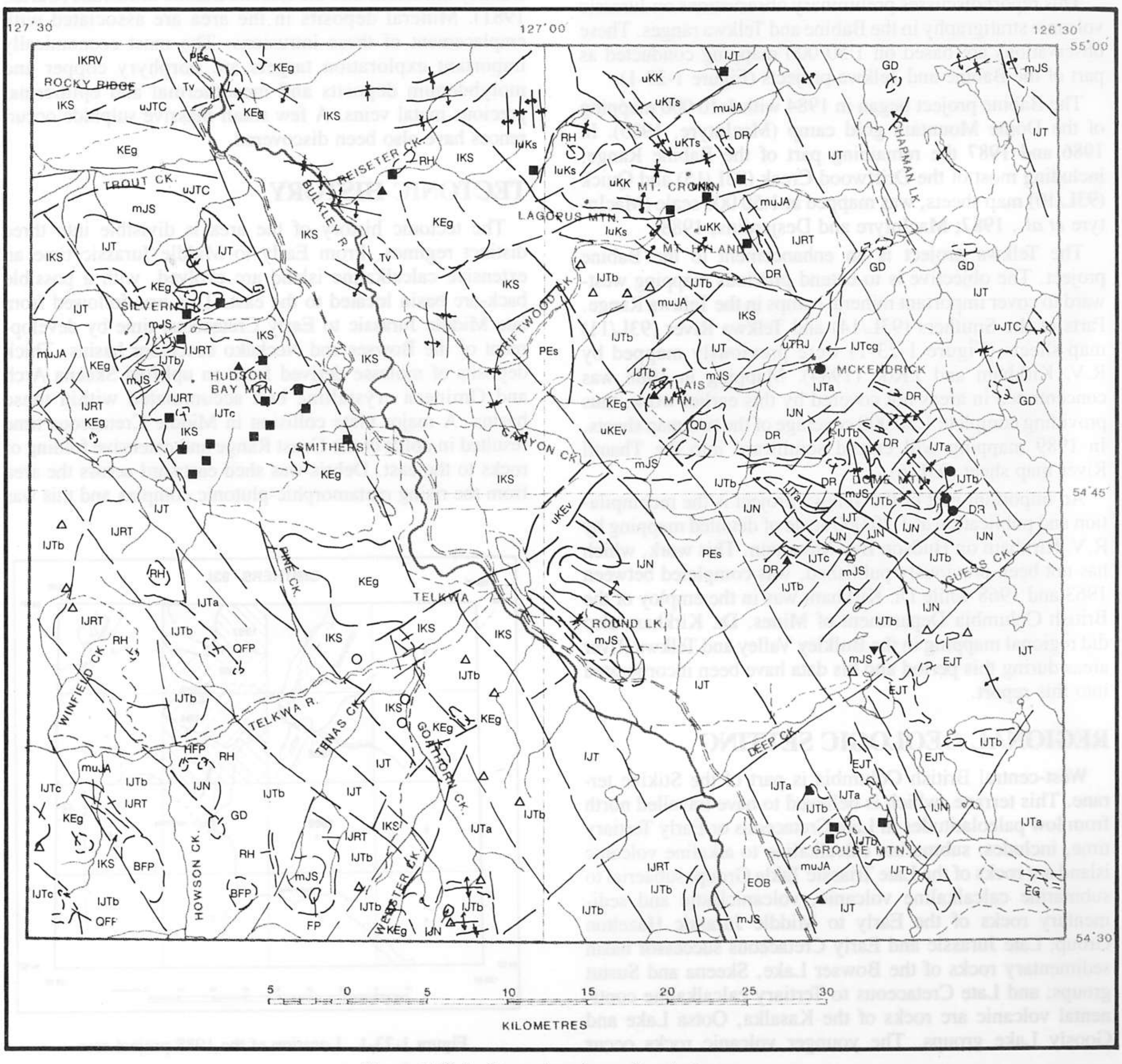


Figure 1-23-2. General geology of project area.

LEGEND

LAYERED ROCKS

PALEOCENE TO MIOCENE

Tv	basalt flows, breccia
EOB	Buck Creek Volcanics: andesite, dacite, breccia, minor basalt
PEs	shale, mudstone, greywacke

UPPER CRETACEOUS TO TERTIARY

OOTSA LAKE GROUP

uKEv	rhyolite, dacite, tuff, breccia, minor andesite
uKTs	tuff, shale, siltstone, greywacke

UPPER CRETACEOUS

KASALKA GROUP

uKK	Brian Boru Formation: porphyritic andesite, tuff, breccia, minor basalt

LOWER TO UPPER CRETACEOUS

luKs	red to maroon phyllite, shale, orange siltstone, chert-quartz pebble conglomerate, greywacke

LOWER CRETACEOUS (ALBIAN)

SKEENA GROUP

lKS	Red Rose Formation: shale, micaceous greywacke, chert, pebble conglomerate, mudstone, coal bearing
lKRV	Rocky Ridge Volcanics: anguite phyric flows, breccia, hornblende andesite, aphanitic basalt

UPPER JURASSIC (OXFORDIAN TO KIMMERIDGIAN)

BOWSER LAKE GROUP

uJTc	Trout Creek Assemblage: greywacke, conglomerate, siltstone, coquinoid sandstone, minor coal

LOWER TO UPPER JURASSIC

HAZELTON GROUP

MIDDLE TO UPPER JURASSIC (CALLOVIAN TO OXFORDIAN)

muJA	Ashman Formation: marine black shale, siltstone, greywacke

MIDDLE JURASSIC (BAJOCIAN TO CALLOVIAN)

mJS	Smithers Formation: feldspathic sandstone, greywacke, siltstone, shale, minor pebble conglomerate, very fossiliferous

LOWER JURASSIC (PLEINSBACHIAN TO TOARCIAN)

lJRT	Nilkitkwa Formation, Red Tuff Member: red, well-bedded air fall tuff, minor ash flow tuff
lJN	Nilkitkwa Formation: marine shale, calcareous siltstone, limestone, minor chert, conglomerate at base

LOWER JURASSIC (SINEMURIAN TO LOWER PLEINSBACCHIAN)

lJT	Telkwa Formation: undivided andesite, dacite, rhyolite, basalt, flows and pyroclastics
lJTc	Siliceous Pyroclastic Facies: quartz-feldspar phyric ash flows, ignimbrite, breccia, siliceous air fall tuff, red tuff, basalt, rhyolite flows.
lJTb	Basalt Flow-Red Tuff Facies: amygdaloidal angite phyric basalt, basaltic tuff, red tuff and epiclastics
lJTa	Andesitic Pyroclastic Facies: andesitic air fall tuff, breccia, feldspar phyric andesite flows, feldspathic epiclastics, minor basalt, rhyolite
lJTcg	Basal Conglomerate: heterolithic volcanic conglomerate

UPPER TRIASSIC OR LOWER JURASSIC

uTRJ	greenstone with granitic lenses

INTRUSIVE ROCKS

LATE CRETACEOUS TO EOCENE

KEg	undivided granitic intrusions; GD – granodiorite; OD – quartz dioritie; DR – diorite; RH – rhyolite; FP – feldspar porphyry; BFP – biotite-feldspar porphyry; HFP – hornblende-biotite-feldspar porphyry

EARLY JURASSIC

EJT	Topley Intrusions: undivided granitic intrusions

MINERAL OCCURRENCES

- ▲ porphyry Cu-Mo
- ■ Ag-Pb-Zn-Cu veins and shears
- ● Au-Ag-Cu-Pb-Zn quartz veins
- Δ Cu-Ag veins and pods
- ▼ Cu-Zn-Ag massive sulphide
- ○ coal

HAZELTON GROUP

The Hazelton Group (Leach, 1910) is a calcalkaline island arc assemblage that evolved in Early to Middle Jurassic time. Tipper and Richards (1976) divide the group into three major formations in the Smithers map area (93L). These are the Late Sinemurian to Early Pliensbachian Telkwa Formation, the Early Pliensbachian to Middle Toarcian Nilkitkwa Formation and the Middle Toarcian to Early Callovian Smithers Formation.

TELKWA FORMATION (lJT)

In the Telkwa Range, a thick section of early Jurassic volcanic rocks constitutes the type area for the Telkwa Formation of the Hazelton Group. Tipper and Richards (1976) describe the typical lithology as "reddish, maroon, purple, grey and green pyroclastic and flow rocks". The formation varies from marine to nonmarine and ranges from Sinemurian to Early Pliensbachian in age. The volcanics in the study area are almost exclusively subaerial and constitute the Howson subaerial facies of the formation. Similar sub-

TABLE 1-23-1

STRATIGRAPHIC AND TECTONIC ELEMENTS STIKINE TERRANE, BRITISH COLUMBIA

Post Orogenic	CENOZOIC	Late Tertiary	PLIE / IO / F	Anahim Volcanics Chilcotin Lavas		BASALT		Development of basin and range morphology, regional Cordilleran uplift.
			M/C		Poplar Butte Volcanics	BASALTIC		
				ENDAKO GROUP	Buck Creek Volcanics		KASTBERG INTRUSIONS QUANCHUS INTRUSIONS BABINE INTRUSIONS NANIKA INTRUSIONS	
Transtensional Volcanic Assemblages		Early Tertiary		OOTSA LAKE GROUP	Goosly Lake Volcanics Babine Volcanics	RHYOLITE TO BASALTIC		Epoch of development of down-drop volcanic basins.
Molasse Assemblages	MESOZOIC	Cretaceous	U	KASALKA GROUP	Brian Boru Formation Tip Top Hill Formation Suskwa River Volcanics	Calc-alkaline andesitic to rhyolitic	BULKLEY INTRUSIONS	Begin uplift of Coastal crystalline belt - welding of Wrangellia and Alexandria to craton.
				Rocky Ridge Volcanics		Conglomerate, Sandstone, Alkaline Basalt		
			L	SKEENA-SUSTUT GROUP		Chert Pebble Congl. Sandstone Black shale, Sandstone, Congl.		Begin uplift of Omineca crystalline belt - welding of Stikinia to craton.
		Jurassic	U	BOWSER LAKE GROUP	Deltaic Assemblages Trout Creek Assemblages Ashman Formation	Congl., Silst., Greywacke, Silst., Shale		Development of Bowser Basin.
Island Arc Assemblages			L	HAZELTON GROUP	Smithers Formation Nilkitkwa Formation	Calc-alkaline, marine and non-marine Volcanics and Sediments Polymictic Congl.	OMINICA INTRUSIONS TOPLEY INTRUSIONS	
		Triassic	U	TAKLA-STUHINI GROUP	Savage, Dewar, and Mooseevale Formations	Alkaline Mafic Volcanics, Sediments and limestone		Stikinia an independent arc terrane, separated from craton.
	PALEOZ.	Permian Penn Miss		STIKINE ASSEMBLAGE		Limestone, Chert, Rhyolite, Andesite Basalt		

Modified after Richards,1988

aerial volcanic rocks crop out in the southern half of the Babine Range. Northeast of the map area the Howson facies grades into the Babine shelf and Kotsine submarine facies (Tipper and Richards, 1976).

The Telkwa Formation is Sinemurian or older based on sporadic fossil fauna within the stratigraphic succession (Tipper and Richards, 1976). In the Babine Range the formation is overlain by marine sedimentary beds containing Late Sinemurian to Pliensbachian pelecypods, predominantly *Weyla*. These rocks are part of the Nilkitkwa Formation. In the Telkwa Range the marine sedimentary beds of the Nilkitkwa Formation are absent or very thin; thin-bedded red tuffs that are mapped as the Red Tuff member of the Nilkitkwa Formation (Tipper, 1976) overlie the Telkwa Formation. In the Telkwa River area shallow-marine sedimentary beds of the Smithers and Ashman formations onlap the red tuffs. In the Goathorn Creek area the Smithers and Ashman formations are absent and the Early Cretaceous coal measures of the Skeena Group sit directly on Telkwa Formation (Koo, 1984).

Andesitic pyroclastics and flows are the predominant lithologies of the lower part of the Howson facies of the Telkwa Formation. A distinctive unit of interbedded amygdaloidal basalt flows and red tuffs overlies the andesitic pyroclastic package. In the Babine Range the basaltic flows are in part submarine. Locally felsic pyroclastics overlie and are interfingered with the basaltic flows and red tuffs.

A unit of well-bedded marine sediments and red tuffs overlies and is in part interbedded with the Telkwa volcanics. The sediments and red tuffs are mapped as part of the Nilkitkwa Formation. Tipper (1979) describes a similar stratigraphic sequence in the Whitesail Lake area.

Our mapping in the Babine and Telkwa ranges suggests the Telkwa Formation is divisible into four major facies. These facies are characterized by their predominant lithologies. In ascending stratigraphic order they are: (1) a heterolithic basal conglomerate; (2) maroon feldspathic tuffs, breccias, epiclastics and andesitic flows; (3) massive aphyric to augite-feldspar-phyric amygdaloidal flows and interbedded red tuffs

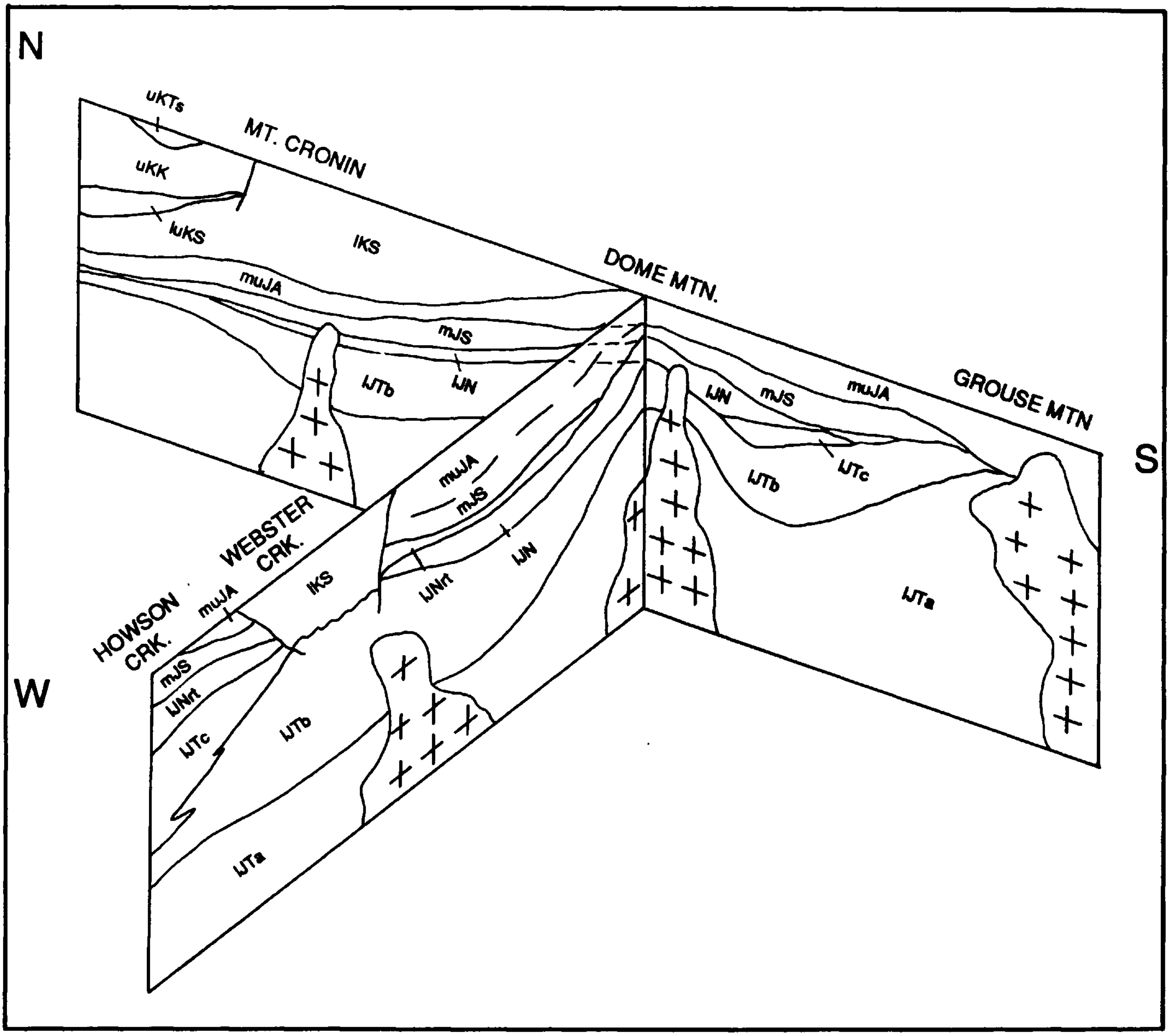


Figure 1-23-3. Stratigraphic fence diagram. *See* Table 1-23-1 for explanation of symbols.

or epiclastics; and (4) siliceous pyroclastics, rhyolite flows and minor red tuffs and basalt flows. The siliceous pyroclastic facies is only present locally; the andesitic pyroclastic and basaltic flow facies are widespread within the study area. Jurassic stratigraphic relationships between the Babine and Telkwa ranges are illustrated in Figure 1-23-4.

The contact between Facies 3 and 4 is generally gradational, both in a lateral and vertical sense, and is typical of a facies boundary. On Dome Mountain a heterolithic erosional conglomerate occurs at the contact between Facies 2 and 3 suggesting an unconformity separates a lower, predominantly andesitic pyroclastic package from an upper, essentially bimodal basalt-rhyolite package. Amygdaloidal flows have not been observed in the lower andesitic pyroclastic package and their absence may serve as a useful criterion for distinguishing the two divisions. Further work is required to confirm the validity of this subdivision.

We initially put the basaltic flows and red tuffs into the Nilkitkwa Formation because of the apparent unconformable relationship with underlying andesitic pyroclastics and apparent conformable relationship with overlying sediments of the Nilkitkwa Formation. However, in the Telkwa Range, a thick section of amygdaloidal flows and red tuffs, that we believe is correlative with similar rocks in the Babine Range, constitutes part of the type area for the Telkwa Formation. Therefore, in order to preserve the original definition of the Telkwa Formation, we also include these rocks as a facies of the Telkwa Formation.

Basal Conglomerate

As discussed in a previous report (MacIntyre *et al.*, 1987) the base of the Telkwa Formation may be exposed near the crest of Mount McKendrick. Here, a poorly-sorted heterolithic conglomerate containing leucogranite clasts is the

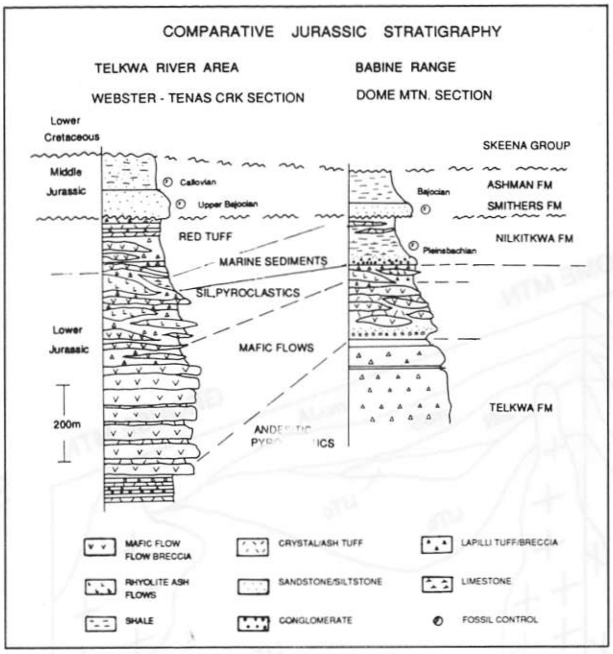


Figure 1-23-4. Comparative Jurassic stratigraphy, Telkwa River and Babine Range.

basal member of a fining-upward sequence of maroon lapilli and crystal tuffs. The tuffs are typical of the lower part of the Telkwa Formation. Below the conglomerate, on the steep north-facing slope of Mount McKendrick, is a thick section of greenstone intruded by leucogranitic lenses. This section is atypical of the Hazelton Group and is believed to be older, perhaps Triassic.

Andesitic Pyroclastic Facies

Maroon to greenish grey feldspathic pyroclastic rocks with minor feldspar-phyric andesite flows underlie the area south of Mount McKendrick (MacIntyre *et al.*, 1987). Fining-upward sequences beginning with volcanic breccia or lapilli tuff and grading upward into thin-bedded crystal and ash tuff are common. These fine-grained tuffs are strongly foliated and tightly folded in places. Beds of maroon to red tuffaceous mudstone, sandstone and pebble conglomerate occur sporadically throughout the section, representing periods of erosion between volcanic cycles.

On Dome Mountain, coarse flow breccias comprised of blocks of feldspar-phyric andesite in a feldspar-rich matrix are common, suggesting proximity to an Early Jurassic eruptive center (MacIntyre, 1985). These coarse breccias are overlain by strongly foliated, thin-bedded maroon to red tuffs. A similar section of thin-bedded tuff and epiclastic rocks underlies a thick section of massive aphyric basalt flows along the southern limit of the Telkwa map sheet and may correlate with rocks in a similar stratigraphic position in the Babine Range.

With the exception of the section described above, the transition from andesitic pyroclastics to overlying basaltic flows and red tuffs is not well exposed in the Telkwa River area. However, Tipper and Richards (1976) describe a measured section from the Loljuh Creek area south of the Telkwa map sheet that we believe transects this contact. The section is shown in Figure 1-23-5. We would place the boundary between the lower andesitic pyroclastic facies and overlying basaltic flow facies at the base of the first amygdaloidal flow.

Basaltic Flow and Red Tuff Facies

Up to 300 metres of aphyric to augite-feldspar-phyric basaltic flows with interbeds of maroon to red crystal and lapilli tuff and related epiclastic rocks underlies the area south of Webster and Tenas creeks. The basaltic flows are fine grained, dark grey to black and relatively unaltered. They are probably basaltic in composition. Flow-top breccia with zeolite cement is common near the top of the section. Locally the flows are amygdaloidal. The flows are resistant and form steep cliff faces along the north side of the northern tributary of Dockrill Creek and in the headwaters of Goathorn, Webster and Tenas creeks. These basaltic flows are correlated with a much thinner section of amygdaloidal flows and red tuffs that overlies andesitic pyroclastic rocks in the Babine Range (Figure 1-23-4). This correlation is based on similar stratigraphic positions.

A medium to thick-bedded unit of interbedded amygdaloidal flows, maroon to grey lapilli and crystal tuff, volcanic breccia, lahar and quartz-feldspar-phyric ash-flow tuff caps the thick section of basaltic flows in the Goathorn – Webster Creek area. A typical section through this unit is shown in Figure 1-23-6. The gradual transition from predominantly massive flows at the base into interbedded flows, tuffs and epiclastics and finally into predominantly red airfall tuff and tuffaceous mudstone with sporadic amygdaloidal flows, is typical of the basaltic flow/red tuff facies of the Telkwa River area.

Whole-rock chemistry has been completed on a number of samples of basalt from the basalt/red tuff facies of the Telkwa Formation. Unfortunately fresh samples are very difficult to obtain from this unit. Two relatively unaltered samples were collected from the Grouse Mountain area in 1987. The results of these analyses are presented in Table 1-23-2. The samples analyzed had SiO_2 values around 47 per cent and TiO_2 values around 0.80 per cent. Na_2O is variable, ranging from 1.93 to 4.87 per cent; K_2O is relatively low. These analyses suggest the basalts belong to the calcalkaline or subalkaline suite of volcanic rocks. Their chemistry is similar to that of volcanic rocks found in young volcanic island arcs.

Siliceous Pyroclastic Facies

The upper part of the basaltic flow/red tuff facies contains sporadic beds of cream to grey-weathering, quartz-feldspar-phyric ash flow, spherulitic rhyolite and siliceous lapilli tuff. A typical section is exposed north of Winfield Creek (Figure 1-23-7). Toward the Howson Range, along the southeast and easterly borders of the map area, the felsic pyroclastic beds become sufficiently numerous within the section to define a distinct facies. Locally beds of welded ash-flow tuff and ignimbrite occur in this facies and rhyolite domes may also be part of this succession. Well-bedded red tuffs of the

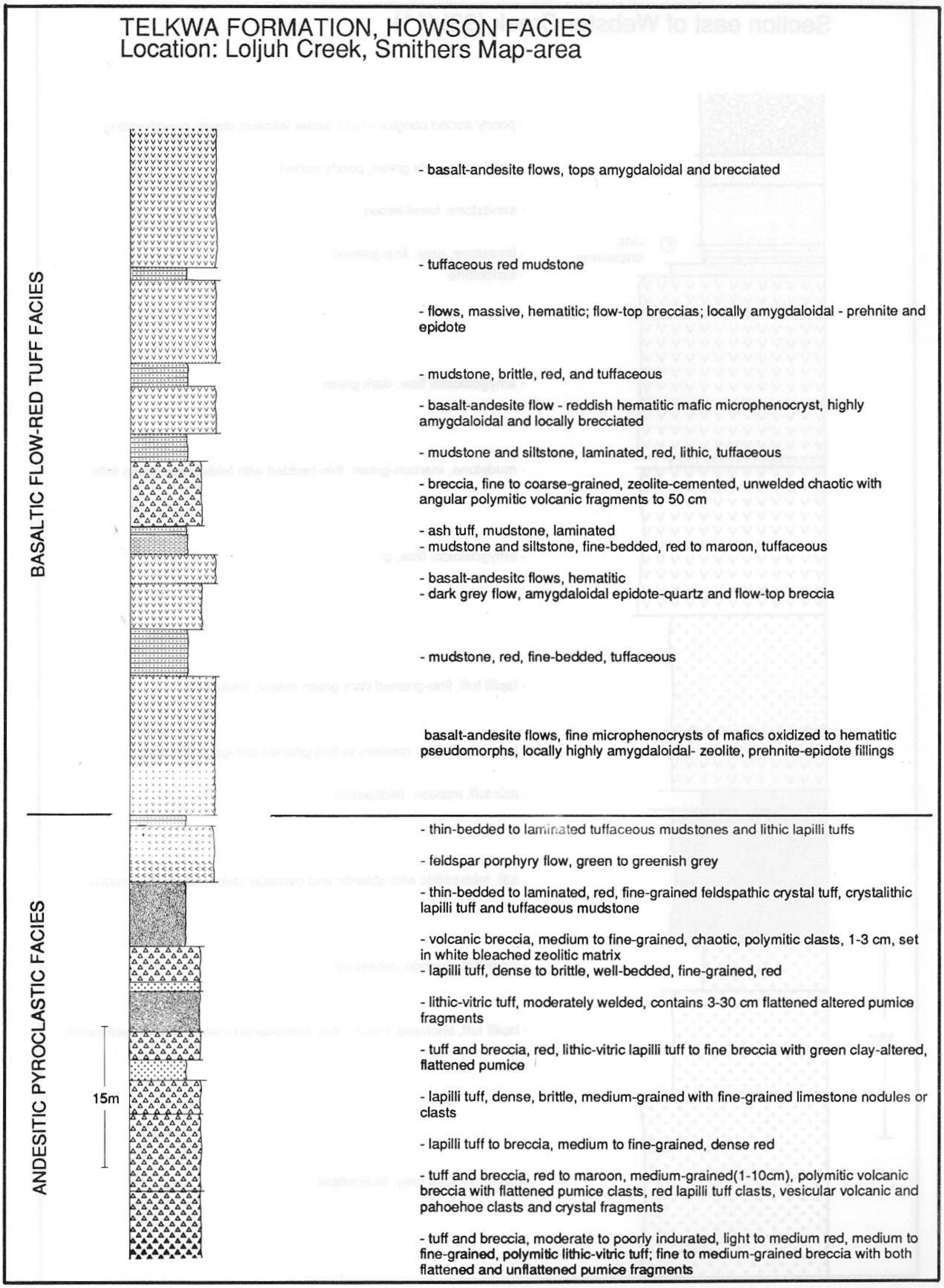


Figure 1-23-5. Stratigraphic section, Loljuh Creek area (modified after Tipper and Richards, 1976).

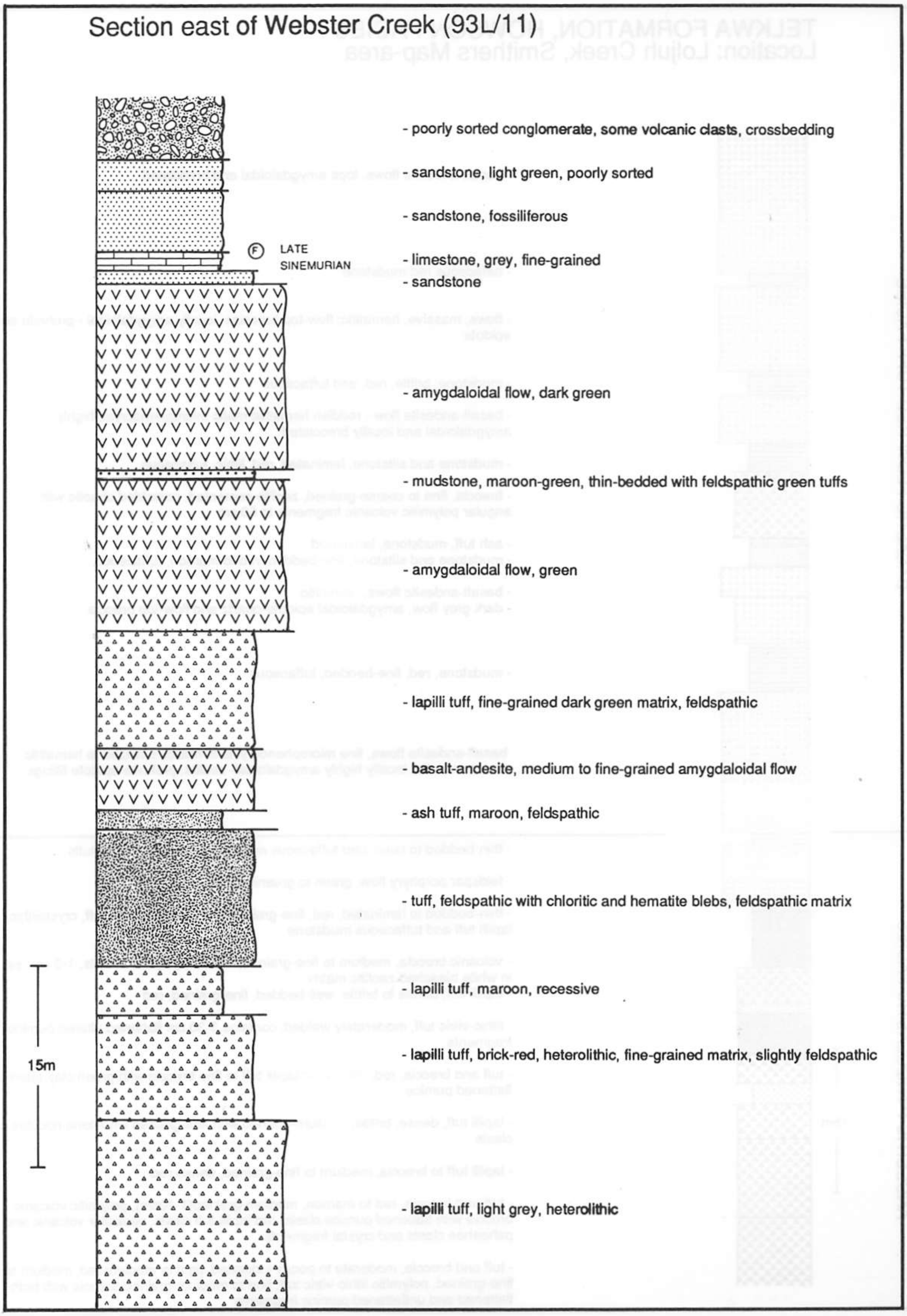


Figure 1-23-6. Stratigraphic section east of Webster Creek. Transition zone between basaltic flow–red tuff facies of Telkwa Formation and overlying Red Tuff member of the Nilkitkwa Formation.

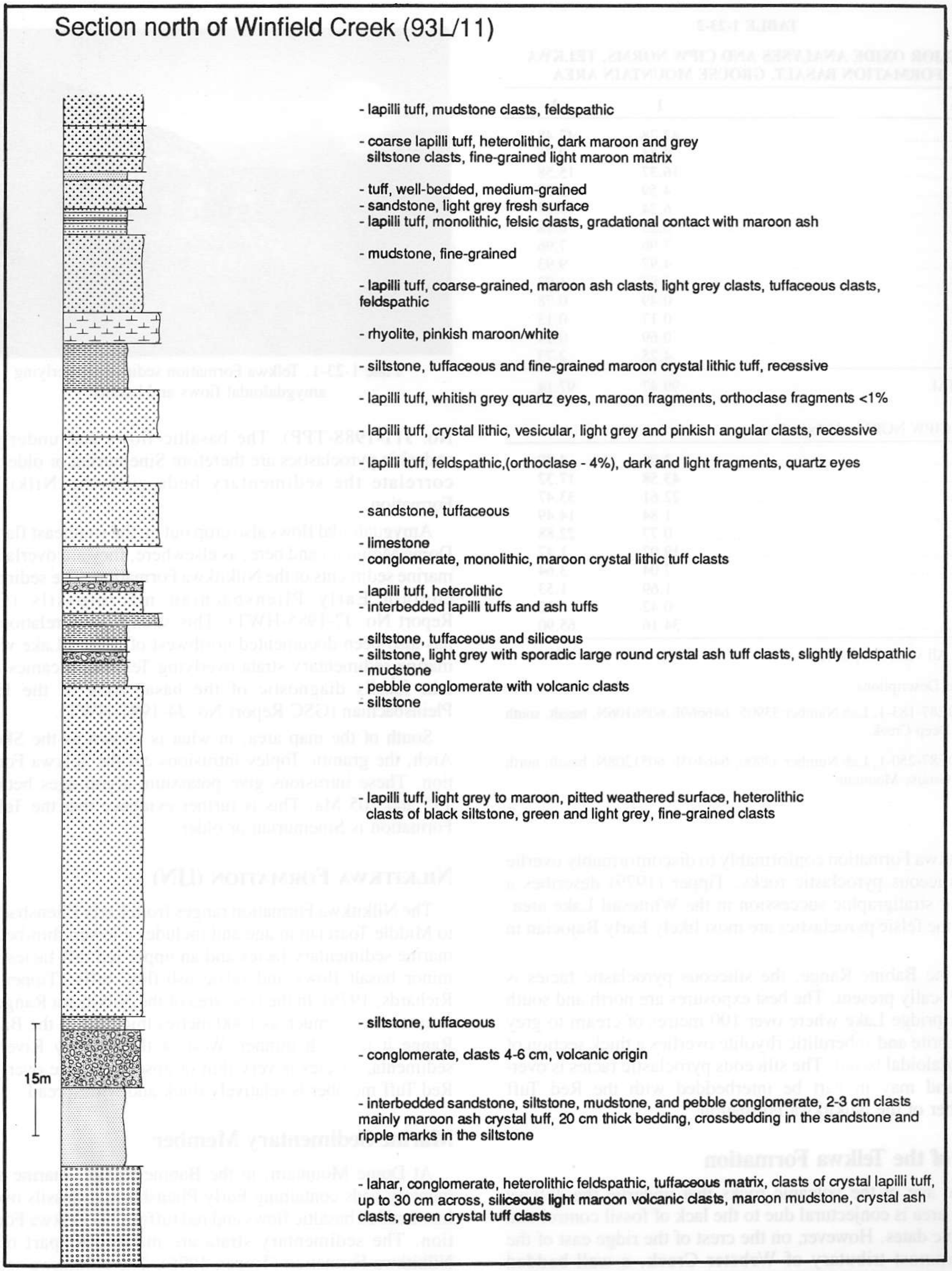


Figure 1-23-7. Section north of Winfield Creek. Transitional into overlying Red Tuff Member of Nilkitkwa Formation.

TABLE 1-23-2

MAJOR OXIDE ANALYSES AND CIPW NORMS, TELKWA FORMATION BASALT, GROUSE MOUNTAIN AREA

Oxide	1	2
SiO_2	47.78	47.48
TiO_2	0.84	0.76
Al_2O_3	16.37	15.58
Fe_2O_3	4.59	2.37
FeO	6.24	7.17
MnO	0.25	0.18
MgO	7.96	7.96
CaO	4.97	9.93
Na_2O	4.87	1.93
K_2O	0.49	0.78
P_2O_5	0.17	0.13
CO_2	0.69	0.14
LOI	4.25	2.73
TOTAL	99.47	97.14

CIPW NORM - Volatile Free		
or	3.06	4.89
ab	43.58	17.32
an	22.61	33.47
di	1.84	14.49
hy	0.77	22.88
ol	19.02	1.47
mt	7.04	3.64
il	1.69	1.53
ap	0.42	0.32
AN=	34.16	65.90

N.B.: All values in per cent.

Sample Descriptions:

1—PDE87-183-1, Lab Number 33905, 646669E,6056106N, basalt, south of Deep Creek.

2—PDE87-250-1, Lab Number 33906, 646403E,6051208N, basalt, north of Grouse Mountain.

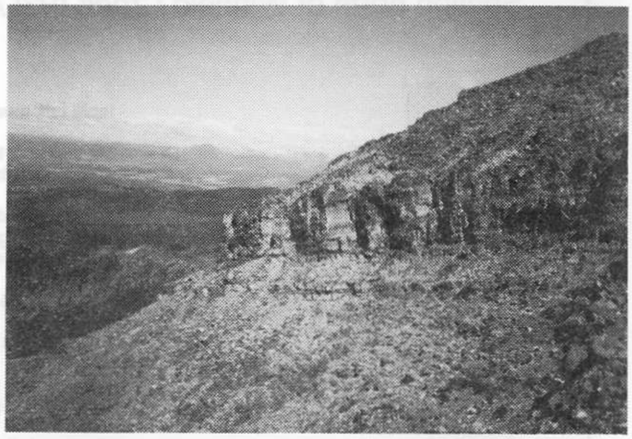


Plate 1-23-1. Telkwa Formation sediments overlying amygdaloidal flows and basalts.

Nilkitkwa Formation conformably to disconformably overlie the siliceous pyroclastic rocks. Tipper (1979) describes a similar stratigraphic succession in the Whitesail Lake area. Here the felsic pyroclastics are most likely Early Bajocian in age.

In the Babine Range, the siliceous pyroclastic facies is only locally present. The best exposures are north and south of Burbridge Lake where over 100 metres of cream to grey ignimbrite and spherulitic rhyolite overlies a thick section of amygdaloidal basalt. The siliceous pyroclastic facies is overlain and may in part be interbedded with the Red Tuff member of the Nilkitkwa Formation.

Age of the Telkwa Formation

The age of the volcanic rocks that underlie the Telkwa River area is conjectural due to the lack of fossil control and isotopic dates. However, on the crest of the ridge east of the easternmost tributary of Webster Creek, a well-bedded section of very fossiliferous limestone, sandstone and pebble conglomerate caps a thick section of interbedded amygdaloidal flows and tuffs (Figure 1-23-6; Plate 1-23-1). The sediments contain the pelecypod *Weyla* and are probably Late Sinemurian or Early Pliensbachian in age (GSC Report No. J11-1988-TPP). The basaltic flows and underlying andesitic pyroclastics are therefore Sinemurian or older. We correlate the sedimentary beds with the Nilkitkwa Formation.

Amygdaloidal flows also crop out on the southeast flank of Dome Mountain and here, as elsewhere, they are overlain by marine sediments of the Nilkitkwa Formation. The sediments contain Early Pliensbachian macrofossils (GSC Report No. J7-1985-HWT). This stratigraphic relationship has also been documented northwest of Round Lake where marine sedimentary strata overlying Telkwa volcanics contain fossils diagnostic of the basal zone of the Early Pleinsbachian (GSC Report No. J4-1987-HWT).

South of the map area, in what is known as the Skeena Arch, the granitic Topley intrusions cut the Telkwa Formation. These intrusions give potassium-argon ages between 195 and 205 Ma. This is further evidence that the Telkwa Formation is Sinemurian or older.

Nilkitkwa Formation (lJN)

The Nilkitkwa Formation ranges from Early Pliensbachian to Middle Toarcian in age and includes a lower, thin-bedded marine sedimentary facies and an upper red tuff facies with minor basalt flows and felsic ash-flow tuffs (Tipper and Richards, 1976). In the type area of the Nilkitkwa Range the formation is as much as 1000 metres thick but in the Babine Range it is much thinner. West of the Bulkley River the sedimentary facies is very thin or absent, but the overlying Red Tuff member is relatively thick and widespread.

Marine Sedimentary Member

At Dome Mountain, in the Babine Range, marine sedimentary beds containing Early Pliensbachian fossils overlie interbedded basaltic flows and red tuffs of the Telkwa Formation. The sedimentary strata are mapped as part of the Nilkitkwa Formation (Tipper, 1976). The Nilkitkwa section begins with coarse conglomerate beds containing granitic and felsic volcanic clasts, and grades upward into thin-bedded argillite and siltstone. The felsic volcanic clasts are probably derived from the felsic pyroclastic facies of the Telkwa Formation.

Limestone and chert beds occur in the lower part of the section and help distinguish Nilkitkwa rocks from younger, lithologically similar formations. Shallow-water fossiliferous limestone, interbedded with pebble conglomerate and feldspathic sandstone, is particularly common where Nilkitkwa sediments onlap Telkwa volcanics in the Telkwa River area. Here the sediments are close to a Late Sinemurian-Early Pliensbachian strand line.

Sedimentary beds containing Early to Late Pliensbachian fossils (GSC Fossil Report J4-HWT-1987) are also found northwest of Round Lake and are included with the Nilkitkwa Formation. The sedimentary beds are overlain by red tuffs that have been mapped as the Red Tuff member of the Nilkitkwa Formation (Tipper, 1976). To the east of Round Lake, sandstones containing probable Middle Jurassic fauna overlie the red tuffs. This stratigraphic succession is similar to that observed further to the west in the Webster Creek area of the Telkwa Range.

In the Telkwa Range, on the ridge just east of the easternmost tributary of Webster Creek, a section of very fossiliferous well-bedded, shallow-water sandstone, conglomerate and limestone caps a thick section of interbedded amygdaloidal basaltic flows and red to grey tuffs and lahars (Figure 1-23-6). Fossils collected from this locality are Late Sinemurian or Pliensbachian in age (GSC Fossil Report J11-1988-TPP). Although slightly older, these beds have a similar stratigraphic position to the basal beds of the Nilkitkwa Formation on Dome Mountain. If these rocks are correlative then the base of the Nilkitkwa sedimentary sequence is diachronous, younging slightly to the northeast. Slight variations in the age of basal beds of the Nilkitkwa Formation may reflect onlapping of sediments onto a series of volcanie islands as the Nilkitkwa marine transgression progressed.

Above Silvern Lake, on the northwest flank of Hudson Bay Mountain, thin beds of fossiliferous limestone and sandstone overlie amygdaloidal flows and are overlain by the Red Tuff member of the Nilkitkwa Formation. The limy beds have the same stratigraphic position as similar beds at Dome Mountain, Round Lake and east of Webster Creek, and are therefore mapped as part of the Nilkitkwa Formation.

Red Tuff Member

The Red Tuff member of the Nilkitkwa Formation is comprised of medium to thin-bedded red to maroon ash, crystal and lapilli tuff, and related epiclastic rocks with subordinate beds of grey ash-flow tuff and amygdaloidal basalt. Good sections of the member are exposed in the Webster, Tenas and Glacis creeks drainage area and in the area northeast of Winfield Creek (Fignre 1-23-7).

In the Telkwa Range, shallow-marine sediments of the Smithers Formation overlie the Red Tuff member of the Nilkitkwa Formation. However, in the Babine Range the Smithers Formation sits directly on the Nilkitkwa marine sediments; the Red Tuff member is apparently absent.

West of Howson Creek a good section of well-bedded red tuffs is exposed along the crest of a northwest-trending ridge. The red tuffs overlie and in part are interfingered with siliceous pyroclastic rocks of the Telkwa Formation. Thin beds of shallow-water, fossiliferous limestone, sandstone and pebble conglomerate locally occur in the zone of transition between these two facies; these sediments, where present, are correlative with the lower marine sedimentary beds of the Nilkitkwa Formation.

In the Tenas Creek area, the red tuffs occur at the top of the volcanic succession and are conformahly to disconformably overlain by sandstones of the Smithers Formation. The sandstones contain Late Bajocian ammonites (Sections XIV and XX, Tipper and Richards, 1976). The red tuffs are therefore pre-Late Bajocian in age. Elsewhere in the Smithers area, the Red Tuff member is known to be Toarcian in age (Tipper and Richards, 1976).

In the Winfield Creek area a good section through the Red Tuff member is exposed along the north side of the most southerly ridge. Several eruptive cycles are recognized, each beginning with lapilli tuff and fining upward into red crystal and ash tuff. Some of the cycles begin with a grey ash flow with flattened pumice clasts. The eruptive cycles are locally separated by beds of marl, volcanic sandstone and pebble conglomerate. A typical cycle is shown diagrammatically in Figure 1-23-8.

Smithers Formation (mJS)

The Smithers Formation is a sequence of shallow-water marine sediments containing predominantly Bajocian ammonites and pelecypods. The formation marks the end of volcanism and the beginning of an extensive marine transgression that progressively onlapped volcanic rocks exposed in the Skeena Arch. The transgression continued into early Late Jurassic time.

In the Telkwa River area, the stratigraphic succession appears to be nearly complete, beginning with shallow-marine sediments of the Smithers Formation and grading up-section into finer-grained, deep-water sediments of the Ashman Formation. This stratigraphic sequence is well documented on Ashman Ridge, northwest of the current map area (Tipper and Richards, 1976).

The base of the Smithers Formation is exposed in the Tenas Creek area and on the northwest flank of Hudson Bay Mountain. In both localities the formation appears to be conformable with the underlying Red Tuff member of the Nilkitkwa Formation. The base of the formation is probably diachronous, younging to the south as it onlaps older strata. In the Tenas Creek area the basal beds of the formation contain Late Bajocian ammonite fauna; on Ashman Ridge to the north, beds at a similar stratigraphic position contain Middle Bajocian fauna.

Ashman Formation (muJA)

As mentioned above, the Ashman Formation appears to conformably overlie beds of the Smithers Formation and appears to be part of a continuous fining-upward sedimentary succession. Where the two formations are exposed in a continuous fining-upward sequence, as on Ashman Ridge and in the Tenas Creek area, the contact is defined largely on the age of contained fossils rather than lithological differences. In the study area fauna collected from the Ashman Formation are predominantly Callovian in age, but like the

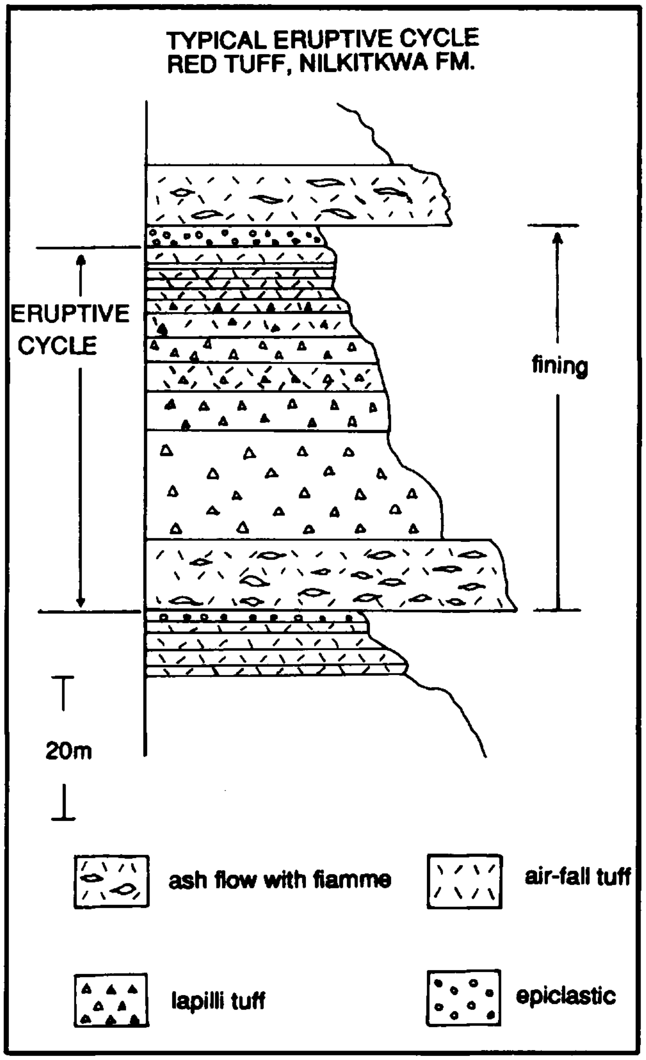


Figure 1-23-8. Typical eruptive cycle, Red Tuff member, Nilkitkwa Formation.

Smithers Formation, the base of the formation is probably diachronous.

In the current study, the boundary between the Ashman and Smithers formations is set where fine-grained clastic sediments predominate over shallow-water sandstones and pebble conglomerates. Using this lithostratigraphic definition, the Ashman Formation is predominantly well-bedded, fine-grained dark grey siltstone and black shale. Quartzose sandstone and pebble conglomerate beds occur sparsely within the succession. The Ashman Formation is a moderate to deep-water turbidite sequence that was deposited during a major Middle Jurassic marine transgression. This marine transgression began with deposition of the shallow-water, near-shore Smithers Formation.

Tipper and Richards (1976) include the Ashman Formation with the Middle to Late Jurassic Bowser Lake Group whereas the Smithers Formation is included with the Hazelton Group. The group boundary occurs within a fining-upward sedimentary sequence that may represent a continuous stratigraphic section ranging from Bajocian to Callovian. If this is true then the Smithers and Ashman formations should be in the same group. In the study area the two formations are included as part of the Hazelton Group; Bowser Lake rocks are restricted to fluvial and deltaic facies that reflect a Middle to Late Jurassic marine regression and regional uplift.

BOWSER LAKE GROUP

The Bowser Lake Group includes marine and nonmarine successor-basin sediments and minor volcanics ranging from Late Bajocian to Kimmeridgian in age. The sediments were deposited in the Bowser Basin, north of the study area. The Skeena Arch formed the southern limit of the basin. A Middle Jurassic marine transgression was followed by uplift of the Skeena Arch and shedding of coarse detritus northward into a shrinking Bowser Basin.

TROUT CREEK ASSEMBLAGE (uJTC)

Coarse-grained, poorly sorted chert-pebble conglomerates, sandstones and siltstones of the alluvial-deltaic, coarsening-upward Trout Creek assemblage disconformably to conformably overlie the Ashman Formation. The Trout Creek assemblage is Late Oxfordian to Early Kimmeridgian in age and represents the start of uplift of the Skeena Arch and concomitant shedding of coarse detritus northward into the Bowser Basin as prograding deltaic fans. The base of the Trout Creek assemblage is diachronous, younging northward into the basin.

The only rocks mapped as part of the Trout Creek assemblage within the map area are the coarse conglomerates in the type area near Trout Creek (Tipper, 1976).

POST-JURASSIC ROCKS

Early Cretaceous Skeena and Sustut successor basin deposits, and Middle Cretaceous to Eocene Kasalka and Ootsa Group continental volcanics unconformably overlie Hazelton and Bowser Lake Group rocks. The Cretaceous Bulkley intrusions and the Tertiary Babine intrusions cut the Jurassic rocks and are the source of most of the mineral occurrences in the area. The post-Jurassic rocks have been described in previous reports (MacIntyre *et al.*, 1987; MacIntyre and Desjardins, 1988) and are beyond the scope of this paper.

STRUCTURAL STYLE

Jurassic rocks in the Telkwa River area are exposed as a series of tilted fault blocks. In general the beds are not folded and very little penetrative cleavage was observed. The volcanic members are often quite fresh with little or no alteration. This is in contrast to the chlorite-epidote-altered Jurassic rocks of the Babine Range which have been folded and have a well-developed penetrative foliation. It is not clear why there is such a difference in structural style between the two ranges.

DISCUSSION

The Telkwa stratigraphic succession indicates that Early Jurassic volcanism began with eruption of predominantly andesitic pyroclastic material, probably from numerous vents located south of the map area. This was followed by a short hiatus and erosion of the volcanic pile prior to widespread outpouring of basaltic lava and deposition of red airfall tuff. Late in this volcanic cycle, siliceous ash flows and rhyolite were erupted from volcanic centres located south and west of the map area. Early Jurassic plutons are exhumed along the axis of the Skeena Arch and in the Howson Ranges. These plutons probably formed at depth beneath major early Jurassic eruptive centres.

Three volcanic-sedimentary cycles are recognized in the Early to Middle Jurassic stratigraphic succession. At the base is a lower andesitic pyroclastic section that grades up into a very thin (or absent) marine to nonmarine sedimentary member containing Sinemurian fossils. This is overlain by a second volcanic-sedimentary cycle that begins with a bimodal volcanic sequence that includes thick accumulations of subaerial amygdaloidal basalt and interbedded red tuff and epiclastics, and local accumulations of siliceous pyroclastics and rhyolite flows. Marine sedimentary strata of the the Late Sinemurian to Pliensbachian Nilkitkwa Formation onlap this volcanic succession. The final volcanic-sedimentary cycle begins with subaerial red tuff and felsic pyroclastics of the Nilkitkwa Formation which is onlapped by marine sediments of the Smithers and Ashman formations.

Each volcanic-sedimentary cycle is separated by a disconformity. Sedimentary members onlap and are interfingered with volcanic members and typically fine upward into progressively deeper water facies, that is, they represent marine transgressions. The sedimentary members may be absent where uplift and erosion has occurred prior to the next volcanic cycle. Each volcanic cycle is distinguished by compositional and lithological differences and therefore mapped as a separate volcanic facies.

MINERAL DEPOSITS

As discussed in a previous report (MacIntyre *et al.*, 1987), mineral deposits in the Smithers area can be subdivided into four groups. These are: (1) mesothermal and epithermal gold-silver-bearing quartz veins; (2) copper-silver veins and pods in mafic volcanic rocks; (3) copper-zinc-silver massive sulphide deposits associated with bimodal submarine volcanics; and, (4) porphyry copper-molybdenum deposits associated with quartz monzonite to granodiorite intrusions.

The showings in the Telkwa River area are mostly Type 2 – copper-silver veins and pods in mafic volcanic rocks. These showings may in part be associated with porphyry copper mineralization at depth. Showings on Hudson Bay Mountain are most likely related to the large porphyry copper-molybdenum system within the core of the mountain.

The preferred host rocks for copper-silver occurrences, as elsewhere in the map area, are the amygdaloidal basalt flows of the upper Telkwa Formation. Intense epidote-calcite-chlorite alteration is often associated with this type of occurrence. There is no obvious control to their distribution, although occurrences in the Webster and Cabinet Creek areas are near a granodioritic intrusion.

WEBSTER CREEK – CABINET CREEK AREA

In the headwaters of Webster creek, a large stock of granodiorite of probable Late Cretaceous age intrudes basaltic flows of the upper Telkwa Formation. A zone of disseminated pyrite and magnetite with associated propylitic alteration is superimposed on hornfelsed volcanic rocks surrounding the stock. A stockwork vein system containing pyrite, minor chalcopyrite and molybdenite is locally present within the pyrite-magnetite zone.

High-grade pods of pyrite, chalcopyrite, and magnetite in a gangue of altered country rock, quartz, and epidote, occur locally along flow contacts in the area north of the stock. The strongest mineralization appears to be near dyke contacts. Also present are calcite and quartz stringers that carry malachite, bornite, chalcopyrite, azurite, chalcocite, tetrahedrite, hematite and minor disseminated specularite. These showings crosscut faults and shears in dark green to maroon basalt of the Telkwa Formation.

In the Cabinet Creek area, quartz veins and isolated pods containing high-grade concentrations of chalcopyrite, bornite and tetrahedrite with minor specularite and galena, cut basaltic flows of the Telkwa Formation.

WINFIELD CREEK AREA

In the Winfield Creek area chalcocite, chalcopyrite and bornite occur as veinlets and amygdule fillings in basaltic flows, crystal and lithic tuffs and siliceous ash flows. Here the showings appear to be related to a fault zone that trends 130 degrees and dips 75 degrees south.

HUDSON BAY MOUNTAIN

Numerous high-grade zinc-lead-silver veins occur in the area peripheral to the Glacier Gulch porphyry molybdenum deposits. This area was mapped by R.V. Kirkham from 1963 to 1968. His data is currently being recompiled in preparation for publication.

SUMMARY

The major conclusions from fieldwork completed in 1988 are:

(1) Mafic flows, felsic pyroclastics and red tuffs in the Telkwa River area correlate with a similar but much thinner section in the Babine Range. These rocks, previously mapped as Nilkitkwa Formation in the Babine Range, are now included as an upper division of the Early Jurassic Telkwa Formation.

(2) The thinning of volcanic members and the corresponding thickening of marine sedimentary members of both the Telkwa and Nilkitkwa formations to the northeast suggests a change from subaerial to submarine facies in this direction during Late Sinemurian to Early Pliensbachian time.

(3) The Telkwa Formation is divisible into four facies in the map area. These facies are characterized by their predominant lithologies. In ascending stratigraphic order they are heterolithic basal conglomerate; andesitic pyroclastics; basaltic flows and red tuffs and; siliceous pyroclastics and rhyolite flows. The overlying Nilkitkwa Formation includes a lower marine sedimentary member and an upper red tuff member.

(4) The Early Jurassic volcanics of the Telkwa River area are relatively undeformed and unaltered compared to similar rocks in the Babine Range. Vertical tectonics rather than folding and thrust faulting are the predominate structural style.

(5) Vein and disseminated mineralization in the Hudson Bay Mountain – Telkwa River area is related to hydrothermal systems generated by emplacement of porphyritic intrusions in Late Cretaceous and early Tertiary time.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of the Geological Survey of Canada in providing valuable fossil identifications. Discussions with Dr. H.W. Tipper have been most informative. Mike Custance and Audrey Perry ably assisted the authors during the course of fieldwork and their cheerfulness under less than ideal weather conditions was greatly appreciated.

REFERENCES

Carter, N.C. (1981): Porphyry Copper and Molybdenum Deposits West-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 64, 150 pages.

Koo, J. (1984): The Telkwa, Red Rose, and Klappan Coal Measures in Northwestern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1983, Paper 1984-1, pages 81-90.

Leach, W.W. (1910): The Skeena River District, *Geological Survey of Canada*, Summary Report, 1909.

MacIntyre, D.G. (1985): Geology of the Dome Mountain Gold Camp, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1984, Paper 1985-1, pages 192-213.

MacIntyre, D.G., Brown, D., Desjardins, P., and P. Mallett (1987): Babine Project (93L/10,15), *B.C.Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, page 201-222.

MacIntyre, D.G. and Desjardins, P. (1988): Babine Project (93L/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 181-193.

Richards, T.A. (1988): Geologic Setting of the Stikine Terrane, Geology and Metallogeny of Northwestern British Columbia, *Smithers Exploration Group – Geological Association of Canada*, extended abstracts, page A-75.

Tipper, H.W. (1976): Smithers B.C. (93L), *Geological Survey of Canada*, Open File Map 351.

——— (1979): Jurassic Stratigraphy of the Whitesail Lake Map Area, British Columbia, *Geological Survey of Canada, in* Current Research, Part A, Paper 79-1a, pages 31-32.

Tipper, H.W. and Richards, T.A. (1976): Jurassic Stratigraphy and History of North-central British Columbia, *Geological Survey of Canada*, Bulletin 270, 73 pages.

GEOLOGY OF THE GERMANSEN LANDING AREA, BRITISH COLUMBIA (93N/10, 15)

By Filippo Ferri and David M. Melville

KEYWORDS: Regional geology, Germansen Landing, Manson Creek, Intermontane Belt, Omineca Belt, Slide Mountain Group, Takla Group, Manson fault zone, precious metal veins, listwanite.

INTRODUCTION

The Manson Creek 1:50 000 mapping project is in the second year of a 4-year program which will cover an area straddling the boundary between the Intermontane and Omineca tectonic belts within the Canadian Cordillera. The main aims of this program are: to provide detailed geological base maps, to update the mineral inventory database for the area, and to place known mineral occurrences within a geological framework. During 1988, mapping was completed in the north half of the Germansen Lake map area (93N/10) and the south half of the Germansen Landing map area (93N/15).

The project area is located some 200 kilometres north-northwest of Prince George (Figure 1-24-1). Ground access is by all-season gravel road from either Fort St. James or Mackenzie. The map area is drained by the Omineca River in the north and the Germansen River system in the south. Most of the area is forested with only the regions around Germansen Mountain, Plughat Mountain and Nina Creek extending above treeline.

REGIONAL SETTING

The map area lies largely within the Intermontane Belt and only the northeastern corner is underlain by Omineca Belt lithologies (Figure 1-24-2). All rocks west of this tectonic boundary are considered allocthonous with respect to the North American craton (Monger *et al.*, 1982).

Within the study area the Omineca Belt is represented by miogeoclinal rocks of the Proterozoic Ingenika Group and a sequence of carbonates and siliciclastics of Lower to Middle Paleozoic age (Armstrong, 1949; Gabrielse, 1975) and their highly metamorphosed and deformed equivalents in the Wolverine complex. The Intermontane Belt consists of the Late Triassic to Early Jurassic Takla Group, Middle Paleozoic to Early Triassic Slide Mountain Group and possible Harper Ranch equivalents which are Middle to Late Paleozoic in age. These are intruded by the Early Cretaceous Germansen batholith and the Triassic to Cretaceous Hogem batholith (Garnett, 1978). In the project area the contact between the two belts is assumed to be a west-side-down normal fault. This was inferred from mapping in the Manson Lakes area (93N/9) to the southwest and was based on the abrupt change in metamorphic grade across the contact (Ferri and Melville, 1988a and b).

The Slide Mountain Group is composed of a sequence of sedimentary, volcanic and igneous rocks which represent a

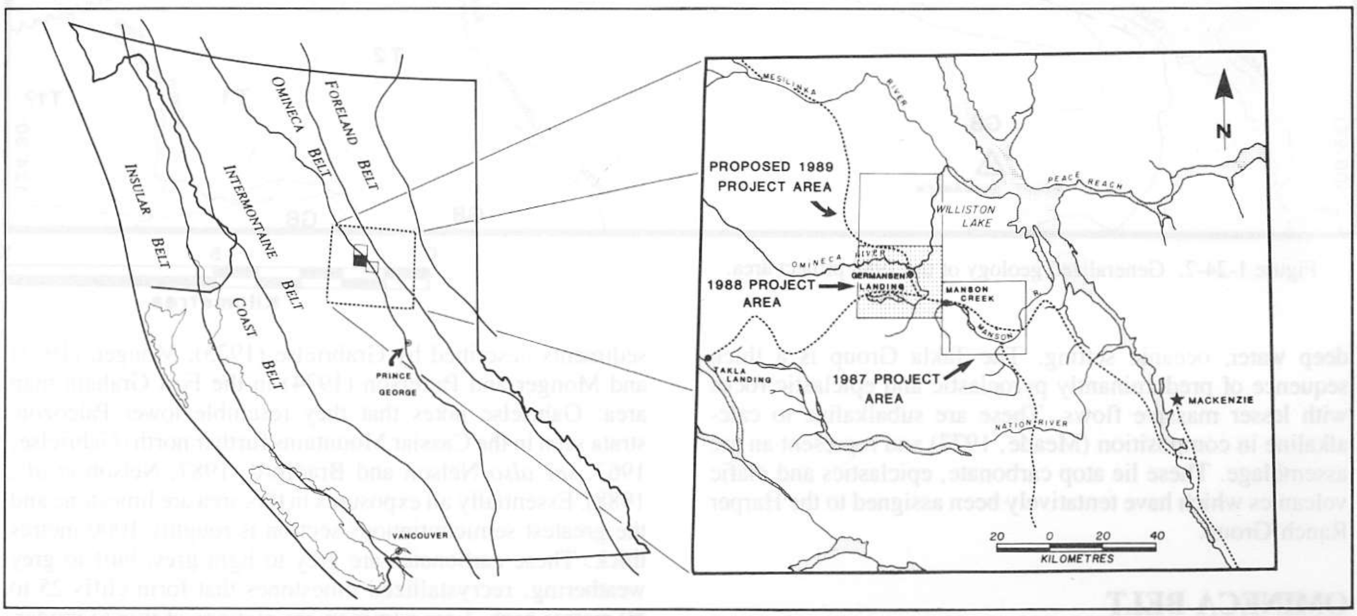


Figure 1-24-1. Location of the map area within the tectonic framework of the Canadian Cordillera. Expanded section indicates major geographic features around the map area as well as previous and proposed map areas.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

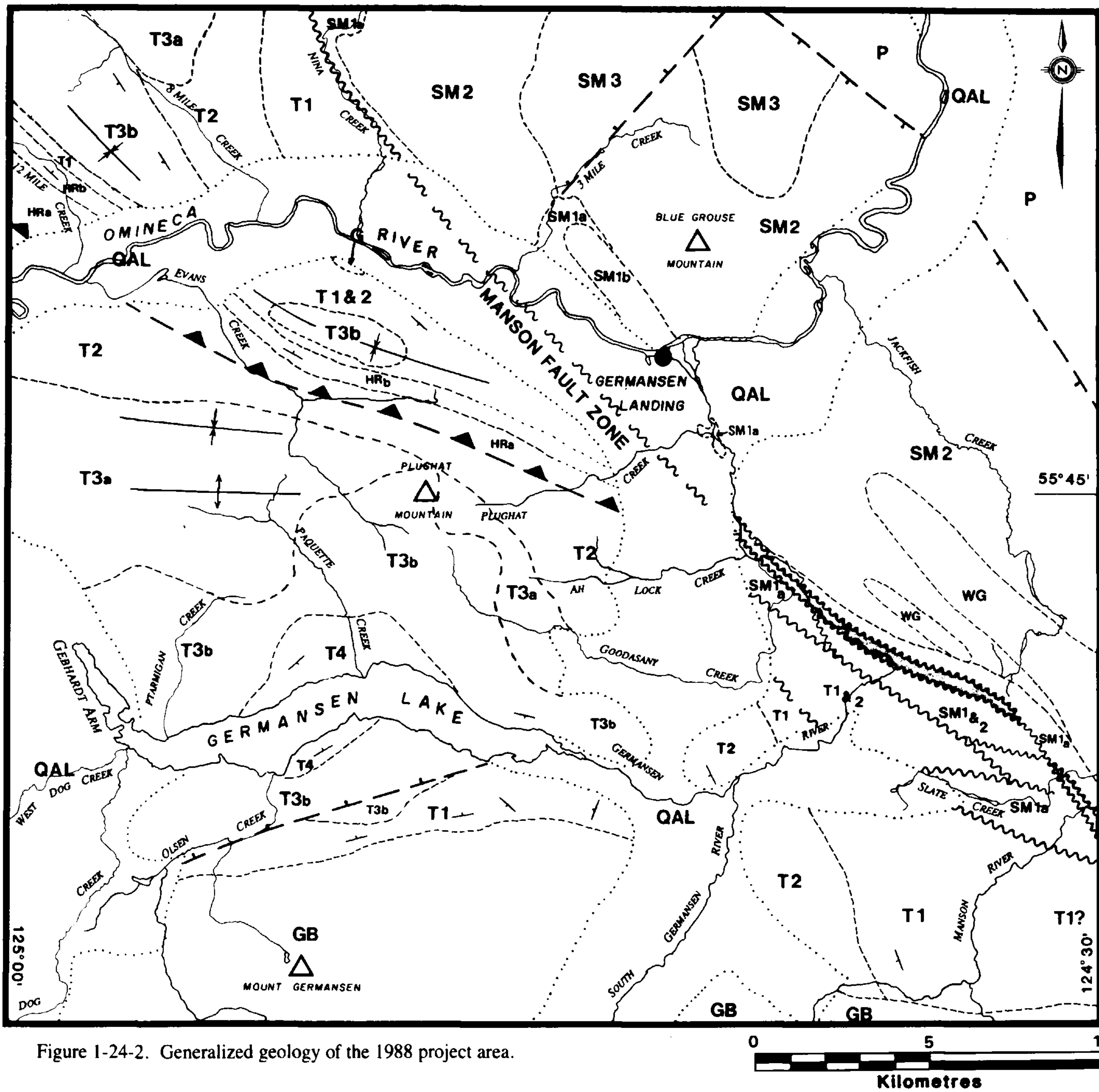


Figure 1-24-2. Generalized geology of the 1988 project area.

deep water, oceanic setting. The Takla Group is a thick sequence of predominantly pyroclastic and epiclastic rocks with lesser massive flows. These are subalkaline to calc-alkaline in composition (Meade, 1977) and represent an arc assemblage. These lie atop carbonate, epiclastics and mafic volcanics which have tentatively been assigned to the Harper Ranch Group.

OMINECA BELT

Omineca Belt lithologies are sparsely exposed in the northeastern corner of the map area. They are tentatively assigned an Early to Middle Paleozoic age based on their stratigraphic position and lithological similarity to Paleozoic sediments described by Grabrielse (1975), Monger, (1973) and Monger and Patterson (1974) in the Fort Graham map area. Gabrielse notes that they resemble lower Paleozoic strata seen in the Cassiar Mountains further north (Gabrielse, 1963; *see also* Nelson and Bradford, 1987; Nelson *et al.*, 1988). Essentially all exposures in this area are limestone and the greatest semicontinuous section is roughly 1000 metres thick. These carbonates are grey to light grey, buff to grey weathering, recrystallized limestones that form cliffs 25 to 50 metres high. Less common are sections of thin to moderately bedded, more argillaceous and darker grey, platy limestone which has a fetid odour when broken. These limestones can be found interbedded with very thin, crenulated, slate layers.

LEGEND

LAYERED ROCKS

QUATERNARY

QAL — *Till, gravel, sand, silt and alluvium*

UPPER TRIASSIC/LOWER JURASSIC

TAKLA GROUP

T4 — *Volcanic sandstone and conglomerate*

T3 — *(a) Agglomerates, tuffaceous breccias, epiclasitcs and minor mafic volcanic flows (b) Massive flows and pyroclastics with minor epiclastics*

T2 — *Volcanic sandstone, conglomerate, minor siltstone and argillite*

T1 — *Argillite, siliceous argillite, siltstone and minor chert, limestone, volcanic wackes and volcanic sandstone*

UPPER PALEOZOIC/LOWER TRIASSIC

SLIDE MOUNTAIN GROUP

SM3 — *Upper: Massive to pillowed basalts, volcanic breccia, minor argillite and chert*

SM2 — *Middle: Argillite, siliceous argillite, siltstone, cherts, and minor mafic volcanic, volcaniclastics, sandstone, conglomerate and ribbon chert*

SM1 — *Lower: (a) Phyllite, argillite, calcareous phyllite, carbonate, and minor quartzose siltstone/wacke, ribbon chert (b) Dacite tuff (c) ultramafics*

MIDDLE/UPPER PALEOZOIC

HARPER RANCH(?)

HR — (a) *Carbonate,* (b) *fine grained clastics and mafic volcanics*

LOWER/MIDDLE PALEOZOIC

P — *Carbonate and minor argillaceous limestone and sandstones*

INTRUSIVE ROCKS

UPPER CRETACEOUS

GERMANSEN BATHOLITH

GB — *Foliated granodiorite, pegmatites, and aplite dykes*

JURASSIC OR YOUNGER

G — *Gabbro*

UPPER PALEOZOIC/LOWER TRIASSIC

WG — *Gabbro and foliated gabbro (Wolf Ridge Gabbro)*

Only a few scattered outcrops of quartzose sediments were seen. These are cream to buff-weathering, massive to thickly bedded sandstones which may exhibit limonitic staining.

INTERMONTANE BELT

HARPER RANCH(?) GROUP

A sequence of mafic volcanics, fine-grained clastics and carbonate rocks underlies argillites, volcanic sandstones and conglomerates of Unit 1 of the Takla Group in the north-central part of the map sheet (south of the Omineca River and along Evans Creek). The carbonate unit is some 500 metres thick and can be traced for nearly 20 kilometres. No limestone unit of this thickness and extent has been previously described in the lower part of the Takla Group in this area (*see* Roots, 1954; Armstrong, 1949) or from the Takla and its equivalents north and south along Quesnellia. These rocks are therefore believed to be basement to the Takla Group and are included in the Harper Ranch Group (*see* Monger, 1977; Price *et al.*, 1985).

The limestone is generally a massive cliff-forming unit though bedding can sometimes be seen as faint platy partings. It is grey to light grey on fresh surfaces and dark grey to grey-brown weathering. It is finely recrystallized and has a fetid odour when broken. It is commonly cut by numerous quartz-calcite veins with various orientations.

A sequence of mafic volcanics and fine-grained clastic rocks underlies the limestone along Evans Creek and has been grouped with it. These volcanics are dark green to grey-brown, generally massive and less frequently pillowed. They are generally aphanitic though pyroxene-plagioclase porphyries are also present. These rocks are highly chloritized with calcite and prehnite/pumpellyite filling vugs.

The clastic rocks are very immature sandstones to siltstones. They are grey to grey-green, massive and coarse grained with the chloritized matrix comprising up to 20 per cent of the rock. The majority of the clasts are plagioclase and quartz crystal fragments.

SLIDE MOUNTAIN GROUP

The Slide Mountain Group rocks were originally grouped with Cache Creek stratigraphy seen further to the west (Armstrong, 1949; Roots, 1954; Monger, 1973). It is predominantly a sedimentary sequence with igneous and volcanic rocks becoming more abundant towards the top (Figure 1-24-3). It comprises black phyllite, argillite, siltstone, chert, diorite and gabbro, mafic to intermediate volcanic rocks, felsic tuffs and ultramafites with minor carbonate, greywacke, sandstone and ribbon chert. The stratigraphy has been subdivided into lower, middle and upper units (Figure 1-24-3). The subdivisions proposed in this paper vary somewhat from those proposed in the Manson Lakes area (Ferri and Melville, 1988b). The lower division corresponds to

Units SM1, SM5 and SM6 of Ferri and Melville, the middle division to Unit SM4 and the upper division to unit SM3.

Lower Division

The lower division is composed of phyllite, argillite, calcareous phyllite and carbonate, with lesser quartzose siltstone or quartz wacke, ribbon chert and carbonate. Lenticular bodies of altered ultramafite occur within this unit, primarily along the Manson fault zone. A dacitic tuff body is also present. An accurate stratigraphic thickness cannot be determined due to its structural complexity and the lack of distinct internal stratigraphy.

The phyllites are dark grey to black and typically thinly bedded and graphitic. They grade into and are interlayered with graphitic argillites which are moderately to thickly bedded. These argillites are often quite siliceous and appear cherty. A penetrative cleavage is dominant in the phyllites but becomes less pervasive in the argillites.

Dark grey to black, thinly bedded graphitic argillaceous limestone grades vertically into the phyllites and argillites. Carbonate sections are characterized by massive, buff-weathering limestone up to 5 metres thick, such as crop out along the road on the north side of Slate Creek, approximately 3 kilometres west of Manson Creek. Layers of argillaceous sandstone to wacke, varying from a few centimetres to tens of centimetres thick, are a minor constituent of the lower division. They weather grey to light brown and lack internal structure.

The lower division also contains lenticular bodies of ultramafite which are restricted to the Manson fault zone, south of the Omineca River, and are poorly exposed along the Germansen River valley as well as a few kilometres west of Manson Creek. Based on previous mapping to the southeast (Ferri and Melville, 1988a), three types of altered ultramafite are present: serpentinite, talc-serpentine bodies and talc-ankerite-serpentine schists. Fault contact relationships of these bodies with the surrounding phyllites are characteristic along this belt.

Serpentinite bodies are the most abundant; they are essentially pure serpentine with lesser amounts of disseminated talc, ankerite and epidote which may accompany quartz veining. Serpentinites are generally magnetic and may contain veins of chrysotile. These rocks are well exposed immediately south of the Farrel showing (Figure 1-24-5, Table 1-24-1) on the north side of the Germansen River. Talc may form up to 50 per cent of the serpentinite, as either disseminated grains or fine-grained masses up to 1 centimetre in diameter. The talc serpentinites are weakly foliated.

Bodies of mariposite(fuchsite)-magnetite-quartz-talc-ankerite schist (listwanites) are also found in this zone and are well exposed at the bend in the Germansen River, approximately 10 kilometres northwest of Manson Creek. The listwanites are grey-green to rusty brown weathering, coarsely crystalline and commonly contain porphyroblasts of ankerite.

A northwesterly trending dacite tuff is poorly exposed northwest of Germansen Landing. No contact relationships with the surrounding rocks were seen. It is grey to cream on fresh surface, grey to brown weathering and massive, composed of up to 30 per cent quartz clasts, 5 to 10 per cent plagioclase and potassic feldspar crystal fragments, 1 to 2 percent muscovite and biotite plus minor hornblende and zircon. The groundmass is recrystallized to sericite, carbonate, quartz and chlorite. The quartz exhibits resorption embayments and the mica is commonly bent. The tuff contains a penetrative foliation parallel to structures in the Slide Mountain Group.

Similar tuffs are interbedded with the phyllites and argillites of the lower division of the Slide Mountain Group. In old hydraulic pits along the Germansen River, approximately 2 kilometres south of Germansen Landing, tuff beds 20 centimetres to more than 2 metres thick are in sharp contact or grade into the phyllites and argillites. The tuff beds commonly contain rip-up clasts of argillite and fill scour channels in the sediments. They are white to cream in colour, tan to rusty weathering and may contain up to 80 per cent coarse quartz and feldspar crystal fragments which are sometimes graded.

Middle Division

This division is informally known as the siliceous sediment division and is composed of argillite, siliceous argillite, siltstone and cherts, with lesser mafic volcanics, volcaniclastics, sandstone, conglomerate and ribbon chert. This division also contains numerous bodies of gabbro and diabase. It is best exposed on Blue Grouse Mountain, immediately northeast of Germansen Landing.

The argillites and siliceous argillites are grey to grey-green, moderately to massively bedded and may contain a spaced to penetrative cleavage. They grade into or are interlayered with massive to thickly bedded grey-green to greenish siltstones. The siltstones may contain a coarser fraction composed of feldspar crystal fragments indicating that these "siltstones" may in fact be crystal tuffs. This is also suggested by the abundance of mafic alteration minerals (chlorite, epidote, prehnite/pumpellyite) within these layers.

Massive to thickly bedded chert is interlayered with the above lithologies. The chert is typically grey to light grey but may be cream to white, beige, maroon or dark grey. Ribbon chert with thin chert layers (1 to 5 centimetres) separated by thinner, cleaved siliceous argillite was seen only rarely.

The upper part of this division also contains massive, dark green to green plagioclase and pyroxene-phyric mafic to intermediate flows. Flows range up to 30 metres thick and are locally associated with breccias of similar composition. These volcanics are highly altered to chlorite and epidote with the feldspars being strongly sericitized.

Polymict sandstones, wackes and conglomerates are a minor component of the middle division. These are thin to moderately bedded, often interlayered with siltstone and seen in sections up to 10 metres thick. They are composed of subrounded to rounded clasts of chert, quartz, carbonate, argillite(?), volcanic fragments and rare potassic feldspar crystal fragments. The volcanic fragments are feldspar-pyroxene porphyries.

Sill and dyke-like bodies of fine to coarsely crystalline gabbro and diabase intrude the layered rocks. These bodies range from a few metres to over several hundred metres in

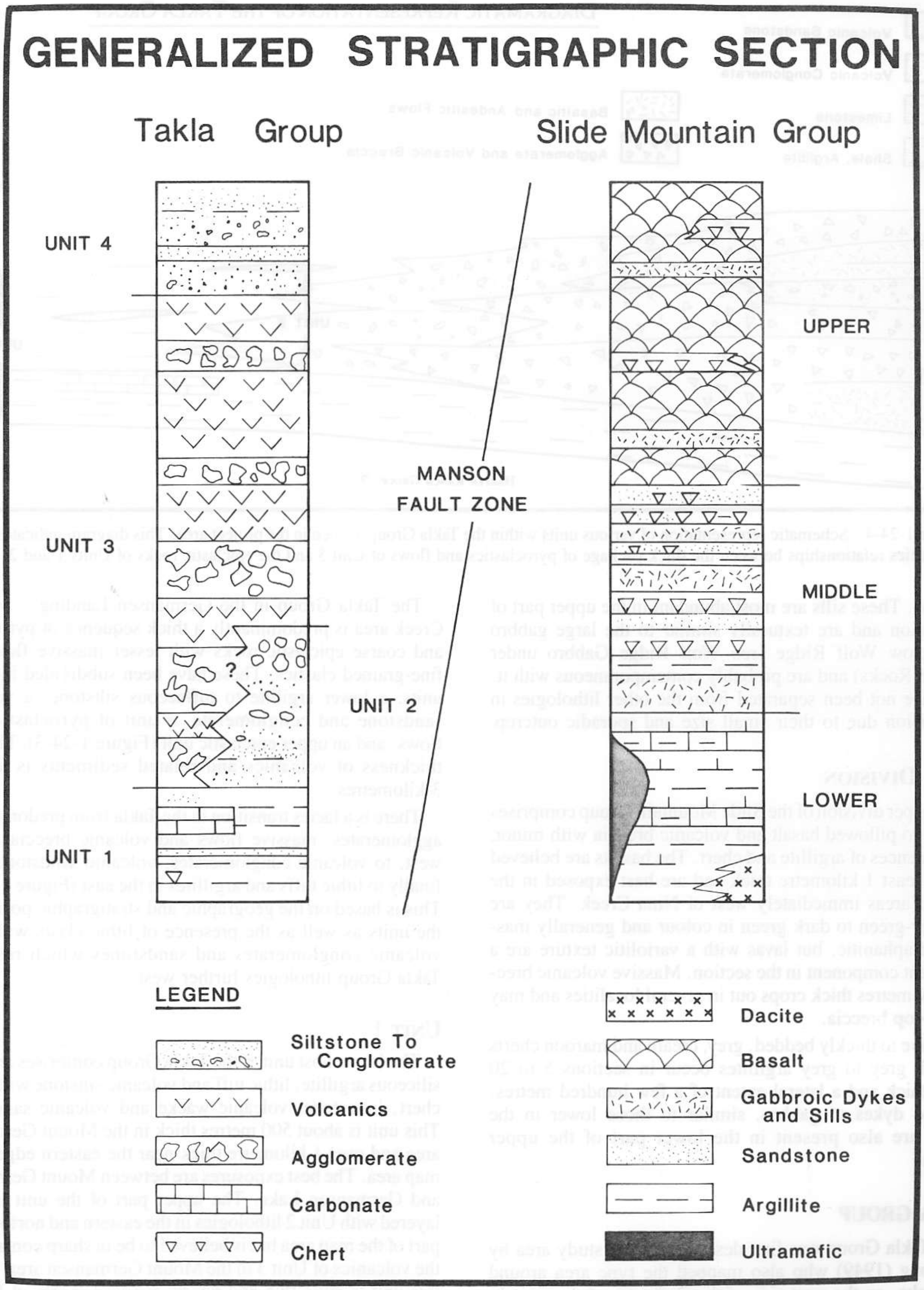


Figure 1-24-3. Generalized stratigraphic column (not to scale) for the Takla and Slide Mountain Groups as seen within the project area.

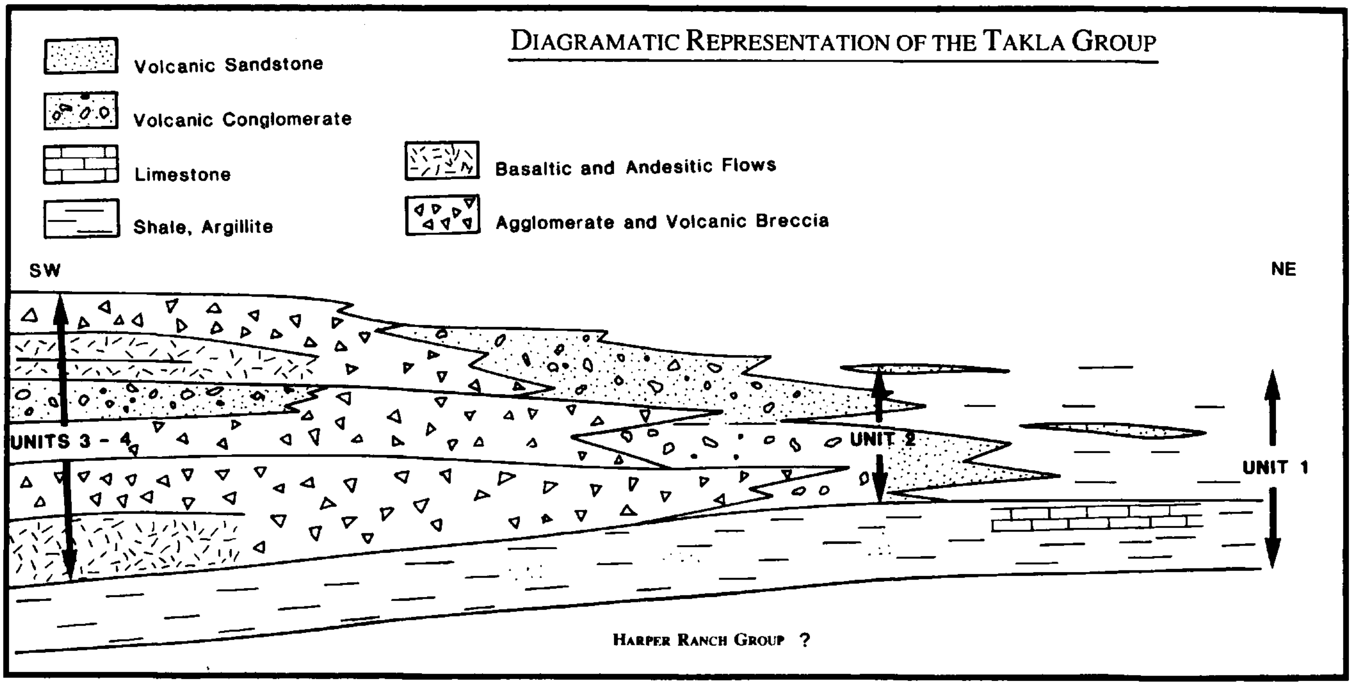


Figure 1-24-4. Schematic representation of various units within the Takla Group as seen in the project area. This diagram indicates the facies relationships between the thick package of pyroclastics and flows of Unit 3 and the epiclastic rocks of Units 1 and 2.

thickness. These sills are most abundant in the upper part of the division and are texturally similar to the large gabbro body below Wolf Ridge (*see* Wolf Ridge Gabbro under Intrusive Rocks) and are probably contemporaneous with it. They have not been separated from the other lithologies in this division due to their small size and sporadic outcrop.

Upper Division

The upper division of the Slide Mountain Group comprises massive to pillowed basalt and volcanic breccia with minor, thin sequences of argillite and chert. The basalts are believed to be at least 1 kilometre thick and are best exposed in the highland areas immediately west of Nina Creek. They are dark grey-green to dark green in colour and generally massive and aphanitic, but lavas with a variolitic texture are a significant component in the section. Massive volcanic breccia a few metres thick crops out in several localities and may be flow-top breccia.

Massive to thickly bedded, grey, cream and maroon cherts and dark grey to grey argillites occur in sections 5 to 20 metres thick and a lateral extent of a few hundred metres. Sills and dykes of gabbro, similar to those lower in the section are also present in the lower part of the upper division.

TAKLA GROUP

The Takla Group was first described in the study area by Armstrong (1949) who also mapped the type area around Takla Lake, on the west side of the Cache Creek terrane. In the present study area, Meade (1974, 1975, 1977) described Takla Group rocks in the area south and west of Germansen Lake.

The Takla Group in the Germansen Landing – Manson Creek area is predominantly a thick sequence of pyroclastic and coarse epiclastic rocks with lesser massive flows and fine-grained clastics. These have been subdivided into four units: a lower argillite to tuffaceous siltstone, a volcanic sandstone and conglomerate, a unit of pyroclastics and flows, and an upper epiclastic unit (Figure 1-24-3). The total thickness of volcanics and related sediments is at least 3 kilometres.

There is a facies transition in the Takla from predominantly agglomerates, massive flows and volcanic breccias in the west, to volcanic conglomerates, volcanic sandstones, and finally to lithic tuffs and argillites in the east (Figure 1-24-4). This is based on the geographic and stratigraphic position of the units as well as the presence of lithic clasts within the volcanic conglomerates and sandstones which resemble Takla Group lithologies further west.

Unit 1

The lowermost unit of the Takla Group comprises argillite, siliceous argillite, lithic tuff and volcanic siltstone with lesser chert, limestone, volcanic wacke and volcanic sandstone. This unit is about 500 metres thick in the Mount Germansen area and over 1 kilometre thick near the eastern edge of the map area. The best exposures are between Mount Germansen and Germansen Lake. The upper part of the unit is interlayered with Unit 2 lithologies in the eastern and northeastern part of the map area but is believed to be in sharp contact with the volcanics of Unit 3 in the Mount Germansen area. Where this unit is quite thin and poorly exposed, north of Plughat Mountain, it has been grouped with Unit 2.

The argillites are thin to moderately bedded, cream to rusty weathering and typically grey on fresh surfaces. They are sometimes graphitic and contain abundant finely disseminated pyrite. The argillites may be quite siliceous and are interlayered with dark grey to grey graphitic cherts. Minor limestone sequences (less than 1 metre) or beds 1 to 30 centimetres thick are sometimes present.

The siltstones are cream to beige in colour, thin to moderately bedded and fairly siliceous. They occur both interbedded with the argillites and as sections 1 to 10 metres thick. The coarser siltstones contain subangular clasts of feldspar, feldspar porphyry, and rare argillite and quartz. Some of these "siltstones" have the characteristics of waterlain lithic tuffs as opposed to volcanic siltstones.

Thin to thickly bedded volcanic sandstones, conglomerate and some volcanic breccia are exposed in the upper part of this unit. The sandstone clasts are subangular and composed of feldspar crystal fragments, feldspar and augite-feldspar porphyries, augite crystal fragments and rare quartz and argillite. Clasts within the conglomerates and breccias are predominantly feldspar-augite porphyries, aphanitic volcanics and minor argillite. In the eastern part of the map area these lithologies grade into the overlying volcaniclastic rocks of Unit 2.

Unit 1 commonly contains a spaced cleavage; spacing varies from a few millimetres to several centimetres. Cobbles are commonly stretched parallel to the cleavage and the rock generally breaks along this surface.

Unit 2

Unit 2 is characterized by volcanic sandstone and conglomerate with lesser siltstone, and argillite. The best exposures are on the small knolls north and south of the confluence of the Germansen and the South Germansen rivers. The unit is over 1 kilometre thick in the eastern part of the map area but pinches out towards Mount Germansen.

The sandstones are grey to dark grey-green, massive, and typically coarse grained with isolated cobbles. The majority of the clasts are feldspar porphyries of various types, but hornblende and/or pyroxene feldspar porphyries and feldspar, hornblende and pyroxene crystal fragments are also present. They are subangular to subrounded and the lithic clasts are typical of Takla Group lithologies further west. The matrix is typically finely crystalline chlorite though some parts contain prehnite/pumpellyite infills.

Massive to poorly sorted volcanic conglomerates and breccias are typically matrix supported, with the matrix being a volcanic sandstone as described above. Clasts range from 0.5 to 30 centimetres, are polymict and are composed of vesicular to amygdaloidal basalts, hornblende and/or pyroxene feldspar porphyries, feldspar porphyries and rare chert or argillite. The volcanic clasts are identical to Takla Group volcanic lithologies further east (*see* Figure 1-24-4).

The lower parts of Unit 2 contain sections of argillite and volcanic(?) siltstone similar to those described in Unit 1. These finer grained lithologies contain a spaced cleavage which is not as well developed in the conglomerates. Deformation within the conglomerates is evidenced by flattened clasts.

Unit 3

This unit is predominantly pyroclastic in nature with lesser massive flows, epiclastic rocks and minor dioritic sills and dykes. It outcrops primarily north and south of Germansen Lake and also in the northwestern corner of the map area. The thickness of the unit varies from 1 to 2 kilometres and its contact with Unit 2 is generally gradational but fairly sharp with Unit 1. East of Plughat Mountain tuffaceous breccias of Unit 3 give way eastward, over a broad interval, to volcanic conglomerates and sandstones of Unit 2. Unit 3 has been subdivided into two broad sub-units; Subunit 3a is composed predominantly of pyroclastics, agglomerates, tuffaceous breccias, lapillistones and volcanic sediments with lesser massive flows, and Subunit 3b is predominantly flows and pyroclastics with lesser volcanic sediments. Subunit 3a is areally more extensive than Subunit 3b.

Unit 3 is green, grey-green, grey, grey-brown or maroon and maroon to brown weathering. The principal lithologies are hornblende and/or augite ± serpentinized olivine-feldspar porphyry agglomerates, lapillistones with lesser flows and tuffites. The more mafic volcanic rocks are slightly magnetic and appear as broad highs on aeromagnetic maps. Less common are aphanitic volcanics. Individual flows and agglomerates vary from a few metres to tens of metres thick. They are basaltic to andesitic in composition (Meade 1975, 1977) with mafic minerals comprising up to 30 per cent of the rock. Approximately 8 kilometres west of Plughat Mountain is a sequence of coarsely bladed feldspar porphyry flows and agglomerates which are distinct from the other porphyritic volcanics in the Takla Group. The feldspars are generally sericitized and chlorite, prehnite, pumpellyite and epidote are the main alteration minerals in the groundmass and amygdules. Biotite and actinolite appear near the contact with the Germansen batholith. This unit generally does not display a penetrative fabric, but a weak foliation or cleavage is developed where these rocks rest on the sediments of Unit 1 in the Mount Germansen area. Agglomerates have no internal structure and are commonly polymict, especially towards the eastern contact.

Grey to grey-green tuffaceous siltstones and volcanic sandstones are interlayered with agglomerates and flows northwest of Plughat Mountain. These epiclastic rocks are moderately to thickly bedded and exposed in sections up to 10 metres thick. Further northwest the unit is characterized by polymict volcanic sandstones, conglomerates and agglomerates.

Grey finely crystalline limestone is found in the upper part of this unit and crops out on the northeastern shore of Germansen Lake. This limestone is up to 25 metres thick and has been traced discontinuously for several kilometres. It is generally massive but in places bedding is manifest as thin, discontinuous, darker grey and coarser grained layers.

Unit 4

Unit 4 is a poorly exposed sequence of massive to poorly bedded, dark grey to grey volcanic sandstone and conglomerate exposed in a syncline centred on Germansen Lake. The conglomerates are matrix supported with the clasts consisting of porphyries similar to those in Unit 3. The thickness of this unit, based on structural cross-sections, is estimated to be upwards of 1 kilometre.

INTRUSIVE ROCKS

WOLF RIDGE GABBRO

Northwest-trending gabbro bodies intrude the lower and middle divisions of the Slide Mountain Group below and to the northwest of Wolf Ridge. These rocks are green to dark green on fresh surfaces and light brown to rusty brown weathering. They typically contain from 40 to 60 per cent sericitized plagioclase with the remainder being pyroxene, hornblende and rare biotite. They are fine to medium grained although pegmatitic phases crop out along the crest of Wolf Ridge. This unit has a characteristic weak mineral lineation with an accompanying very weak planar fabric which may grade into a mylonitic fabric.

These intrusions are very similar in appearance to gabbro/diorite bodies within the middle division of the Slide Mountain Group and are thought to be coeval with them. Contacts with enclosing rocks are often faults but these lenticular bodies are thought to be intrusions, up to 1.5 kilometres thick, within the sediments of the Slide Mountain Group.

GERMANSEN BATHOLITH

The southern sixth of the map area is underlain by the Germansen batholith. It is best exposed on the alpine slopes of Mount Germansen. South of Germansen Lake its contact parallels bedding within the Takla sediments and volcanics but in the southeast the contact cuts diagonally across the rocks of the Takla Group.

The batholith comprises foliated hornblende biotite granodiorite composed of 40 to 50 per cent plagioclase, 20 to 25 per cent quartz, 15 to 20 per cent potassic feldspar and 10 to 15 per cent biotite and hornblende. Accessory minerals include apatite, zircon and magnetite(?). It commonly contains large potassic feldspar phenocrysts aligned along the foliation. The foliation varies from barely perceivable to moderate and is produced by recrystallization and flattening of quartz and mica around feldspar grains which show no annealing textures. The foliation generally parallels the intrusive contact and is associated with a steep mineral lineation indicating that this fabric may be related to emplacement.

Pegmatites of similar composition intrude the batholith and the smaller dykes also contain a penetrative fabric. Aplite dykes also cut the Germansen batholith throughout its exposure.

Monzonite to quartz monzonite intrudes the Germansen batholith and segments of the Olsen Creek fault zone. These rocks occur as dykes up to 15 metres wide and as irregular bodies over 20 metres in diameter. They are plagioclase, potassic feldspar and quartz phyric with the quartz displaying resorbed margins. The matrix is composed of fine-grained plagioclase, potassic feldspar and muscovite. Accessories are biotite, hornblende and zircon. This unit does not display the fabric seen in the other phases.

The contact of the batholith with the surrounding sediments is steeply dipping with numerous fine-grained apophyses extending into argillites, tuffs and siltstones of Unit 1 of the Takla Group. There is no evidence of chilling at the margin.

Potassium-argon dating of granodiorite from near Mount Germansen yield dates of 106 ± 3 Ma and 86 ± 3 Ma for hornblende and biotite respectively (Meade, 1975). Dating by the authors on a two-mica granite phase of the Germansen batholith near Mount Gillis yielded a date of 107 ± 4 Ma on biotite.

GABBRO

A small body of gabbro intrudes the Takla Group, 1 kilometre south of the mouth of Nina Creek. It is grey, massive, medium to coarsely crystalline and contains a weak to moderate foliation which trends northwesterly. It is composed of plagioclase (50 per cent), pyroxene (30 per cent), sphene(?) (10 per cent) and hornblende, sericite and calcite. This unit does not resemble the Wolf Ridge gabbro and its exact age is unknown.

STRUCTURE

The area may be divided into three broad structural domains: the Paleozoic(?) carbonates, the Slide Mountain (which includes the Manson fault zone), and the Takla. These domains are all separated by major faults, the most notable being the Manson fault zone. The Slide Mountain Group and Paleozoic carbonates are separated by a west-side-down normal fault.

PALEOZOIC CARBONATE DOMAIN

Bedding is the dominant planar fabric in this domain. Strikes are generally northwesterly with southwest dips. Lack of marker units prohibited the delineation of large-scale structures but a scatter of data and several mineral lineations indicate a shallow southeasterly plunge.

SLIDE MOUNTAIN DOMAIN

Structural elements within the Slide Mountain Group trend northwesterly. The lack of marker horizons inhibits the mapping of large-scale structures but the spread of bedding attitudes within the sediments of the middle division indicates broad folds (wavelengths of 3 to 7 kilometres) which plunge gently southeast.

Cleavage is well developed within the lower division phyllites; it is vertical to steeply dipping to the northeast and is typically the only planar feature observed. Within the upper parts of the Slide Mountain Group, cleavage is only found in the argillaceous sequences. Tight southeasterly plunging folds are occasionally associated with this cleavage.

In the northern part of the map area a northeasterly trending, north-side-down normal fault places basalts of the upper division against sediments of the middle division. The movement on this fault is supported by the unbroken succession and southeasterly plunge of the northern strata.

The most prominent structure in the map area is the Manson fault zone which separates two suspect terranes and is the locus of precious metal vein mineralization. The fault zone trends northwesterly and varies from a few hundred metres to over a kilometre in width. Lenses of altered ultramafite are found within the zone and are clearly delineated by aeromagnetic data. Subhorizontally stretched fault-breccia clasts and phyllite clasts (within tuff beds), slickensides and fibrous crystal growths all indicate strike-slip motion, though the sense of motion has not been deduced.

The Manson fault zone separates the Takla Group from the Slide Mountain Group. This is clearly shown in the Nina Creek area and the area between Slate Creek and the Germansen River. The Slate Creek lineament is probably a splay off the Manson fault zone and in this area fault slices of Takla Group sediments are contained in the fault zone.

TAKLA DOMAIN

Structures within the Takla Group vary somewhat from those in the other domains. Generally, broad structures have an easterly trend in the western part of the map area and swing into parallelism with the Manson fault zone as they are traced eastward. Only the lower unit of the Takla Group consistently exhibits a penetrative cleavage which becomes more sporadic within Unit 2 and rare or absent within Units 3 and 4.

Major faults in this sequence include the Olsen Creek fault, a north-side-down normal fault, and the Evans Creek fault, here assumed to be a thrust. The Evans Creek fault is required if the thick carbonate unit tentatively assigned to the Harper Ranch Group is the basement to the Takla Group.

METAMORPHISM

Metamorphism is generally middle greenschist grade or lower. Contact metamorphism around the Germansen batholith produces biotite and actinolite in the volcanics and sediments of the Takla Group.

Within the Slide Mountain Group chlorite and muscovite are the principal metamorphic minerals, with epidote and calcite as accessories. Typical metamorphic mineral assemblages in the Takla Group are chlorite ± muscovite ± prehnite ± pumpellyite ± epidote ± carbonate present as groundmass alteration or vesicle fillings in the volcanics.

MINERALIZATION

Table 1-24-1 lists the known mineral occurrences within the map area. Except for a few copper showings within the Takla volcanics, most of the prospects are associated with the Manson fault zone (Figure 1-24-5). Precious metals are found in sulphide-bearing quartz-carbonate veins associated with listwanites along the fault zone [for example Farrel, Flagstaff (Motherlode)] and disseminated in altered rocks of the Takla and Slide Mountain groups (QCM claims).

The listwanite alteration is characterized by disseminated and/or porphyroblastic ankerite and pyrite with accompanying sericitization and silicification of the host rocks. An excellent example of the progressive alteration of mafic volcanics is exposed approximately 3 kilometres north of the confluence of the South Germansen and Germansen rivers, along the main road between Manson Creek and Germansen Landing. At this locality relatively undeformed chloritized mafic volcanics are progressively altered to a mariposite-pyrite-muscovite-quartz-carbonate schist over a distance of 20 metres. This carbonate rock is more strongly foliated than the surrounding volcanics indicating proximity to a shear zone which may have been a conduit for hydrothermal fluids.

FARREL SHOWING

The Farrel vein-hosted precious metal showing is located on the north shore of the Germansen River approximately 6 kilometres south of Germansen Landing. Quartz-carbonate veins which vary in width from 0.5 to 5 metres are mineralized with tetrahedrite, chalcopyrite and free gold. Eight 1-metre channel samples across the vein yielded values ranging from 1.30 to 32.57 grams per tonne gold (Davis and Aussant, 1984). The hostrocks are talc schist and mafic volcanics 10 to 20 metres north of a serpentinized ultramafic body. In core samples, the most encouraging gold value (4.11 grams per tonne gold) was obtained from a slightly altered volcanic (Davis and Aussant, 1984). These veins are not extensive but are typical of other precious metal showings in the area (McAllister, 1987; Ferri and Melville, 1988a; Armstrong, 1949).

QCM Claims

The QCM claims are located north of the Slate Creek headwaters and east of the Germansen River. They are underlain by Slide Mountain Group sediments, volcanics and ultramafics, and Takla Group epiclastic rocks. Both units have been affected by quartz-carbonate alteration and contain the assemblage albite-muscovite-quartz-ankerite-pyrite (Fox, 1981, Riccio *et al.*, 1982).

Soil geochemistry located two anomalous gold zones, each approximately 3000 metres long by 50 to 300 metres wide with gold in soils up to 2950 ppb (Fox, 1981). Further work delineated two zones, Flag and Central; the latter is 200 metres by 300 metres and open to the southeast with gold in soil ranging from less than 10 ppb to 4200 ppb (Riccio *et al.*, 1982). Bedrock below and around the central zone consists of quartz-carbonate-altered epiclastics of the Takla Group. Values of up to 3700 ppb and 1800 ppb gold were returned from two consecutive 1 metre chip samples in trenches (Riccio *et al.*, 1982). These results led to a reverse-circulation drilling program consisting of 4 holes totalling 412 metres. All these holes penetrated quartz-carbonate-altered Takla Group volcanic sandstones which had accompanying quartz veining (Riccio, 1983). Median gold values were 130 ppb (Hole 4) to 170 ppb (Hole 1). In Hole 2, a 5-metre section averaged 1.8 grams per tonne gold with a 1-metre section of 3.2 grams per tonne. Several 1-metre sections returned over 1 gram per tonne gold.

Generally, gold anomalies coincide with pyrite concentrations within the country rock and with quartz veinlets suggesting stockwork as opposed to vein mineralization as at the Farrel prospect.

DISCUSSION

A few generalizations can be made about precious metal mineralization in the area: (1) it is localized along the Manson fault zone, (2) it is associated with serpentinite and listwanite, and (3) it is associated with a silica-carbonate

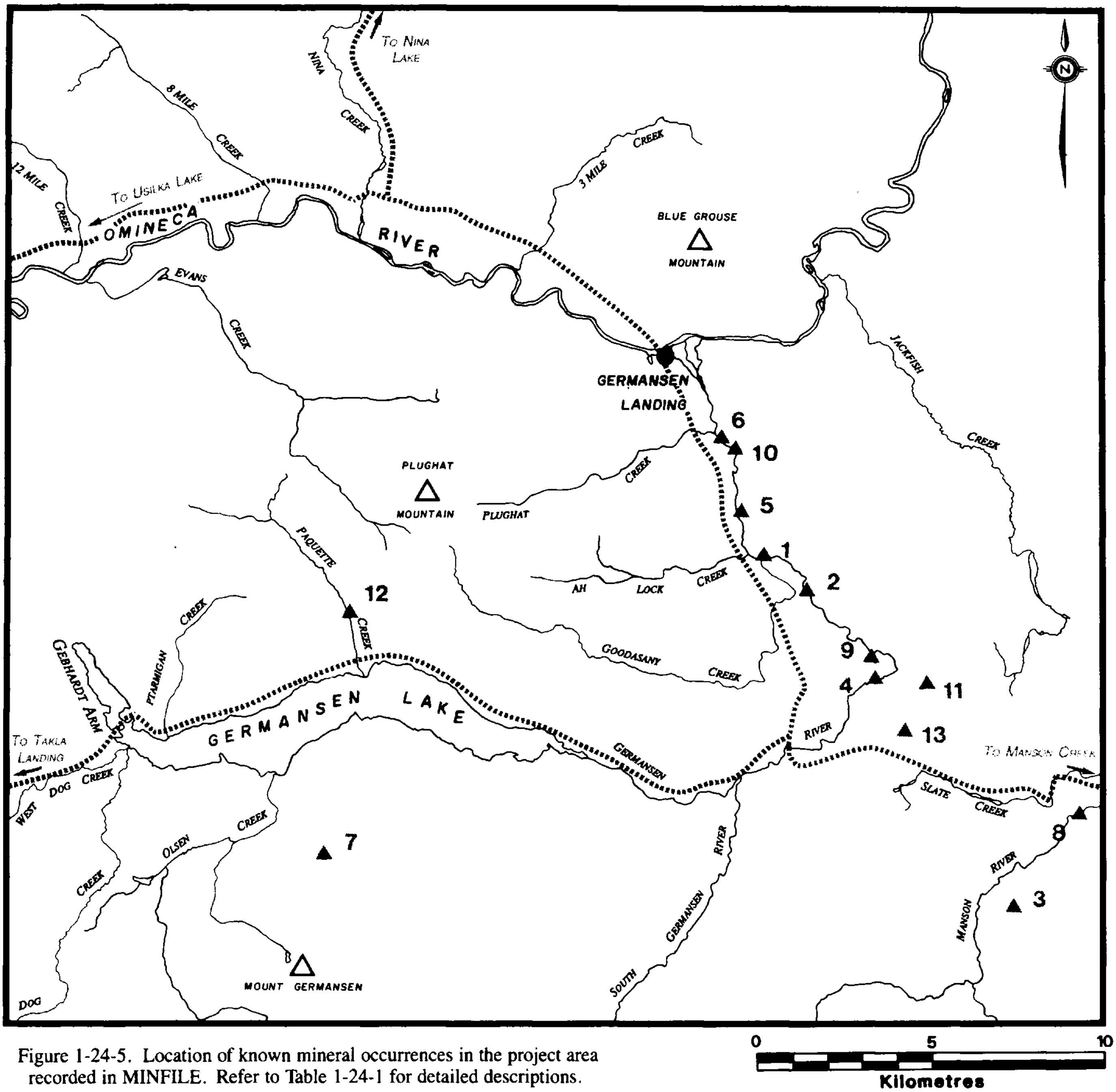


Figure 1-24-5. Location of known mineral occurrences in the project area recorded in MINFILE. Refer to Table 1-24-1 for detailed descriptions.

alteration. In the immediate map area ultramafite bodies are not identified north of the Omineca River and south of Gaffney Creek (Ferri and Melville, 1988a). This is also the known extent of lode and placer showings associated with altered ultramafite bodies. The association of gold-bearing veins with listwanites and serpentinized ultramafics in ophiolites of suture zones has long been known (Buisson and Leblanc, 1986). This same relationship appears to be present in the Manson Creek – Germansen Landing area.

SUMMARY

The north half of the Germansen Lakes (93N/10) and south half of the Germansen Landing (93N/15) sheets are largely underlain by rocks of the Takla and Slide Mountain groups of the Intermontane Belt. The Slide Mountain Group is subdivided into three units; a lower phyllite-argillite unit, a middle siliceous sediment unit and an upper basaltic unit. The Takla Group is made up of four units; the lower two units being epiclastic, the succeeding unit being predominantly pyroclastic and the fourth a thin upper epiclastic unit. The general trend within these volcaniclastics is for pyroclastics and flows in the west to give way to epiclastics eastward.

The major structural feature in the area is the Manson fault zone which is a strike-slip fault of unknown sense and displacement. It has numerous ultramafic and listwanite bodies along its trace and appears to have localized precious metal

TABLE 1-24-1
TABLE OF MINERAL OCCURRENCES (93N/10–NORTH HALF and 93N/15–SOUTH HALF)
(Refer to Figure 1-24-5 for locations)

Map	Type	MINFILE Number	Name	Economic Minerals	Geological Description
1	Asbestos	093N 115	Germansen River	Chrysotile	Asbestos is found in varying amounts in a serpentinized ultramafic body near and within the Manson fault zone.
2	Ultramafic-hosted base and precious metals	093N 116	Ah-Hoo Creek	Pentlandite, platinum, gold	Mineralization disseminated in pyrrhotite-bearing serpentinized ultramafic bodies within and near the Manson fault zone.
3	"	093N 022	Blackhawk	Galena, sphalerite, chalcopyrite, tetrahedrite, gold	Approximately nine quartz veins ranging from 38 to 150 cm wide within fractured and weakly metamorphosed Slide Mountain sediments near the Germansen batholith contain massive sulphides.
4	"	093N 024	Motherlode (Flagstaff)	Azurite, malachite, gold, tetrahedrite, chalcopyrite	Mineralization occurs in a shear related to the Manson fault separating a quartz-carbonate-altered andesite(?) and a pyritiferous argillite(?) of the Slide Mountain Group.
5	"	093N 025	Farrell	Tetrahedrite, chalcopyrite, gold	Mineralization occurs in three quartz veins in quartz-carbonate-altered and sheared Slide Mountain rock (andesite?) within the Manson fault zone.
6	Vein-hosted base and precious metals	093N 026	Sunset	Chalcopyrite, gold, silver	A pyrite and chalcopyrite-bearing quartz vein approximately 3 metres wide follows the plane of schistosity in quartz-rich schists near the Manson fault zone.
7	"	093N 029	Erickson	Chalcopyrite, silver, gold	Two quartz veins (20 and 40 cm wide) in sheared argillite of the Takla Group are intruded by aplite dykes near the Germansen batholith.
8	"	093N 063	Discovery Bar	Galena, sphalerite, tetrahedrite	Numerous quartz stringers are sparsely mineralized in a 3.65-metre shear zone separating quartz-carbonate-altered schists and black phyllites of the Slide Mountain Group.
9	"	093N 130	Not named	Tetrahedrite, gold	"
10	"	093N 144	Not named	Chalcopyrite, gold, galena, tetrahedrite	Numerous folded and semi-continuous pyritiferous quartz veins containing varying amounts of mineralization hosted by a well-foliated and pyritiferous quartz-rich schist.
11	"	093N 145	Not named	Chalcopyrite, tetrahedrite	Mineralization occurs in several quartz veins in Slide Mountain volcanics and sediments.
12	Volcanogenic (proximal) disseminated sulphides	093N 153	Not named	Chalcopyrite	Mineralization occurs in pyritiferous Takla Group andesitic flows, agglomerates and volcanic sandstones.
13	Disseminated/stockwork precious metals	093N 198	QCM Claims	Gold	Gold occurs disseminated or in quartz vein stockwork within quartz-carbonate-altered Takla volcaniclastics near the Manson fault zone.

vein mineralization which is associated with a quartz-sericite-carbonate alteration.

ACKNOWLEDGMENTS

We would like to thank Ron Arksey for cheerful and competent assistance in the field and in the office. Special mention is given to Sean Horgan for endless, amusing summer days. As well, we would like to extend our appreciation for the hospitality provided by Don and Irene Gilliland of the Gilliland Lodge. Finally, special thanks to Vicki, of Northern Mountain Helicopters, for cheerful conversations while waiting on the helicopter.

REFERENCES

Armstrong, J.E. (1949): Fort St. James Map Area, Cassiar and Coast Districts, British Columbia, *Geological Survey of Canada*, Memoir 252, 210 pages.

Buisson, G. and Leblanc, M. (1986): Gold Bearing Listwaenites (Carbonitized Ultramafic Rocks) in Ophiolite Complexes: *in* Metallogeny of Basic and Ultrabasic Rocks, J.M. Gallagher, R.A. Iscear, C.R. Neary and H.M. Prichard, Editors, *The Institution of Mining and Metallurgy*, pages 121-132.

Davis, J.W. and Aussant, C. (1984): Manson Creek Project, Road Building and Drilling Report, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 12130.

Ferri, F. and Melville, D.M. (1988a): Manson Creek Mapping Project (93N/9), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 169-180.

——— (1988b): Geology of the Manson Lakes Map Sheet, 93N/9, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-12.

Fox, M. (1981): Geological, Geochemical and Geophysical Report Flume 1-5 Mineral Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 8957.

Gabrielse, H. (1963): McDame Map-area, Cassiar District, British Columbia, *Geological Survey of Canada*, Memoir 319, 138 pages.

——— (1975): Geology of Fort Grahame E1/2 Map-area, British Columbia, *Geological Survey of Canada*, Paper 75-33, 28 pages.

Garnett, J.A. (1978): Geology and Mineral Occurrences of the Southern Hogem Batholith, *B.C. Ministry of Mines and Petroleum Resources*, Bulletin 70, 75 pages.

McAllister, S.G. (1987): Geological and Geochemical Report on the Fair Claim, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 16602.

Meade, H.D. (1974): Geology of Germansen Lake Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, Number 1, pages 43-46.

——— (1975): Geology of the Germansen Lake Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map Number 19.

——— (1977): Petrology and Metal Occurrences of the Takla Group and Hogem and Germansen Batholiths, North-central British Columbia, Unpublished Ph.D. Thesis, *University of Western Ontario*.

Monger, J.W.H. (1973): Upper Paleozoic Rocks of the Western Canadian Cordilleran, *Geological Survey of Canada*, Paper 73-1 Part A, pages 27-28.

——— (1977): Upper Paleozoic Rocks of the Western Canadian Cordillera and Their Bearing on Cordilleran Evolution, *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

Monger, J.W.H. and Paterson, I.A. (1974): Upper Paleozoic and Lower Mesozoic Rocks of the Omineca Mountains, *Geological Survey of Canada*, Paper 74-1, Part A, pages 19-20.

Monger, J.W.H., Price, R.A and Tempelman-Kluit, D.J. (1982): Tectonic Accretion and the Origin of the Two Major Metamorphic and Plutonic Belts in the Canadian Cordillera, *Geology*, Volume 10, pages 70-75.

Nelson, J., and Bradford, J.A. (1987): Geology of the Area Around the Midway Deposit, Northern British Columbia (104O/16) *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 181-192.

Nelson, J., Bradford, J.A., Green, K.C. and Marsden, H. (1988): Geology and Patterns of Mineralization, Blue Dome Map Area, Cassiar District, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 233-243.

Price, R.A., Monger, J.W.H. and Roddick, J.A. (1985): Cordilleran Cross-section: Calgary to Vancouver. *In* Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera. Edited by Templeman-Kluit, D.J., *Geological Society of America*, Cordilleran Section, Annual Meeting, Vancouver, 3-1, pages 3-85.

Riccio, L. (1983): Reverse Circulation Drilling Report on the QCM 1-5 Mineral Claims, Manson Creek Project, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assesment Report 11627.

Riccio, L., Atkinson, M. and Scott, A. (1982): Geological, Geochemical and Geophysical Report on the QCM 1-5 and OPEC 1-10 Mineral Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assesment Report 10746.

Roots, E. F. (1954): Geology and Mineral Deposits of Aiken Lake Map-area, British Columbia, *Geological Survey of Canada*, Memoir 274, 246 pages.

TECTONIC EVOLUTION OF UPPER PROTEROZOIC INGENIKA GROUP, NORTH-CENTRAL BRITISH COLUMBIA (94C/12)

By K. Bellefontaine
McGill University

KEYWORDS: Regional geology, stratigraphy, structural geology, metamorphism, Ingenika Range, Ingenika Group, Swannell Formation, Swannell fault, Swannell antiform.

INTRODUCTION

This report is a summary of a 2-year mapping project conducted in the Ingenika Range of north-central British Columbia. It incorporates and reinterprets data from Bellefontaine and Minehan (1988). The study area is located in the Ingenika Range of the Omineca Mountains (94C/12, Orion Creek). The area is bounded to the southwest and east by the Swannell River, to the northwest by Wrede Creek, and to the northeast by the Ingenika River (Figure 1-25-1).

The Ingenika Range consists of Late Proterozoic miogeoclinal rocks of the Omineca crystalline belt that extend the length of the Canadian Cordillera. To the east the Pelly fault brings similar clastic rocks of Late Proterozoic and Early to Middle Paleozoic age into contact with the older strata. In the western part of the range the miogeoclinal rocks abut the Triassic and Jurassic, probable island arc rocks, of the Lay Range assemblage and Takla Group, along the Swannell fault. In much of the Ingenika Range the miogeoclinal rocks dip gently eastwards, but near the Swannell fault the dominant structure is a northwest-plunging regional-scale postmetamorphic antiform that extends the length of the Swannell Ranges and is here referred to as the Swannell antiform.

The aim of this project was to study the structural and metamorphic history of the Ingenika Group, to investigate the nature of the faulted contact between the Omineca and Intermontane belts, to deduce the history of movement on the Swannell fault, and to determine the origin of the Swannell antiform.

Detailed structural measurements were taken along several transects across the area, and parts of the western limb of the Swannell antiform were mapped at a scale of 1:15 000.

PREVIOUS WORK

Roots (1954) defined two main stratigraphic units in the Ingenika Range and crudely delineated the major antiformal structure and metamorphic zonations of the area. Mansy and Gabrielse (1978) described and correlated a stratigraphy for Upper Paleozoic rocks in the Omineca and Cassiar mountains. More recently, Mansy (1986) completed an extensive regional stratigraphic and structural study of the miogeoclinal rocks exposed throughout the Omineca Mountains. He made broad interpretations of the structure and stratigraphy of the Ingenika Range, and mapped the distribution of metamorphic isograds around the Swannell antiform. His research also provided two geothermometers for the present study area.

The region around Chase Mountain, directly southeast of the Ingenika Range, was studied in detail by Parrish (1976a, 1976b). He documented doubly plunging structures in complexly deformed rocks at the northern edge of the high-grade Wolverine Complex. Gabrielse (1985) discussed the orientation and movement on the Swannell fault in the overall tectonic framework of the Canadian Cordillera.

STRATIGRAPHY

Rocks in the Ingenika Range belong to the Ingenika Group of the Windermere Supergroup, which forms a clastic wedge extending the length of the Canadian Cordillera (Mansy and Gabrielse, 1978). The Ingenika Group is subdivided into four formations, the lowermost of which, the Swannell Formation, is well exposed in the Ingenika Range. The Swannell Formation has been correlated with the lower part of the Horsethief Creek Group in the northern Purcell Mountains, the Kaza Group in the northern Cariboo Mountains and the middle unit of the Miette Group in the Rocky Mountains (Young *et al.*, 1973; Mansy and Gabrielse, 1978).

The stratigraphy in the Ingenika Range is dominated by monotonous sequences of variably metamorphosed micaceous schist, quartzose schist and metaquartzite, with complete gradation between these rock types. Relatively unmetamorphosed carbonaceous sandstones and grits overlie the schistose rocks.

Previous regional work by Mansy (1986) has resulted in the subdivision of the Swannell Formation into several units. Although a detailed stratigraphy for the Ingenika Range could not be established due to the absence of marker beds, the overall distribution of rock types in the area is consistent with Mansy's interpretation. The core of the antiform is dominated by schistose metaquartzites with interlayered micaceous and quartz-rich schists. The eastern limb consists mainly of thickly bedded (metre scale) grits and gritty sands with minor micaceous schist and laminated phyllite. Grits and sands, commonly with a carbonaceous matrix, together with carbonates and minor phyllites, occur along the west limb of the antiform. Rocks commonly display graded bedding and more rarely channelling.

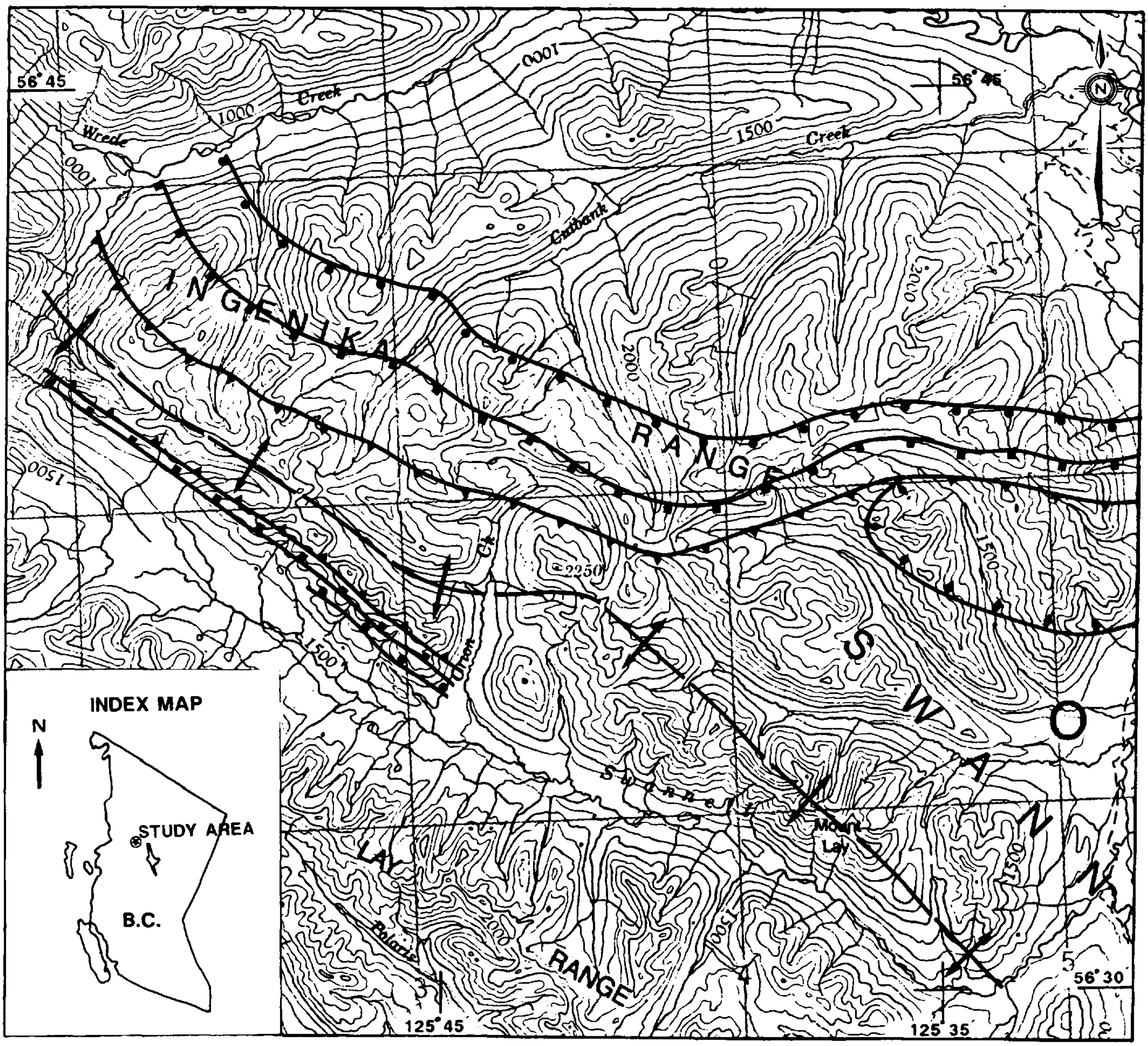


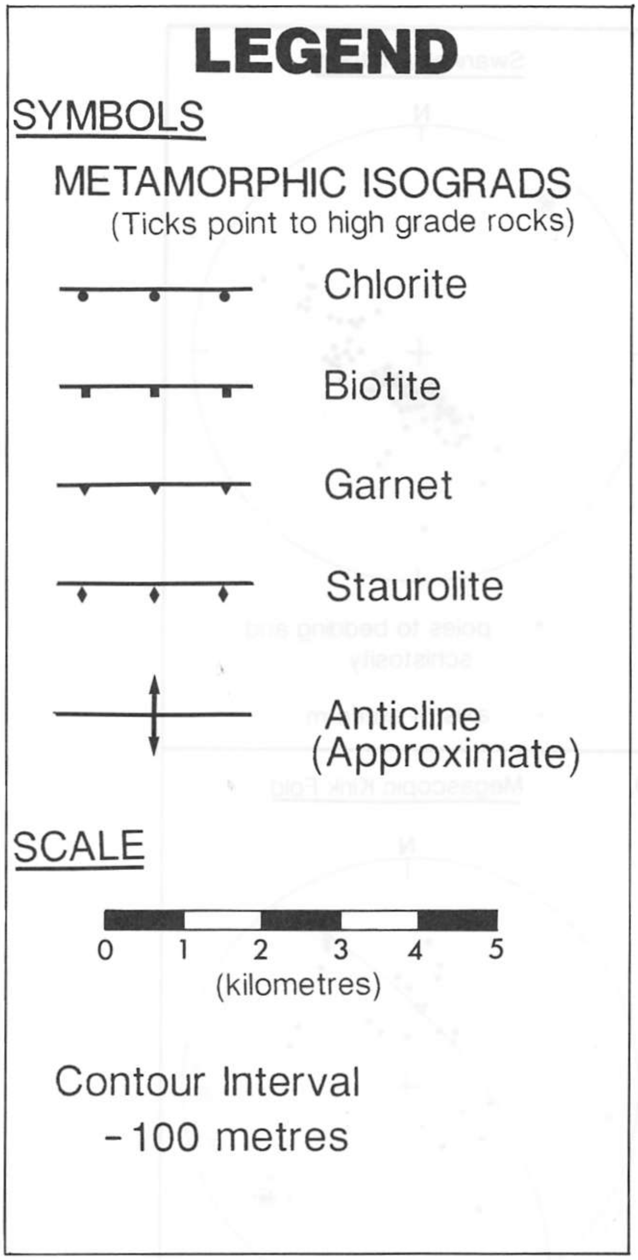
Figure 1-25-1. Location map of Ingenika Range showing D_1 metamorphic isograd distribution and approximate attitude of the axial surface trace of the Swannell antiform (after Mansy via Gabrielse, personal communication, 1987).

The thickness of the Swannell Formation is very difficult to estimate due to repetition of strata and the structural complexities of the area. The northeastern limb of the antiform is approximately 1500 metres thick and the base and top of the Swannell Formation are not exposed. Given the scarcity of outcrop-scale folds this may reflect a minimum thickness, although the possibility of tectonic thickening through bedding-parallel thrusting cannot be entirely discounted.

STRUCTURE

Ingenika Group rocks in the Swannell Ranges have experienced two major phases of deformation, followed by several late-stage events. The first phase of deformation is evidenced by typically tight to isoclinal, northwest-plunging folds with pervasive axial planar S_1 schistosities (Figure 1-25-2a). They are predominantly observed in very competent quartz-rich schists and metaquartzites in which only the noses of folds are commonly preserved (Plate 1-25-1). Outcrops consisting of isolated fold hinges, often with opposing senses of closure, are a consequence of major shearing parallel to the limbs of folds. Except for these rare F_1 closures, D_1 deformation is apparent only from bedding cleavage relationships.

All F_1 folds observed are upward facing and northeast verging, where vergence could be established. The D_1 structures are therefore compatible with a northeast-directed tectonic transport during the earliest deformation event. Since all folds observed are upward facing there is no evidence for the development of large-scale recumbent structures during



D_1 deformation. Widespread rolled fabrics in the garnets of pelitic schists indicate that metamorphism was broadly synchronous with the D_1 deformation event.

Second-phase structures are characteristically open and upright folds that are devoid of cleavage. They are associated with the Swannell antiform, which is itself a large F_2 fold. The Swannell antiform folds the metamorphic isograds associated with D_1, as well as the bedding and S_1 schistosity (Figures 1-25-1 and 1-25-2b). It has a steep southwestern limb (135/60SW), and a moderately dipping northeastern limb (120/35NE) and is weakly inclined toward the southwest with a shallow northwesterly plunge. Tight to isoclinal F_1 folds are rotated around the antiform in the same fashion as bedding and schistosity. Outcrop-scale F_2 folds were mainly observed on the southwestern limb of the antiform where they are abundant. The southwestern limb lies directly northeast of the Swannell fault and is characterized by a cascade of southwest-vergent folds, in which bedding and S_1 schistosity steepen from the regional southwest-dipping limb orientation through vertical and then turnover into shallow northeast-dipping strata that lie above slide zones (Figure 1-25-2c). These folds probably reflect drag due to southwest-vergent motion on the slide zones.

The slide planes have an average strike of 125 degrees and dip 45 degrees northeast. They are generally localized in schistose lithologies and are commonly recognized in the field by subhorizontal benches without outcrop. Since they are abundant only in the immediate vicinity of the Swannell fault, and have strikes similar to that of the fault, it is probable that they developed in association with movement on it. Therefore, these slides and their associated drag folds provide evidence for a southwesterly vergence. The fault itself is not exposed in the region and passes through the broad valley of the Swannell River. Its dip is not known with certainty, but the slide zones indicate it may dip 45 degrees northeast in this region. The Swannell fault is probably a thrust plane on which Ingenika Group rocks were transported southwest over Lay Group rocks. This conforms with the views of Mansy (1972, 1974) but differs from that of Gabrielse (1985). The simplest interpretation based on available data is that the Swannell antiform is a large drag fold associated with the same motion on the Swannell fault as on the slide planes.

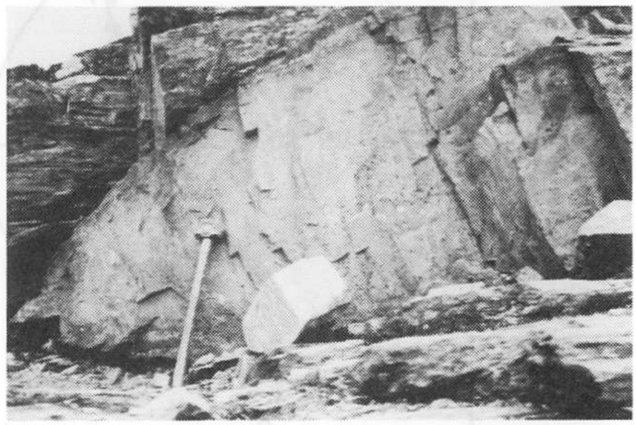


Plate 1-25-1. Isolated closure of F_1 fold in metaquartzite, surrounded by quartz mica schists, looking west.

In contrast to the southwestern limb, D_2 deformation on the northeastern limb of the Swannell antiform is restricted to west-vergent, open, upright folds that are parasitic to the antiform (Plate 1-25-2) and bedding-parallel slickensides with small-scale minor folds displaying westerly vergence. F_2 folds throughout the region are broadly coaxial with F_1 folds, but are demonstrably postmetamorphic and related to deformation with a vergence in the opposite direction to that obtained in D_1. Therefore, there is little doubt they reflect a distinct tectonic event. This more brittle deformation also produced strong crenulation folds and lineations in micaceous schists. There may be more than one generation of crenulation lineations, however, the coaxial nature of the

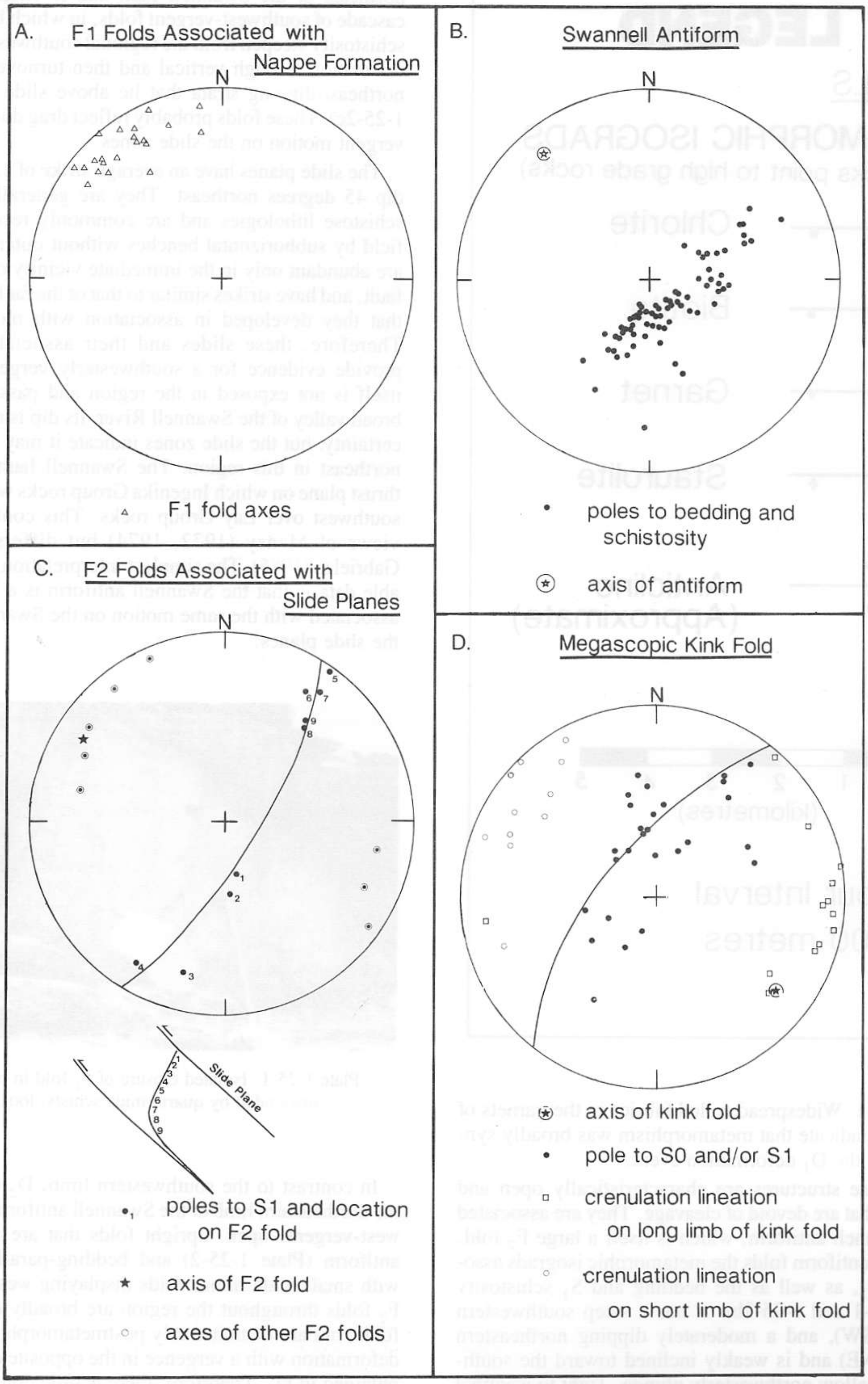


Figure 1-25-2. Equal-area stereonet plot of structural data from the Ingenika Range: (a) F_1 folds associated with east-verging nappe deformation, (b) Swannell antiform, (c) F_2 folds associated with slide planes on southwestern limb of Swannell antiform, (d) megascopic kink fold.

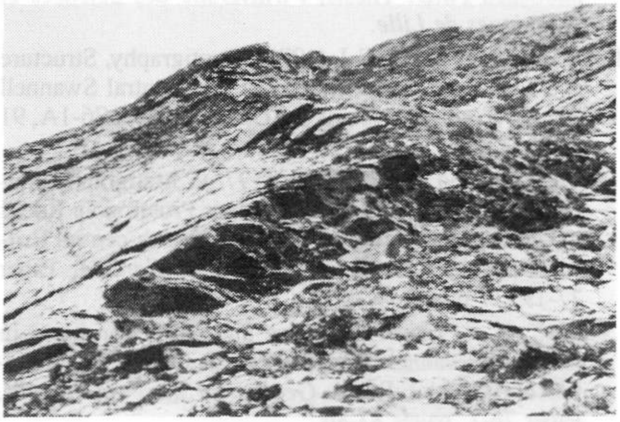


Plate 1-25-2. Northwest-plunging F_2 parasitic fold on northeastern limb of Swannell antiform, looking south.

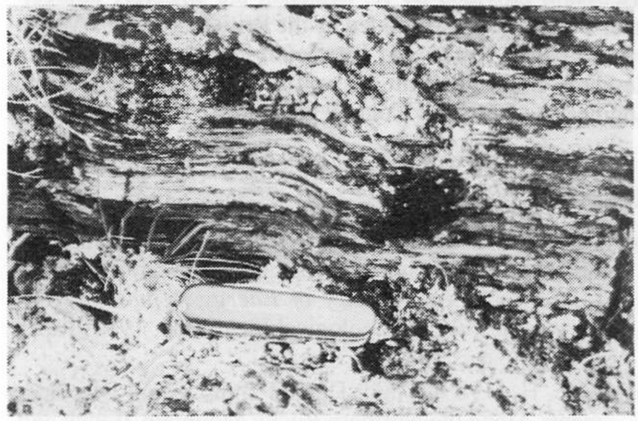


Plate 1-25-3. Small-scale dextral kink on southwest limb of Swannell antiform.

crenulations and the F_1 and F_2 fold axes makes distinction between them impossible. Refer to Figure 1-25-3 for a schematic tectonic profile of the Swannell antiform.

Sinistral and dextral kinks occur at all scales in the study area. They are concentrated on the southwest limb of the antiform and are probably related to a late-stage movement on the fault. However, interpretation of kink data is difficult since kinks are superimposed on beds of many different attitudes. Structural data for one large-scale (25 metre) kink indicates refolding of the crenulation lineation around an axis plunging 25 degrees at a trend of 140° (Plate 1-25-3), with a sense of kinking compatible with a late-stage sinistral motion on the Swannell fault.

METAMORPHISM

Regional Barrovian-type metamorphism occurred throughout the Swannell Ranges and reached at least staurolite grade in the Ingenika Range (Mansy and Dodds, 1976; Mansy, 1986). The distribution of metamorphic isograds mapped by Mansy was confirmed by mapping in the field area (Figure 1-25-1). In several places a change in metamorphic grade was found to coincide with bedding-parallel slickenside surfaces, thus implying some structural control on the position of isograds.

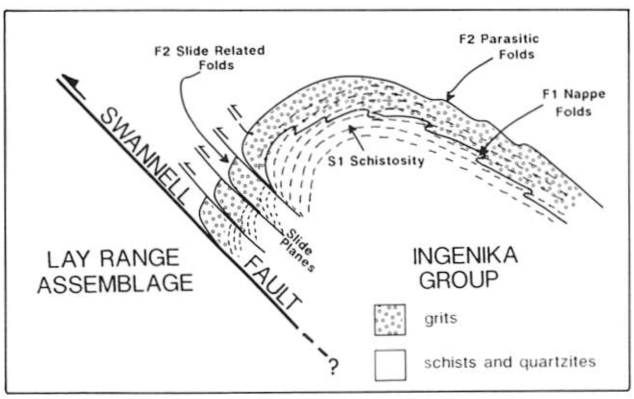


Figure 1-25-3: Schematic tectonic profile of Swannell antiform, looking northwest.

Chlorite, biotite and garnet isograds on the east limb of the Swannell antiform are evenly and widely distributed, while those on the western limb are more tightly spaced and complicated by F_2 folding. Mineralogical relationships indicate at least two phases of metamorphism, the first of which appears to be higher grade. The following observations are similar to those made by Mansy and Dodds (1976).

The first phase of metamorphism reached the highest grades and produced idioblastic staurolite up to 4 centimetres in length, and deep red garnet porphyroblasts up to 2 centimetres in diameter. The garnets frequently contain rolled fabrics indicating formation during D_1 nappe deformation. Biotite and muscovite developed along schistosity planes during this phase. Chloritic rinds and shadows around garnets reflect retrograde metamorphism.

The second stage of metamorphism is characterized by small (up to 5 millimetres), pale pink, relatively unaltered garnets, and coarse-grained biotite (up to 1 centimetre), that crosscut the D_1 schistosity. Given the apparently brittle character of D_2 deformation, the growth of these garnets probably predated D_2 and may reflect a thermal relaxation following crustal thickening during D_1 deformation.

CONCLUSIONS

The Ingenika Group in the Ingenika Range has a polyphase tectonic history. The first observed deformation involved northeast-vergent structures and synchronous regional metamorphism. The second phase of deformation is characterized by the concomitant development of the west-verging Swannell fault and the Swannell antiform. The Swannell fault in this region appears to be a west-verging D_2 thrust that places Upper Proterozoic miogeoclinal rocks of the Omineca Belt on top of Triassic and Jurassic exotic, oceanic terranes of the Intermontane Belt. Limited late kinking is compatible with late-stage sinistral motion on the Swannell fault, the extent of which is unknown.

ACKNOWLEDGMENTS

The author thanks Dr. A. Hynes for rigorous discussions in the field and review of the manuscript. Field assistance and discussion provided by K. Minehan are sincerely appreciated. This project was funded by the British Columbia Ministry of Energy, Mines and Petroleum Resources Geoscience Research Grant Program, as well as a Natural Sciences and Engineering Research Council grant to A. Hynes.

REFERENCES

Bellefontaine, K. and Minehan, K. (1988): Summary of Fieldwork in the Ingenika Range, North-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 195-198.

Gabrielse, H. (1985): Major Dextral Transcurrent Displacements Along the Northern Rocky Mountain Trench and Related Lineaments in North-central British Columbia, *Geological Society of America*, Bulletin, Volume 96, pages 1-14.

Mansy, J.L. (1972): Stratigraphy and Structure of the Ingenika Group in Finlay and Swannell Ranges, *in* Report of Activities, Part A, *Geological Survey of Canada*, Paper 72-1, pages 29-32.

——— (1974): Operation Finlay, *in* Report of Activities, Part A, *Geological Survey of Canada*, Paper 74-1, pages 17-18.

——— (1986): Géologie de la Chaine d'Omineca des Rocheuses oux Plateaux Intérieurs (Cordillère Canadienne) Son Évolution Depuis le Précambrien, Unpublished Ph.D. Thesis, *l'Université des Sciences et Techniques de Lille*.

Mansy, J.L. and Dodds, C.J. (1976): Stratigraphy, Structure and Metamorphism in Northern and Central Swannell Ranges, *Geological Survey of Canada*, Paper 76-1A, 91 pages.

Mansy, J.L. and Gabrielse, H. (1978): Stratigraphy, Terminology and Correlation of Upper Proterozoic Rocks in Omineca and Cassiar Mountains, North-central British Columbia, *Geological Survey of Canada*, Paper 77-19, 17 pages.

Parrish, R. (1976a): Structure and Metamorphism in Southern Swannell Ranges, British Columbia, *in* Report of Activities, Part A, *Geological Survey of Canada*, Paper 76-1, pages 83-86.

——— (1976b): Structure, Metamorphism and Geochronology of the Northern Wolverine Complex near Chase Mountain, Aiken Lake Map-area, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 89 pages.

Roots, E.F. (1954): Geology and Mineral Deposits of Aiken Lake Map-area, British Columbia, *Geological Survey of Canada*, Memoir 274, 246 pages.

Young, F.G., Campbell, R.B. and Poulton, T.P. (1973): The Windermere Supergroup of the Southeastern Cordillera *in* Belt Symposium, Volume 1, Department of Geology, *University of Idaho and Idaho Bureau of Mines and Geology*, Moscow, Idaho, pages 181-203.

TAKLA GROUP VOLCANO-SEDIMENTARY ROCKS, NORTH-CENTRAL BRITISH COLUMBIA: A SUMMARY OF FIELDWORK (94D/9)

By K. Minehan
McGill University

KEYWORDS: Regional geology, Intermontane Belt, Ingenika Ranges, Takla Group, stratigraphy, subaqueous pyroclastic flows, transcurrent faulting.

INTRODUCTION

This report summarizes field data collected during two field seasons from Upper Triassic Takla Group rocks of the Canadian Cordillera. The project was undertaken to determine the paleotectonic environment of a well-defined rock package within the allochthonous Intermontane Belt.

Takla Group volcano-sedimentary rocks occur in Quesnellia, a possible arc and subduction complex, which forms part of Terrane 1 of Monger and Price (1979). Terrane 1 was formed by late Triassic time by the amalgamation of four subterranes which are, from east to west; Slide Mountain or Eastern, Quesnellia, Cache Creek and Stikinia. By late Jurassic, Terrane 1 had collided with North America (Monger *et al.*, 1982).

The Pinchi fault is a prominent lineament trending north-northwest through the south-central portion of the Intermontane Belt. It extends from 52° north to 56° north where it joins the Ingenika and Findlay faults. Gabrielse (1985) calculated a pre-Late Cretaceous dextral transcurrent displacement of 100 kilometres for the once continuous Kutcho and Pinchi faults. The Kutcho and Pinchi faults are displaced along the Ingenika and Findlay faults which moved dextrally a distance of 110 kilometres in mid-Cretaceous and possibly more recent times. Rocks assigned to the Takla Group have been identified on both sides of the Pinchi fault. Previous work on Takla rocks in the McConnell Creek map area has been concentrated west of the Pinchi fault and conclusive stratigraphic correlations across the fault have not been made.

The stratigraphy was first defined and mapped by Lord (1948). Subsequent work by Church (1973, 1974) and others focused on the geology near Sustut Peak, where Falconbridge Nickel Mines Limited discovered extensive copper showings in 1971. Monger (1977a) subdivided the volcano-sedimentary rocks of the Takla Group west of the Pinchi fault into Dewar, Savage Mountain and Moosevale formations. East of the Pinchi fault the group remains undifferentiated.

The area of study, approximately 75 square kilometres, is located in the Omineca Mountains east of the Pinchi fault, in the southwestern part of the Ingenika Ranges. It is bounded to the southeast by a fault slice of Lay Range assemblage and to the northeast by the Swannell fault and Proterozoic miogeoclinal rocks of the Ingenika Group. Excellent exposure on prominent ridges is characteristic, although limited road access necessitates helicopter transportation. Preliminary fieldwork was conducted in 1987 and is summarized in Bellefontaine and Minehan (1988).

GENERAL GEOLOGY

Takla Group rocks within the study area are a diverse suite of volcanic, volcaniclastic and sedimentary rocks which were deposited subaqueously. Volcanic and volcaniclastic rocks are plagioclase and pyroxene porphyries of intermediate composition. In Bellefontaine and Minehan (1988) pyroxene was misidentified as amphibole. The strata, which have been metamorphosed to greenschist grade (Monger, 1977a, 1977b), are cut by several major northwest-trending transcurrent faults. The general geology is presented in Figure 1-26-1.

STRATIGRAPHY

The stratigraphic succession, approximately 3400 metres thick, consists predominantly of interlayered volcanogenic breccia, volcanogenic sandstone and volcanogenic siltstone. Volcanic flows and sediments also occur. The fining-upward volcaniclastic sequences described by Bellefontaine and Minehan (1988) have been reinterpreted using a nongenetic classification. The fragmentation proeess is inferred to have been pyroclastic, based on the presence of vesicular fragments, agglomerate bombs, altered pumice and possible welding textures. Whether they were deposited pyroclastically or epiclastically, however, is not clear. The volcaniclastic units are characterized by volcanic breccia fining upwards through volcanogenic sandstone and siltstone. They range in thickness from several metres to several hundred metres.

Five major northwest-trending transcurrent faults divide the map area into six stratigraphically distinct fault blocks. The stratigraphic relationships found in most fault blocks are broadly consistent with these fining-upward units.

Fault Block A (Figure 1-26-1) is characterized by typical fining-upward units in the lower 1450 metres of the stratigraphic section. In the upper 200 metres, there are at least three simple lava flows and their associated flow-top breccias. With the exception of an interlayered sandstone and rusty siltstone unit 10 metres thick, which occurs near the top of the section, Block B consists of approximately 750 metres of repeating volcaniclastic units. Block C is comprised

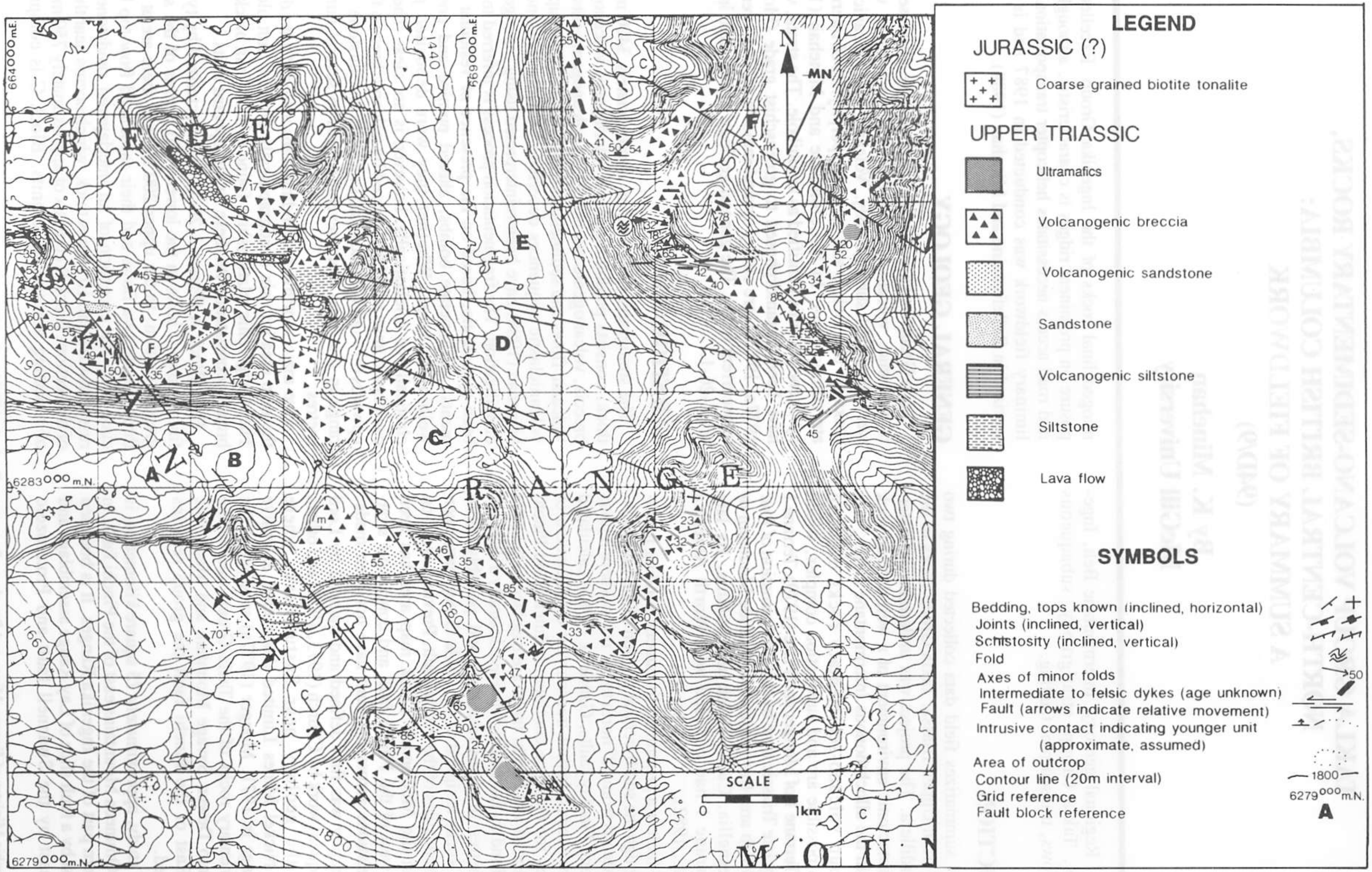


Figure 1-26-1. General geology of Takla Group rocks in the study area, north of Johanson Lake. Adapted from Bellefontaine and Minehan (1988).

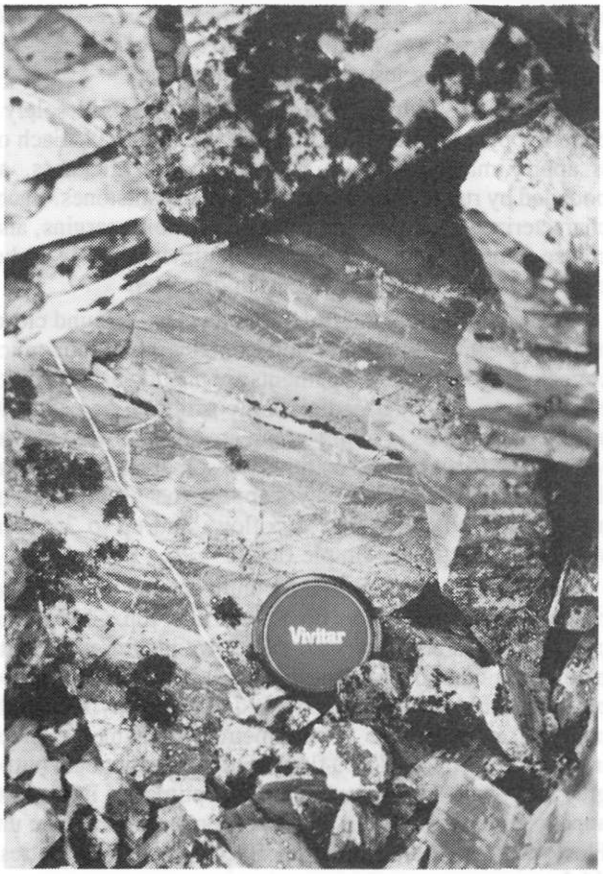


Plate 1-26-1. Typical, finely bedded and laminated green-grey volcanogenic siltstone.

Plate 1-26-2. Thin bed of volcanogenic sandstone bounded by fine crystal-rich volcanogenic breccia.

wholly of fining-upwards units with a total thickness of approximately 870 metres. Block D is anomalous in the map area, consisting largely of black, sometimes rusty, sedimentary siltstone, and composite lava flows. Minor breccia is also present. The total thickness is approximately 760 metres. Volcaniclastic units are also dominant in the 800 metres of stratigraphy exposed in Block E, but massive, black pyritic siltstone does occur near the bottom of the section. Block F is comprised of approximately 200 metres of breccia.

Small-scale soft-sediment deformation in the form of convolute folds and irregular laminations occasionally occurs in siltstone and volcanogenic siltstone units. Large-scale soft-sediment folding is found in the south-central part of the map area in an interlayered siltstone and sandstone unit.

Volcanogenic siltstone is differentiated from massive, dark grey, often rusty siltstone by its green-grey colour and close association with crystal-rich volcanogenic sandstone and breccia. It also often exhibits wavy millimetre-scale laminations of alternating dark and pale green colour, presumably reflecting alternating concentrations of plagioclase and pyroxene (Plate 1-26-1). Bed thicknesses range from several millimetres to several centimetres for volcanogenic siltstone, and up to several metres for siltstone.

Green-grey volcanogenic sandstone (Plate 1-26-2) is composed predominantly of plagioclase and pyroxene crystals. It is interlayered with volcanogenic siltstone and fine breccia in beds commonly graded and upward facing, averaging 10 centimetres in thickness, or as massive units attaining thicknesses of 115 metres. Sandstone is not a common rock type in the study area. It is usually carbonaceous and found interlayered with laminated rusty siltstones. In one locality sandstone exhibits oscillation ripple marks characterized by 20-centimetre wavelengths and 4-centimetre amplitudes, indicative of a shallow water environment.

Volcanogenic breccias are divided into two basic groups. The first group occurs at the base of fining-upward sequences and shows evidence of epiclastic processes. The breccias vary in thickness from several centimetres to a maximum of 350 metres. Recessive zones of carbonaceous matrix confined to the top of beds, or occurring as large irregular patches, are characteristic (Plate 1-26-3). The groundmass is always plagioclase and pyroxene porphyritic, and the concentration and morphology of each mineral phase often change within an individual unit. The pyroclasts include cognate lithic (juvenile magmatic) and accidental lithic fragments, and crystals (Plates 1-26-2 and 1-26-4). The phenocrystic shape in the groundmass and in cognate fragments is most commonly rounded wispy plagioclase and euhedral pyroxene. Plagioclase laths and anhedral pyroxene are rare exceptions. Phenocrysts range in size from a few millimetres to 1 centimetre.

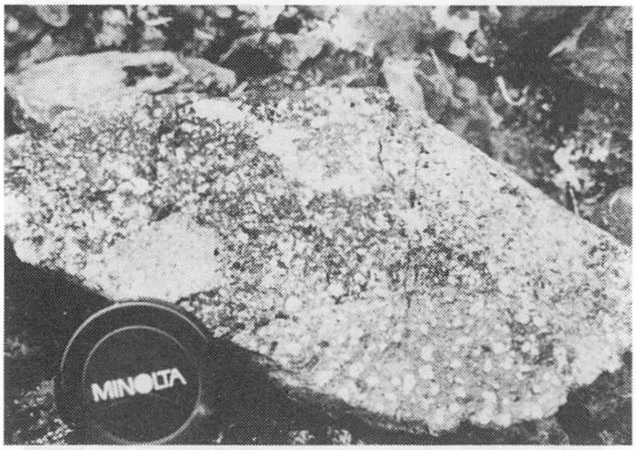


Plate 1-26-3. Recessive carbonaceous patch in polymictic volcanogenic breccia.

Plate 1-26-4. Typical, coarse-grained polymictic volcanogenic breccia. Fragments shown are of varied composition and texture.

Polymictic cognate magmatic fragments, although all of roughly intermediate composition, show some variation in composition and texture. Accidental lithic fragments are purple-grey and buff-coloured carbonate and green-grey volcanogenic siltstone. Dark red siltstone fragments, vesiculated magmatic fragments of intermediate composition, altered pumice and agglomerate bombs are rare. Fragment sizes range from a few millimetres up to 45 centimetres with the majority being less than 10 centimetres.

In Block B, four breccia units are comprised solely of euhedral pyroxene crystals in a pale green matrix. Each one is approximately 1 metre in stratigraphic thickness, and bounded by rusty, laminated volcanogenic siltstones. Each is characterized by fine-grained top and bottom margins, and a coarse centre approximately 50 centimetres thick, where crystals are up to 0.5 centimetre in diameter.

The second group, the flow-top breccias, is found closely associated with flow units and contains only monomictic cognate fragments. The fragments are plagioclase and pyroxene porphyries of intermediate composition. Fragments average 10 centimetres in diameter but are larger toward the flow tops where hyaloclastite textures are sometimes recognized. These units attain thicknesses of approximately 1 metre when associated with compound lava flows and up to 25 metres when associated with simple flows.

Lava flows are recognized by unbrecciated igneous material grading upward into a brecciated flow top. Chilled basal contacts are rarely observed. All flows identified are intermediate in composition and plagioclase and pyroxene porphyritic. Anhedral plagioclase and euhedral pyroxene phenocrysts average 2 to 3 millimetres in diameter. In one instance, a compound lava flow, containing abundant purple-grey carbonate fragments up to 50 centimetres in diameter, appears to have disrupted and incorporated a carbonate unit. Flow units, excluding flow-top breccia, average 5 metres in thickness.

INTRUSIVE ROCKS

The layered rocks are cut by abundant intermediate to felsic dykes and sills which commonly change direction drastically over short distances. They average 1 to 3 metres in thickness and usually do not have chilled margins. Green intermediate dykes are plagioclase and pyroxene porphyritic while buff-coloured felsic dykes may contain anhedral biotite, amphibole needles and quartz eyes. Phenocrysts average 0.5 centimetre in diameter but occasionally reach 2 centimetres. Crosscutting relationships between intermediate and felsic dykes demonstrate that intermediate dykes are the youngest.

Massive mafic igneous rocks outcrop in several locations. These units are dark green in colour and contain small amphibole and plagioclase phenocrysts. Grain size increases from fine to medium away from the inferred contacts, which are faulted in several cases. Although intrusive relationships are not apparent, there is no evidence for flow origin. It is possible that these mafic bodies are satellite intrusions of the Alaskan-type ultramafite which outcrops to the northeast and southwest of the map area (Tipper *et al.*, 1981).

A coarse-grained biotite-rich tonalitic pluton occurs in the southernmost part of the map area. Although the contact zone is epidote rich and highly fractured as a result of local fault movements, intrusive relationships are evident. Jurassic to Tertiary granitic plutonism has been widespread in Takla rocks (Monger, 1977a), and the tonalitic intrusion may be of similar age.

DEFORMATION

The Takla Group is cut by several major northwest-striking vertical to moderately east-dipping transcurrent faults. Numerous minor faults of various orientations and movement directions are also observed. The fault zones are characterized by closely spaced fractures, epidote alteration, pyrite and quartz veining. Serpentine alteration, native sulphur and malachite are rare. Fine-bladed crystals of yellowish green epidote are developed over widths of tens of metres, and occasionally up to 100 metres either side of fault zones. Euhedral cubic pyrite commonly 2 millimetres in diameter, but occasionally reaching up to 5 millimetres, is also common within several metres of fault zones. A shear fabric may be developed parallel to the fault. Where a shear zone deforms a porphyritic unit, the phenocrysts are extensively smeared. Major northwest-trending faults have rotated bedding, demonstrating a dextral sense of movement. Small-scale kink folding is also associated with some major faults. In Block E, minor steeply dipping reverse faults with minimum displacements of 1 metre, and their associated shear zones, occur at intervals of approximately 20 metres (Plate 1-26-5).

INTERPRETATION

Takla Group rocks in the study area are considered to be pyroclastic products of at least one highly explosive eruption. They have many characteristics compatible with formation from pyroclastic flows. However, these same characteristics are typical of high-velocity turbidity currents (Walker, 1984). They consist of monotonous upward-fining units in which all beds can be explained using the Bouma sequence.

Very little is known about the physical interaction between hot gas-supported particulate pyroclastic flows and a cold body of water, and the boundary conditions that exist between them (Cas and Wright, 1987). It is not clear whether a flow can maintain its cohesion upon entering water, or if epiclastic processes become dominant. If water is ingested through the flow front and mixed into the body of the flow, a water particulate debris flow or granular mass flow may develop (Walker, 1984). To convincingly prove that these rocks are deposits of subaqueous pyroclastic flows, a high emplacement temperature must be demonstrated.

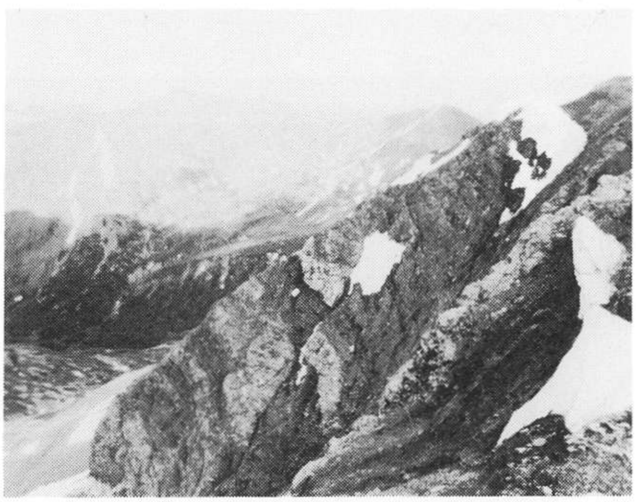


Plate 1-26-5. Steeply dipping reverse faults with minimum 1 metre displacements.

The study of facies variations within flow units may shed some light on this problem. However, the analysis and interpretation of facies and their associations are difficult in the area of study, due to the effects of diagenesis and metamorphism, and because large displacements across major transcurrent faults do not allow facies correlations between fault blocks.

Future work will involve detailed microscopic and microprobe examination to determine the exact character of the Takla rocks and whether these volcaniclastic mass-flow deposits are primary eruptive products or if epiclastic processes are involved in their deposition; geochemical studies will be done to determine their tectonic affinity.

ACKNOWLEDGMENTS

The writer is grateful to Dr. A. Hynes and K. Bellefontaine for guidance and assistance in the field and for their review of this manuscript. Northern Mountain Helicopters Limited provided logistical support and they, together with other geological field parties working in the area, contributed invaluably to our success and well-being during the two seasons of study. The fieldwork was supported by a Natural Sciences and Engineering Research Council grant to A. Hynes, as well as by a grant from the British Columbia Geoscience Research Grant Program, Ministry of Energy, Mines and Petroleum Resources.

REFERENCES

Bellefontaine, K. and Minehan, K. (1988): Summary of Fieldwork in the Ingenika Range, North-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 195-198.

Cas, R.A.F. and Wright, J.V. (1987): Volcanic Successions, Modern and Ancient, *Allen and Unwin Limited*, London.

Church, B.N. (1973): Geology of the Sustut Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration and Mining in British Columbia, pages 411-455.

——— (1974): Geology of the Sustut Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration and Mining in British Columbia, pages 305-310.

Gabrielse, H. (1985): Major Dextral Transcurrent Displacements along the Northern Rocky Mountain Trench and Related Lineaments in North-central British Columbia, *Geological Society of America*, Bulletin, Volume 96, pages 1-14.

Lord, C.S. (1948): McConnell Creek Map-area, Cassiar District, British Columbia, *Geological Survey of Canada*, Memoir 251, 72 pages.

Monger, J.W.H. (1977a): The Triassic Takla Group in McConnell Creek Map-area, North-central British Columbia, *Geological Survey of Canada*, Paper 76-29, 45 pages.

——— (1977b): Revised Stratigraphy of the Takla Group, North-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 14, pages 318-326.

Monger, J.W.H. and Price, R.A. (1979): Geodynamic Evolution of the Canadian Cordillera – Progress and Problems, *Canadian Journal of Earth Sciences*, Volume 16, pages 770-791.

Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J. (1982): Tectonic Accretion and the Origin of the Two Major Metamorphic and Plutonic Welts in the Canadian Cordillera, *Geology*, Volume 10, pages 70-75.

Tipper, H.W., Woodsworth, G.J. and Gabrielse, H. (1981): Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America, *Geological Survey of Canada*.

Walker, R.G. (1984): Turbidites and Associated Coarse Clastic Deposits, *in* Facies Models, Geoscience Canada, Reprint Series 1, *Geological Association of Canada*, 317 pages.

VOLCANIC CENTRES IN THE STEWART COMPLEX (103P AND 104A, B)

By D.J. Alldrick

KEYWORDS: Regional geology, Stewart complex, volcanic centres, Hazelton Group, Stuhini Group, Bowser Lake Group.

INTRODUCTION

Upper Triassic to Lower Jurassic volcanic sequences surround and underlie sedimentary rocks of the Middle Jurassic Bowser Lake Group in central British Columbia. The large lobe of Lower Jurassic strata exposed along the western edge of the Bowser Basin (Figure 1-27-1) has been termed the Stewart complex (Grove, 1986).

The Stewart complex is well known as the setting for the Iskut, Sulphurets, Stewart and Kitsault (Alice Arm) gold-silver mining camps. Several camp-scale mapping programs have been undertaken since 1911 and Hanson (1929, 1935) mapped the southern part of the district during the 1920s and 30s. The first mapping and compilation study of the entire region was completed between 1965 and 1968 by E.W. Grove (1986) who presented a composite stratigraphic column and discussed correlation problems created by facies changes.

This report presents a reconstruction of the Upper Triassic and Lower Jurassic stratigraphy and paleotopography within the Stewart complex, based on fieldwork started in 1982. The interpretations are derived from a study of facies variations along strike, calculations of stratigraphic thicknesses and a review of modern analogues in volcanic arc environments (Figure 1-27-2). The coloured geological maps in Grove's 1986 bulletin are good location maps for topographic features mentioned in this report.

STRATIGRAPHY

Nomenclature for early to middle Mesozoic strata in northwest British Columbia is evolving. Differing formational subdivisions within the Hazelton Group have been proposed by Tipper and Richards (1976), Grove (1986), Thomson *et al.* (1986), Thorkelson (1988) and Diakow (in preparation). Anderson (personal communication, 1988) suggested stratigraphic division into four regionally extensive groups while retaining locally defined formation names wherever practical. Proposed formational and group names for the Stewart complex are presented in Table 1-27-1, together with a brief summary of characteristic lithologic features.

FACIES RELATIONSHIPS

The significance of facies changes within volcanic and sedimentary rocks of andesitic stratovolcanoes has been reviewed by Williams and McBirney (1979), Moore and Morton (1982), Ayres (1982), MacKay School of Mines (1983), Easton and Easton (1984), Fisher and Schmincke (1984), Kokelaar and Howells (1984), Wood and Wallace (1986), and Cas and Wright (1987). In particular, Fisher and Schmincke, Wood and Wallace, and Cas and Wright provide tables of diagnostic criteria. Facies indicators used in this study are discussed in the following sections, and the paleotopographic reconstructions are presented in Figures 1-27-3, 4 and 5.

VENT FACIES (CENTRAL FACIES)

The only vent-facies rocks identified within the Stewart complex are located on the west edge of the Mount Dilworth snowfield. Vent facies include very coarse angular megabreccias (Plate 1-27-1), and an accumulation of milled boulders of fallback breccia (Plate 1-27-2) in close association along strike. These breccia textures are displayed within the Premier Porphyry feldspar-hornblende crystal tuffs that are the extrusive equivalent of Premier Porphyry dykes which cut the underlying rocks.

PROXIMAL FACIES

Diagnostic features of the proximal volcanic facies have been identified in four widely separated areas within the complex and occur in the Stuhini Group and are coincident in the Unuk River, Betty Creek and Mount Dilworth formations of the Hazelton Group, indicating the Lower Jurassic extrusive centres were relatively long-lived (2 to 3 million years).

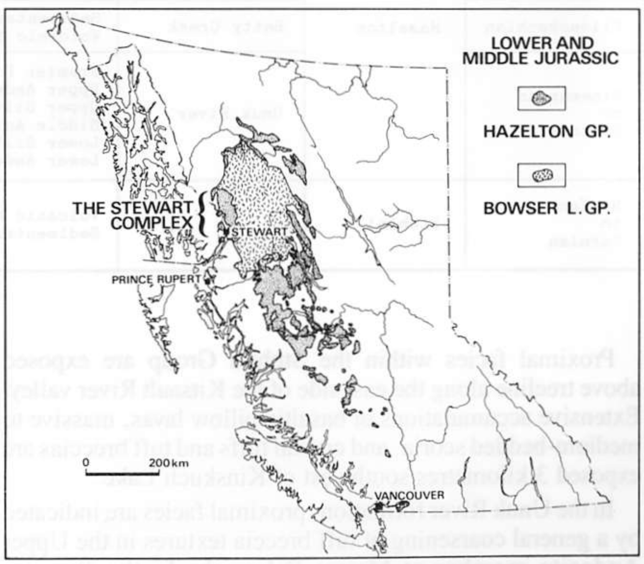


Figure 1-27-1. Distribution of the Hazelton Group in British Columbia.

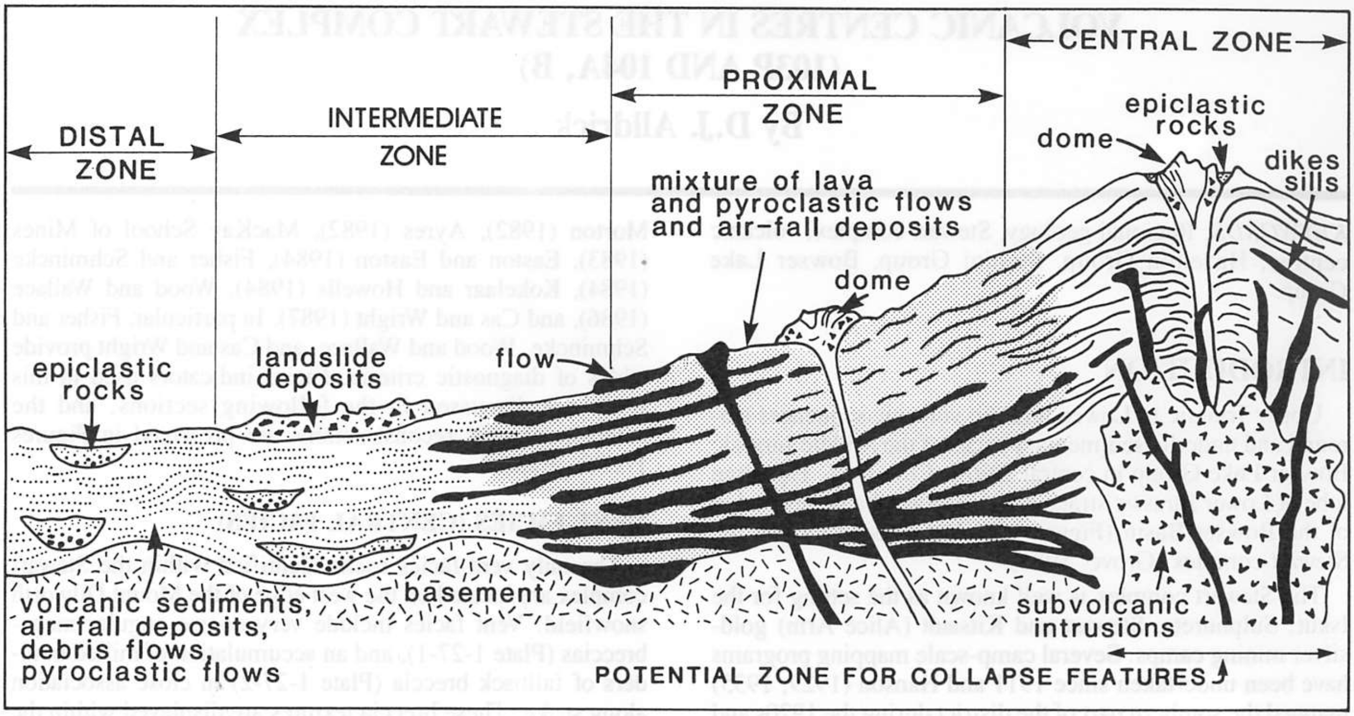


Figure 1-27-2. Facies variation in a stratovolcano (modified from Williams and McBirney, 1979).

TABLE 1-27-1. FORMATIONS.

AGE	GROUPS	FORMATIONS	MEMBERS	LITHOLOGIES
Bathonian	Bowser Lake	Ashman	Main Sequence Basal Conglomerate	Turbidites, wackes, intraformational conglomerates Chert pebble conglomerates
Bajocian to Toarcian	Spatsizi(?)	Salmon River	Pyjama Beds Basal Limestone	Thin bedded, alternating siltstones and mudstones Gritty, fossiliferous limestone
Toarcian		Mount Dilworth	Upper Lapilli Tuff Middle Welded Tuff Lower Dust Tuff	Dacitic lapilli tuff with flow-banded clasts Dacitic welded ash flow and lappilli tuff Dacitic dust tuff
Pliensbachian	Hazelton	Betty Creek	Sedimentary Members Volcanic Members	Hematitic volcaniclastic sediments,and turbidites Andesitic to dacitic tuffs and flows
Sinemurian to Hettangian(?)		Unuk River	Premier Porphyry Upper Andesite Upper Siltstone Middle Andesite Lower Siltstone Lower Andesite	Two feldspar + hornblende porphyritic tuffs Massive tuffs with local volcaniclastic sediments Turbidites, minor limestones Massive tuffs and minor volcaniclastic sediments Turbidites Massive to bedded ash tuffs
Norian to Carnian	Stuhini		Volcanic Members Sedimentary Members	Pyroxene porphyry flows and tuffs Turbidites, limestones, conglomerates

Proximal facies within the Stuhini Group are exposed above treeline along the east side of the Kitsault River valley. Extensive accumulations of basaltic pillow lavas, massive to medium-bedded scoria, and crystal tuffs and tuff breccias are exposed 3 kilometres southwest of Kinskuch Lake.

In the Unuk River formation, proximal facies are indicated by a general coarsening of tuff breccia textures in the Upper Andesite member at Mount Dilworth. In the Premier Porphyry member, thick blankets of rhythmically bedded, thinly laminated to thin-bedded airfall crystal tuffs crop out along the south side of Brucejack Lake (Plate 1-27-3), on the upper west slope of Troy Ridge, and eastward (uphill) of the Premier minesite (Plate 1-27-4). These latter units are locally welded and may display columnar jointing. In one exposure bomb sags are preserved within bedded crystal tuff of the Premier Porphyry member (Plate 1-27-5).

Proximal facies in the Betty Creek formation are indicated by wedging out of sedimentary units toward paleotopographic highs, the presence of columnar-jointed dacitic ash-flow tuff units, and preservation of extensive pillow lava units. Smaller scale proximal indicators include accumulations of accretionary lapilli (Plate 1-27-6) and armoured lapilli (Plate 1-27-7). Proximal base-surge dune forms provide directional indicators (Plate 1-27-8).

Plate 1-27-1. Monolithic megabreccia of blocks of potassium feldspar megacrystic lava in similar crystal tuff. West edge of Mount Dilworth snowfield.

Plate 1-27-2. Vent-facies fallback breccia of milled boulders of Premier porphyry in similar matrix material. Outcrop 150 metres north of Plate 1-27-1.

Within the Mount Dilworth formation, proximal facies in the middle member are indicated by fiammé-rich welded ash flows with well-preserved cooling units. In the upper member, delicately swirled flow-banded dacitic bombs and spatter show progressive coarsening along strike toward a vent. Base-surge dunes occur locally near Mount Dilworth. Pale bluish grey chalcedonic veins which cut the upper member may have been deposited from heated fluids moving up and away from the welded middle member.

INTERMEDIATE FACIES

In the Stewart complex diagnostic features of the transitional or intermediate facies include: zones of lateral facies change from strongly welded to weakly welded ash flows (that is, the disappearance of fiammé along strike), roughly equal proportions of sediments and tuffs, rapid thickening of epiclastic sedimentary wedges along strike, predominance of fine lapilli tuffs and ash tuffs, and the presence of minor lenses of pillow lava with limited strike extent.

DISTAL FACIES

Distal volcanic facies indicators within the Stewart complex include a predominance of thin-bedded turbidite sequences with minor limestones, waterlain dust-tuff beds, and local pillow-breccia beds and mature heterolithic conglomerates. All these features are well displayed in both Upper Triassic and Lower Jurassic strata in the McTagg Creek area and along the Johnstone Icefield to the north. This region at the north of the Sulphurets map sheet records either a major gap between centres along an arc, or the fore-arc or back-arc sedimentary basin. A similar, perhaps less distant, basin is suggested by the thick succession of sedimentary rocks with minor interbedded tuffs in the vicinity of the 4-Js mineral prospect west of Heel Lake.

SUBAERIAL VERSUS SUBAQUEOUS FACIES

A distinction between subaerial and subaqueous depositional environments places important constraints on genetic models for mineral deposits and therefore on exploration strategies. Together with trace element studies and lead isotope data, facies analysis can help distinguish between island arc and continental margin tectonic settings for ancient stratovolcanoes.

In the Late Triassic Stuhini Group, the abundance of major carbonate units, thick sections of turbiditic sediments and characteristic pillow lavas all indicate a subaqueous environment.

Rocks of the Hazelton Group include both subaerial and submarine facies. Abundant small-scale interbeds of turbidites and limestone clearly indicate the Unuk River formation andesites are subaqueous where they are exposed in the Kitsault and Sulphurets areas. The absence of interbedded limestones and turbidites in the Stewart area, together with the presence of minor hematitic epiclastic conglomerate lenses, suggests the formation may have accummulated above the wave base in the Mount Dilworth – Premier area. The Betty Creek formation is dominantly subaerial in character but facies are alternately subaerial and subaqueous in the Brucejack Lake area and entirely subaqueous further north and west. The Mount Dilworth formation is predominantly subaerial in character but it may have been deposited subaqueously in its most northerly exposures.

STRATIGRAPHIC THICKNESS

Study of stratigraphic thickness variations for the whole thickness of the Hazelton Group did not help delineate volcanic centres, probably because rapid erosion levelled many of the volcanic edifices. Careful documentation of the stratigraphic thickness of individual formations indicates striking changes; thinner formations are most useful because they are more easily traced through complications from folding and faulting.

ANDESITIC STRATOVOLCANOES (REGIONAL BASINWARD THINNING)

The thickness of the Unuk River formation varies from a maximum of 4500 metres in the Stewart area to as little as 500 metres in parts of the Kitsault valley. The Kitsault valley section is interpreted as an intermediate facies because of the overall formational thinning, the increased proportion of interbedded subaqueous sediments (both turbidites and lime-

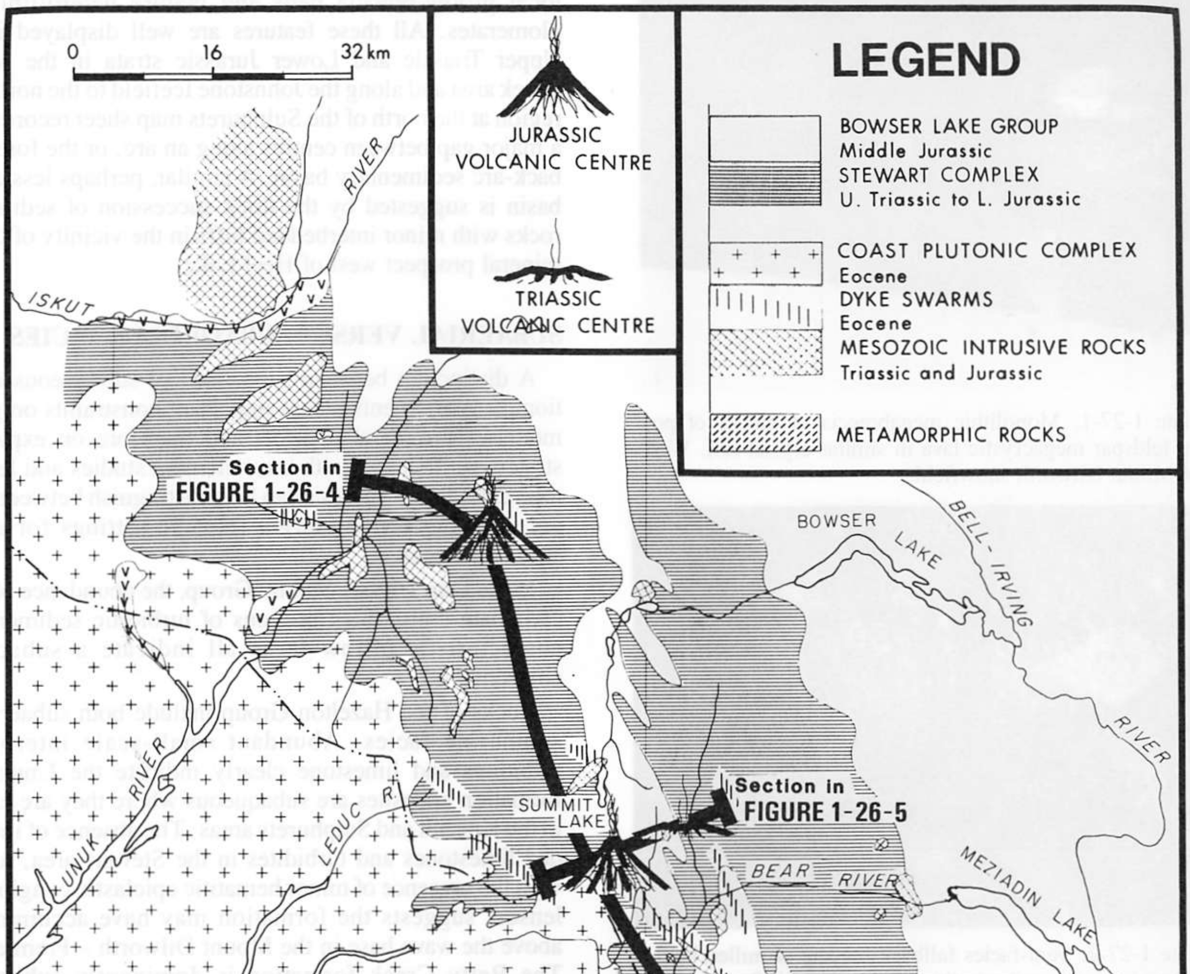


Figure 1-27-3. Distribution of the Stewart complex showing the locations of section lines for Figures 1-27-4 and 1-27-5.

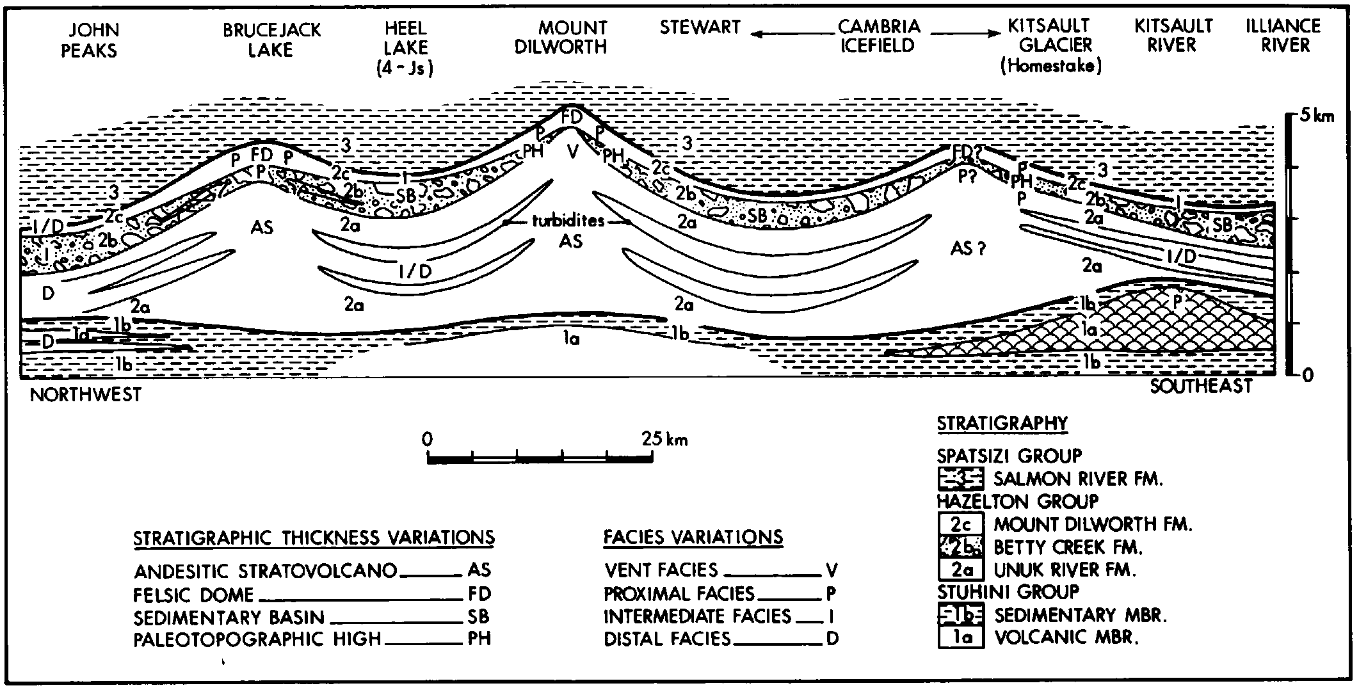


Figure 1-27-4. North-south schematic reconstruction through the Stewart complex.

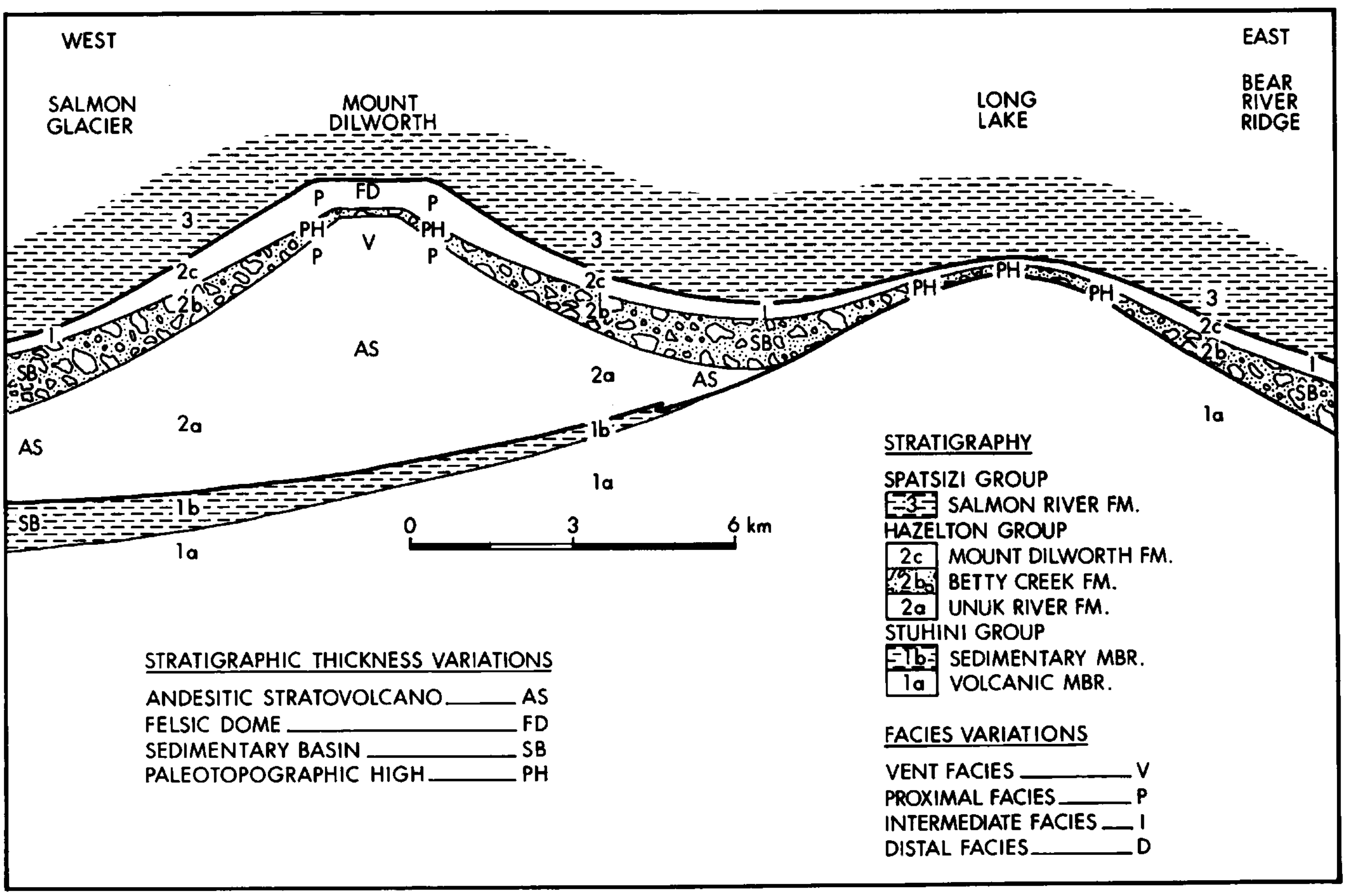
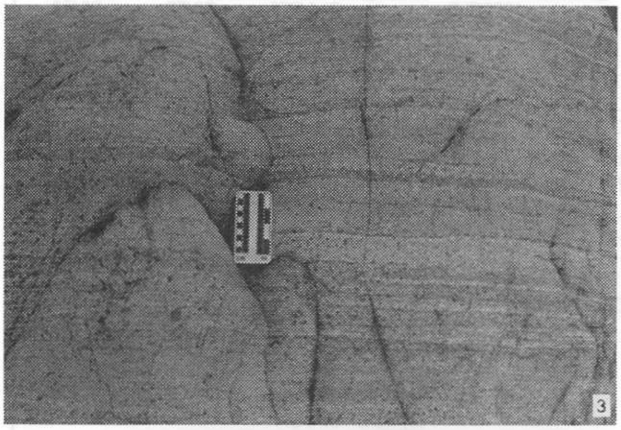
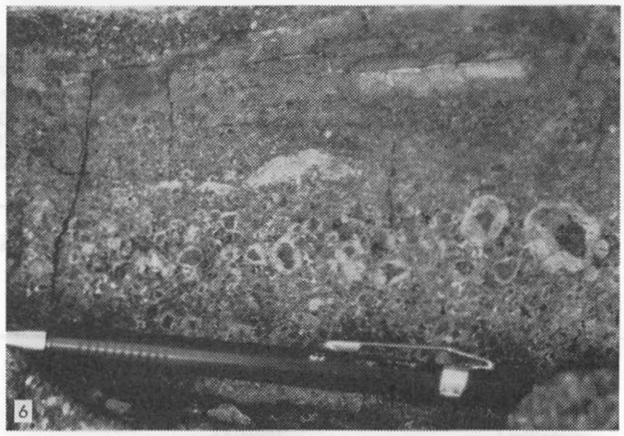


Figure 1-27-5. West-east schematic reconstruction through the Stewart complex.





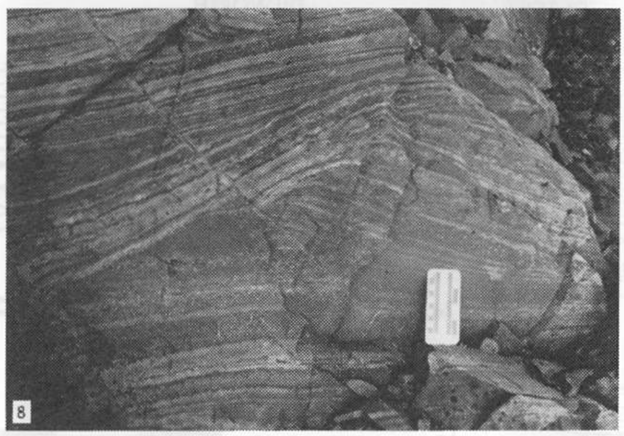


Plate 1-27-3. Thin-bedded, rhythmically bedded, airfall plagioclase crystal tuff. Premier porphyry member. Outcrop 150 metres southeast of Brucejack Lake.

Plate 1-27-4. Thin-bedded, welded, airfall plagioclase crystal tuff. Note single larger potassium feldspar crystal. Premier Porphyry member. Outcrop to the east and uphill from Premier open pit.

Plate 1-27-5. Bomb sag in well-bedded potassium feldspar megacrystic, airfall plagioclase crystal tuff. Premier Porphyry member. Outcrop 200 metres east-southeast of Brucejack Lake.

Plate 1-27-6. Graded bed of fine accretionary lapilli and armoured lapilli, Betty Creek formation. Outcrop 600 metres east of Iron Cap mineral prospect, at snowline.

Plate 1-27-7. Armoured lapilli in lahar deposit, Betty Creek formation. Outcrop 250 metres north of the toe of Bruce Glacier.

Plate 1-27-8. Base-surge dune form in thin-bedded airfall ash tuff indicates blast direction was from left (north). Outcrop 4 metres above Plate 1-27-6.

stones), and a general decrease in lapilli size to fine lapilli. Sediment-hosted, stratabound mineral deposits in the Kitsault area (for example, Kit, MINFILE 103P 245) are similar to those associated with flank deposits on island arc volcanoes in the southwest Pacific.

FELSIC DOMES (LOCAL BASINWARD THINNING)

The Mount Dilworth formation ranges in thickness from 20 metres up to 200 metres. In contrast to the Betty Creek formation, Mount Dilworth strata seem to thicken progressively toward areas of proximal facies that are interpreted as paleotopographic highs. This distribution can be attributed to the highly viscous nature of most felsic flows and some welded tuffs.

SEDIMENTARY BASINS (REGIONAL BASINWARD THICKENING)

The Betty Creek formation shows spectacular thickness changes over relatively short strike lengths. Between Mount Dilworth and the west slope of Mitre Mountain thickness increases from 4 to 1200 metres and further north may be even greater. This is interpreted as a progressively basinward-thickening wedge on the flanks of a volcanic cone.

PALEOTOPOGRAPHIC HIGHS (LOCAL THINNING OF SEDIMENTARY UNITS)

Paleotopographic highs can be interpreted from a combination of features, but are mainly recognized as a consequence of stratigraphic thinning in sedimentary rocks. This is a useful concept in situations where, for example, wedging out of sedimentary strata indicates a proximal setting but there are no proximal or vent facies in the associated volcanic strata. Such a situation occurs at the north end of Long Lake, where a large outcrop area of massive augite porphyry is draped by a thin veneer of Betty Creek conglomerates and sandstones that thicken progressively southward (Figure 1-27-5; Dupas, 1985).

DISCUSSION

Upper Triassic volcanic centres were probably developed within the Stewart complex but are not well exposed or preserved. The massive augite porphyry exposure at the north end of Long Lake is a paleotopographic high that may represent one such centre. Extensive exposures of proximal to intermediate facies augite porphyry flows and bedded crystal tuffs in the Kitsault valley suggest that systematic mapping within the unit would locate another Upper Triassic extrusive centre in that area. Reported pillowed augite porphyry flows just east of the Granduc mine (P. McGuigan, personal communication, 1984) indicate another area which needs further study. The Upper Triassic centres are not coincident with those of Early Jurassic age, although the Long Lake and Mount Dilworth vents are close together.

Lower Jurassic volcanic centres in the Unuk River formation are located in the Big Missouri–Premier area, in the Brucejack Lake area, and may exist along the southwest edge of the Cambria Icefield, northwest of the Kitsault Glacier and the Homestake mineral prospect. West and northwest of Brucejack Lake this formation shales-out into a major basin of distal sediments. A smaller sedimentary basin is exposed in the area around the 4-Js mineral prospect to the southeast.

Volcanic centres within the Lower Jurassic Betty Creek formation seem more diffuse, possibly indicating a long history of eruption or a distribution of facies controlled by Unuk River formation topography. One vent area is near the Mitchell Glacier and additional centres possibly occur near the toe of the Knipple Glacier and at the northeast end of Kinskuch Lake.

Volcanic centres are well documented in the Mount Dilworth formation; on Mount Dilworth, in the Mitchell Glacier area, and near the west side of the Kitsault Glacier.

Several large areas within the Stewart complex remain unmapped, thus there are no data on the location of other volcanic centres around the perimeter of the Cambria Icefield and further to the east, in the large region around the Todd Icefield and in the entire area west of Snippaker Creek. Within the published map sheets, two areas that have not been examined in detail are the southeastern part of the Kitsault map area along the Illiance River and a region within the Sulphurets map area along the east side of the Frankmackie Icefield.

CONCLUSIONS

Regional mapping has delineated three volcanic centres in Lower Jurassic strata and two probable vent areas in Upper Triassic rocks of the Stewart complex. There is a spatial coincidence between volcanic centres throughout Early Jurassic time that cannot be extended back to Late Triassic time. This suggests there may have been a common magma chamber and vent for Lower Jurassic volcanic rocks in different formations and a fixed subvolcanic heat source over a prolonged period in the Early Jurassic.

The two longest-lived Early Jurassic centres, Brucejack Lake–Mitchell Glacier and Mount Dilworth–Premier, coincide with major gold-silver deposits and dozens of precious metal prospects. This coincidence of mineralization and major eruptive centres is real, not a factor of more detailed mapping within the mineralized areas. A similar correlation of mineral deposits with stratovolcanoes in arc environments has been recognized in the southwest Pacific (Figure 1-27-6).

RECOMMENDATIONS

Four additional tests of this correlation between mineralization and eruptive centres would be:

- a study of stratigraphy and facies relationships around the well-mineralized Illiance River valley,
- a similar program in the Todd Icefield area,
- an investigation of the prediction that a volcanic centre (with associated mineralization?) must lie somewhere to the northwest of the Homestake prospect, and
- a mapping program in the richly mineralized Iskut River–Snippaker Creek area.

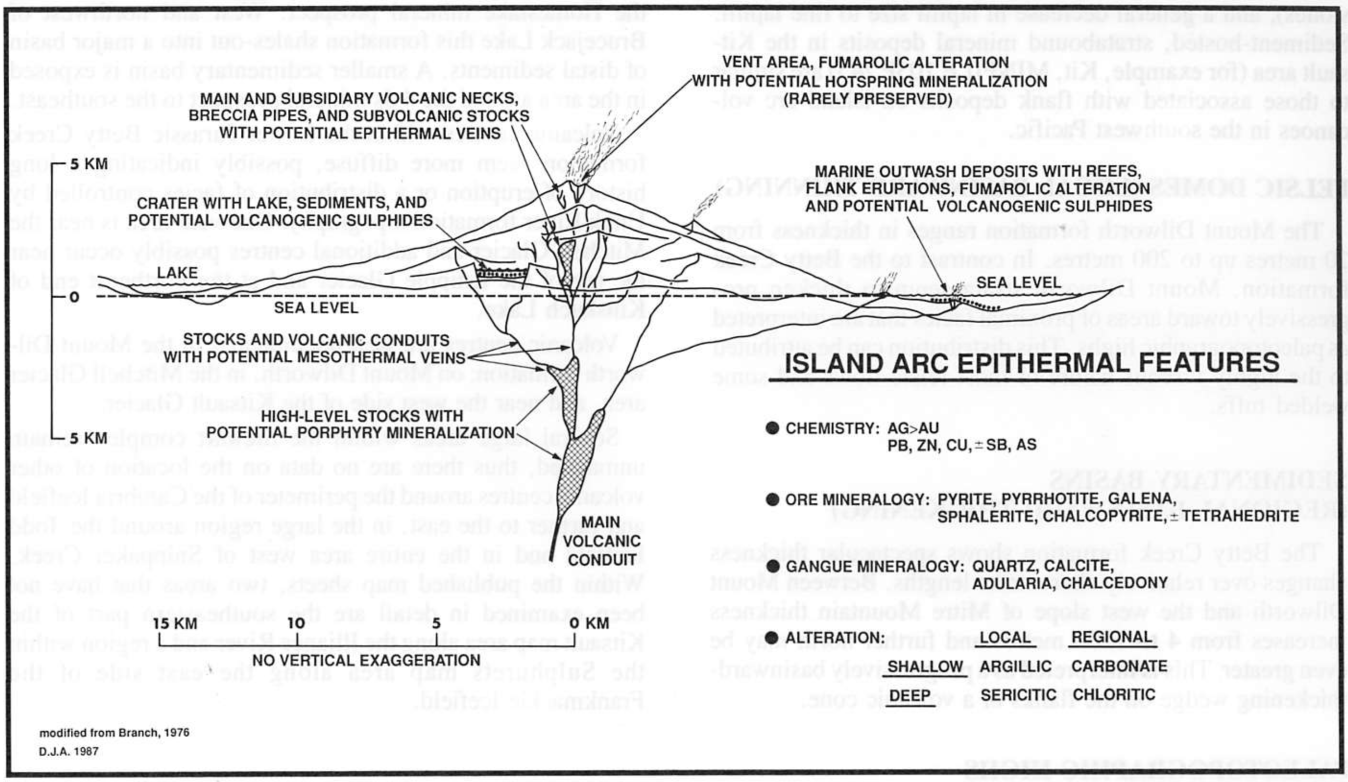


Figure 1-27-6. Distribution of ore deposits within a stratovolcano (modified from Branch, 1976).

REFERENCES

Ayres, L.D., Editor (1982): Pyroclastic Volcanism and Deposits of Cenozoic Intermediate to Felsic Volcanic Islands, *Geological Association of Canada*, Short Course Notes, Volume 2, 365 pages.

Cas, R.A.F. and Wright, J.V. (1987): Volcanic Successions – Modern and Ancient, *Allen and Unwin*, 528 pages.

Diakow, L.J. (in preparation): Geology of the Toodoggone Volcanics, Unpublished Ph.D. Thesis, *University of Western Ontario*.

Dupas, J.P. (1985): Geology of the Spider Claim Group on Long Lake (104A/4), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 308-315.

Easton, R.M. and Easton, M.G., Editors (1984): Growth and Evolution of Volcanic Edifices, *Geological Association of Canada*, Short Course Notes, Volume 4, 200 pages.

Fisher, R.V. and Schmincke, H.U. (1984): Pyroclastic Rocks, *Springer-Verlag*, 472 pages.

Grove, E.W. (1986): Geology and Mineral Deposits of the Unuk River – Salmon River – Anyox Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 63, 152 pages.

Hanson, G. (1929): Bear River and Stewart Map Areas, Cassiar District, British Columbia, *Geological Survey of Canada*, Memoir 159, 84 pages.

——— (1935): Portland Canal Area, British Columbia, *Geological Survey of Canada*, Memoir 175, 179 pages.

Kokelaar, B.P. and Howells, M.F., Editors (1984): Marginal Basin Geology, *The Geological Society*, Special Publication Number 16, 322 pages.

MacKay School of Mines (1983): Volcanic Rocks and Their Vent Areas, *MacKay School of Mines*, Short Course Notes.

Moore, J.M. and Morton, R.L. (1982): Physical Volcanology Applied to Metavolcanic Rocks, *Carleton University*, Short Course Notes.

Thomson, R.C., Smith, P.L. and Tipper, H.W. (1986): Lower to Middle Jurassic (Pliensbachian to Bajocian) Stratigraphy of the Northern Spatsizi Area, North-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, pages 1963-1973.

Thorkelson, D.J. (1988): Jurassic and Triassic Volcanic and Sedimentary Rocks in Spatsizi Map Area, North-central British Columbia, *in* Current Research, Part E, *Geological Survey of Canada*, Paper 88-1E, pages 43-48.

Tipper, H.W. and Richards, T.A. (1976): Jurassic Stratigraphy and History of North-central British Columbia, *Geological Survey of Canada*, Bulletin 270, 73 pages.

Williams, H., and McBirney, A.R. (1979): Volcanology, *Freeman, Cooper and Co.*, 397 pages.

Wood, J. and Wallace, H., Editors (1986): Volcanology and Mineral Deposits, *Ontario Geological Survey*, Miscellaneous Paper 129, 183 pages.

UNUK MAP AREA
(104B/7E, 8W, 9W, 10E)

By J.M. Britton, I.C.L. Webster and D.J. Alldrick

KEYWORDS: Regional geology, Stuhini Group, Hazelton Group, Iskut, Unuk, Sulphurets, polymetallic sulphides, nickel, platinum group, copper-iron skarn, gold-silver veins, porphyry copper-molybdenum, Regional Geochemical Survey.

INTRODUCTION

This report describes preliminary results of regional geological mapping in the Unuk River valley as part of the Iskut-Sulphurets project, a multi-year study of the mineral deposits in this newly emerging gold belt (Figure 1-28-1). The project commenced in 1987 in the Sulphurets map area (Britton and Alldrick, 1988). Its goals are:

- to define regional stratigraphy and structure,
- to produce 1:50 000 and 1:20 000-scale geological maps,
- to document mineral occurrences, and
- to develop genetic models of mineralization.

The Unuk map area is roughly centred on the confluence of the north and south forks of the Unuk River and comprises 1250 square kilometres of northern rain forest, sub-alpine plateaus and glacier-clad peaks. Access is by helicopter from Stewart, 70 kilometres to the southeast. One airstrip for fixed-wing aircraft was built in the 1960s on upper Snippaker Creek and float planes have been landing at Tom MacKay Lake since the 1930s. Elevations range from 100 metres to 2500 metres above sea level. About 25 per cent of the area is covered with permanent ice and snow. Valleys are steep-sided and U-shaped. Vegetation below treeline is a dense mixture of alpine fir, spruce and hemlock with slide alder, stinging nettles and devil's club in local profusion. Winter arrives early and stays late; temperatures are not severe but

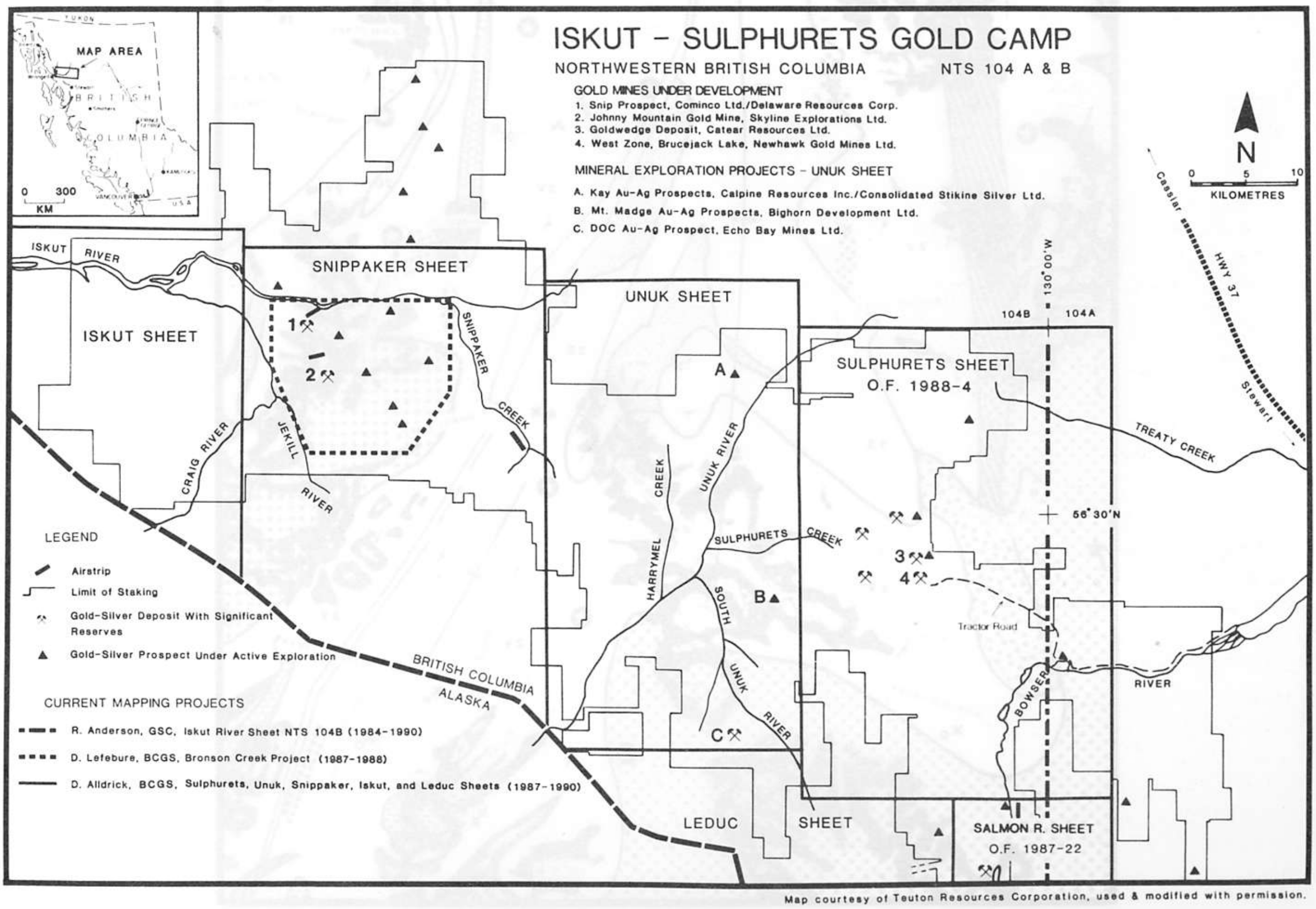


Figure 1-28-1. Iskut-Sulphurets gold camp: precious metal deposits and current mapping projects.

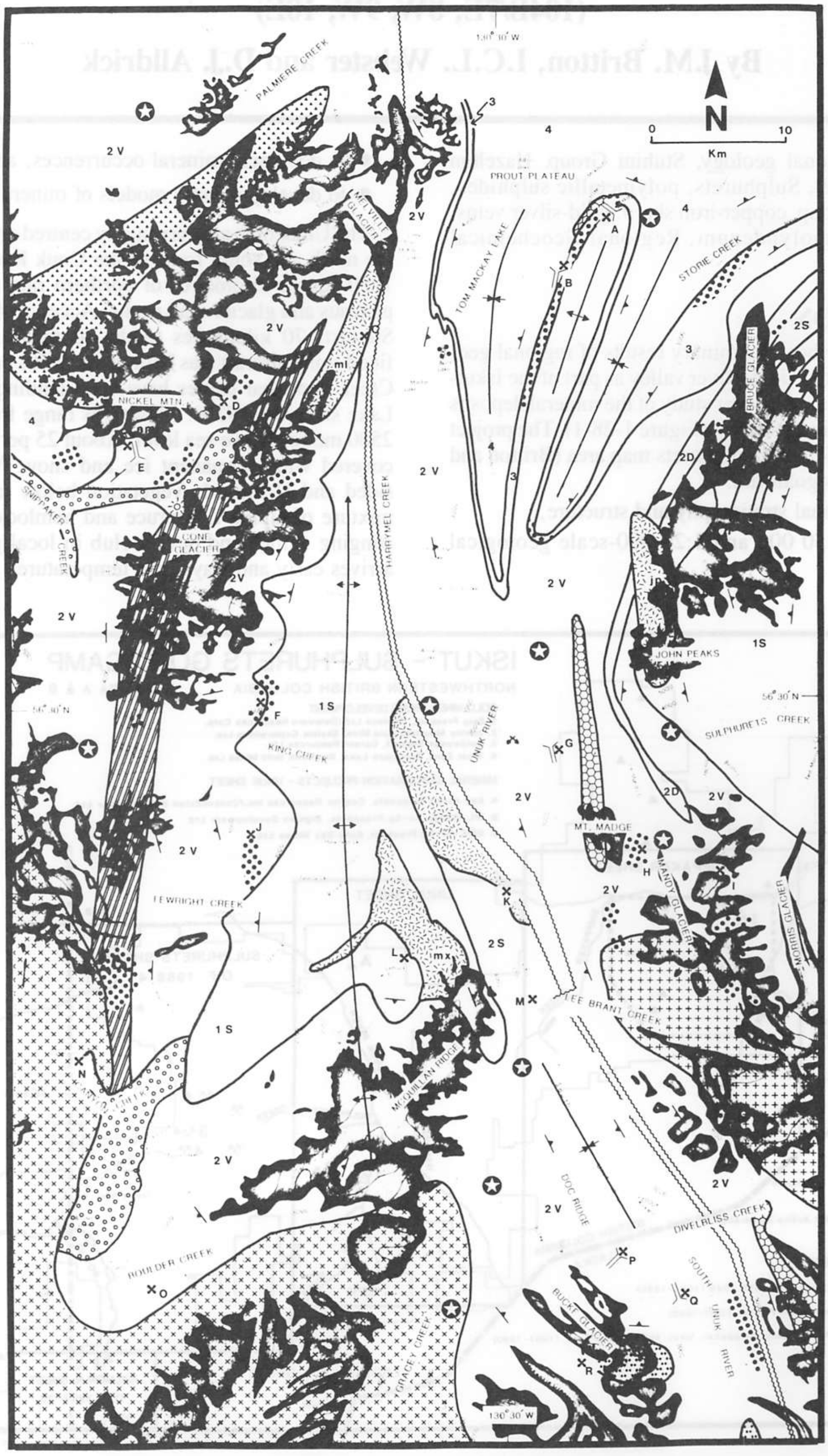


Figure 1-28-2. Geology and mineral deposits, Unuk map area.

LEGEND

INTRUSIVE ROCKS

Age	Unit
Eocene	King Creek Dyke Swarm
Eocene	Coast Plutonic Complex
Eocene	Lee Brant Stock
Jurassic	Lehto Porphyry
L Jurassic to U Triassic	Diorite and Gabbro: Nickel Mountain (nm), John Peaks (jp), Melville (mv), Max (mx)
U Triassic	Meta-quartz-diorite

STRATIFIED ROCKS

Age	Unit	Description
Recent to Pleistocene		Basalt Flows and Tephra
M Jurassic	4	Marine-basin Turbidites
L Jurassic	3	Felsic Pyroclastics
L Jurassic	2 D V S	D = Dacite Marker V = Andesitic Volcanics (with <40% sediments) S = Sediments (with <40% volcanics)
U Triassic	1 V S	

SYMBOLS

Compositional layering (bedding; foliation)

Contact

Anticline; syncline

Harrymel-South Unuk shear

Pillow lavas

Recent volcanic vent

Gossan

Adit

Stream sediment gold values >90th percentile

Mineral occurrence .... $\times_R$

Placer occurrence

MINERAL OCCURENCES

	NAME	COMMODITY
A	Emma	Au,Ag,Pb,Zn,Cu
B	MacKay	Au,Ag,Pb,Zn,Cu
C	Copper King	Cu,Fe
D	Colagh	Cu
E	E&L Nickel	Ni,Cu
F	Cole	Cu,Au,Ag
G	Cumberland/Daly	Au,Ag
H	Mt. Madge (C-10)	Au,Ag,Zn
I	Mt. Madge (GFJ)	Au,Ag,Cu,Zn
J	VV	Cu,Mo,Au,Ag
K	Chris & Anne	Cu,Fe
L	Max	Fe,Cu
M	Unuk Jumbo	Fe,Cu
N	Black Bear	Au,Pb,Zn
O	Boulder Creek	Pb,Zn,Au,Cu
P	Doc	Au,Ag,Pb,Cu
Q	Globe	Au,Ag,Pb,Cu
R	Alf	Au,Ag

snowfall is heavy, beginning soon after Labour Day at higher elevations. Summers are cool and wet.

PREVIOUS AND CURRENT WORK

The pioneering work of Forrest Kerr in the 1920s (Kerr, 1948) approaches the western boundary of the map area but earliest geological coverage was published in 1957 by the Geological Survey of Canada as part of Operation Stikine. E.W. Grove (1971, 1986) mapped the entire area between 1964 and 1970 incorporating geological mapping done by Newmont Mines Limited between 1959 and 1962. Thesis studies include work by R.H. Seraphim (1948) on the Halport (now Doc) vein, D.A. Donnelly (1976) on the Kay claims, and M.H. Gunning (1986) on the stratigraphy and structure of the Prout Plateau area. J.A. Fillipone of The University of British Columbia is presently conducting a structural study of deformed areas adjacent to the Coast plutonic complex, including an area along the South Unuk River. Other sources of information include annual reports of the Minister of Mines, assessment reports and the Ministry's property file.

The whole of NTS 104B is currently being mapped by R.G. Anderson of the Geological Survey of Canada (Anderson, 1989). The results of a regional stream sediment sampling program conducted over this area in 1987 were released in July, 1988 (National Geochemical Reconnaissance, 1988). A synthetic aperture radar (SAR) survey proposed by the province has been completed by the Canada Centre for Remote Sensing, Energy, Mines and Resources Canada, to outline major structures in the Iskut-Sulphurets gold belt.

Fieldwork was conducted from July 4 to September 14, 1988. Traverse data were recorded on 1:15 000 airphoto enlargements and compiled on 1:20 000 and 1:50 000 base maps.

EXPLORATION HISTORY

Placer gold has been prospected on the Unuk River and its tributaries since the 1880s (Wright, 1907) and was worked on Sulphurets Creek near its confluence with the Unuk River as early as 1895. No production was recorded. Earliest hard-rock mining ventures include small adits driven into gold-silver-lead veins at the Globe and Cumberland/Daly prospects around the turn of the century. In 1932, silver and gold-bearing lead-zinc-copper deposits were found east of Tom MacKay Lake and have been explored intermittently ever since. In 1946 the late Tom McQuillan discovered the Halport (now Doc) gold-silver quartz vein along the south fork of the Unuk River. Increased exploration in the wake of the Granduc discovery in 1953 located the E & L nickel-copper deposit in 1958 and the Max copper-iron skarn deposit in 1960. The push for porphyry-style mineralization resulted in the discovery of copper-molybdenum deposits (Cole and VV) north and south of King Creek in the 1970s.

Unlike the Sulphurets and Iskut gold camps to the east and west, there is relatively little current exploration in the Unuk map area. The Tom MacKay Lake prospects are under investigation by Calpine Resources Incorporated. The discovery of coarse visible gold in float near Mount Madge is being followed up by Bighorn Development Corporation. Echo Bay Mines Limited optioned the Doc property in October, 1988 and began an aggressive drilling and underground exploration program (George Cross News Letter No. 196/1988).

GEOLOGIC SETTING

The map area is situated in the southern Boundary Ranges of the Coast Mountain physiographic belt. The contact between the Coast plutonic complex and the Intermontane tectonic belt traverses the southwest corner of the map area. Most of the area is in the Stikine terrane with a small area of "undivided metamorphics" in the southwest, adjacent to the Coast complex (Wheeler and McFeely, 1987).

The area is underlain by a thick (more than 5 kilometres) succession of Upper Triassic to Lower Jurassic volcano-sedimentary arc-complex lithologies capped by Middle Jurassic marine-basin sediments. Strata have been cut by a variety of plutons representing at least four intrusive episodes spanning late Triassic to Tertiary time. These include synvolcanic plugs, small stocks, dyke swarms, isolated dykes and sills, as well as the batholithic Coast plutonic complex. The stratigraphic sequence has been folded, faulted and metamorphosed mainly during Cretaceous time but some Triassic strata are polydeformed and may record an earlier deformational event. Remnants of Pleistocene to Recent basaltic flows and tephra are preserved west of the Unuk-Harrymel drainage.

STRATIGRAPHY

Reconstruction of the stratigraphy has proved an intractable task. Much of the area is underlain by thick, monotonous sequences of fine-grained andesitic tuffs, tuffaceous wackes and siltstones. The rocks have been divided into several lithostratigraphic units that form a discontinuous succession spanning Carnian to Bajocian time.

Sufficient fossil, radiometric and lithostratigraphic data exist to permit broad correlation with the main Mesozoic groups of northwestern British Columbia: Stuhini, Hazelton (including Spatsizi) and Bowser Lake. More specific correlation with formations, members or facies within these groups is not yet possible. There is no field evidence for a major hiatus or unconformity between Triassic and Jurassic strata, although local unconformities no doubt abound, given the depositional (island arc) setting of these rocks.

TRIASSIC

Triassic strata (Unit 1 and the lower part of Unit 2, Figure 1-28-2) equivalent in age to the Stuhini Group of Souther (1971) crop out northeast of John Peaks, west of Harrymel Creek and on McQuillan Ridge.

Fossil evidence suggests the oldest rocks are those on McQuillan Ridge where crushed fragments of *Halobia* (a Carnian index fossil) were found by Newmont Mines Limited (Grove, 1986). These rocks can be divided into three lithostratigraphic sequences of undetermined lateral extent. The lowest consists of thin-bedded siltstones, immature fine-grained wackes, impure limestones and andesitic tuffs that locally attain a considerable thickness. Andesitic tuffs may be laminated to massive, aphyric or hornblende-feldspar-phyric. Limestones that distinguish this unit occur as thin beds or discontinuous lenses that show extensive recrystallization and highly disrupted internal structure. Thickest lenses (up to 30 metres) are located near the confluence of Gracey Creek and South Unuk River.

The second sequence is a poorly exposed package of crudely layered and massive andesitic tuffs and flows with minor limestone lenses.

Overlying this, only on McQuillan Ridge, are green-grey and purple andesitic to dacitic pyroclastic rocks, locally distinguished by coarse (up to 1 centimetre) hornblende phenocrysts. Plagioclase and minor augite are also present as phenocrysts. These pyroclastic rocks have lithologic similarities to Hazelton volcanics of the Sulphurets map area (Alldrick and Britton, 1988) and may in fact be Lower Jurassic.

Northeast of John Peaks, Triassic rocks consist of a thick sequence, perhaps repeated by folds, of immature clastic sediments with tuffaceous interbeds and rare augite porphyry breccias. *Monotis* (a Norian index fossil) has been found near the top of this succession (Gunning, 1986). *Monotis* has also been found west of Harrymel Creek (Grove, 1986) in an area not mapped this year.

JURASSIC

Most of the Unuk map area is underlain by rocks of the Hazelton Group (Units 2 and 3, Figure 1-28-2). Strata in the east and west halves of the map area cannot be directly correlated. This is due to a structural discontinuity that traverses the map area parallel to (and east of) South Unuk River and Harrymel Creek. The structure is interpreted as a major east-dipping shear zone with normal offset, exposing different structural levels and stratigraphic sections.

On the east half of map sheet, a single, westward-facing, but locally overturned, sequence of interbedded volcanics and lesser sediments extends from Storie Creek in the north to Divelbliss Creek in the south. It attains a thickness of 1 to 2 kilometres. Local stratigraphic markers permit correlation along the section for distances of 1 to 5 kilometres.

The best stratigraphic sections are immediately north and south of John Peaks. Further south the section is obscured by the Lee Brant stock. The basal contact with Triassic strata appears to lie near the top of the thick sequence of clastic sedimentary rocks within which *Monotis* is found. Neither an angular unconformity nor a widespread conglomerate marks this lower contact. Jurassic volcanic rocks range in composition from basaltic andesite to rhyodacite; andesite and dacite, locally with columnar jointing, are the most common. On the whole, volcanic and volcaniclastic rocks are more abundant than sedimentary rocks. Limestones are rare or absent in the Lower Jurassic sections. Pillow lavas, breccias, and felsic pyroelastics, including spherulitic rhyolite, serve as markers in the John Peaks area. Another local marker is a polymictic conglomerate distinguished by very well-rounded granitic boulders, cobbles and pebbles, some of which may be derived from the Mitchell suite of monzonitic intrusions exposed to the east (Britton and Alldrick, 1988). This conglomerate occurs at several horizons over a 100 to 200-metre stratigraphic interval, possibly repeated by folding or faulting.

In the west half of the map area Lower Jurassic strata are mostly andesitic volcanics and volcaniclastics, but locally include felsic lapilli and welded tuffs, and basaltic pillow lavas. Lateral continuity of units is poor. One local marker north of Nickel Mountain is a medium to dark green fine-grained andesite with sharply angular, pink, siliceous (or silicified) clasts up to several centimetres across. South of Nickel Mountain maroon, bedded airfall tuffs with fine-grained hematitic chips indicate subaerial volcanism. These rocks are similar to the bedded maroon pyroclastics seen on McQuillan Ridge.

Lower Jurassic volcanism terminated with a thin, but regionally extensive blanket of felsic pyroclastics that include welded tuffs and rare flows (Mount Dilworth formation; Unit 3, Figure 1-28-2). These rocks are white weathering or rusty where pyritiferous. Best exposures are north of John Peaks where the unit forms a dip-slope leading down toward Storie Creek and Unuk River. Rocks include waxy, grey to white, dacitic lapilli tuffs, bedded ash tuffs and welded tuffs; layering on centimetre to metre scale is common. Based on fossil evidence elsewhere (Alldrick, 1987; Brown, 1987) these rocks are Toarcian.

On Prout Plateau, east of Tom MacKay Lake, a package of rhyolitic volcanics and volcaniclastics is host to the MacKay silver-lead-zinc prospects (Donnelly, 1976). The sequence appears to form a tight anticline-syncline pair between Unuk River and Harrymel Creek. These rocks are tentatively correlated with the Mount Dilworth formation on the basis of structural position and age. The unit sits below a thick sequence of Middle Jurassic sedimentary rocks. The age of this extensive felsic unit is bracketed by a Pliensbachian fossil below and a Bajocian fossil above (Donnelly, 1976). Evidence against correlation with Mount Dilworth is the occurrence of pillow lavas immediately above the felsic volcanics (a phenomenon not observed elsewhere in the Stewart complex at the base of Middle Jurassic sediments) and dissimilarity of rock textures east and west of the Unuk River. Prout Plateau felsic volcanics, especially those east of the MacKay prospect, are carbonaceous, black and white mottled, locally flow-banded and autobrecciated rocks, with less evidence of airfall deposition. This may simply reflect a facies variation. Alternatively these rocks may be better correlated with felsic sequences associated with pillow lavas found lower in the Jurassic succession (for example, at John Peaks).

Middle Jurassic sedimentary rocks (Unit 4; Figure 1-28-2) crop out mainly in the northeast corner of the map area, extending southwestwards along Unuk River and onto Prout Plateau. They consist of a thick sequence of thinly bedded turbiditic siltstones and fine sandstones (Salmon River formation of Grove, 1986) perhaps correlative with the Spatsizi Group (Thomson *et al.*, 1986; Brown, 1987). On Prout Plateau a distinctive arenite-conglomerate unit with black chert clasts may be correlated with the Bajocian and younger Ashman Formation of Tipper and Richards (1976).

The rock sequences seen in the field are the products of a long-lived, mostly submarine, volcanic island arc. Individual volcanic centres, marked by coarse ejecta and flows, were short-lived (1 to 2 Ma), recurring at any given location at perhaps 5 to 6 million-year intervals. Volcanic and sedimentary processes operated concurrently. Volcanic edifices were built and eroded rapidly; periods of volcanic quiescence are marked by sedimentary interbeds. Finer grained sedimentary and volcaniclastic facies accumulated at a distance from the volcanic axis in back-arc or inter-arc basins.

PLEISTOCENE AND RECENT

Pleistocene and Recent basaltic flows and tephra are preserved in Copper King, Snippaker and King creeks west of the Harrymel-Unuk drainage. One volcanic centre within the map area consists of a severely eroded mound at the toe of Cone Glacier, on which unconsolidated tephra, flows and minor pillows can be seen. Most flows occupy valley bottoms and commonly show columnar jointing. Their poor preservation suggests eruption onto or under ice. The original distribution of these rocks has been much modified by glacial retreat.

INTRUSIVE ROCKS

Stratified rocks have been intruded by a series of plutons, sills, dykes, and dyke swarms of distinctly different compositions and textures. Preliminary radiometric data indicate a range in age from Late Triassic to Eocene.

The oldest intrusion is an inclusion-rich, foliated to gneissic hornblende-biotite quartz diorite centred on Bucke Glacier. A Late Triassic zircon date (R.G. Anderson, personal communication, 1988) establishes a minimum age for the meta-andesitic tuffs that host the pluton. Contacts are not well defined due to the gneissic fabric of both plutonic and host rocks

Dioritic stocks up to 20 square kilometres in area outcrop on McQuillan Ridge and near Melville Glacier. The McQuillan Ridge stock, called the Max diorite after the copper-iron skarn deposit with which it is associated, is an irregular body that ranges in composition from quartz diorite to hornblende diorite. Rocks are mesocratic to melanocratic. Contacts are both sharp and gradational with adjacent Triassic sediments and volcanics (Grove, 1986). The pluton is mostly unfoliated.

The Melville Glacier stock is a thin sheet-like intrusion along the inferred contact between Triassic and Jurassic strata. It consists of a mesocratic, fine to medium-grained, hornblende-biotite diorite to quartz diorite.

Two small gabbroic stocks occur in the map area. One, underlying John Peaks, is a medium to coarse-grained hornblende gabbro or diorite that forms an isolated plug about 4 square kilometres in area. It has sharp discordant contacts with Upper Triassic and Lower Jurassie strata. Minor gabbroic sills extend to the north and south, up to 1 kilometre from the main body of the pluton. At Nickel Mountain a pyroxene gabbro intrudes thin-bedded tuffs, cherts and siltstones of possible Toarcian age (Grove, 1986). The gabbro is medium to coarse grained, granular to ophitic, locally orbicular, and composed of plagioclase and pyroxene with up to 20 per eent olivine (Jeffrey, 1967). It crops out over an area of less than 2 square kilometres.

Newly discovered this year, the Lehto porphyry is a granodiorite to syenite with potassium feldspar, plagioclase and hornblende phenocrysts. Potassium feldspar phenocrysts are very coarse, up to 4 centimetres long, sharply euhedral, and typically coral or salmon pink. The Lehto porphyry crops out in the northwest corner of the map area as an elongate northeast-trending body roughly 10 kilometres long by 2 kilometres wide. Its southwestern limit in Snippaker Creek valley has not been determined. An associated, subparallel northeast-trending dyke swarm cuts immediately adjacent country rocks and includes locally aphyric aplite, monzonite and microdiorite at the northeastern end. The main porphyritic phase may be equivalent to other potassium feldspar plagioclase porphyries of the Texas Creek granodiorite suite that exhibit a common spatial association with precious metal deposits in the Stewart, Sulphurets and Iskut gold camps.

The Lee Brant stock located east of the South Unuk River is the largest discrete pluton in the map area. It crops out over 40 square kilometres and consists of a homogeneous, coarse-grained, leucocratic, hornblende-biotite quartz monzonite, with large potassium feldspar phenocrysts. Contacts with country rocks are discordant, sharp but unchilled. Country rocks are contact metamorphosed mostly to biotite hornfels facies, locally to garnet hornfels facies. Narrow dykes of quartz monzonite occur up to 200 metres from the main body of the pluton. On the basis of textural and mineralogical similarities with the Summit Lake and Texas Creek plutons to the southeast, a Jurassic age was proposed (Britton and Alldrick, 1988). Preliminary potassium-argon data on both biotite and hornblende separates indicate an Early Eocene age.

The Coast plutonic complex underlies the southwestern corner of the map area. It displays a variable composition ranging from biotite granite east of Gracey Creek to biotite-hornblende quartz diorite north of Boulder Creek and probably contains many discrete stocks. Country-rock contacts are sharp, discordant and thermally metamorphosed. The age of these intrusions is Eocene, based on dating in the Stewart area (Alldrick *et al.*, 1987) but the complex may include remnants of Jurassic granitoids.

On the west side of the map area is a north-trending belt of dykes, called the King Creek swarm, that extends from Canyon Creek to Nickel Mountain. The limits in Figure 1-28-2 show where dykes exceed 50 per cent of the exposed bedrock. In places bedrock consists entirely of dykes. Individual dykes are up to 10 metres wide and appear to anastomose, crosscutting one another at oblique angles. Compositions range from rhyodacite to andesite; textures from aphanitic to holocrystalline. Most dykes are white-weathering, medium-grey andesite to dacite with fine to coarse feldspar phenocrysts in an aphanitic groundmass. More felsic dykes may display flow banding; more mafic dykes tend to be coarser grained (for example diabase and hornblende diorite). The dykes form resistant ridges; in sections underlain by siltstones the only prominent outcrops are dykes. Total width of the swarm suggests there has been country-rock extension in the order of 500 to 1000 metres. They are thought to be the same age as the Portland Canal dyke swarm which yields Early Eocene potassium-argon dates (Alldrick *et al.*, 1987).

STRUCTURE

FAULTS

Normal faults in the map area are mesoscopic structures with relatively small offsets. Minor reverse faults have been observed that repeat better defined stratigraphic sections, for example at the toe of Bruce Glacier. Mapping these faults is not easy and depends on the recognition of local stratigraphic markers or repeated sequences of rock types. Actual fault surfaces or zones are rarely seen. Failure to recognize these structures leads to false conclusions about stratigraphic order, at least on a local scale. They are possibly quite common and may have developed concurrently with regional folding.

A northwest-trending belt of shearing, marked by mainly schistose rock fabrics, can be traced along the eastern valley slopes of South Unuk River. It dips to the northeast and represents a major normal fault that has moved the northeast side down. This structure passes along strike into the subvertical Harrymel Creek fault. Harrymel Creek valley is a 20-kilometre-long, north-trending topographic feature that may extend, with offsets, into Forrest Kerr Creek to the north. It is a zone of recent faulting that may represent a long-lived crustal break.

FOLDS

Soft-sediment, primary folds can be seen in well-preserved sequences such as exposures south of John Peaks. Regional folds, interpreted on the basis of lithologic correlation, are seen in the felsic marker (Mount Dilworth formation) which forms a tight anticline-syncline pair between Unuk River and Harrymel Creek. Limestone units southwest and northeast of South Unuk River form dip slopes into the valley bottom and thus define a northwest-trending syncline. Strata on McQuillan Ridge define a broad south-plunging anticline with steep-dipping limbs. This anticline extends the length of the exposed Upper Triassic west of Harrymel Creek although the axis seems to flatten or plunge to the north near Melville Glacier. More work is needed to resolve the structure west of this Triassic sequence.

METAMORPHISM

Regional metamorphic grade is lower greenschist facies, characterized by saussuritized plagioclase, chloritized mafic minerals, and conversion of clay constituents to white mica. Within 1 kilometre of the Coast plutonic complex, especially east of Gracey Creek, metamorphic grade rises to lower amphibolite facies. Rocks have a markedly gneissic appearance including agmatitic migmatites. These grade through a series of mylonitic zones into rocks of more easily determined protolith.

Dynamie metamorphic effects are on the whole more conspicuous, imparting foliation to finer grained rocks which locally display phyllitic textures. Foliation intensity varies over distances of a few metres, with stretching of lapilli clasts in coarse pyroclastics and minor transposition of compositional layering in finer grained rocks. Deformational effects are most noticable in marble-bearing sequences which show boudinage, convolute fold forms and highly contorted remnants of tuffaceous interbeds. In South Unuk River valley, thicker limestone units consist of lenses of marble with strike lengths in the order of only tens of metres, despite an appearance of regional stratigraphic continuity. What probably was a continuous bed has now been tectonically dismembered.

The age of metamorphism is Cretaceous (Alldrick *et al.*, 1987). However, near the contact of the Coast plutonic complex, granitic dykes thought to be offshoots of the complex have been mylonitized, indicating that deformation has also occurred after this Eocene intrusive event.

The Max and Lee Brant stocks and Coast plutonic complex have contact metamorphic aureoles, mostly biotite-hornblende hornfels. At one location adjacent to the Lee Brant stock (north of Lee Brant Creek) patchy almandine garnet may be found. The size of the pluton seems to govern the size of the aureole. Most hornfels occurs within a few hundred metres of the contact.

MINERAL DEPOSITS AND EXPLORATION POTENTIAL

The map area is midway between the Iskut and Sulphurets gold camps but has attracted little of the intense exploration activity that characterizes them. Although completely staked, the Unuk Valley saw only three major exploration projects in 1988: at Prout Plateau, Mount Madge and Doc Ridge. Field observations coupled with the recently released Regional Geochemical Survey results (B.C. RGS 18), MINFILE compilations, and recently announced exploration results, suggest that the mineral potential of the valley has been under-rated. This section describes selected mineral deposits and emphasizes the potential for new precious metal discoveries.

There are 55 mineral occurrences listed in MINFILE, ranging from showings to developed prospects, including one past producer. Most can be classified into one of four nongenetic categories: stratabound, intrusive contacts, veins, and disseminations.

STRATABOUND

Stratabound mineralization consists almost exclusively of pyritic zones and lenses contained within a particular stratum or restricted set of strata. The best examples are the MacKay prospects (MINFILE 104B 008), located beside Eskay Creek, which consist of at least eight distinct mineralized zones occurring over a strike length of 1800 metres within a sequence of felsic volcanics. They are now being explored by Calpine Resources Incorporated. Preliminary drilling on the 21 zone intersected almost 30 metres assaying 25 grams gold and 38 grams silver per tonne, including 16 metres of 45.6 grams gold and 68.2 grams silver per tonne (George Cross News Letter No. 213/1988). Another of these prospects, the 22 zone produced 10 tonnes of hand-picked gold-silver ore. Best assays were 150 grams gold and 4900 grams silver per tonne (Harris, 1985; 1987). Both stockwork and massive sulphide mineralization are exposed in the Emma adit. Stockwork mineralization is primarily galena and/or sphalerite with varying amounts of tetrahedrite, jamesonite and polybasite in quartz veinlets and silicified breccias in dacitie to rhyolitic pyroclastics. Massive mineralization consists of small pods and lenses of sphalerite, galena and pyrite.

The deposits have been variously interpreted as silicified shear zones (Harris, 1985) or volcanogenic massive sulphide deposits (Donnelly, 1976). In either model there is room for considerable extension down dip and along strike. Mapping this year identified pyritic siliceous zones up to 7 kilometres along strike to the south within the same sequence of felsic volcanics. Other gossanous zones were seen from the air where this unit crosses the Unuk River. More work needs to be done to define local controls on mineralization but the entire strike length of this unit is a target for detailed exploration.

INTRUSIVE CONTACTS

Deposits in this category show a close spatial and temporal relationship with igneous intrusions. A genetic link is highly probable. Three deposits in this category are the E & L nickel-copper prospect (MINFILE 104B 006), and the Max (MINFILE 104B 013) and Chris-Anne (MINFILE 104B 125) copper-iron skarns.

The E & L deposit is located in the headwaters of Snippaker Creek, about 1 kilometre south of the summit of Nickel Mountain. The prospect was explored for its nickel and copper potential in the 1960s and 1970s by diamond drilling and a 450-metre exploration adit. Drill-indicated reserves are 2.8 million tonnes of 0.7 per cent nickel and 0.6 per cent copper (Sharp, 1965).

Mineralization at the E & L occurs within two medium to coarse-grained, olivine-pyroxene gabbro bodies. These roughly triangular plugs are each approximately 1300 square metres in area and are probably connected. They intrude a sequence of argillites, tuffaceous siltstones and grey dacitic ash tuffs that strike northwesterly with moderate to steep southwesterly dips. Mineralization consists of pyrrhotite, pentlandite and chalcopyrite with lesser amounts of pyrite and magnetite. In the northwestern gabbro mineralization extends up to the contact with the sediments whereas in the southeastern gabbro mineralization is confined to the pluton. Diamond drilling has delineated pipe-like pods and disseminations of sulphides to a depth of 120 metres. There has been no reported evaluation of the potential for platinum-group elements in these gabbros. A grab sample of massive sulphide collected in 1987 assayed 225 ppb platinum, 299 ppb palladium, 1.4 per cent copper, 2.14 per cent nickel, 710 ppm cobalt, 58 ppb gold and 2 ppm silver.

The Max prospect lies on the northwest side of McQuillan Ridge, between the Unuk and South Unuk rivers, at elevations between 455 and 1500 metres. Massive magnetite with lesser pyrrhotite and chalcopyrite occur in skarn-altered sedimentary rocks adjacent to a diorite stock. Garnet, epidote, actinolite and diopside characterize the skarn assemblage. Drilling has indicated a reserve of 11 million tonnes at 45 per cent iron (Canadian Mines Handbook 1973-1974, page 432).

The Chris-Anne prospect lies approximately 3 kilometres east of the Max. Skarn mineralization is reported in limestone beds which are up to 10 metres thick and that are interbedded with volcaniclastics. Magnetite and pyrrhotite-rich layers, from 0.5 to 7 metres thick, with minor chalcopyrite, extend over a distance of 1 kilometre. There are minor intrusive bodies reported on the property. Grades range from 0.1 to 0.4 per cent copper (Allen and MacQuarrie, 1981). Some recent stream sediment geochemistry results on this hillside were high in gold (T. Heinricks, personal communication, 1988).

The gold potential of these skarn deposits does not appear to have been tested. Based on recent skarn studies (Ettlinger and Ray, 1988) McQuillan Ridge has many features that are associated with gold-enriched skarns elsewhere in the province: sequences of calcareous and tuffaceous host rocks; structural deformation; intrusion by dioritic I-type granitoids; and contact metamorphism and recrystallization. Some auriferous skarns are enriched in cobalt, an element that may be a useful pathfinder. Regional Geochemical Survey data show high cobalt values in three streams draining the ridge.

VEINS

High-grade precious metal quartz veins are the target of exploration programs at Mount Madge by Bighorn Development Corporation, and at the Doc prospect by Echo Bay Mines Limited. Veins on these prospects illustrate the variety found in the map area.

The Mount Madge prospects are located south of Sulphurets Creek near its confluence with Unuk River, on the east and west sides of Mandy Glacier. Two different targets are being evaluated (Kruchkowski and Sinden, 1988). On the west the C-10 prospect (MINFILE 104B 240) is a stockwork of thin quartz veinlets, locally with thicker quartz lenses, in intensely altered, fine-grained tuffaceous andesite or dacite. Quartz veinlets locally form up to 30 per cent of the rock. The alteration assemblage consists of quartz and sericite with up to 10 per cent pyrite. Chalcopyrite and traces of sphalerite are also present. The rocks are strongly foliated to schistose and are very similar to the broad alteration zones seen at Brucejack Plateau 12 kilometres to the northeast (Britton and Alldrick, 1988). Soil samples locally return analyses in excess of 1 ppm gold.

Two kilometres to the east, Ken Konkin discovered a massive pyrite-siderite float boulder with visible gold. Prospecting uphill led to the discovery of the GFJ veins (MINFILE 104B 233), apparently flat-lying, zoned, siderite-quartz-sulphide veins that returned assays up to 121 grams per tonne gold (Kruchkowski and Sinden, 1988). The veins are poorly exposed. Float blocks seen this year display symmetrical zoning from margin to core across vein widths of 10 to 15 centimetres. Vein margins are 1 to 2 centimetres of thin white quartz layers separated by hairline accumulations of very fine-grained tin-white sulphide, probably arsenopyrite. The core is a very coarse-grained intergrowth of siderite, milky quartz and cubes and clusters of pyrite, with lesser amounts of sphalerite and chalcopyrite as crystals and irregular masses. Rare tetrahedrite and visible gold have been observed (K. Konkin, personal communication, 1988). The veins cut variably foliated andesitic ash tuffs with thin interbeds of foliated to schistose siltstones.

The Doc prospect (MINFILE 104B 014) is located at treeline on a ridge overlooking the South Unuk River, opposite the mouth of Divelbliss Creek. The prospect consists of several west-northwest-trending quartz veins up to 2 metres wide that have surface strike lengths of up to 275 metres (Gewargis, 1986). The main veins (Q17, Q22) are massive white quartz with sparse sulphide mineralization (5 to 10 per cent) consisting of galena, pyrite, chalcopyrite and sphalerite with associated specular hematite and magnetite. Precious metal values are mostly confined to the sheared edges of veins and immediately adjacent wall rock. Shear zones with very little quartz may also return good values. Seraphim (1948) observed that gold was associated with either specular hematite or with galena and pyrite, but not with chalcopyrite and pyrite assemblages. The veins are a true fissure type, crosscutting folded and metamorphosed andesitic tuffs and thin-bedded sediments, including marble, that have been intruded by irregular dioritic dykes or sills and small monzodioritic plugs. The veins are different from any others seen in the Sulphurets or Unuk map areas. They have very restricted wallrock alteration aureoles, no apparent zoning, and appear to be limited to a few large fluid pathways. In this they display characteristics of mesothermal veins. Structural control of the vein sets has not been determined but may be due to fractures related to folds in the host rocks. Total mineral inventory of the Q17 and other veins is given as 426 000 tonnes with 9.26 grams per tonne gold and 44.91 grams per tonne silver (Northern Miner, November 7, 1988).

DISSEMINATED DEPOSITS

Porphyry-type disseminated pyrite, chalcopyrite and molybdenite mineralization occurs immediately north and south of King Creek, west of Harrymel Creek. Two properties have been worked: the VV to the south and the Cole to the north.

The VV property (MINFILE 104B 079) is the site of a heavily weathered monzonitic intrusive body in fault contact, on the east and west, with layered andesitic lapilli tuffs and tuff breccias with minor siltstone and calcareous sandstone interbeds. The stock is 250 metres wide, at least 6 kilometres long, strikes northerly and dips steeply to the west, parallel to the country rocks. Chalcopyrite occurs in quartz stockworks and as fine disseminations within the monzonite. Molybdenite, sphalerite, malachite and azurite have also been reported (Winter and McInnis, 1975; Mawer, *et al.*, 1977). Representative assays give 0.34 per cent copper, 0.003 per cent molybdenum, 2.1 grams per tonne silver, and 0.8 gram per tonne gold. Maximum gold and silver values obtained were 8.64 grams per tonne gold and 19.54 grams per tonne silver (Mawer, *et al.*, 1977).

The Cole prospect (MINFILE 104B 209) is situated approximately 4 kilometres north of the VV claims; it appears to be on strike with the same fault system and has similar intrusive and country rocks. Mineralization consists of up to 10 per cent pyrite, as disseminations and fracture fillings. Minor chalcopyrite and malachite have been reported but the bedrock source of the gold-silver soil anomalies has not been located (Korenic, 1982; Gareau, 1983). Reported assays range up to 0.43 per cent copper; 7.12 grams per tonne gold and 13.03 grams per tonne silver. Gold and copper values show a positive correlation on both properties.

RECONNAISSANCE GEOCHEMISTRY

Geochemical survey results for stream sediment samples collected over the whole of NTS 104B in 1987 were published in July, 1988 (B.C. RGS-18). In the Unuk map area almost every known precious metal prospect is associated with high gold values. Known gold deposits are also associated with high but variable values for such pathfinder elements as silver, arsenic, antimony or barium. For a reconnaissance survey this is a remarkable success rate. High gold values (greater than 90th percentile) not associated with known gold prospects occur along Gracey Creek, King Creek, Snippaker Creek, Boulder Creek, on the south end of Prout Plateau and on the east side of Unuk River near John Peaks (Figure 1-28-2).

Drainages from the Sulphurets gold camp and Prout Plateau (site of the MacKay prospects) have very similar geochemical signatures with elevated gold, silver, arsenic mercury, antimony and barium. Base metal values are also high.

Drainages from the northwest corner of the map area and the adjacent Snippaker map sheet, in particular the area between Snippaker and Palmiere creeks, show high values in a wide suite of elements including gold, silver, barium, lead, zinc, cadmium and manganese with scattered highs in copper, tin, tungsten and molybdenum. Mercury, arsenic and antimony analyses are low. The area contains some small but well-developed gossans. Interestingly, this high gold-silver, low mercury-arsenic-antimony pattern is similar to that of the Iskut gold camp 15 kilometres to the west. The close spatial association of these anomalies, gossans and the Lehto potassium-feldspar porphyry may be significant. There are no records of precious metal exploration in this area.

A cluster of samples from the headwaters of Harrymel Creek are high in mercury, silver, arsenic, antimony and fluorine. One mercury value (3 ppm) is the highest for the whole of NTS 104B. This element association may indicate high-level epithermal mineralization or possible ongoing geothermal activity along this structure.

In Divelbliss Creek, coincident high tungsten, molybdenum and fluorine and above-average molybdenum analyses include the highest tungsten and fluorine results recorded for NTS 104B, F and G. There are no known tungsten deposits in this area. Near Stewart, the Eocene Hyder pluton is spatially and probably genetically associated with molybdenite and tungsten mineralization. Recent potassium-argon dates for the Lee Brant stock at the headwaters of Divelbliss Creek indicate an Eocene age. The stock has a contact metamorphic aureole that may be the source of these anomalies.

ACKNOWLEDGMENTS

The authors are grateful for the excellent field assistance of Colin Russell, Todd Kemp and Malcolm Smith who stoically endured a summer that never seemed to arrive. Our thanks also go to Magna Ventures Ltd., Bighorn Development Corporation, and, especially, Catear Resources Ltd. for accommodation and hot showers on cold days. Limar Industries Ltd., Vancouver Island Helicopters Ltd. and Northern Mountain Helicopters Ltd. provided efficient expediting and transportation.

REFERENCES

Alldrick, D.J. (1987): Geology and Mineral Deposits of the Salmon River Valley, Stewart Area (104A, 104B), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-22.

Alldrick, D.J. and Britton, J.M. (1988): Geology and Mineral Deposits of the Sulphurets Area (104A/5, 12; 104B/8, 9) *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-4.

Alldrick, D.J., Brown, D.A., Harakal, J.E., Mortensen, J.K. and Armstrong, R.L. (1987): Geochronology of the Stewart Mining Camp (104B/1), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 81-92.

Allen, D.G. and MacQuarrie, D.R. (1981): Geological, Geophysical and Geochemical Report on the South Unuk River Property, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 9723, 15 pages.

Anderson, R.G., (1989): A Stratigraphic, Plutonic and Structural Framework for the Iskut River Map Area (NTS 104B), Northwestern British Columbia, Current Research, Part E, *Geological Survey of Canada*, Paper 89-1E.

Britton, J.M. and Alldrick, D.J. (1988): Sulphurets Map Area (104A/5W, 12W, 104B/8E, 9E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 199-209.

Brown, D.A. (1987): Geological Setting of the Volcanic-hosted Silbak Premier Mine, Northwestern British Columbia (104A/4, 104B/1), Unpublished M.Sc. Thesis, *The University of British Columbia*, 219 pages.

Donnelly, D.A. (1976): A Study of the Volcanic Stratigraphy and Volcanogenic Mineralization on the Kay Claim Group, Northwestern British Columbia, Unpublished B.Sc.Thesis, *The University of British Columbia*, 59 pages.

Ettlinger, A.D. and Ray, G.E. (1988): Gold-enriched Skarn Deposits of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1987, Paper 1988-1, pages 263-279.

Gareau, M.B. (1983): Geochemical Assessment Report on the Cole Claim, Skeena Mining Division (104B/7E and 10E), *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 11673, 16 pages.

Geological Survey of Canada (1957): Stikine River Area, British Columbia (104A, B, G, H, I, J), Map 9-1957.

Gewargis, W.A. (1986): 1986 Diamond Drilling Report on the Doc Claims Property, South Unuk River, British Columbia (104B/8W), *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 15615, 45 pages.

Grove, E.W. (1971): Geology and Mineral Deposits of the Stewart Area, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Bulletin 58, 219 pages.

——— (1986): Geology and Mineral Deposits of the Unuk River–Salmon River–Anyox Area, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Bulletin 63, 152 pages.

Gunning, M.H. (1986): Late Triassic to Middle Jurassic (Norian to Oxfordian) Volcanic and Sedimentary Stratigraphy and Structure in the Southeastern Part of the Iskut River Map Sheet, North-central British Columbia, Unpublished B.Sc. Thesis, *The University of British Columbia,* 85 pages.

Harris, C.R. (1985): Report on Kay and Tok Claims, Eskay Creek, Unuk River, British Columbia, Unpublished Report for *Golden Coin Resources Ltd.*, 15 pages.

——— (1987): Report on Tok and Kay Claims, Eskay Creek, Unuk River, British Columbia, Skeena Mining Division (104B/9W), Unpublished Report for *Consolidated Stikine Silver Ltd.*, 12 pages.

Jeffrey, W.G. (1967): Iskut River: E and L, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Annual Report, 1966, pages 31-34.

Kerr, F.A. (1948): Lower Stikine and Western Iskut River Areas, British Columbia, *Geological Survey of Canada,* Memoir 246, 94 pages.

Korenic, J.A. (1982): Assessment Report of Geological, Geochemical, and Geophysical Work Performed on the Cole Claim in 1981, Skeena Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 10474, 18 pages.

Kruchkowski, E.R. and Sinden, G.W. (1988): Report on Corey Claim Group, Stewart, British Columbia, Skeena Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 17404, 18 pages.

Mawer, M., Bojczyszyn, T., McInnis, M. and Garratt, G. (1977): Year-end Report, Mount Dunn Property, British Columbia (104B/7), *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 6234, 31 pages.

National Geochemical Reconnaissance 1:250 000 Map Series (1988): Iskut River, British Columbia (NTS 104B), *Geological Survey of Canada,* Open File 1645, *B.C. Ministry of Energy, Mines and Petroleum Resources.* RGS-18.

Seraphim, R.H. (1948): A Gold-specularite Deposit, Unuk River, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia.*

Sharp, W.M. (1965): Report on Geological Investigation of the E & L Nickel-copper Prospect and Vicinity Near Snippaker Creek, Iskut River District, Liard Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 741, 24 pages.

Souther, J.G. (1971): Geology and Mineral Deposits of Tulsequah Map-area, British Columbia, *Geological Survey of Canada*, Memoir 362, 84 pages.

Thomson, R.C., Smith, P.L. and Tipper, H.W. (1986): Lower to Middle Jurassic (Pliensbachian to Bajocian) Stratigraphy of the Northern Spatsizi Area, North-central British Columbia, *Canadian Journal of Earth Sciences,* Volume 23, Number 12, pages 1963-1973.

Tipper, H.W. and Richards T.A. (1976): Jurassic Stratigraphy and History of North-central British Columbia, *Geological Survey of Canada,* Bulletin 270, 73 pages.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America, *Geological Survey of Canada,* Open File 1565.

Winter, C.Q. and McInnis, M.D. (1975): Geological and Geochemical Report on the VV 1-6 Claims, Mount Dunn Area, British Columbia (104B/7), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 5616, 12 pages.

Wright, F.E. (1907): The Unuk River Mining Region of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Annual Report, 1906, pages H68-H74.

GEOLOGY OF THE SCUD RIVER AREA, NORTHWESTERN BRITISH COLUMBIA (104G/5, 6)

By Derek A. Brown and Michael H. Gunning

KEYWORDS: Regional geology, Scud River, Stikine assemblage, Stuhini Group, Hickman batholith, Jurassic intrusions, porphyry mineralization.

INTRODUCTION

The first summer of 1:50 000 geological mapping for the Stikine project was completed in the Scud River (104G/5) and Scud Glacier map areas (104G/6) in 1988. Fieldwork focused on Upper Paleozoic Stikine assemblage and Upper Triassic Stuhini Group stratigraphy and structure, plutonic suites, and mineral potential. The work will provide an updated geology map to complement recently released Regional Geochemical Survey (RGS) data. The Stikine assemblage was divided into four stratigraphic units and intrusive rocks were grouped into four plutonic suites. Samples were collected for geochemical (71), microfossil (75), macrofossil (31) identification and potassium-argon isotopic dating (7).

Concurrently, J. Logan and V. Koyanagi (1989, this volume) mapped the two adjoining sheets to the south (104G/3, 4). Nixon *et al.* (1989, this volume) examined the Hickman ultramafic complex in the southwest corner of the project area to evaluate its platinum-group-element potential. Our efforts in 1989 will concentrate on Upper Triassic and younger rocks along the eastern margin of the Coast Belt in map areas to the north (104G/10, 11). The work will complement the Geological Survey of Canada mapping in the Telegraph Creek map area in 1990.

LOCATION AND ACCESS

The map area is 150 kilometres southwest of Dease Lake and is accessible by helicopter, small aircraft or boat (Figures 1-29-1 and 1-29-3). A gravel airstrip suitable for DC-3 and smaller aircraft is located at the confluence of the Scud and Stikine rivers. The Stikine River provides float-plane and river-boat access to the western half of the Scud River map sheet.

The area is rugged with glacially steepened valley walls and 40 per cent alpine glacier cover. Jagged peaks of the Coast Mountains reach elevations over 2785 metres; the Spectrum Range east of Schaft Creek and the terrain north of Butterfly Creek are more subdued. Along the Stikine valley, near the mouth of the Scud River, there are more than 50 prehistoric stone cairns at elevations between 1100 and 1300 metres (Figure 1-29-3, Plate 1-29-1). Kerr described these, however little is known about them except that they may have been built by ancient Interior or Coastal Indians.

PREVIOUS WORK

Initial geological studies along the Stikine River were made in 1863 when a group of Russian geologists came to assess the area's mineral potential (Alaska Geographic Society, 1979). G.M. Dawson and R. McConnell were the first Canadian geologists to explore the Stikine River valley in 1887. Forrest Kerr worked along the Stikine River from the International border to Telegraph Creek (Kerr, 1927, 1929, 1930, 1931, 1948a).

Regional mapping by Souther (1972) produced the most complete geological study of the Telegraph Creek map area (104G). He divided the Stikine assemblage into pre-Permian and Permian units and described the Triassic rocks and the Hickman batholith in detail. Later work (Souther and Symons, 1974) established the Mount Edziza complex 20 kilometres northeast of the present study.

Biostratigraphic studies of the Stikine assemblage by Pitcher (1960), Monger (1977a), Anderson (1988) and Holbek (1988) in areas south of the Scud River have established a Devonian to Permian age range. To the north, Read (1984) documented the geology of the Stikine Canyon region.

From 1955 to 1975 exploration activity focused on the Galore Creek and Schaft Creek porphyry copper deposits (Figure 1-29-1). Upper Triassic volcanic and plutonic rocks were described and isotopic dates published. Mineralization in the Mess Creek area, 30 kilometres to the east, was studied by Holbek (1988). Recently, companies have actively explored the area for precious metal deposits.

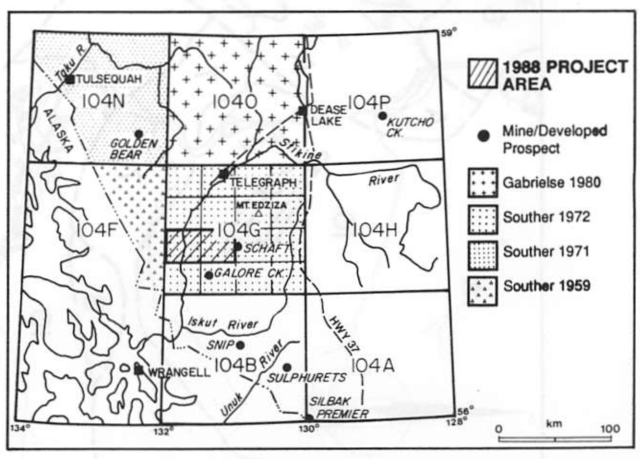


Figure 1-29-1. Location map for Stikine Project 1988.

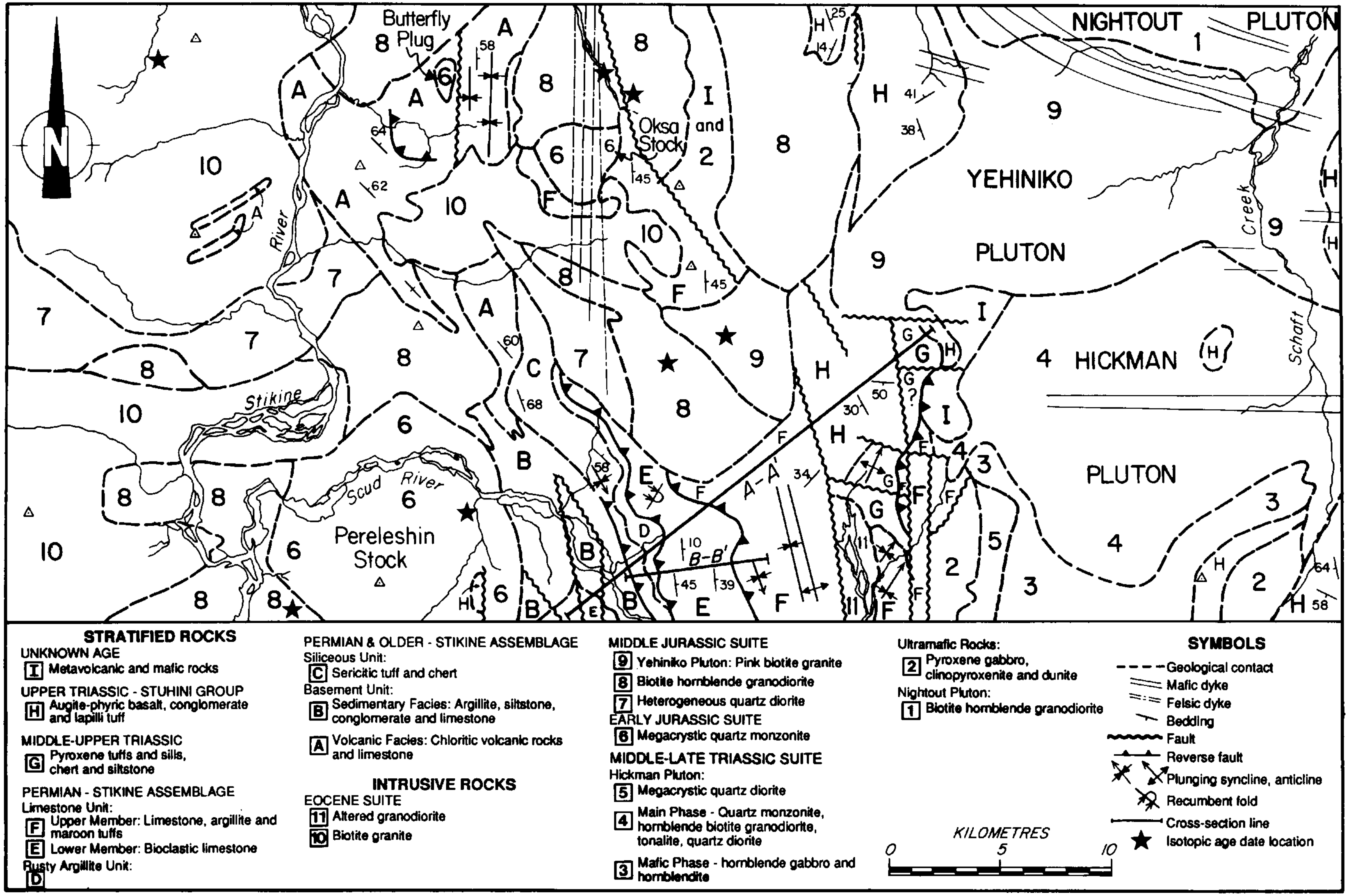


Figure 1-29-2. Simplified geology of the Scud River and Scud Glacier map areas (104G/5, 6).

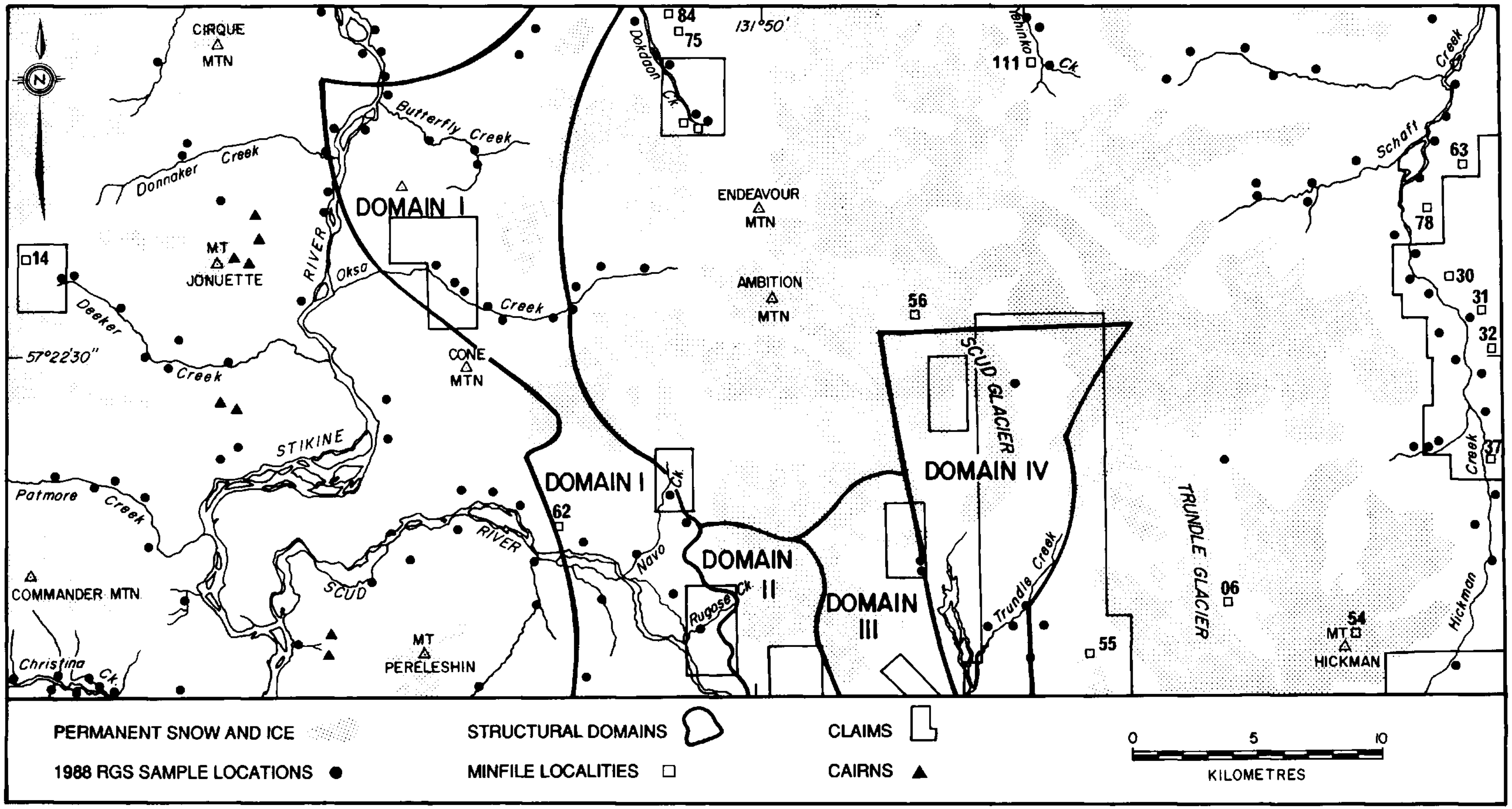


Figure 1-29-3. Scud River and Scud Glacier location map with RGS sample locations, MINFILE localities, claim locations and structural domains.

REGIONAL GEOLOGY

The map area straddles the boundary between the Coast and Intermontane tectonic belts. The Stikine terrane, an integral part of the Intermontane Belt, underlies the map area and is made up of Middle Paleozoic to Mesozoic eugeoclinal rocks, overlapped by the Bowser Lake Group, which outcrops 45 kilometres to the east.

Three of roughly ten major lithotectonic packages in northwestern British Columbia occur in the project area: Paleozoic Stikine assemblage sedimentary and volcanic rocks; unnamed Middle Triassic sedimentary rocks; and Upper Triassic Stuhini Group volcanic and sedimentary rocks.

STRATIGRAPHY

Paleozoic and Mesozoic stratified rocks are exposed in the central part of the map area (Figure 1-29-2) and are described below.

PALEOZOIC STIKINE ASSEMBLAGE

The term "Stikine assemblage" (Monger, 1977b) includes Paleozoic rocks in Stikinia of Early to Middle Devonian, Mississippian and Permian age (Pitcher, 1960; Monger, 1977a; Anderson, 1988; Logan and Koyanagi, 1989, this volume). Representative rocks occur in a northwest-trending belt across the project area and are best exposed in a 2000-metre section along the north side of the Scud River. The assemblage comprises basal (Permian? and older) cleaved intermediate metavolcanic and metasedimentary rocks (the "basement unit") overlain by silicic to felsic tuff (Unit C, the siliceous unit), rusty argillite (Unit D) and a thick sequence of Permian platformal limestone (Units E and F, Figures 1-29-4 and 1-29-5).

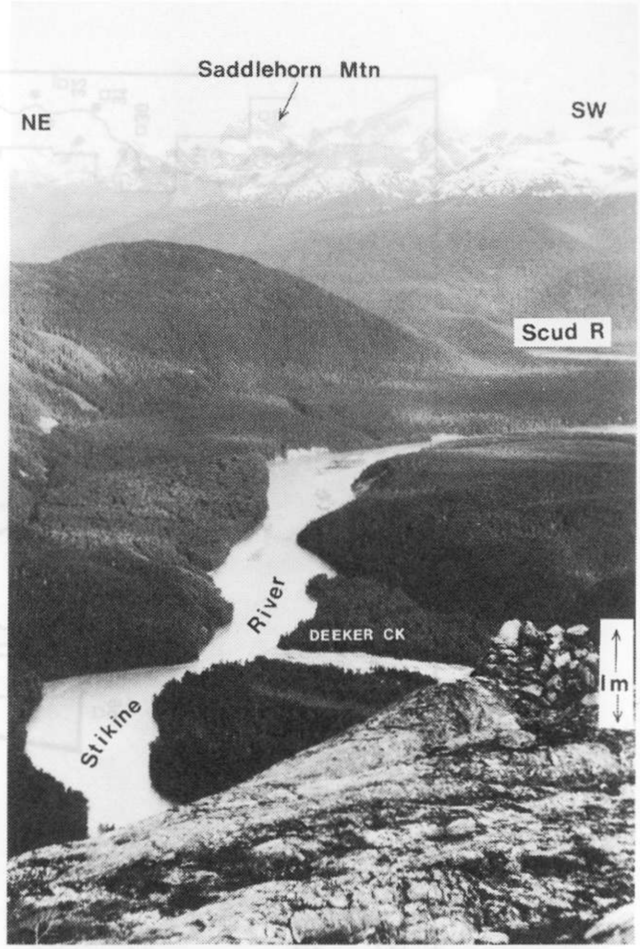


Plate 1-29-1. View southeast to prehistoric stone cairn built on a prominent knoll above the Stikine River.

BASEMENT UNIT (UNITS A, B)

The basement unit, over 1000 metres thick, consists of a northern **volcanic facies** and southern **sedimentary facies** that interfinger northwest of Navo Creek.

The **volcanic facies** (Unit A, Figure 1-29-2) consists of predominantly green, hornblende and chlorite-altered, pyroxene-bearing volcaniclastic rocks (including chlorite schist and heterolithic breccia) and subordinate phyllitic pyroxene-feldspar-porphyritic andesite sills or flows. An extensive chlorite schist member (greater than 500 metres thick), with elliptical (flattened?) lithic fragments and intercalated silicic tuff horizons, occurs near the top of the volcanic facies. Two framework-supported, heterolithic volcanic breccia members (20 to 30 metres thick) and silicic and plagioclase crystal tuff beds, are interlayered with the chlorite schist member. Siliceous tuff predominates towards the top of the basement unit and grades into the siliceous unit.

The basement volcanic rocks are similar in composition and appearance to the Stuhini Group, however, their stratigraphic position, more strongly deformed, metamorphosed and altered character are diagnostic and suggest an older age.

The **sedimentary facies** (Unit B) comprises light grey to pale green phyllitic greywacke, siltstone, calcareous siltstone, graphitic argillite, argillaceous chert and pebble conglomerate with a prominent platy to sericite-chlorite foliation. It is recessive and poorly exposed in the Scud River valley. The polymictic conglomerate contains subrounded to subangular argillite, siltstone and rare limestone clasts in a sandy matrix.

Discontinuous recrystallized limestone horizons with poorly preserved crinoid stems occur in both facies. The grey to white, well-bedded to massive limestones are up to 200 metres thick.

Basement unit lithologies indicate contemporaneous shallow-marine deposition to the south and andesitic volcanism to the north, with discontinuous limestone accumulation in both facies. The transition from andesitic to felsic volcanism probably reflects evolution of an Early Carboniferous(?) arc.

SILICEOUS UNIT (UNIT C)

The siliceous unit is at least 500 metres thick and extends from Rugose Creek to Butterfly Creek (Figure 1-29-3). The upper contact is an angular disconformity on which steeply dipping tuff beds are overlain by gently dipping, rusty argillite south of Navo Creek. However, locally along the creek, the contact is structurally comfortable.

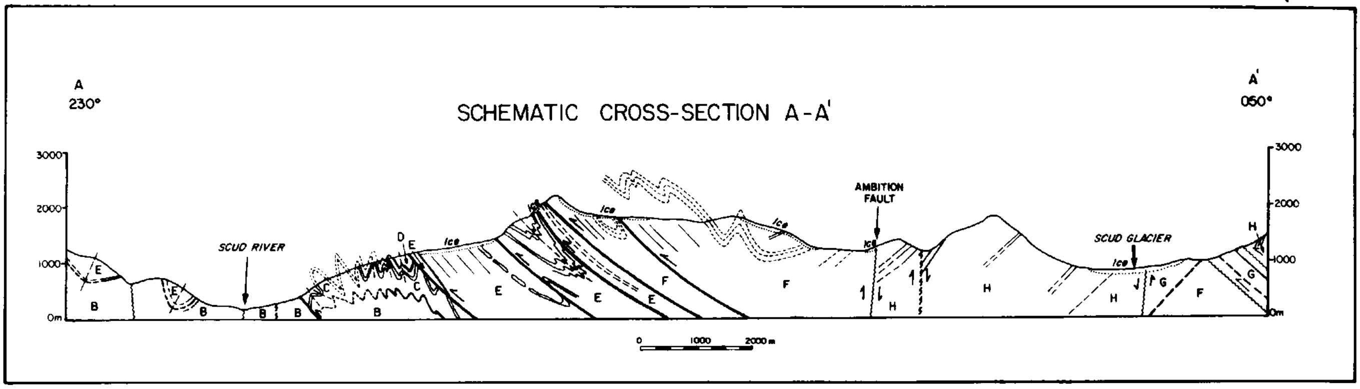


Figure 1-29-4. Schematic cross-section A-A′ from the Scud River to the Scud Glacier.

The unit is characterized by weakly foliated white to pale green, fine-grained to aphanitic silicic to felsic ash tuff, lapilli tuff and tuffaceous siltstone with lesser chert. Pyrite euhedra, up to 1 centimetre in diameter, form conspicuous rusty weathering spots in some exposures. Varicoloured cherts predominate toward the top of the section with thin grey to buff dolomitic limestone and argillite beds and lenses. Prominent planar laminae and beds contain load casts, flame structures, fining-upward sequences and local crossbeds and syndepositional small-scale growth faults which consistently indicate a northeast-facing stratigraphy.

The silicic rocks are interpreted to be a tuffaceous distal turbidite facies of explosive felsic volcanism. The uppermost limy siltstone and argillite indicate the cessation of volcanism. The basement and siliceous units are believed to be pre-Permian because they are more deformed and altered than the Permian limestone that lies stratigraphically above them; this is in accord with the interpretations of both Souther (1972) and Kerr (1948a). The angular discordance between the siliceous and rusty argillite units probably reflects a deformational event.

Rusty Argillite Unit (Unit D)

The distinctive rusty weathering black argillite, siltstone and sandstone unit which overlies the siliceous unit is restricted to the southeast side of Navo Creek. It is 100 metres thick at most and pinches out to the north and south. Bedding-parallel bands of pyrite and/or pyrrhotite are ubiquitous and comprise up to 5 per cent of the rock. A gradational contact (over 30 metres) with overlying dark grey micritic limestone marks a transition from an anoxic deep-water basin to a shallow-water stable platform setting. This unit has stratabound massive sulphide potential.

Limestone Unit (Units E, F)

Overlying the rusty argillite is a thick (greater than 1000 metres) sequence of structurally disrupted limestone (Figures 1-29-2, 1-29-4 and 1-29-5). East of Rugose Creek, lower and upper members are divisible. The divisions do not conform to the "Permian" and "Permian and Older" strata of Souther (1972) because conodont and macrofossil identifications suggest the lower member is at least as young as late Early Permian (M.J. Orchard and E.W. Bamber, personal communications, 1988).

The **lower member (Unit E)** comprises over 700 metres of dark grey micritic limestone, interbedded argillite and thinly bedded bioclastic limestone. A sharp contact separates lower and upper members. Dark grey, fine to medium-grained micritic limestone and minor black argillite form the lower part (less than 100 metres). The upper part consists of more than 600 metres of centimetre to decimetre-thick beds of grey limestone. Irregular concordant siliceous layers and pods are common; they are interpreted to be diagenetic features. Rugose corals up to 30 centimetres long, tabulate corals (*Syringopora*?), brachiopods, crinoid-stem fragments, sponge spicules, fusulinids, bryozoa and rare gastropods make up a diverse fauna in the unit. The corals are undeformed to slightly flattened, many are complete and intact suggesting limited transport or postdepositional deformation.

The **upper member (Unit F)** comprises primarily massive white to buff limestone with subordinate interbedded argillite and tuff which underlie the highest peaks (for example, Ambition Mountain). It is overlain unconformably by Upper Triassic shale south of the map area (Logan and Koyanagi, 1989, this volume). East of the toe of the Scud Glacier, Lower Permian limestone and tuff are disconformably overlain by Middle to Upper Triassic cherty sediments (Figure 1-29-6). Further east, Unit F is duplicated by a west-directed, probable post-Triassic, thrust.

In addition, massive limestone and dark grey argillite, irregular siliceous layers and pods are also common. Intermediate to felsic, maroon and green tuff and tuffaceous wacke/mudstone are diagnostic of the top part of this member. The tuff occurs as concordant lenses and structurally disrupted discordant bodies up to 50 metres thick. Some tuff beds are welded and eutaxitic.

Interbedded with maroon and green feldspar crystal lithic tuff is well-bedded, fusulinid-rich grey to maroon limestone (Figures 1-29-5 and 1-29-6; E.W. Bamber, personal communication, 1988). Heterolithic volcanic fragments are present within the limestone. Maroon and green plagioclase crystal-lithic ash to lapilli tuff and green silicic siltstone overlie the tuffaceous limestone.

The thick accumulation of limestone with boreal Permian faunas indicates near-shore, shallow-water sedimentation on

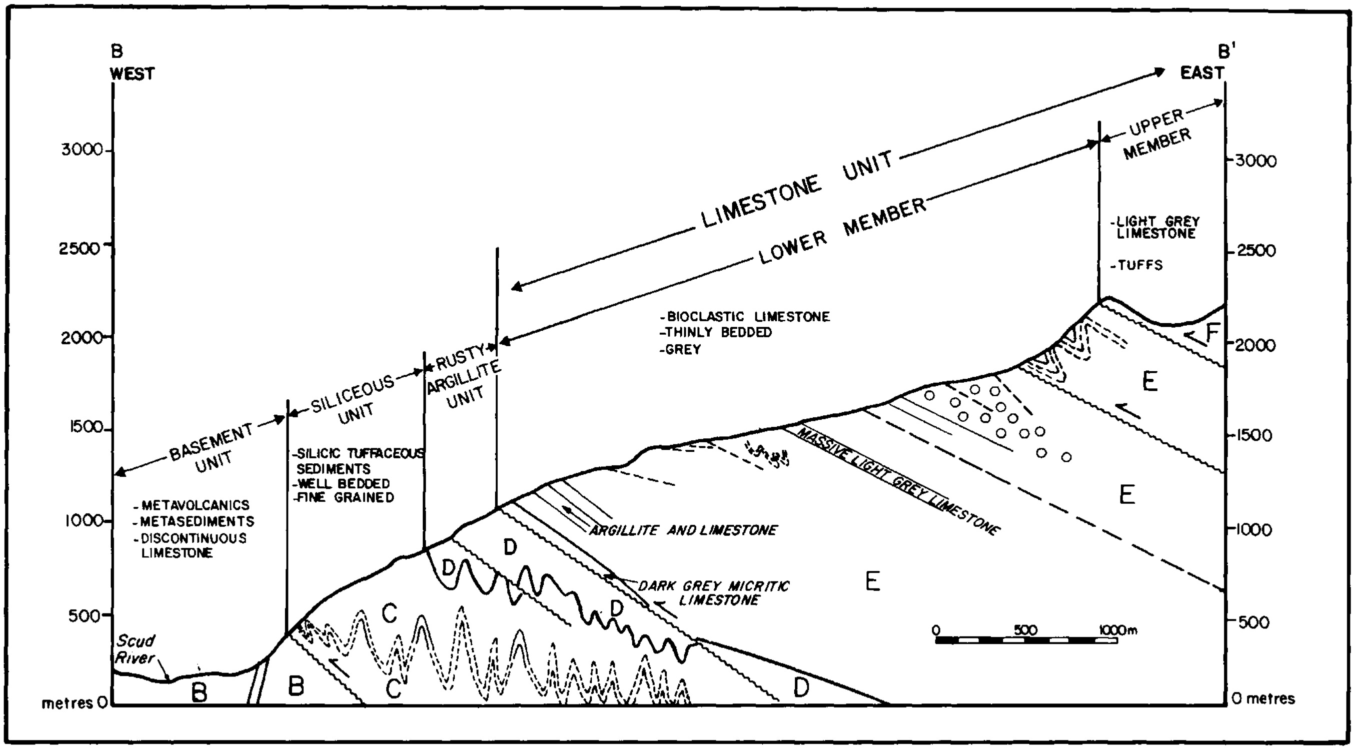


Figure 1-29-5. Schematic cross-section B-B′ of the Stikine assemblage near Rugose Creek.

a platform (E.W. Bamber, personal communication, 1988). The maroon and green tuffs represent isolated, episodic explosive Permian volcanism into an oxidizing, shallow-marine environment.

Regional correlation is hindered by deformation and facies changes. Permian rocks are missing due to nondeposition in the Mess Creek area, 30 kilometres to the east (Holbek, 1988) but the Permian limestone succession extends along strike at least 100 kilometres to the northwest (Tulsequah map area) and at least 50 kilometres to the south (Iskut map area).

MIDDLE TRIASSIC(?) ROCKS (UNIT G)

At the toe of the Scud Glacier a 200-metre-thick section of probable Middle Triassic sedimentary rocks unconformably overlies Permian limestone (Figure 1-29-6). The upper contact with Stuhini Group pyroxene-bearing volcaniclastics and basalt flows is conformable. Similar geological relationships occur in the Terrace area (G.J. Woodsworth, personal communication, 1988).

The sequence consists of black, brick-red and green chert and silicic mudstone. Well-bedded ribbon chert is overlain by argillaceous chert and highly contorted and disharmonically folded graphitic argillite. Identical ribbon chert and maroon tuff crop out in Trundle Creek, 4 kilometres south of the Scud section. The top of the succession is composed of well-bedded green siltstone and greywacke intercalated with thin shale layers. Shale rip-up fragments and local crossbeds in coarse clastics are distinctive.

The age of this section is poorly defined. A granodiorite stock, considered coeval with the Hickman pluton, intrudes the sediments and the Upper Triassic Stuhini Group overlies the sequence, suggesting a Middle to Late Triassic age.

UPPER TRIASSIC STUHINI GROUP (UNIT H)

The Stuhini Group, defined by Kerr (1948b), includes rocks in the Taku River valley of the Tulsequah map area and other Upper Triassic volcanic and sedimentary rocks that lie above a Middle Triassic unconformity and below the Late Triassic Sinwa limestone (Figure 1-29-1; Souther, 1971). In the study area, Stuhini Group volcanic rocks occur as large north-trending blocks or pendants between intrusive rocks. The best-exposed stratigraphy occurs as partly fault-bounded exposures west of the Scud Glacier.

The group comprises augite-phyric basalt flows, sills and volcaniclastics with minor andesite flows, volcanic breccia and tuff. Abrupt lateral facies changes and block faulting hinder stratigraphic reconstruction, however, the component lithologies are described below (Figure 1-29-6). The Stuhini Group is the youngest stratigraphic unit in the project area.

The base of the Upper Triassic sequence comprises distinctive medium-grained pyroxene-bearing mafic volcaniclastics. They occur as planar, graded beds of variable thickness with rare flame structures. Augite-crystal volcanic sandstone contains rounded grey chert clasts and rare augite porphyritic basalt clasts. Centimetre-scale syndepositional growth faults occur locally. Pyroxene-phyric basalt sills or flows are thin (less than 2 metres) with symmetrical fine-grained chilled margins and locally vesicular interiors. These basalts may correlate with the "eastern facies" of the Stuhini Group as used by Anderson (1988).

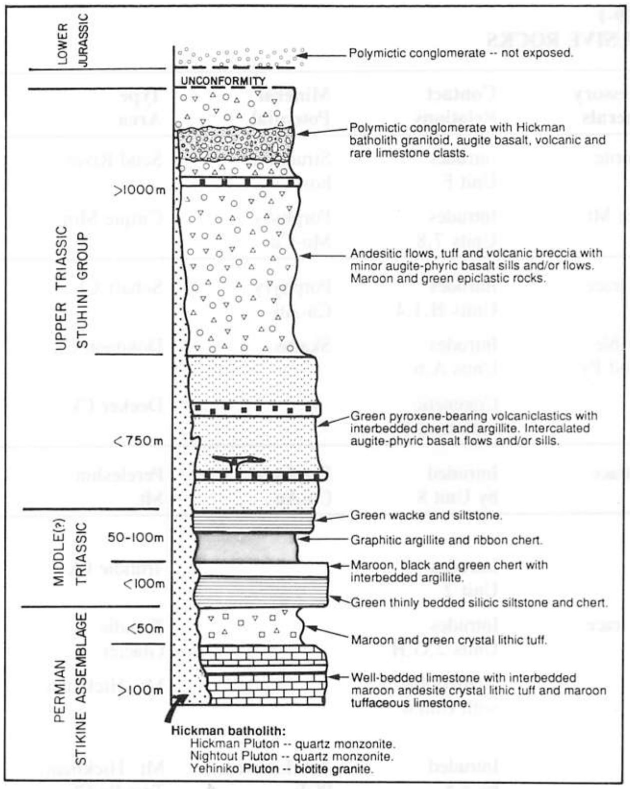


Figure 1-29-6. Schematic Triassic stratigraphic column for the Scud Glacier area.

Overlying the volcaniclastic strata are green, hornblende-feldspar-phyric andesite flows. Heterolithic volcanic breccia comprising angular green and maroon andesitic to basaltic fragments in a fine-grained volcanic matrix are less important. Matrix and framework-supported polymictic conglomerates contain prominent clasts of light grey granitoid, together with variably epidotized volcanic rocks, dark green augite basalt, and rarely amphibolite, limestone and ultramafite. Poorly sorted, maroon, crystal-rich epiclastic rocks display graded bedding and occur throughout the section. Pale green to grey, fine-grained to aphanitic, silicic and felsic tuffs near Schaft Creek are interpreted to be waterlain ash tuffs.

The Stuhini Group is a bimodal suite with mafic/intermediate rocks evolving to less abundant felsic rocks. It represents a terrain with basaltic to felsic subaerial and subaqueous volcanism, in part reworked by fluvial processes with contemporaneous shallow-marine deposition. The coarse breccias indicate significant relief and the diverse clast compositions indicate significant unroofing of the Hickman batholith with synchronous erosion of the upper portion of the Upper Triassic volcanic pile.

METAVOLCANIC AND MAFIC INTRUSIVE(?) ROCKS (UNIT 1)

Metavolcanic, mafic and lesser ultramafic intrusive(?) rocks on Dokdaon and Endeavour mountains, east of the Scud Glacier, east of Trundle Creek, and northeast of Mount Hickman (Figure 1-29-2) are dark grey to black, fine to medium grained and of unknown protolith. Textures vary from biotite schist to massive or brecciated pyroxenites and metavolcanic rocks. Local faint layering, interpreted to be relict bedding, indicates at least part of the unit is mafic volcanic material. Pyroxene-phyric basalt flows or sills are recognized in some localities. However, on Dokdaon and Endeavour mountains, massive amphibolitic rocks grade into ultramafic rocks that appear to intrude Permian limestone.

Souther (1972) used the same term to encompass nondescript mafic rocks and he suggested they could be in part metamorphosed Permian dolomitic limestone. No evidence was found for this although there does seem to be a spatial association with Permian limestone. The Scud Glacier body, intruded by the Hickman pluton, may represent Permian metavolcanic rocks.

INTRUSIVE ROCKS

Plutonic rocks underlie 75 per cent of the project area and are well exposed due to the rugged topography. Four composite plutonic suites are defined (Table 1-29-1): Middle(?) to Late Triassic; Early Jurassic; Middle Jurassic; and Eocene.

MIDDLE(?) TO LATE TRIASSIC SUITE

The Hickman batholith covers 1200 square kilometres of which half is in the eastern part of the project area. The batholith is a composite body composed of three, I-type plutons: the Middle(?) to Late Triassic Nightout and Hickman plutons and the Middle Jurassic Yehiniko pluton (Souther, 1972; Holbek, 1988). The older plutons are subvolcanic intrusions, spatially and genetically associated with coeval Stuhini Group volcanic rocks.

NIGHTOUT PLUTON (UNIT 1)

The Nightout pluton occupies 80 square kilometres in the northeast corner of the map area. It is composed of a medium-grained, equigranular, mesocratic hornblende-biotite granodiorite to quartz monzodiorite. Titanite is a common, locally medium-grained, accessory mineral. Mafic inclusions are common along pluton margins. The pluton is lithologically similar and coeval with the main phase of the Hickman pluton that lies 10 kilometres to the south.

Potassium-argon isotopic ages of 236 ± 18 Ma for biotite and 228 ± 16 Ma for hornblende (two sigma errors; Holbek, 1988) suggest a Late Triassic age for the pluton.

ULTRAMAFIC ROCKS (UNIT 2)

Ultramafic rocks are found in the Mount Hickman, Trundle Creek and Endeavour Mountain areas. The ultramafic rocks are intruded by the main phase of the Hickman pluton.

The Mount Hickman ultramafic complex forms an oblong body about 5 kilometres long and 3 kilometres wide. It comprises mainly medium-grained, equigranular, black to tan-weathering clinopyroxenite and olivine clinopyroxenite which contains 10 to 15 per cent fractured serpentinized olivine and 3 to 5 per cent euhedral chromite and magnetite

TABLE 1-29-1
SUMMARY OF INTRUSIVE ROCKS

Plutonic Suite	Phase (Unit)	Isotopic Age(K-Ar)	Rock Name	Accessory Minerals	Contact Relations	Mineral Potential	Type Area
Eocene	Unit 11		Altered Gd	Chlorite	Intrudes Unit F	Structural host	Scud River
	Unit 10		Bi Gr	Trace Mt	Intrudes Units 7,8	Porphyry Mo-Cu	Cirque Mtn.
Middle Jurassic	Yehiniko Pluton(9)	Bi 172 ± 12 Ma	Hb-Bi Gr	Mt, trace Ti	Intrudes Units H,1,4	Porphyry Cu-Au	Schalt Ck
	Unit 8		Bi-Hb Gd to Qz Mz	Variable Ti and Py	Intrudes Units A,6	Skarns	Dokdaon Ck
	Unit 7		Bi-Hb Di to Qz Di	Py	Cogenetic with Unit 8		Deeker Ck
Early Jurassic	Unit 6		Hb Qz Mz to Gr	Ti, trace Mt	Intruded by Unit 8	Porphyry Cu-Au	Pereleshin Mt.
Middle to Late Triassic	Hickman Pluton: Unit 5		Megacry Qz Di	Py	Intrudes Unit 2		Trundle Ck
	Main Phase (4)	Bi 209 ± 15 Ma	Hb-Bi Gd to Qz Mz	Mt, trace Ti	Intrudes Units 2,G,H		Trundle Glacier
	Mafic Phase (3)		Hb-Gabbro	Mt	Gradational with Unit 4		Mt. Hickman
	Ultramafic Rocks (2)		Ol-Pxt, Dunite	Mt, Cr	Intruded by 4,5	Asb,Listwanite PGE	Mt. Hickman, Trundle Ck
	Nightout Pluton (1)	Bi 236 ± 18 Ma	Hb-Bi Gd to Qz Mz	Ti	Not seen	Porphyry Cu-Au	Schaft Ck

Note 1. Isotopic dates from Holbek (1988) with 2 sigma errors.
Note 2. Hickman batholith = Hickman pluton, Yehiniko pluton, Nightout pluton.

Abbreviations: Asb = Asbestos; Au = Gold; Bi = Biotite; Cr = Chromite; Ck = Creek; Cu = Copper; Di = Diorite; Gd = Granodiorite; Hb = Hornblende; Megacry = Megacrystic; Mo = Molybdenite; Mt = Magnetite; Mz = Monzonite; Mt. = Mount; Ol = Olivine; PGE = Platinum group elements; Py = Pyrite; Px = Pyroxene; Pxt = Pyroxenite; Qz = Quartz; Sy = Syenite; Ti = Titanite.

(Nixon *et al.*, 1989, this volume). Part of the core is a small dunite body with serpentinized and fresh olivine. The dunite core surrounded by clinopyroxenite, abundance of magnetite and lack of orthopyroxene are characteristic of Alaskan-type ultramafic complexes (Nixon and Rublee, 1988). The ultramafic phase intrudes plagioclase-porphyritic andesitic flows tentatively correlated with the Stuhini Group.

The Trundle Creek ultramafic body comprises variably serpentinized, fine-grained pyroxenite. It is in fault contact with Permian limestone and is intruded by the megacrystic quartz diorite phase (Unit 5). The north-trending Endeavour Mountain body displays attributes of both the ultramafic bodies and metavolcanic rocks. Leucoxene was noted by Souther (1972) which led him to suggest a volcanic protolith.

Hickman Pluton

The composite Hickman pluton underlies an area of 300 square kilometres and is made up of three distinct phases as described below with the oldest first.

The **mafic phase (Unit 3)** is composed of a medium-grained, equigranular, hornblende gabbro and plagioclase-bearing hornblendite. The contact with the main phase is gradational locally and elsewhere mafic xenoliths (Unit 3) occur within the main phase.

The heterogeneous **main phase (Unit 4)** is the most extensive and is dominated by medium-grained, equigranular, dull grey hornblende-biotite granodiorite to quartz monzodiorite. Tonalite and quartz diorite are subordinate and their relationship to the main body is uncertain. Magnetite and rare titanite are accessory minerals. Late Triassic potassium-argon ages of 209 ± 15 Ma (biotite) and 221 ± 16 Ma (hornblende; Holbek, 1988) were determined for the main phase. It intrudes ultramafite, the mafic phase of the pluton, Stuhini Group volcanic rocks near Schaft Creek, and Middle Triassic sediments at the toe of the Scud Glacier.

Megacrystic quartz diorite (Unit 5) outcrops on the west margin of the Hickman pluton. It is a large intrusive body (12 square kilometres) that outwardly resembles the megacrystic quartz monzonite (Unit 6), however, the rectangular megacrysts, up to 5 centimetres long and comprising 60 to 80 per cent of the rock, are plagioclase, not potassium feldspar. Quartz (up to 20 per cent) and about 10 per cent hornblende, altered biotite and magnetite fill interstitial spaces between megacrysts.

The body intrudes ultramafic rocks along its western contact, however, the character of its eastern margin is uncertain. The body is at least spatially associated with the Hickman pluton. At one locality it has a gradational, poorly defined contact with the main phase (Unit 4) and in another it intrudes the mafic phase (Unit 3). It may be Late Triassic or Early Jurassic in age.

EARLY JURASSIC SUITE (UNIT 6)

MOUNT PERELESHIN STOCK

The Mount Pereleshin stock is a circular body, about 10 kilometres in diameter. It is composed of grey, medium-grained, porphyritic hornblende quartz monzonite to granite. Potassium feldspar megacrysts account for 20 to 40 per cent of the rock; anhedral quartz, 10 to 25 per cent, and fresh euhedral black hornblende and trace biotite, 10-20 per cent. Large titanite crystals, magnetite and apatite are distinctive accessory minerals. Fine-grained mafic inclusions are common. West of Mount Pereleshin this body is intruded by hornblende-biotite granodiorite of Unit 8.

BUTTERFLY CREEK PLUG

The Butterfly Creek plug is a small elongate body about 1 kilometre wide and less than 2 kilometres long, located northwest of the headwaters of Butterfly Creek. Foliated potassium feldspar megacrysts are abundant (up to 70 per cent), coarse grained (up to 5 centimetres) and distinctive. Epidotized and chloritized hornblende comprise less than 5 per cent of the rock. Disseminated pyrite and magnetite are important accessories locally. A mylonitic northeast margin and a commonly finer grained and chloritic selvage marks the contact with chloritic, foliated basement rocks of the Stikine assemblage.

A dyke-like polymictic intrusive breccia crops out on the northeast side of Butterfly Lake. It contains fragments of green, grey and black chert, granitic rocks and potassium feldspar crystals, in a dark green, chloritie matrix.

A biotite hornfels contact metamorphic aureole surrounds this intrusion and contains an altered metamorphic mineral believed to be relict andalusite(?); if so, shallow emplacement is indicated.

OKSA CREEK STOCK

The Oksa Creek stock is about 3 kilometres in diameter and is exposed in the headwaters of Oksa Creek. It is a massive, coarse to medium-grained crowded megacrystic quartz monzonite. Abundant potassium feldspar megacrysts (up to 60 per cent), hornblende (up to 25 per cent), coarse-grained titanite (up to 2 centimetres) and epidote (up to 5 per cent) are distinctive.

Similar orthoclase-megacrystic quartz monzonite to syenite stocks with aegirine-augite, biotite and garnet outcrop in the Galore Creek area to the south, where they are related to porphyry copper mineralization. Three potassium-argon ages for hydrothermal biotite from the main Galore Creek intrusive body range from 177 ± 18 to 201 ± 14 Ma (White *et al.*, 1968; all dates are recalculated using decay constants of Steiger and Jäger, 1977). Early Jurassic alkaline plutonism is associated with mineralization on a regional scale from Silbak Premier (Brown, 1987) northward to Sulphurets and Galore Creek. Although the alkaline intrusions in the project area are not hosted by Triassic or Jurassic volcanic rocks, they warrant further exploration.

MIDDLE JURASSIC SUITE

Three different intrusive phases make up the Middle Jurassic suite. Two phases, quartz diorite (Unit 7) and hornblende granodiorite (Unit 8), occur in the western and central parts of the map area. The third phase, the Yehiniko pluton (Unit 9), together with the adjacent Nightout and Hickman plutons, constitutes the Hickman batholith in the eastern part of the map area.

QUARTZ DIORITE (UNIT 7)

The oldest, most mafic and heterogenous phase of this suite is best exposed in an east-trending body south of Deeker Creek. It is composed mainly of medium-grained, equigranular biotite hornblende diorite to monzodiorite. Less common are mafic pegmatites and hornblendites, characterized by irregular dark patches of coarse-grained acicular hornblende (up to 3 centimetres), and scattered interstitial quartz, plagioclase and potassium feldspar.

A highly deformed contact between foliated diorite-amphibolite schlieren (Unit 7) and foliated limestone (Unit E) is exposed in the headwaters of Navo Creek; there the contact zone contains layers and pods of garnet and garnet-diopside skarn up to 75 metres from the contact.

HORNBLENDE BIOTITE GRANODIORITE (UNIT 8)

This intermediate phase is the most extensive and underlies 350 square kilometres of the southeastern and central parts of the map area. It is composed of mesocratic, medium-grained, equigranular hornblende-biotite quartz monzodiorite to granodiorite. Titanite is a ubiquitous accessory mineral. Miarolitic cavities are common near Mount Pereleshin. This phase is compositionally similar to, and difficult to distinquish from, the Nightout pluton, however, it is isotopically younger.

The contact with quartz diorite (Unit 7) is gradational south of Deeker Creek. Elsewhere, diorite occurs as angular xenolithic blocks in granodiorite, or intruded along joints by Unit 8.

Granodiorite intrudes and disrupts bedding and cleavage in basement limestone between Navo and Oksa creeks. Hornblende from the granodiorite phase east of Galore Creek has a discordant potassium-argon age of 197 ± 10 Ma (hornblende) and 120 ± 10 Ma (biotite; Panteleyev, 1976).

YEHINIKO PLUTON (UNIT 9)

The Yehiniko pluton outcrops over an area of 200 square kilometres and is composed of a medium-grained, equigranular, distinctive flesh to salmon-pink biotite hornblende granite. It is distinquished from the biotite granite (Unit 10) by its flesh to tan colour and higher mafic content, which includes hornblende. The rock contains 30 to 40 per cent quartz, 30 per cent potassium feldspar, 25 per cent plagioclase and 10 to 15 per cent mafic minerals. Plagioclase is moderately saussuritzed, unlike the inferred younger biotite granite (Unit 10). Magnetite and subordinate titanite are ubiquitous. Along the Scud Glacier, the pluton intrudes pyroxene-porphyritic Stuhini Group volcanic rocks on the east and the Nightout and Hickman plutons to the north and south, respectively. The Yehiniko pluton biotite has a potassium-argon age of 172 ± 12 Ma (Holbek, 1988).

EOCENE SUITE

BIOTITE GRANITE (UNIT 10)

The youngest plutonic suite comprises biotite granite of about 350 square kilometres area in the central and western parts of the map area. It is composed of a medium to coarse-grained, equigranular to quartz-phyric, dull grey to pink, biotite granite. Quartz is commonly coarse grained and makes up 40 to 50 per cent of the rock: potassium feldspar, 30 per cent (locally forming megacrysts); plagioclase, 20 per cent; and biotite, less than 4 per cent comprise the balance. Miarolitic cavities filled with quartz, epidote and pyrite occur near Oksa Creek.

Limestone blocks within the granite are skarnified, foliated and exhibit two-dimensional, "chocolate tablet" boudinage at Mount Jonquette where exoskarn in limestone pendants and endoskarn within the intrusion are exposed. Biotite granite intrudes Stikine limestone in the headwaters of Oksa Creek where exoskarn (two garnet phases, diopside, epidote and wollastonite) extends up to 10 metres from the irregular contact. Boudinaged calc-silicate layers and pods in grey marble contain quartz cores surrounded by radiating wollastonite needles and an outer rim of diopside. Malachite-stained fractures occur near the contact, in both the limestone and intrusions.

The granite phase intrudes diorite (Unit 7) and granodiorite (Unit 8) north of Oksa Creek. Contacts are very irregular and distinguishing this phase from the pink granite of the Yehiniko pluton is often difficult; both have prominent joint sets.

Two small plugs south of Galore Creek, included in this phase, yielded potassium-argon ages of 48.9 ± 4 and 53.5 ± 4 Ma for biotite (Panteleyev, 1975 and 1976).

FELDSPAR-PORPHYRITIC GRANODIORITE (UNIT 11)

A north-trending body of limonitic porphyritic granodiorite along the Scud River is elongate subparallel to a major fault. The body contains prominent white plagioclase laths in a fine-grained green groundmass. The rock is anomalous in its degree of fracturing and pervasive propylitic alteration relative to the other intrusions. Chlorite, sericite and pyrite are abundant. The granodiorite intrudes Permian limestone and apparently crosscuts the fault zone because postemplacement movement along the fault is minor.

The intense hydrothermal alteration and apparent structural control of the intrusion suggest it has mineral potential. The Trophy Gold property is located to the south (104G/3) along the same fault system. The age of this porphyry is unknown; it is tentatively grouped with the Tertiary suite, but may correlate with an unaltered granodiorite south of the Scud River (104G/3) that yielded an Early Jurassic age (White *et al.*, 1968).

DYKES

Dykes of different age, composition and orientation are abundant. Felsic dykes are the most prominent. A steeply dipping, north-striking felsic dyke swarm extends more than 20 kilometres from the headwaters of Navo Creek to Dokdaon Creek across an area 2 kilometres wide (Figure 1-29-2). The buff-weathering, quartz-phyric dykes are 1 to 7 metres wide. Some are flow banded and others are stained with manganese oxide on joint surfaces. These felsic dykes cut a swarm of vesicular basalt dykes in the Oksa Creek area. The vertical, north-striking mafic dykes are generally narrower, closer spaced and more uniform in width. The felsic dykes may be related to Eocene Sloko Group subaerial volcanic rocks exposed farther to the north.

East-trending, olivine(?)-pyroxene-porphyritic basalt dykes are generally less than 3 metres wide and form two major swarms up to 3 kilometres wide. The most significant exposures occur in the centre of the Hickman pluton and near the Yehiniko-Nightout pluton contact. In these areas, they intrude both Middle Jurassic and older plutonic rocks of the Hickman batholith and volcanic rocks of the Stuhini Group. These mafic dykes are probably Miocene or younger, and related to the Mount Edziza complex.

METAMORPHISM

Metamorphic grade ranges from lower greenschist in the Stikine basement unit to subgreenschist in the Stuhini Group. Chlorite-sericite-pyrite comprise the greenschist assemblage. Stuhini Group amygdaloidal basalts contain low pressure and temperature zeolites and, therefore, were never deeply buried. The timing of metamorphism is unconstrained in the study area.

STRUCTURE

Four structural domains are defined on the basis of fold geometry, foliation and bounding faults (Figure 1-29-3). These domains are a preliminary attempt to sort field data. In general, stratified rocks above the rusty argillite (that is, Permian and younger) are less deformed and lack the pervasive foliation found in the older rocks.

Domain I is confined to the basement and siliceous units and is characterized by a steep to vertical, northwest-striking chlorite-sericite foliation and upright, tight to isoclinal chevron folds that plunge gently to the southeast, as observed in Navo and Rugose creeks (Plate 1-29-2; Figures 1-29-4 and 1-29-5). Where folds are not visible, bedding-cleavage intersections indicate strata are tightly folded. The deformation accounts for at least 35 per cent shortening of the siliceous unit in the Rugose Creek area. Lithic fragments are flattened in the foliation plane with length-to-width strain ratios of 10 to 1.

Following this early deformation, a period of southwest-directed compression produced southwest-verging minor folds and reverse faults. Asymmetric west-verging, northwest-trending minor folds and crenulations occur near Oksa Mountain (Plate 1-29-3). Folds are distinctly southwest-verging near reverse faults. Locally beds are overturned to the southwest on the hangingwall of inferred thrust faults. Domain I appears to be an imbricated stack of southwest-directed thrusts involving basement and siliceous unit rocks crosscut on the west by intrusive rocks.

Domain II is characterized by apparently uniform, shallow to moderate easterly dips in the rusty argillite and limestone succession. In fact, the domain is complicated by east-dipping reverse (thrust?) faults, as in Domain I, and recumbent folds. A large recumbent syncline with S, Z and M-type minor folds can be followed along a cliff face for over 2 kilometres on the north side of Rugose Glacier. The upper limb is truncated by a fault inferred to be an east-dipping, west-directed thrust. Minor fault splays occur lower in the section. These thrusts are consistent with faults mapped by Souther (1972) in 104G/3, where Permian limestone overlies Middle Triassic shale and siltstone. The section was structurally thickened by folding and thrust faulting and beds were locally overturned. Common southwest-verging asymmetric minor folds (Plate 1-29-4) geometrically similar to Domain I, suggest that the entire sequence may be on the northeast limb of a larger anticlinorium, however, the southwest limb was not recognized.

The lower, western boundary of this domain is either an angular unconformity or a detachment fault between the often steeply dipping siliceous unit and the moderate northeast-dipping rusty argillite unit that is conformable with overlying Permian limestone. The upper, eastern boundary is largely covered by ice, but is interpreted to be a detachment between Domains II and III, which exhibit different fold styles.

Domain III forms a narrow zone of large, upright, open to tight, north-trending folds in the upper member limestone (Unit F), between Domain I and the north arm of the Scud

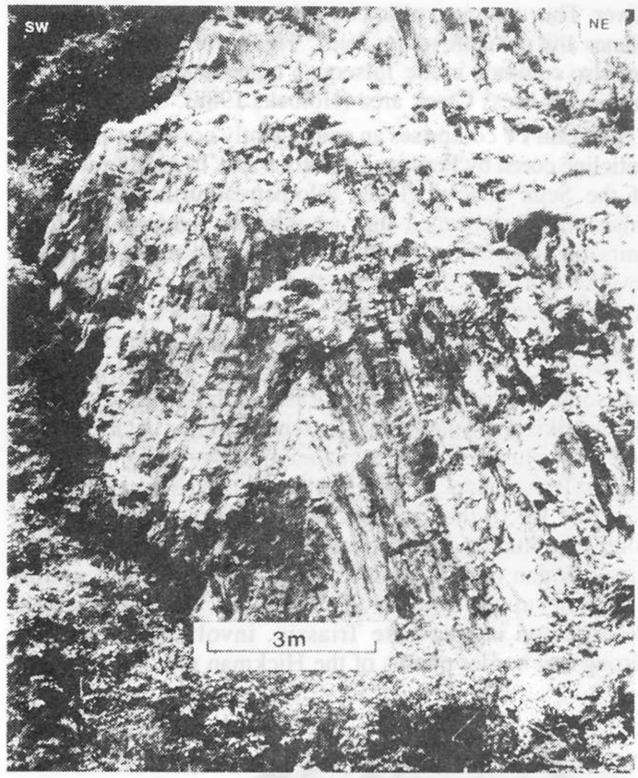


Plate 1-29-2. View southeast to tight, upright chevron fold that is characteristic of siliceous unit (Unit C) in structural Domain I.

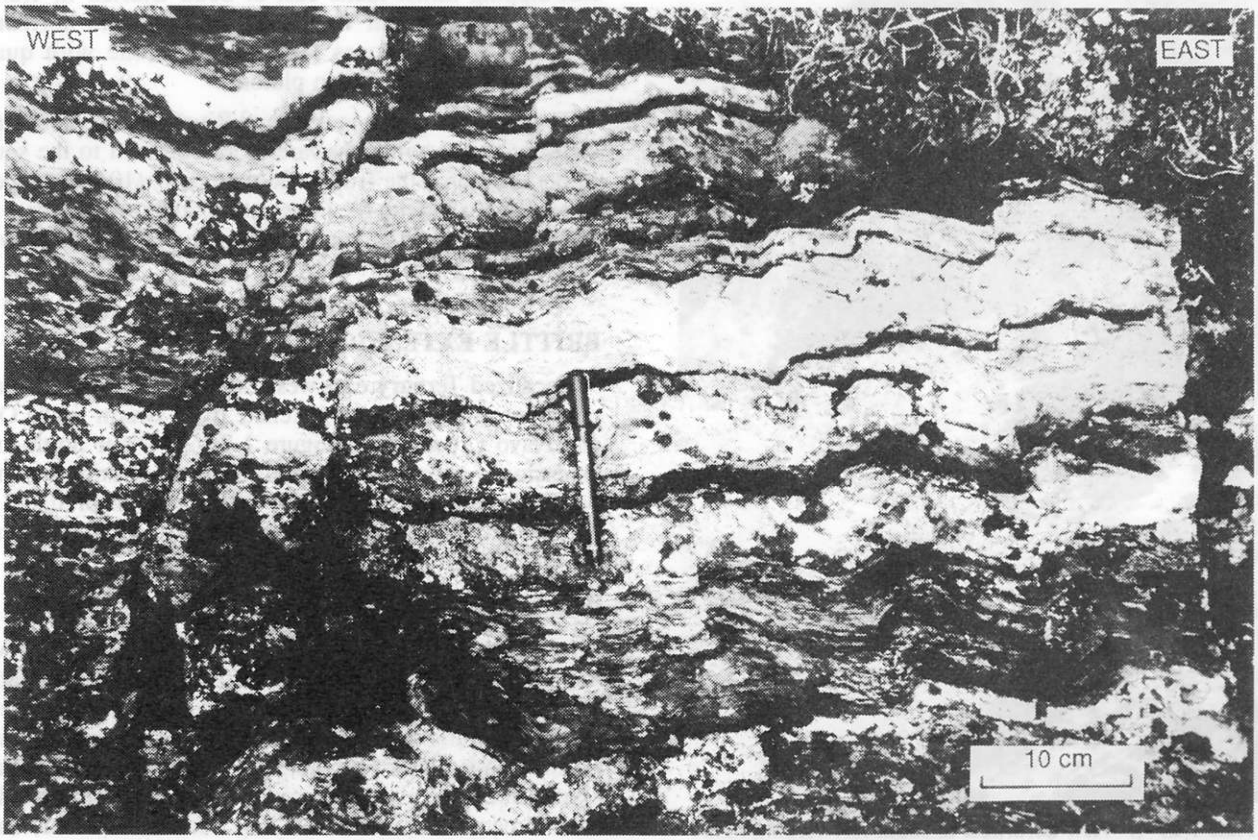


Plate 1-29-3. View north to west-verging, asymmetric minor folds in well-foliated silicic tuff of the volcanic facies (Unit A) in structural Domain I.

River. This zone is typified by folds with near-vertical axial planes and parasitic minor folds. Tight, north-trending folds are also common in the Tulsequah map area (Souther, 1971) and in the Mess Creek area (Holbek, 1988).

Domain IV comprises an open, gently northeast-plunging anticline cored by Permian limestone and Triassic strata, east of the Scud Glacier. Three kilometres further south, the limestone is deformed into asymmetric synform-antiform pairs disrupted by faults, interpreted to be southwest-directed reverse (thrust?) faults. The thrust faults, delineated by strongly foliated zones up to 2 metres wide, occur either within or above a Permian(?) limestone east of Scud Glacier. Folds adjacent to the thrusts are gently southeast plunging and southwest verging, with northeast-dipping axial planes. West-striking normal faults crosscut the thrust faults. Local, northeast-plunging tight syncline-anticline pairs involving Upper Triassic rocks extend as far as the Hickman pluton. Near the toe of the Trundle Glacier, a large, upright, tight southeast-plunging anticline is intruded by a border phase of the Hickman pluton, which itself is reverse faulted against limestone in the core of the anticline. The contractional deformation is post-Late Triassic, involving the Stuhini Group and border phases of the Hickman pluton.

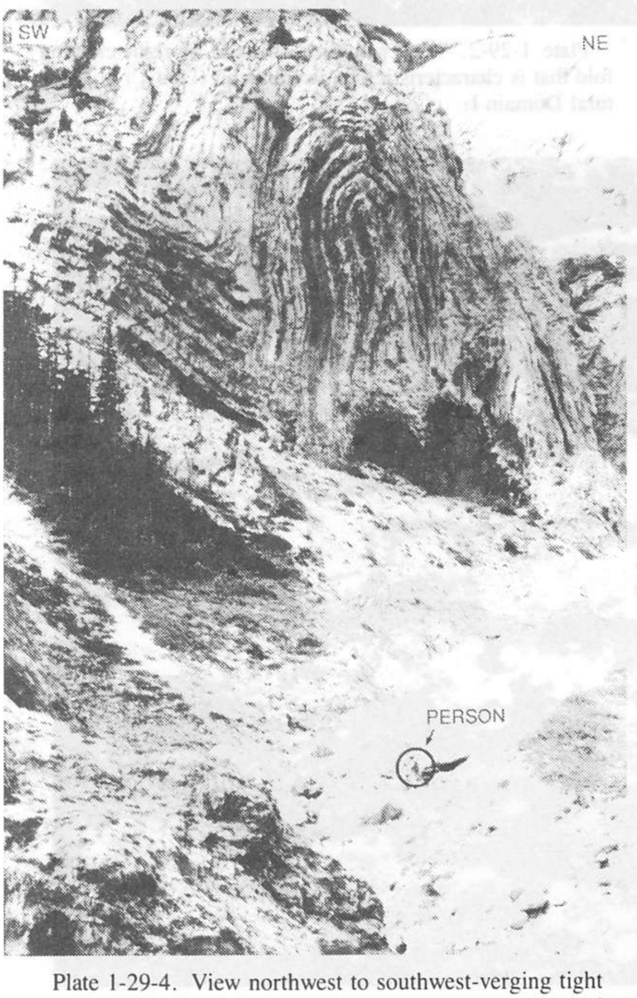


Plate 1-29-4. View northwest to southwest-verging tight to isoclinal folds in lower limestone (Unit E) in structural Domain II.

FAULTING

Five sets of faults identified in the Scud River area include: (1) northeast-dipping reverse faults; (2) north-trending vertical faults; (3) steep to vertical, northwest-striking faults; (4) west-striking extensional faults; and (5) northeast-striking shear zones.

A northeast-dipping set of reverse faults in Domains I and II forms an imbricate stack of Stikine assemblage rocks. East of Scud Glacier mylonitic Permian limestone was thrust onto thinly bedded Permian(?) limestone, argillite and volcanics. Near Cone Mountain one of these faults juxtaposes basement volcanics and foliated granodiorite (Unit 8). Therefore, the deformation is probably post-Early Jurassic. Platy, planar mylonites are associated with ductile faults. Foliated intrusions associated with reverse faults have a penetrative biotite and/or chlorite foliation.

North-trending vertical to steeply east-dipping normal faults separate Permian limestone from Stuhini Group volcanics near the toe of Scud Glacier and extend south to Sphaler Creek (104G/3). The coplanar Mess Creek fault zone, 30 kilometres to the east, was active from Early Jurassic to post-Pleistocene (Souther and Symons, 1974).

Northwest-striking faults occur along the Scud River valley and some predate the north-trending set (Souther, 1972).

Narrow west-striking extensional fault zones are subvertical or dip gently to the north. North-side-down motion on the faults postdates the north-trending faults and northeast-dipping thrust faults east of Scud Glacier. In Trundle Canyon a prominent west-striking fault with horizontal slickensides juxtaposes Permian limestone with quartz monzonite of the Hickman pluton.

The youngest faults in the Scud River area are **northeast-striking shear zones** that are more common to the south. Mineralization at the Trophy Gold property (104G/3) appears to be associated with the intersection of the small shears and major north-trending faults (D.B. Forster, personal communication, 1988).

BRITTLE EXTENSION

Localized Tertiary east-west extension is evident from a prominent steeply dipping, felsite dyke swarm in the Oksa and Navo Creek areas (Figure 1-29-2). Older north-south extension is indicated by a prominent east-striking swarm of basalt dykes in the Hickman batholith that predates the Tertiary rhyolite dykes but must be post-Middle Jurassic.

DEFORMATION OF INTRUSIONS

In general, intrusions are massive unfoliated bodies with steep contacts. Along Oksa Creek, pluton intrusion either crosscut moderately dipping, little-deformed limestone or induced bedding-parallel cleavage in limestone whose orientation changes with proximity to the granodiorite contact. Other structures in intrusive rocks are scattered, narrow (less than 1 metre wide), east-trending ductile and brittle shear zones superimposed on massive granitoids west of the Stikine River.

STRUCTURAL SYNTHESIS

The marked structural discordance between Domains I and II suggests a pre-Permian deformational event that folded and cleaved the basement and siliceous units prior to limestone deposition. Two phases of deformation are assumed, based on fold geometry and orientation, although no interference patterns were observed. Farther south, near Sphaler Creek, there is evidence of a post-Mississippian, pre-Permian unconformity (Souther, 1972) that supports this interpretation.

The ages of deformation are poorly constrained and are difficult to correlate regionally. In the Grand Canyon of the Stikine River, 50 kilometres to the north-northeast, there is an older north-northeast and a younger west-northwest structural trend (Gabrielse *et al.*, in preparation). Middle Jurassic (Toarcian to Bajocian) southwest-directed folding and thrusting of the Upper Triassic King Salmon assemblage in the Cry Lake map area has been documented by Thorstad and Gabrielse (1986). Pre-Early Cretaceous east-northeast-trending folds are found in the northwest corner of the Bowser Basin (Gabrielse *et al.*, in preparation). Evenchick (1986) identified Cretaceous to Early Cenozoic northeast contraction in the Bowser and Sustut basins.

Souther (1972) used the term "Tahltanian orogeny" to describe a Permo-Triassic event that deformed Middle Triassic and older rocks. A pre-Permian thermal event is evident in conodont colour alteration indices greater than 5 for Permian and older strata and less than 5 in Triassic and younger rocks (Anderson, 1988). The presence of fusulinid-bearing limestone boulders in Upper Triassic conglomerate suggests the Paleozoic section was eroded in the map area.

GEOCHEMISTRY – STREAM SEDIMENT SAMPLING

Data from the 1987 Regional Geochemical Survey (RGS) were released for the Telegraph (104G) and Sumdum (104F) map sheets in July 1988 and include analyses of 136 silt and water samples collected from within the project area (Figure 1-29-3).

Arbitrarily determined anomalous samples fall in the 90th percentile and higher for the entire sample population for each element on both the Telegraph and Sumdum map sheets. Known deposits in the area such as Galore Creek and Schaft Creek display strong stream-sediment signatures. In addition, many multi-element anomalies are present in little-explored and unstaked areas.

Precious metal anomalies are scattered. Only five stream sediment samples are anomalous in gold, and only one of these is anomalous in other base or precious metals. The highest gold value (258 ppb) came from a sample on Christina Creek in the southwest corner of the map area where an Eocene pluton outcrops. Samples along this creek are also anomalous in barium, tungsten and molybdenum. Anomalous gold, silver, arsenic, lead, cadmium, tungsten and molybdenum values at the head of Dokdaon Creek are one of the strongest multi-element anomalies in the map area. The area is underlain by Middle Jurassic granodiorite (Unit 8) and the mineralization located on the Marg claims (MINFILE 104G 058, 089) may be the anomaly source.

Several other significant multi-element anomalies are located east of the toe of the Scud Glacier, in the middle reaches of Oksa and Schaft creeks, and near the headwaters of Hickman and Yehiniko creeks.

Samples along Yehiniko Creek at the northern edge of the project area are anomalous in silver, arsenic, antimony, copper, lead, cadmium, tungsten and cobalt. The stream drains an area underlain by Upper Triassic volcanic rocks and the anomalies may be associated with the Yehiniko East copper showing (MINFILE 104G 111) located farther upstream. Midway up Oksa Creek there are several samples anomalous in silver, arsenic, lead, barium, cadmium, tungsten, tin and fluorine. This area is underlain primarily by basement volcanic rocks (Unit A) near the contact with several different plutonic bodies.

West of the toe of the Scud Glacier, two sample sites are anomalous in silver, lead, cadmium, tin and molybdenum. This area is underlain by Upper Triassic sedimentary and volcanic rocks and Permian limestone with a major north-trending fault juxtaposing the units. On Schaft Creek there are several very strong multi-element anomalies. These sites are anomalous in arsenic, copper, lead, zinc, barium, tungsten and molybdenum. The area is underlain by both the Yehiniko and Nightout plutons, near their eastern contact with Upper Triassic volcanic rocks. These samples occur 10 kilometres north of the Schaft Creek porhyry copper deposit.

The two ultramafic bodies associated with the Hickman pluton have strong nickel-cobalt anomalies. On lower Trundle Creek, the samples are also highly anomalous in arsenic and antimony. This area contains numerous north-trending faults juxtaposing and crosscutting Permian and Triassic strata and the Hickman ultramafic body. East of Mount Hickman, near the headwaters of Hickman Creek, two samples are highly anomalous in nickel and cobalt and probably reflect the Hickman mafic and ultramafic phases outcropping to the west. These samples however, are also anomalous in silver, arsenic, antimony and tin. The area is underlain by Upper Triassic volcanic rocks near the eastern contact of the Hickman pluton.

The study area contains one-third of all samples from the Sumdum and Telegraph sheets that are anomalous in tungsten. Fluorine and uranium anomalies occur almost exclusively within Lower and Middle Jurassic and Eocene plutonic rocks in the western half of the project area. This may provide a useful geochemical signature for differentiating these plutonic suites from the Hickman batholith. There are no mercury anomalies and only two vanadium anomalies.

MINERALIZATION

The project area lies within a metallogenic belt that hosts precious and base metal deposits from Alice Arm north to the Taku River, along the eastern margin of the Coast Belt. The remoteness and rugged topography are key factors influencing the economics of exploration in the Scud River area.

Prospectors first came into the Stikine River valley in search of placer gold during the late 1800s. Activity peaked during the early 1860s, however, production was insignificant. During the early 20th century, attention turned to the

TABLE 1-29-2
SUMMARY OF MINFILE OCCURRENCES (104G/5 AND 6)

Number (104G)	Name	Commodity	Economic Minerals	Deposit Type	Description
006	ALBERTA	Cu	Cpy, Mt	Vein	The showing is hosted in a small pendant of Stuhini Group mafic flows and pyroclastics within the Hickman pluton. Chalcopyrite and magnetite occur as fracture fillings with minor malachite.
014	BEN	Mo, W, Ag,	Mo, Cpy, Py, Tet	Vein/Stck	Showing is hosted in a large felsic Tertiary(?) dyke hosted in Eocene biotite granite. Pervasive silica, manganese and sericite alteration host molybdenite, chalcopyrite, pyrite, and tetrahedrite stockworks.
030	NABS 21	Cu	Cpy, Bo	Stck/Dis	Showing is hosted mainly in silicified and chloritized quartz monzonite of the Yehiniko pluton near the contact with the Stuhini Group. Finely disseminated chalcopyrite and lesser bornite occur.
031	NABS 13	Cu	Cpy, Bo	Stck/Dis	Showing is hosted largely in fractured Stuhini Group volcanic rocks near quartz monzonite of the Yehiniko pluton. Stringers of chalcopyrite and lesser bornite occur.
032	NABS 30 FR	Cu, Au Mo	Cpy, Bo, Mo, Py	Stck/Dis	Prospect located immediately north of the Liard copper deposit is hosted mainly in Stuhini Group volcanics near the Yehiniko pluton. Stringers and disseminations of chalcopyrite and bornite occur.
037	HICKS	Cu, Mo	Bo, Cpy, Mo, Py	Stck/Dis	Showing is hosted mainly in Stuhini Group volcanics near the eastern margin of the Hickman pluton. Blebs, stringers and disseminations of pyrite, chalcopyrite, bornite, and lesser molybdenite occur.
054	MOUNT HICKMAN	Asb	Asb	Repl	Showing occurs near the southeast margin of the mafic/ultramafic phase of the Hickman pluton. Narrow seams of antigorite occur in pyroxene gabbros and olivine pyroxenites.
055	MIDDLE SCUD	Cu, Ag	Tet, Agt Cpy	Podiform	Showing occurs within the Trundle Creek ultramafic body along its eastern fault contact with Permian limestone and argillite. Pyroxenite hosts a 75 cm long pod of massive tetrahedrite and chalcopyrite.
056	NORTH SCUD	Cu	Cpy, Bo,	Podiform	Showing occurs within Stuhini Group andesite tuff and breccia near the western margin of the Hickman pluton. Small lenses up to 25 cm long consist of massive chalcopyrite, bornite, and magnetite.
058	MARG WEST	Au, Ag, Cu, W, Mo, Pb	Cpy, Mo, Sch, Gln	Stck	Showing occurs in a 300 by 600 metre pendant of Stuhini Group volcanic breccia within Middle Jurassic granodiorite. Narrow quartz veinlets <10 cm wide occur over a width of 100 metres and contain chalcopyrite, molybdenite, pyrite, scheelite, and minor galena.
062	COS	Cu	Cpy, Bo	Stck	Showing occurs at the contact of pre-Permian limestone with Lower Jurassic orthoclase-megacrystic granite. Mineralization consists of chalcopyrite and bornite stringers within a large skarn zone.
063	LATE	Cu, Au	Cpy, Bo, Ply	Stck/Dis	Showing occurs on a sheared contact between the Yehiniko pluton and flows and pyroclastics of the Stuhini Group. Sulphides consist of pyrite, chalcopyrite and bornite as stringers and disseminations.
075	GU	Cu, Pb, Zn, Mo, W	Cpy, Gln, Sphl, Mo, Sch	Stck	Showing occurs in a small volcanic pendant within a large body of Middle Jurassic granodiorite. Sulphides occur in narrow quartz veinlets within prominant northwest joint sets and consist of chalcopyrite, galena, sphalerite, molybdenite, and rare scheelite.
078	ARC, POST	Cu	Cpy, Bo, Cc, Py	Vein/Dis	Mineralization occurs within purple pyroclastics of the Stuhini Group and along shears within the Yehiniko pluton. Sulphides comprise chalcopyrite, bornite, chalcocite and pyrite as stringers and blebs.
084	GU NORTH	Cu	Cpy	Vein	Showing occurs in a small volcanic pendant within a large body of Middle Jurassic granodiorite. Narrow quartz veinlets peripheral to a 1.5 metre wide ankerite vein contain trace chalcopyrite.
089	MARG EAST	Au, Ag, Cu, W,	Cpy, Py	Vein/Alt	Showing ocurs at the sheared contact of a Stuhini Group volcanic pendant within a Middle Jurassic granodiorite body. Chalcopyrite and pyrite occur in zones of pervasive silica and epidote alteration.
111	YEHINIKO EAST	Cu	Unknown	Unknown	Occurrence comprises unspecified copper mineralization (Souther,1972) along large, possibly fault-controlled alteration zones along the contact of Stuhini Group volcanics and the Yehiniko pluton.

Abbreviations: Alt = Alteration; Agt = Argentite; Asb = Asbestos; Bo = Bornite; Cc = Chalcocite; Cpy = Chalcopyrite; Dis = Disseminated; Gln = Galena; Mo = Molybdenite; Mt = Magnetite; Py = Pyrite; Repl = Replacement; Sch = Scheelite; Sphl = Sphalerite; Stck = Stockwork; Tet = Tetrahedrite; W = Tungsten.

lode deposits (Kerr, 1948a). By the late 1950s the search for asbestos around Mount Hickman had resulted in the discovery of significant copper deposits near Schaft Creek and later Galore Creek. The Silbak Premier, Snip, Sulphurets, Johnny Mountain and Golden Bear projects are prime examples of more recent development of precious metal deposits in the belt (Figure 1-29-1).

MINERAL PROSPECTS

There are 19 known mineral occurrences (16 recorded in MINFILE) and one major prospect in the map area (Table 1-29-2; Figure 1-29-3). Exploration activity was moderate in 1988; Continental Gold Corporation drilled its Trophy Gold property (104G/3). The Regional Geochemical Survey release stimulated additional staking and grassroots exploration. Following are brief descriptions of the important mineral prospects.

SCHAFT CREEK PORPHYRY COPPER-MOLYBDENUM DEPOSITS (MINFILE 104G 090, 099)

The Schaft Creek (Liard Copper) deposits on the eastern side of Schaft Creek were staked in 1957 and have been explored by Silver Standard Mines Ltd., American Smelting and Refining Company, Hecla Mining Company and Teck Corporation. Up to 1975, about 34 500 metres of surface diamond drilling in 115 holes had been completed (Fox *et al.*, 1976). The deposit geology is reviewed by Linder (1975) and Fox *et al.* (1976).

Ninety per cent of copper mineralization (Linder, 1975) is hosted in Stuhini Group volcanic rocks and 10 per cent in felsic dykes and quartz feldspar porphyry correlated with the Early Jurassic Yehiniko pluton. Mineralization is dominantly fault and fracture controlled, and is discordant to volcanic strata. A whole-rock potassium-argon age for mineralized rocks with hydrothermal biotite yielded 185 ± 10 Ma (recalculated with decay constants of Steiger and Jäger, 1977; from Panteleyev and Dudas, 1973), which may indicate the age of mineralization. Ore reserves are 330 million tonnes of 0.40 per cent copper and 0.036 per cent molybdenum with an open-pit stripping ratio of 1.5:1. Precious metal values are estimated at 0.32 gram gold and 1.5 grams silver per tonne (Fox *et al.*, 1976).

BEN OCCURRENCE (MINFILE 104G 019)

The Ben porphyry molybdenum-copper occurrence is located at the headwaters of Deeker Creek, west of the Stikine River. The property was explored in 1962, 1963 and 1971 when about 1150 metres of surface diamond drilling in six holes was completed by Dictactor Mines Limited. The occurrence consists of a zone, up to 1000 metres wide, of argillic, silicic and manganese alteration associated with a fine-grained felsic intrusion of probable Tertiary age and a medium-grained biotite granite (Unit 10). The zone is clearly visible as a huge limonitic stain zone. The showing consists mainly of quartz stringers and disseminations of molybdenite with lesser chalcopyrite, pyrite and tetrahedrite.

MARG WEST AND MARG EAST (MINFILE 104G 058, 089)

The property is located at the headwaters of Dokdaon Creek (Figure 1-29-3) and consists of two prominent limonitic stain zones related to Tertiary(?) felsite dykes that intrude massive biotite hornblende granodiorite (Unit 8). The property was staked in 1958 and mapped in 1980 and 1981 by Teck Corporation. Since then, little work has been done. Isolated pendants of Stuhini Group(?) heterolithic volcanic breccia outcrop along the creek that drains the main showing. Massive, north-trending magnetite-pyrite lenses and pods, up to 5 metres long, parallel the dyke contact. Northwest-striking quartz veins contain pyrite, chalcopyrite, molybdenite, scheelite and minor galena (Folk, 1981).

NEW SHOWINGS

Two types of mineralized boulders were found in Deeker Creek south of the Ben prospect, in the course of this study. The first consisted of rusty weathering, semimassive to massive pyrite layers in fine-grained white vuggy quartz. The second was a vuggy quartz-carbonate vein and breccia with disseminated chalcopyrite, galena and pyrite, and stained with manganese oxide. The source of these rocks is not known. The Ben occurrence is also characterized by weathered surfaces stained with manganese oxide but none of the drill core contained copper and lead mineralization of comparable grade.

At the headwaters of Rugose Creek there is an abundance of skarn material in glacial outwash. The boulders are malachite-stained, limonitic, fine-grained garnet-actinolite rock with disseminated pyrite, with or without magnetite and minor chalcopyrite. The Rugose Glacier overlies the contact of limestone with granodiorite (Unit 8), the probable source area for the float.

Several narrow, buff-weathering, siderite-quartz-pyrite veins and brecciated veins cut green siltstone and amphibolite east of the Scud Glacier. The veins are less than 10 centimetres wide. Similar but more strongly foliated veins with green mica occur along shears within or adjacent to the ultramafic and mafic units. These veins (listwanites) have an untested but potential association with gold mineralization.

AGES OF MINERALIZATION

Limited data suggest Early Jurassic and Tertiary ages of mineralization. Potassium-argon dates for hydrothermal biotite associated with mineralization at Galore and Schaft creeks range from 177 to 201 Ma and about 185 Ma, respectively (White *et al.*, 1968; Panteleyev and Dudas, 1973). These ages indicate an empirical association of mineralization with Lower Jurassic alkaline intrusions and coeval volcanic rocks. Galena from the Trophy property has radiogenic lead isotope signatures typical of Tertiary deposits (J.E. Gabites, personal communication, 1988), which may indicate the approximate age of mineralization.

MINERAL POTENTIAL

The rugged and remote aspect of the study area has hindered mineral exploration. The geological setting is favourable for: (1) calcalkaline porphyry copper-molybdenum deposits (Schaft Creek); (2) alkalic porphyry copper-gold deposits (Galore Creek); (3) porphyry molybdenum deposits (Ben); (4) structurally controlled epigenetic precious metal deposits (Golden Bear and Trophy Gold properties); (5) precious metals in carbonate veins associated with listwanites; (6) skarns; (7) volcanogenic massive sulphides; (9) sediment-hosted massive sulphides in the rusty argillite unit; and (9) platinum-group elements in Alaskan-type ultramafic rocks. However, even Galore Creek is currently subeconomic because of the infrastructure costs in this remote area.

SUMMARY

Preliminary conclusions based on one field season of geological mapping are:

- The Stikine assemblage north of the Scud River comprises six mappable units.
- Middle Triassic sedimentary rocks are overlain with structural conformity by Upper Triassic Stuhini Group rocks.
- Four plutonic episodes are evident, each contains various phases.
- Pre-Early Permian deformation and possibly lower greenschist grade metamorphism is apparent in Domain I.
- Southwest-verging minor folds are characteristic of Domains I and II and indicate pre-Triassic(?) southwest-directed compression.
- Permian, Middle Triassic and Late Triassic rocks are structurally conformable at the toe of the Scud Glacier.
- Three new mineral occurrences were located and the area warrants additional mineral exploration.

ACKNOWLEDGMENTS

We would like to thank Continental Gold Corporation for its logistical support, and Vancouver Island Helicopters, Fly West Air and Dease Lake Expediters for their services. Michael McDonough and David Carmichael were excellent assistants who contributed to the success of the field season. C. Grieg helped prepare mineral separates for potassium-argon dating at The University of British Columbia. R.G. Anderson and D. Lefebure reviewed the manuscript and provided helpful comments.

REFERENCES

Alaska Geographic Society (1979): The Stikine River, Volume 6, Number 4, 94 pages.

Anderson, R.G. (1988): A Paleozoic and Mesozoic Stratigraphic and Plutonic Framework for the Iskut Map Area (104B), Northwestern British Columbia, *Smithers Exploration Group – Geological Association of Canada, Cordilleran Section*, Smithers Workshop, 1988, pages A1-A3.

Brown, D.A. (1987): Geology of the Silbak Premier Mine, Northwestern British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 216 pages.

Evenchick, C. (1986): Structural Style of the Northeast Margin of the Bowser Basin, Spatsizi Map Area, North-central British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 86-1B, pages 733-739.

Folk, P.G. (1981): Report on the Geology, Trenching and Sampling of the Marg and Dok Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 9617, 6 pages.

Fox, P.E., Grove, E.W., Seraphim, R.H. and Sutherland Brown, A. (1976): Schaft Creek, *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, Part B, pages 219-226.

Gabrielse, H., Compiler (1980): Dease Lake, *Geological Survey of Canada*, Open File 707.

Gabrielse, H., Monger, J.W.H., Tempelman-Kluit, D.J. and Woodsworth, G.J. (in preparation): Intermontane Belt, *Decade of North American Geology*, Special Volume.

Geological Survey of Canada (1957): Operation Stikine, Map 9-1957.

Holbek, P.M. (1988): Geology and Mineralization of the Stikine Assemblage, Mess Creek Area, Northwestern British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 174 pages.

Kerr, F.A. (1927): Preliminary Report on Stikine River Area, British Columbia, *Geological Survey of Canada*, Summary Report, 1926, Part A, pages 14A-34A.

——— (1929): Second Preliminary Report on Stikine River Area, British Columbia, *Geological Survey of Canada*, Summary Report, 1928, Part A, pages 11A-26A.

——— (1930): Preliminary Report on Iskut River Area, British Columbia, *Geological Survey of Canada*, Summary Report, 1929, Part A, pages 30A-61A.

——— (1931): Explorations Between Stikine and Taku Rivers, British Columbia, *Geological Survey of Canada*, Summary Report, 1930, Part A, pages 41A-55A.

——— (1948a): Lower Stikine and Iskut River Areas, British Columbia, *Geological Survey of Canada*, Memoir 246, 94 pages.

——— (1948b): Taku River Map-area, British Columbia, *Geological Survey of Canada*, Memoir 248, 84 pages.

Linder, H. (1975): Geology of the Schaft Creek Porphyry Copper Molybdenum Deposit, Northwestern British Columbia, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 68, pages 49-63.

Logan, J.M. and Koyanagi, V.M. (1989): Geology and Mineral Deposits of the Galore Creek Area, Northwestern B.C. (104G/3, 4), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Monger, J.W.H. (1977a): Upper Paleozoic Rocks of Northwestern British Columbia, *Geological Survey of Canada*, Paper 77-1A, pages 255-262.

——— (1977b): Upper Paleozoic Rocks of the Western Canadian Cordillera and their Bearing on Cordilleran Evolution, *Canadian Journal of Earth Science*, Volume 14, pages 1832-1859.

Nixon, G.T., Ash, C., Connelly, J.N. and Case G. (1989): Alaskan-type Ultramafic Rocks in British Columbia: The Hickman, Gnat Lakes and Menard Mafic-Ultramafic Complexes, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Nixon, G.T. and Rublee, V.J. (1988): Alaskan-type Ultramafic Rocks in British Columbia: New Concepts of the Structure of the Tulemeen Complex, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 281-294.

Panteleyev, A. (1975): Galore Creek Map-area, *B.C. Ministry of Energy Mines and Petroleum Resources*, Geological Fieldwork, 1974, Paper 1975-1, pages 59-62.

——— (1976): Galore Creek Map-area, *B.C. Ministry of Energy Mines and Petroleum Resources*, Geological Fieldwork, 1975, Paper 1976-1, pages 79-82.

Panteleyev, A. and Dudas, B.M. (1973): Schaft Creek, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration and Mining in British Columbia, 1972, pages 527-528.

Pitcher, M.G. (1960): Fusulinids of the Cache Creek Group, Stikine River Area, Cassiar District, British Columbia, Canada, Unpublished M.Sc. Thesis, *Brigham Young University*, 64 pages.

Read P.B. (1984): Klastline River (104G/16E), Ealue Lake (104H/13W), Cake Hill (104I/4W), and Stikine Canyon (104J/1E), *Geological Survey of Canada*, Open File 1080.

Souther, J.G. (1959): Chutine Map Area, *Geological Survey of Canada*, Map 7-1959.

——— (1971): Geology and Mineral Deposits of Tulsequah Map Area, *Geological Survey of Canada*, Memoir 362, 76 pages.

——— (1972): Telegraph Creek Map Area, British Columbia, *Geological Survey of Canada*, Paper 71-44, 38 pages.

Souther, J.G. and Symons, D.T.A. (1974): Stratigraphy and Paleomagnatism of Mount Edziza Volcanic Complex, Northwestern British Columbia, *Geological Survey of Canada*, Paper 73-32, 48 pages.

Steiger, R.H. and Jäger, E. (1977): Subcommission on Geochronology: Convention on the Use of Decay Constants in Geochronology and Cosmochronology, *Earth and Planetary Science Letters*, Volume 36, pages 359-362.

Thorstad, L.E. and Gabrielse, H. (1986): The Upper Triassic Kutcho Formation, Cassiar Mountains, North-central British Columbia, *Geological Survey of Canada*, Paper 86-16, 53 pages.

White, W.M., Harakal, J.E. and Carter, N.C. (1968): Potassium-argon Ages of Some Ore Deposits in British Columbia, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 61, pages 1326-1334.

NOTES

GEOLOGY AND MINERAL DEPOSITS OF THE GALORE CREEK AREA, NORTHWESTERN B.C. (104G/3, 4)

By J.M. Logan and V.M. Koyanagi

KEYWORDS: Regional geology, Stikine assemblage, Stuhini Group, Hickman batholith, Galore Creek, alkalic porphyry, Copper Canyon, copper, gold.

INTRODUCTION

The Sphaler Creek (104G/3) and Flood Glacier (104G/4) map areas are located along the western margin of the Intermontane Belt approximately 80 kilometres due south of Telegraph Creek in northwestern British Columbia (Figure 1-30-1). Results of regional mapping and sampling during the 1988 field season are summarized in this report; a 1:50 000 geology and mineral occurrence map will be released as an Open File in early 1989. The focus of the project was to locate and evaluate known and new mineral occurrences and to provide a detailed geological database delineating Paleozoic and Mesozoic stratigraphy in the area.

The map area is centered on Galore Creek and is occupied by rugged high-relief mountains of the Boundary Ranges with numerous snowfields and radiating glaciers. Access is by fixed-wing aircraft from Dease Lake or Smithers to the Scud strip located on the Stikine River, and from there by helicopter.

PREVIOUS WORK

F.A. Kerr carried out geological mapping along the Stikine and Iskut rivers from 1924 to 1929, but it was not until 1948 that his data were published (Kerr, 1948a, b). Other work by the Geological Survey of Canada includes that of Souther (1971, 1972), Monger (1970, 1977), and Anderson (1984, 1989). P. Read has conducted regional mapping for the Geological Survey of Canada (Read, 1984) and feasibility studies for B.C. Hydro. A. Panteleyev carried out mapping in the area, in conjunction with a deposit study of Galore Creek between 1973 and 1975 (Panteleyev, 1975, 1976a, 1977).

The discovery of the Galore Creek porphyry copper deposit by Hudson Bay Mining and Smelting Company Limited in 1955 initiated exploration activity. The present resurgence of mineral exploration in the area is in response to its geological similiarities with the Sulphurets, Iskut and Golden Bear gold camps. Mining and exploration companies active in the map area this year included Continental Gold Corporation (Trophy claims), Equity Engineering Ltd. (JW and Trek/Sphal claims), Cominco Limited (Galore Creek), Canamax Resources Inc.(Copper Canyon) and Corona Corporation (Sphaler Creek claims).

REGIONAL GEOLOGY

The study area (Figure 1-30-2) straddles the boundary between the Intermontane and Coast tectonic belts and is underlain by rocks of the Stikine terrane (Stikinia). At this latitude Stikinia consists of Upper Paleozoic to Tertiary rocks that can be grouped into four tectonostratigraphic packages: a Late Paleozoic to Middle Jurassic island arc suite represented by the Stikine assemblage of Monger (1977), the Stuhini Group (Kerr, 1948) and Hazelton Group equivalent rocks; Middle Jurassic to early Late Cretaceous successor-basin sediments of the Bowser Lake Group (Tipper and Richards, 1976); Late Cretaceous to Tertiary transtensional continental volcanic-arc assemblages of the Sloko Group (Aiken, 1959); and Late Tertiary to Recent post-orogenic plateau basalt bimodal volcanic rocks of the Edziza and Spectrum ranges. Plutonic rocks of Mesozoic and Tertiary age intrude this complex stratigraphy. The most economically important exploration targets are porphyry copper-gold-silver deposits and peripheral mesothermal and shear-zone-hosted precious metal veins.

STRATIGRAPHY

STIKINE ASSEMBLAGE

Rocks of the Stikine assemblage are the oldest rocks in the area; the assemblage consists of Permian, Mississippian and Devonian(?) bimodal flows and volcaniclastics, interbedded carbonate and minor shale and chert. The distinctive volcanics and Permian carbonates have been traced for over 500 kilometres from north of the Stikine River to south of Terrace (Monger, 1977). Kerr (1948a) inferred Devonian ages for some of these rocks and Anderson (1989) has identified a lower to middle Devonian unit near Forrest Kerr Creek, about 20 kilometres to the southeast. Upper Permian fossils have been reported by Rigby (1961), Pitcher (1960), Monger and Ross (1971), Souther (1972), and were found in the course of this study. A complete section from the top of the Stikine assemblage (Upper Permian) down to the Devonian(?), complicated in part by westerly directed thrust faulting, is located in the south-eastern corner of the map area.

Souther (1972) divided the Stikine assemblage into three units: Permian and older sediments, tuffs and intermediate volcanics; a Missisippian limestone; and a Permian limestone.

PERMIAN AND OLDER (Ps, Pv)

Permian and older rocks comprise a package of argillites, mafic to felsic flows, tuffs and epiclastics and, together with

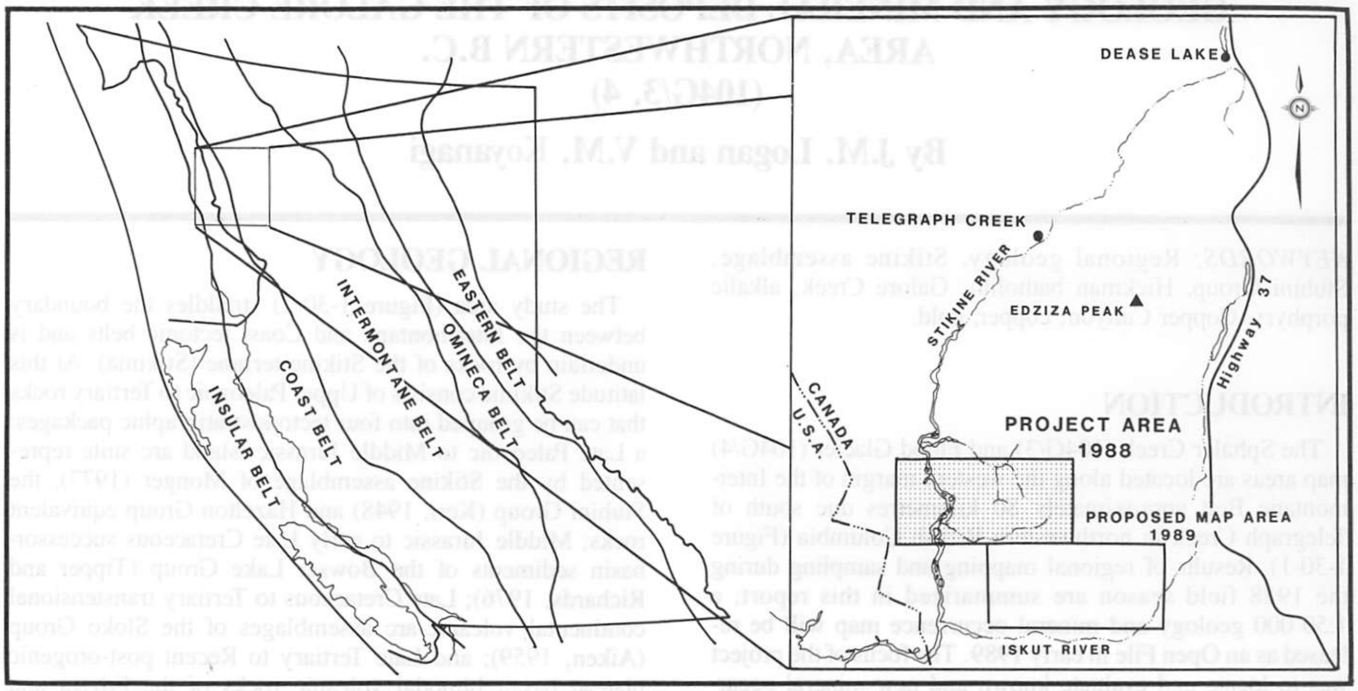


Figure 1-30-1. Location map showing the 1988 map area and the proposed map area for 1989.

Paleozoic limestones, are the most penetratively deformed and metamorphosed rocks in the map area. This sequence of uncertain stratigraphy which, in part, resembles that described by Holbek (1988) in the Mess Creek area to the east, has been identified east of Round Lake (Figure 1-30-3a). A silver phyllite and graphitic argillite unit (**Ps**) is inferred to be the oldest lithology and is overlain by a volcanic package (**Pv**) comprising greenstones and chlorite schists derived from intermediate flows, sills and tuffs at the base, followed by thick section of purple-green ash-lapilli tuff, in turn overlain by plagioclase-phyric flows, sills and volcaniclastics.

Mississippian limestone, intercalated with volcanics and clastic sediments, conformably overlies Unit Pv. The limestones are in turn overlain conformably, and are in faulted contact with volcanic breccias, tuffs and sediments similiar to those which underlie the Mississippian limestone. The intermediate plagioclase-porphyrytic flows and volcaniclastics are megascopically distinct from the more basic pyroxene-porphyritic volcanics of the Upper Triassic Stuhini Group. The Stikine rocks are relatively alkaline (Souther, 1977).

Further west these greenschist facies rocks are exposed in the lower reaches of the Porcupine River; they extend northwestward into the Coast crystalline belt as screens and roof pendants up to 4 kilometres across, where garnet-biotite schists and gneisses are locally developed within these greenschist-facies rocks, due to the effects of contact metamorphism.

MISSISSIPPIAN (ML, MS)

Limestone, containing foraminifera, corals, bryozoa and brachiopods of Late Mississippian age (Mamet, 1976), is exposed on cliffs above Round Lake. The limestone unit is comprised of two distinct members separated by a wedge of chert and phyllitic volcaniclastic rocks (Monger, 1970). Comformably underlying the lower limestone member are mafic and intermediate volcaniclastics, well-bedded tuffs and rare limestone lenses. Solitary horn corals and large crinoid fragments in the limestone are of probable Mississippian age. The base of the underlying volcanics was not defined.

The lower limestone, 60 to 150 metres thick, is a pale grey, coarse-grained crinoidal calcarenite (Figure 1-30-3a). The basal sections are locally ferruginous and contain up to 80 per cent large crinoid stems within a medium-grained calcarenite to micrite matrix. Up-section the crinoid debris is finer grained and graded bedding is well developed. The upper 50 metres of the lower limestone is intercalated with purple and green ash-tuff beds 1 to 2 metres thick; a 3-metre basic flow was noted. The wedge of phyllite, tuff and intraformational limestone-pebble conglomerate (**Ms**) separating the two limestone members has an estimated thickness of less than 250 metres and is conformably overlain by the upper limestone. The upper limestone member, 400 to 500 metres thick, is a light grey, massive-bedded bioclastic calcarenite. Yellow to black layers of amorphous chert, 10 to 40 centimetres thick, define bedding and, on average, comprise 15 per cent of the member. Rare lenses (5 to 15 centimetres thick) of green-purple tuff occur throughout. Bryozoan and solitary corals are abundant in the upper 50 metres. The upper limestone member is conformably overlain by fine-grained green to purple, calcareous lithic ash-tuffs which contain beds of Upper Mississippian limestone (Mamet, 1976). This stratigraphy has been sampled systematically along three separate traverses and 15 samples have been collected for conodont studies.

Monger (1970, 1977) has suggested that a profound pre-Lower Permian unconformity is necessary to explain the disappearance of at least 1500 metres of Mississippian strata over a 5 kilometre strike distance at Round Lake. A north-trending unconformable contact between Early Permian (Wolfcampian) limestones and polydeformed pre-Permian phyllites and metavolcanics (Figure 1-30-2) has been identified and may represent this event. Alternatively, the distribution of Mississippian limestone may reflect paleotopography where limestone accumulated around volcanic highs.

PERMIAN (PL)

Two regionally extensive carbonate units have been recognized and are evidence of a stable continental shelf environment in the Permian (Monger, 1970). Within the map area, Permian limestones 800 to 1000(?) metres thick are exposed at the confluence of the North Scud and South Scud rivers and can be traced southward to the edge of the map area west of Round Lake (Figure 1-30-3). The lowermost limestone overlies pre-Permian, typically greenschist-metamorphosed and penetratively deformed, mafic to intermediate volcanics, volcaniclastics and pelites (Figure 1-30-3a).

The lower 75 metres of limestone are dark grey, thin bedded, argillaceous micrites and calcarenites interbedded with pyritic argillite. Fusulinids, small horn corals, bryozoa and gastropods have been collected from this horizon in addition to conodont samples. These rocks grade upward into 350 metres of pale grey to buff-coloured thin to medium-bedded calcarenite interbedded with yellowish-brown-weathering amorphous chert. These discontinuous interlayers are 10 to 30 centimetres thick and constitute about 20 per cent of the outcrop. The bioclastic component is predominently crinoid stems and assorted fossil fragments, showing graded bedding typical of turbidity current deposition. The fauna is silicified and includes abundant brachiopods (1 to 4 per cent of the rock by volume), bryozoans, and near the base, 1 to 2 per cent horn corals.

Overlying the calcarenite is 100 metres of tan to very light-grey-weathering bryozoan-rich limestone characterized by 5 to 20-centimetre layers containing 30 to 60 per cent bryozoa in a micritic crinoidal matrix and interbedded with bryozoan-poor limestone (Figure 1-30-3a). Overlying limestones (300+ metres) are light grey, massive-bedded bioclastic calcarenites with a fine-grained light grey micritic matrix containing variable percentages (5 to 40) of crinoid stem fragments, sparse bryozoa and silicified brachiopods. Bodies of coarse angular-block breccia are locally present near the base. The breccias are commonly matrix supported and locally ferruginous. They are thought to be peri-platform talus deposits developed outboard of the platform. A recessive section of poorly sorted, fine to medium-grained brown greywacke or tuff (5 metres thick) occurs near the top of the massive limestone section.

A section of Permian limestone exposed on the west side of the South Scud River, between 1390 and 1970 metres elevation, was measured and sampled for conodonts and fusulinids. Preliminary results from fusulinid studies conducted by D. Rhys at The University of British Columbia indicate a range in age from Wolfcampian to lower Guadalupian. Pitcher (1960) has shown similarities of these forms to faunas in the southwestern United States, (McCloud fauna, Skinner and Wilde, 1965). Macrofossils and conodont collections have been submitted for identification.

The Permian limestone is overlain, apparently conformably, by Middle Triassic shale north of Copper Canyon.

MIDDLE TRIASSIC (MTS)

Souther (1972) has mapped a narrow belt of Middle Triassic sediments extending 9 kilometres north from Copper Canyon. A second belt (about 3 kilometres long) of silty argillites containing Middle Triassic fossils (*Daonella* cf. *degeeri* Boehm, Table 1-30-1) has been recognized 3 kilometres east of the South Scud River.

A preliminary stratigraphic section suggests a two-fold division into a lower sequence of silty shales, argillites and limy dolomitic siltstones and an upper sequence of cherty siltstones and rare carbonaceous limestones (Figure 1-30-3b). The entire section is a least 200 metres thick. The lowermost rocks are contorted, rusty calcareous argillites which lie with apparent conformity on Permian limestones. The shales and silty slates of the lowermost sequence contain thin *Daonella*-bearing horizons and a distinctive silver-grey shale containing rusty, round to elliptical concretions. Overlying these shales is a thin-bedded package of black and dark grey siliceous and carbonaceous siltstones, in places limy and containing discontinuous carbonaceous limestones.

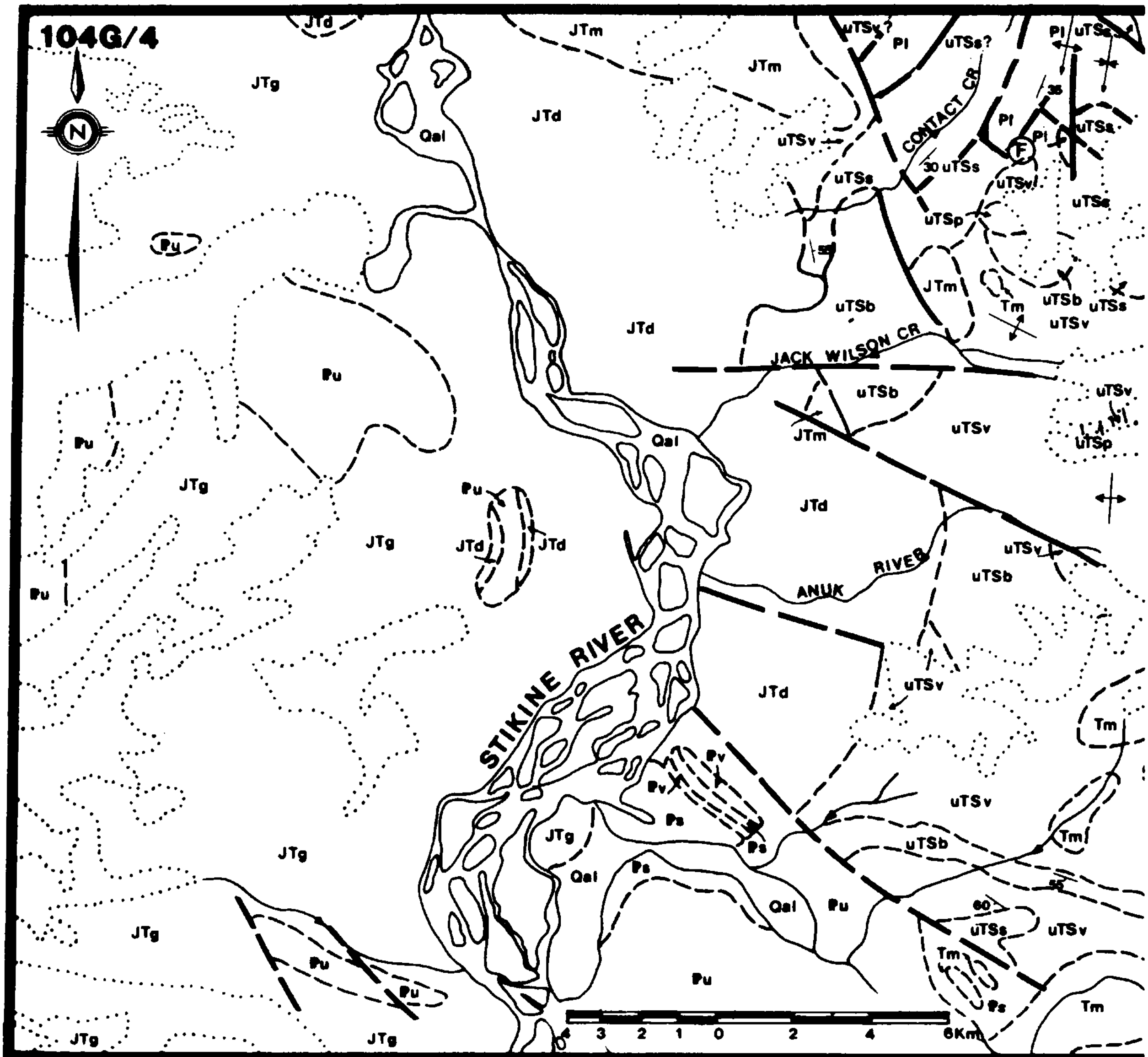
MIDDLE TO UPPER TRIASSIC STUHINI GROUP

The Triassic Stuhini Group (Kerr, 1948) comprises a variety of flows, tuffs, volcanic breccias and sedimentary rocks. These define a volcanic edifice centered on the Galore Creek area and floored by the Stikine assemblage (Monger, 1977). The rocks represent components of an emergent Upper Triassic island arc characterized by shoshonitic and leucitic rocks (de Rosen-Spence, 1985) and distal volcaniclastic and sedimentary turbidites. Stuhini stratigraphy ranges in age from early Carnian to late Norian based on radiometric dates (Anderson, 1983) and fossil ages (Souther, 1972). The Middle Triassic Hickman pluton intrudes these volcanics in the eastern part of the map area, indicating ages as old as Middle Triassic.

Panteleyev (1976) subdivided the Galore Creek volcanic edifice into a lower unit of submarine basaltic and andesitic breceias overlain by more differentiated, partially subaerial, alkali-enriched flows and pyroclastic rocks. The Stuhini of the map area has been divided into five lithological units, described below.

ANDESITE FLOWS AND BRECCIAS (M-UTSV)

Fine to medium-grained massive and fragmental textures are common. Porphyries are trachytic, typically contain 15 to 40 per cent plagioclase phenocrysts and 20 per cent hornblende in a dense green (chloritic) matrix. Compositional similiarity of fragments and matrix in the fragmental



QUATERNARY

Qal — till, alluvium, glacial material

STRATIFIED ROCKS

JURASSIC

Js — sandstone, siltstone, arkose, tuff, polymictic, granite conglomerate, carbonaceous plant material

MIDDLE TO UPPER TRIASSIC
STUHINI GROUP

uTSs — siltstone, sandstone, conglomerate, minor limestone

uTSt — well-bedded green/maroon lapilli-ash tuffs and epiclastics

uTSp — pyroxene-porphyry flows and fragmentals

uTSb — breccia-tuff and fragmentals, lithic crystal tuff, lahar-breccia

m/uTSv — massive andesite flows and tuffs, amygdaloidal basalt

MIDDLE TRIASSIC

mTs — carbonaceous silty shale with elliptical concretions and cherty siltstones

STIKINE ASSEMBLAGE
PERMIAN

Pl — massive, thickly bedded, buff, bioclastic calcarenite, thinly bedded, bioclastic limestone, with chert interbeds and minor epiclastics

PERMIAN AND OLDER

Pv — plagioclase porphyry flows/sills, volcaniclastics, purple ash tuff, chlorite schist, massive flows

Ps — silver phyllite, slate and phyllitic argillite

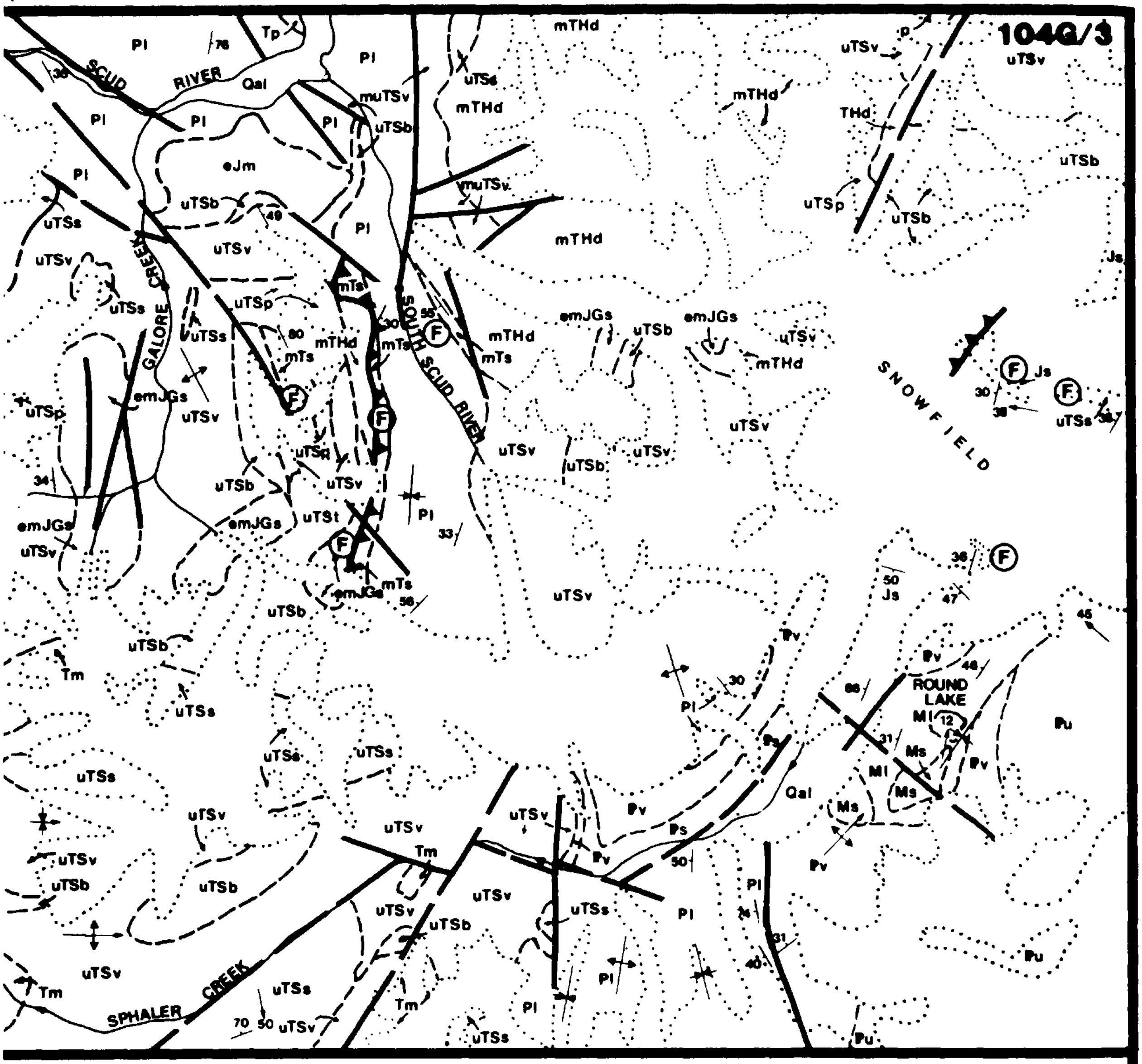
Pu — undivided - green/maroon foliated volcanics, metasediments

MISSISSIPPIAN

Ml — grey, massive, bedded calcarenite with chert interbeds overlying coarse grained crinoidal calcarenite, flows, and tuffs

Ms — phyllite, tuff, intraformational limestone and conglomerate

Figure 1-30-2. Generalized geology map of the Sphaler Creek and Flood Glacier map sheets – 104G/3 and 104G/4.



INTRUSIVE ROCKS

TERTIARY

Tp	plagioclase-porphyritic diorite
Tm	fine-grained biotite quartz monzonite

JURASSIC - TERTIARY
COAST INTRUSIONS

JTg	medium to coarse, pink, hornblende, biotite granite
JTd	medium-grained-biotite-hornblende diorite
JTm	coarse potassium feldspar, megacrystic granite to monzonite

EARLY TO MIDDLE JURASSIC
GALORE CREEK INTRUSIONS

emJGs	syenite, orthoclase porphyritic monzonite

EARLY JURASSIC

eJm	medium to coarse, hornblende, biotite, granodiorite to monzonite

MIDDLE TRIASSIC
HICKMAN BATHOLITH

mTHd	coarse to medium-grained-biotite-hornblende -augite-diorite to monzonite

ULTRAMAFICS

p	pyroxenite

------	geological boundary
——	fault
▲▲▲	thrust fault
....	permanent snow and ice
56	bedding
	plunging syncline
	plunging anticline
35	minor fold axis

TABLE 1-30-1
MESOZOIC FOSSIL COLLECTION

Location:	104 G/3, Copper Canyon UTM 358800E 6333400N Daonella cf. degeeri Boehm
Age:	Middle Triassic, Ladinian.
Location:	104 G/3, Scotch Glacier, Trophy UTM 361000E 6339050N Daonella cf. degeeri Boehm
Age:	Middle Triassic, Ladinian.
Location:	104 G/4, Scud/Jack Wilson UTM 345750E 6343325N Monotis sp.
Age:	Upper Triassic, Upper Norian (Cordilleranus Zone).
Location:	104 G/4, 4 km north Copper Canyon UTM 358225E 63365500N Daonella cf. degeeri Boehm
Age:	Middle Triassic, Ladinian.
Location:	104 G/3, 5.5 km NE of Galore copper deposit UTM 356325E 6337250N Spongiomorph, indet.
Age:	probably Upper Triassic.
Location:	104 G/3, 5.5 km NE of Galore copper deposit UTM 356550E 6337350N Monotis subcircularis Gabb
Age:	Upper Triassic, Upper Norian (Cordilleranus Zone).
Location:	104 G/3, 5.5 km NE of Galore copper deposit UTM 356255E 6337200N Monotis subcircularis Gabb
Age:	Upper Triassic, Upper Norian (Cordilleranus Zone).
Location:	104 G/3, 5.5 km NE of Galore copper deposit UTM 356425E 6337250N Monotis salinaria Bronn
Age:	Upper Triassic, Upper Norian (Cordilleranus Zone).
Location:	104 G/3, East Icefield/Mess Creek UTM 375300E 6337400N Weyla ? sp.
Age:	probably Lower Jurassic.
Location:	104 G/3, 3 km N of Round Lake UTM 375250E 6332550N Pectenid bivalve Lima (Plagiostoma) sp.
Age:	Triassic or Jurassic.
Location:	104 G/3, East Icefield/Mess Creek UTM 376015E 6336630N Monotis subcircularis Gabb
Age:	Upper Triassic, Upper Norian (Cordilleranus Zone).

* Fossils identified by E.T. Tozer.

units makes distinguishing them difficult and, as a result, more andesite may have been mapped than actually exists.

Aphyric Tuff and Breccia (uTSb)

Fragmental rocks vary from block breccias to ash tuffs; lapilli tuffs are the most abundant. Colour varieties are black, green and red, and where epidote and/or hematite preferentially replaces fragments or matrix the rock is mottled. The size and density of fragments varies greatly over short distances and the monolithic nature of fragments and matrix make it difficult to trace these units (Figure 1-30-3b). Three subunits have been recognized and are briefly described.

A lithic-lapilli crystal tuff outcrops along Jack Wilson Creek near the contact with Coast intrusions. Polylithic fragments are subrounded to angular, typically volcanic, with compositions ranging from andesite to rhyolite; euhedral hornblende, plagioclase, and possibly augite phenocrysts are also characteristic. These rocks are commonly foliated. A pervasive propylitic alteration is diagnostic and may reflect contact metamorphism by the Coast intrusions.

A lithic lapilli tuff is interbedded with Upper Triassic siltstones along Contact Creek. This tuff is well consolidated, appears massive in outcrop and is comprised of black subangular fragments in a black matrix. The black colour makes it difficult to distinguish from massive siltstone. Argillic alteration and the absence of sulphides are characteristic.

Lapilli-block tuff is the typical lithology between the Anuk River and Sphaler Creek near the contact with Coast intrusives (Figure 1-30-2). Blocks range in size up to 50 centimetres across, averaging 5 centimetres, and are generally volcanic lithologies but include some sedimentary fragments, occasionally limestone. Minor basalt and andesite flows are interbedded with the tuff.

Green-Maroon Pyroxene Porphyry (uTSp)

Pyroxene porphyry flows and fragmental rocks typify the Stuhini Group. They contain from 15 to 30 per cent euhedral phenocrysts of pyroxene (up to 1 centimetre in size) set in a dense, dark green groundmass of feldspar and pyroxene. These medium to coarsely porphyritic basic flows are interbanded with massive andesitic rocks. Dykes and sills of pyroxene porphyry intrude upper Norian sediments and represent feeders to overlying flows (Figure 1-30-3b). These porphyries cap several peaks and are among the youngest Stuhini Group volcanics.

Thick sections of green to purple augite basalt and andesite breccia form massive outcrops at the head of Hickman Creek and are overlain by purple amygdaloidal basalts. Rare, thin tuffaceous horizons break the monotony of these thick monolithic porphyries.

Green/Maroon Bedded Tuffs and Epiclastics (uTSt)

Purple to maroon, thin-bedded tuffs, epiclastics and siltstones outcrop between Copper Canyon and Galore Creek (Figure 1-30-2). Graded bedding indicates that the beds are overturned in places. Maroon lithic ash tuffs and lapilli tuffs can be traced northwestward where they interfinger with thin-bedded siltstone, conglomerate and pods of clastic limestone. The distinctive maroon colour and well-bedded nature of these rocks suggests they may be a separate suite of volcanics (Jeffery, 1965).

Sediments (uTSs)

Thin, lenticular and locally variable sediments are interbedded with volcanics throughout the map area. They include thin-bedded graded siltstone and sandstone, conglomerate composed of green and purple volcanics, limestone and other sedimentary clasts and clastic limestone (Figure 1-30-3b). Abundant *Monotis subcircularis* Gabb, (Table 1-30-1) indicate a Late Triassic (Cordilleranus Zone) age.

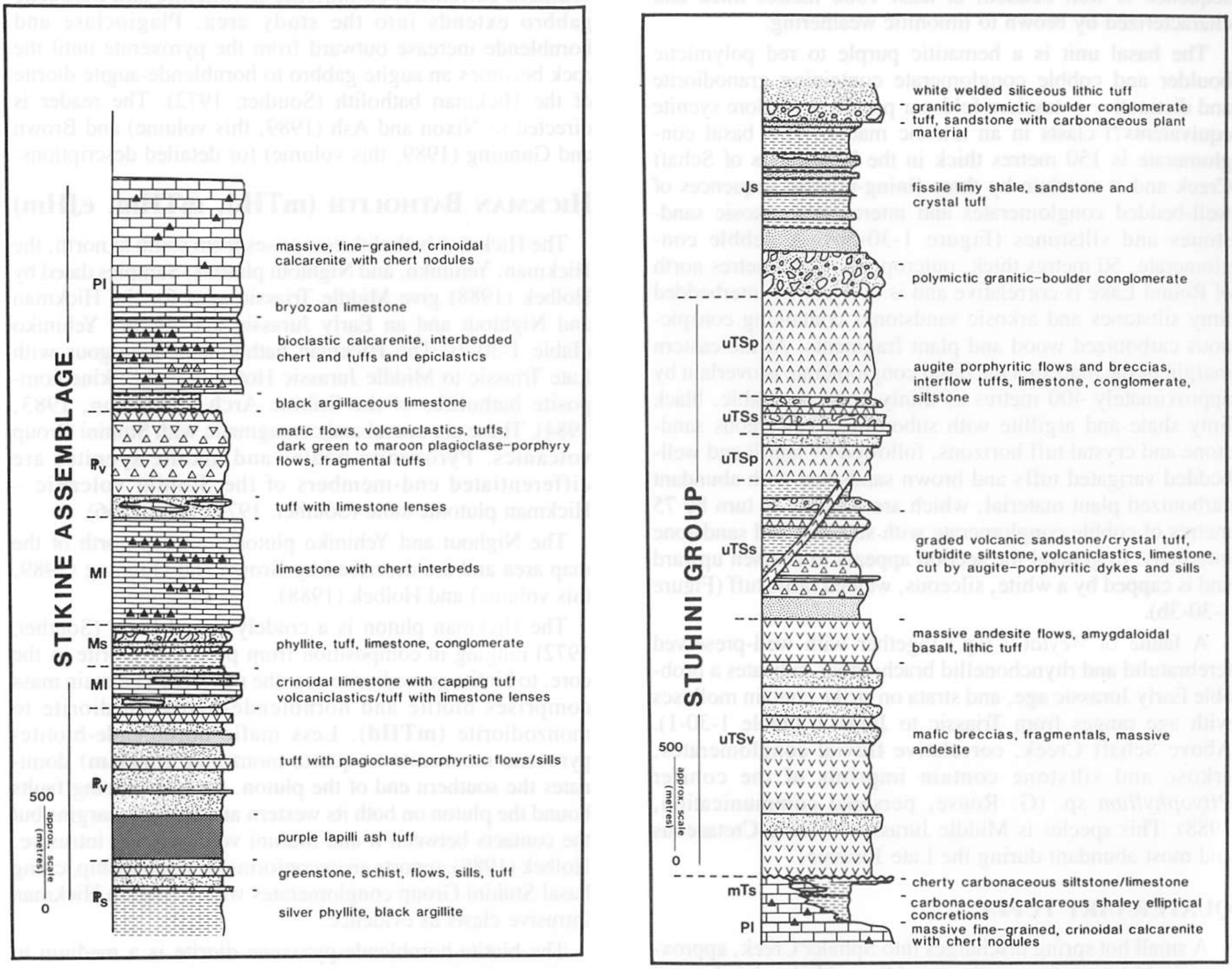


Figure 1-30-3. Schematic stratigraphic sections of a) Paleozoic Stikine assemblage lithologies and b) Mesozoic lithologies of the Upper Triassic Stuhini Group and unnamed Jurassic sediments.

A thick succession of well-bedded tuffaceous and argillaceous sediments and subordinate volcanic breccias outcrops at high elevations between Jack Wilson Creek and Scud River (Figure 1-30-2). These sediments are underlain by Permian limestone above the Scud River and by Upper Triassic volcaniclastics and massive flows along Jack Wilson Creek. The base of the sedimentary succession consists of thin-bedded black calcareous and carbonaceous siltstone, interbedded black lithic tuff and rare limestone; the sequence grades upward into thin variegated siltstone, grey ash tuffs and volcanic sandstone and conglomerate. The lower units are thin, repetitively graded "AE-turbidites", characterized by soft-sediment slumping, faulting and scour-and-fill structures, and are crosscut by volcanic conglomerate and breccia. A distinctive arenaceous unit contains aligned siltstone and limy siltstone clasts in a fine to medium-grained tuffaceous sandstone matrix. The clasts vary from 1 to 50 centimetres long and are elongate parallel to bedding.

Near the eastern margin of the map area a thick succession of gently west-dipping sediments, ranging in age from Triassic to Jurassic, is exposed in a series of nunataks. The Triassic sequence is comprised of green to more commonly limonitic arkosic sandstone, locally with abundant carbonized plant material, interbedded with argillite and maroon volcanic conglomerates. The base of the sequence is not exposed; the top is *Monotis*-bearing calcareous siltstone and interbedded argillite (Table 1-30-1).

Well-bedded, thinly laminated, tightly folded and contorted siltstone, sandstone and calcareous argillite outcrop on the slopes south of Sphaler Creek. These sediments are fissile, weather rusty and are similar to the sediments cropping out between Jack Wilson Creek and the Scud River.

Thin to medium-bedded wacke, volcanic sandstone and volcanic conglomerate, in part calcareous, outcrop on the high peaks between Sphaler and Galore creeks. The absence of siltstone is a distinctive feature in this area.

JURASSIC SEDIMENTS (JS)

Unnamed Jurassic rocks comprise a fault-bounded wedge in the eastern part of the map area (Figure 1-30-2). The sequence is well bedded, at least 1000 metres thick and characterized by brown to limonitic weathering.

The basal unit is a hematitic purple to red polymictic boulder and cobble conglomerate containing granodiorite and distinctive potassium feldspar porphyry (Galore syenite equivalents?) clasts in an arkosic matrix. This basal conglomerate is 150 metres thick in the headwaters of Schaft Creek and is overlain by three fining-upward sequences of well-bedded conglomerates and intercalated arkosic sandstones and siltstones (Figure 1-30-3b). A pebble conglomerate, 50 metres thick, outcropping 3 kilometres north of Round Lake is correlative and is overlain by interbedded limy siltstones and arkosic sandstones containing conspicuous carbonized wood and plant fragments. At the eastern margin of the map area the basal conglomerate is overlain by approximately 400 metres of thinly bedded, friable, black limy shale and argillite with subordinate calcareous sandstone and crystal tuff horizons, followed by lapilli and well-bedded varigated tuffs and brown sandstone with abundant carbonized plant material, which are overlain in turn by 75 metres of cobble conglomerate with siltstone and sandstone interbeds. In general the section appears to coarsen upward and is capped by a white, silceous, welded lithic tuff (Figure 1-30-3b).

A fauna of *Weyla*(?) (sp.) together with well-preserved terebratulid and rhynchonellid brachiopods indicates a probable Early Jurassic age, and strata on strike contain molluscs with age ranges from Triassic to Jurassic (Table 1-30-1). Above Schaft Creek, correlative fluvial conglomerates, arkose and siltstone contain imprints of the conifer *Pityophyllum* sp. (G. Rouse, personal communication, 1988). This species is Middle Jurassic to Early Cretaceous and most abundant during the Late Jurassic.

QUATERNARY TUFFA

A small hot spring discharges into Sphaler Creek, approximately 11 kilometres southwest of Round Lake. It is located on a major north-trending structure which flanks the west side of the Hickman batholith and has deposited calcareous tuffa up to 1 metre thick. The smell of hydrogen sulphide is easily detectable and the tuffa has been sampled for geochemical analysis.

INTRUSIVE ROCKS

Three intrusive episodes are represented in the map area: the Middle Triassic to Middle Jurassic Hickman plutonic suite, coeval with Upper Triassic Stuhini Group volcanics; Jurassic to Tertiary Coast Range plutons, and Tertiary plugs and bimodal dykes. Mineral deposits are spatially and genetically related to the Upper Triassic Stuhini volcanics and comagmatic alkaline plutons.

MIDDLE TRIASSIC – MIDDLE JURASSIC PLUTONIC SUITE

ULTRAMAFICS (P)

The Mount Hickman zoned ultramafic body is a northeast-striking, 6 by 2 kilometre intrusive body which outcrops on Mount Hickman in the northeast corner of the maps area. Its southern extremity, comprising pyroxenite and pyroxene gabbro extends into the study area. Plagioclase and hornblende increase outward from the pyroxenite until the rock becomes an augite gabbro to hornblende-augite diorite of the Hickman batholith (Souther, 1972). The reader is directed to Nixon and Ash (1989, this volume) and Brown and Gunning (1989, this volume) for detailed descriptions.

HICKMAN BATHOLITH (mTHd, mTHm, eJHm)

The Hickman batholith comprises from south to north, the Hickman, Yehiniko, and Nightout plutons. Samples dated by Holbek (1988) give Middle Triassic ages for the Hickman and Nightout and an Early Jurassic age for the Yehiniko (Table 1-30-2). The Hickman batholith is analogous with Late Triassic to Middle Jurassic Hotailuh and Stikine composite batholiths of the Stikine Arch (Anderson, 1983, 1984). These are coeval and comagmatic with Stuhini Group volcanics. Pyroxenite bodies and alkalic syenites are differentiated end-members of the Stuhini volcanic – Hickman plutonic suite (Souther, 1972; Barr, 1966).

The Nighout and Yehiniko plutons outcrop north of the map area and are described by Brown and Gunning (1989, this volume) and Holbek (1988).

The Hickman pluton is a crudely zoned body (Souther, 1972) ranging in composition from pyroxene diorite in the core, to biotite granodiorite near the margins. The main mass comprises biotite and hornblende-pyroxene diorite to monzodiorite **(mTHd)**. Less mafic hornblende-biotite-pyroxene monzonite to quartz monzonite **(mTHm)** dominates the southern end of the pluton. Steeply dipping faults bound the pluton on both its western and eastern margins but the contacts between it and Stuhini volcanics are intrusive. Holbek (1988), reports an unconformable relationship, citing basal Stuhini Group conglomerates which contain Hickman intrusive clasts as evidence.

The biotite-hornblende-pyroxene diorite is a medium to coarse-grained, equigranular rock, massive in outcrop and weakly jointed. Hornblende and augite are variably replaced by chlorite, and together comprise 75 to 80 per cent of the mafic minerals, with biotite the remainder. Potassium feldspar (20 per cent) and quartz (10 to 15 per cent) are interstitial to plagioclase (40 per cent). Magnetite and rare honey-coloured euhedral titanite are accessories. Pegmatitic and porphyritic textures are common and have been described by Souther (1972) north of the map area, at the toe of the Scud Glacier.

Coarse-grained, commonly trachytic, biotite-augite diorite occurs as small bodies distributed along the margins of the batholith (Figure 1-30-2). The rock is coarsely porphyritic with up to 30 per cent sodic plagioclase laths averaging 1.5 centimetres in length. Minerals comprising the matrix are medium-grained biotite, augite, plagioclase and potassium feldspar. Mafic minerals are chloritic and accessories include most notably magnetite to several per cent. Contact relationships with biotite-augite diorite are conflicting over relatively short distances. Wholerock chemistry may provide answers to the relationships between these two intrusives.

The hornblende-biotite monzonite to granodiorite is a medium to coarse-grained, pink weathering massive rock,

TABLE 1-30-2
REGIONAL CHRONOLOGY DATA

Locality	Location UTM E/N	Lithology	Method	Mineral	Age	Reference
Nightout pluton	377000	Hb-Bi	K/Ar	Bi	236±9	1
	6374750	granodiorite		Hb	228±8	1
			Rb/Sr	Bi	232±5*	1
Hickman pluton	370000	Bi-Hb	K/Ar	Hb	221±8	1
	6354500	granodiorite		Bi	209±7	1
			Rb/Sr	Bi	216±4*	1
				WRx	233±23*	1
Yehiniko pluton	365000	Leuco-qtz	K/Ar	Bi	172±6	1
	6366000	monzonite	Rb/Sr	Bi	170±16*	1
				WRx	178±11*	1
Scud River	354000 6344000	Monzonite	K/Ar	Hb	195±6	5
Scud River	352000 6338500	Granite	K/Ar	Bi	185±9	6
Galore Creek	351200 6335400	Hydrothermal alteration	K/Ar	Bi	192±9	6
Galore Creek	351200 6335400	Hydrothermal alteration	K/Ar	Bi	201±7	6
Junction syenite	350000	Syenite	K/Ar	Hb	251±7	5
	6337000			Bi	189±6	5
		Andesite	Rb/Sr	WRx	146±14**	5
Galore Creek	351200 6335400	Hydrothermal alteration	K/Ar	Bi	177±9	6
Copper Canyon	358500 6332750	Syenite	K/Ar	Bi	179.5±9	6
Schaft Creek	380000 6358000	Alteration	K/Ar	Bi	185±5	2
Mess Creek	381000 6335750	Alteration	K/Ar	Ms	192±7	1
Anuk River	343250	Quartz	K/Ar	Hb	197±5	4
	6332800	diorite		Bi	120±5	3
Sphaler Creek	345500 6320800	Quartz monzonite	K/Ar	Bi	53.5±1.6	3
Split Creek	346300 6327800	Alteration	K/Ar	Bi	48.5±1.7	4

Decay constants after Steiger and Jäger (1977).

*Initial $^{87}Sr/^{86}Sr = 0.7038$

**Initial $^{87}Sr/^{86}Sr = 0.70449$

REFERENCES

1. Holbek, P.M. (1988); 2. Panteleyev, A and Dudas, B.M. (1973); 3, 4 & 5. Panteleyev, A. (1975, 1976 & unpublished); 6. White, W.H., *et al.* (1968).

texturally similiar to Unit mTHd. The mafics are hornblende, biotite and augite up to about 20 per cent. These are generally chloritized. Plagioclase (35 per cent) is euhedral, zoned and contains small inclusions of mafic minerals. Potassium feldspar (35 per cent) is poikilitic to interstitial. Quartz (5-10 per cent) is also interstitial.

The monzonite is intruded by north-striking porphyritic monzonite to syenite and basaltic to andesitic flow-banded dykes.

A monzonite stock **(eJHm)** 5 kilometres wide is exposed south of the confluence of the Scud and South Scud Rivers (Figure 1-30-2). The intrusive varies from a medium-grained, equigranular biotite monzonite to a hornblende-biotite quartz monzonite. Euhedral plagioclase and pink potassium feldspar are present in roughly equal amounts. Chloritized mafics form less than 10 per cent, with biotite more common than hornblende. The stock is crudely zoned; the margin is finer grained, hornblende and plagioclase are more abundant and garnets occur locally (endoskarn). Exoskarn has developed in limestones at the intrusive contact. The outcrop pattern suggests the stock is bisected by a northwest striking fault.

Potassium-argon dates (White *et al.*, 1968; Panteleyev, unpublished data; recalculated to new decay constants) of 185±9 and 195±6 Ma on hornblende and biotite, give an Early Jurassic apparent age of emplacement for the stock (Table 1-30-2).

Galore Creek Intrusions (emJGs)

The Galore Creek syenite complex (Barr, 1966) is comprised of a series of ten syenite (orthoclase porphyry) intrusions hosted by coeval Upper Triassic Stuhini Group volcanics. Four of these are most closely associated with the copper deposits; from oldest to youngest these are dark syenite porphyry, garnet syenite megaporhyry, fine-grained porphyritic syenite, and epidote syenite megaporphyry. Allen *et al.* (1976) have described these rocks in detail; the following brief descriptions are condensed from their work.

The dark syenite porphyry is the oldest intrusive. It occurs as plugs and dykes (up to 60 metres wide) and is characterized by short, tabular, white orthoclase phenocrysts in a fine-grained potassium feldspar, biotite and plagioclase matrix. Phenocrysts of pseudoleucite interpreted as evidence of rapid cooling (Barr *et al.*, 1976) suggest the rock crystallized in a subvolcanic environment.

Garnet syenite megaporphyry forms dykes, is grey, contains euhedral orthoclase phenocrysts to about 25 per cent, biotite replaciag euhedral hornblende to abont 25 per cent, and from 1 to 15 per cent garnet as porphyroblasts and in veinlets. The groundmass is foliated and consists of fine-grained potassium feldspar.

Fine-grained porphyritic syenite consists of 10 to 30 per cent white phenocrysts of orthoclase in a light grey to pink groundmass containing up to 5 per cent disseminated biotite or hornblende. Contact relationships indicate the fine-grained porphyritic syenite is younger than the garnet syenite porphyry.

Epidote syenite megaporphyry dykes form a large part of the intrusive complex and are the youngest porphyries in the Galore Creek area. Large phenocrysts of orthoclase form 40 to 60 per cent of the rock. Phenocrysts are zoned and partly replaced along rims by intermediate microcline. Bimodal phenocryst size indicates two generations, an early phase, with phenocrysts averaging 2.5 centimetres long and a younger phase with much smaller phenocrysts. Epidote aggregates up to 15 per cent, are dispersed through the rock giving it a greenish grey colour, and where garnet is abundant in the wall rock the syenite also contains disseminated garnet. Hornblende phenocrysts, replaced in part by biotite and chlorite, form up to 25 per cent of the rock. The groundmass is fine-grained, grey potassium feldspar with accessory amounts of apatite and magnetite, each to 1 to 2 per cent.

Potassium-argon ages (recalculated to new decay constants) from porphyritic epidote syenite (North Junction syenite) gave discorant ages of 257 ± 7 Ma (hornblende) and 189 ± 6 Ma (biotite, Table 1-30-2). The hornblende age is unexpectably old. This syenite, known colloquially as "wipe-out porphyry" (A. Panteleyev, personal communication, 1988), is post mineralization. Drill-core samples have been collected and submitted for uranium-lead zircon dating.

JURASSIC-TERTIARY PLUTONIC SUITE

Coast Range Intrusions

One fourth of the map area is underlain by intrusive rocks of the Coast plutonic complex. Three texturally and compositionally distinct intrusive phases have been mapped (inferred oldest to youngest); potassium feldspar megacrystic granite to monzonite **(JTm)**; biotite hornblende diorite to granodiorite **(JTd)**; and biotite granite **(JTg)**.

Potassium feldspar megacrystic granite (JTm) is a coarse-grained, equigranular to porphyritic hornblende-biotite granite to quartz monzonite which outcrops on the eastern side of Pereleshin Mountain and south of Jack Wilson Creek on Saddle Mountain. The potassium feldspar megacrystic variety contains from 5 to 10 per cent potassium feldspar laths 0.4 to 2.0 centimetres in length. Hornblende and biotite are chloritic and interstitial to roughly equal proportions of equigranular plagioclase and potassium feldspar. Mafics constitute from 5 to 15 per cent of the rock. Quartz is interstitial, and varies from 10 to 20 per cent. Accessories include magnetite and trace pyrite.

Biotite hornblende diorite (JTd) is exposed on the eastern edge of the Coast Complex forming a belt 4 to 5 kilometres wide extending along the eastern side of the Stikine River from Pereleshin Mountain to the Porcupine River. At the confluence of the Porcupine and Stikine rivers the intrusive is roofed by pre-Permian(?) metasediments and metavolcanics. Numerous inclusions of partially assimilated pre-Permian(?) and/or Upper Triassic Stuhini Group(?) volcanics and sediments occur north to Saddle Mountain. The xenoliths are fine grained (1 to 4 metres and larger) and commonly well rounded.

The diorite is massive, medium grained and heterogeneous due to the abundance of inclusions, and is commonly sheared and altered. Megascopically the rock is equigranular, contains about 20 per cent quartz, and has a plagioclase:potassium feldspar ratio of approximately 4:1. Hornblende is more abundant than biotite and both occur as crystals and blebs. The average composition of ten thin sections (Kerr, 1948a) was: andesine, 60 per cent; orthoclase, 13 per cent; quartz, 17 per cent; mafics, predominantly hornblende, 10 per cent. Accessories include magnetite, titanite, apatite and zircon.

Potassium-argon dates (recalculated to new decay constants) for quartz diorite (Anuk River area) give a discordont pair of ages, 197 ± 5 Ma for hornblende and 120 ± 5 Ma for biotite (Table 1-30-2).

Biotite granite (JTg) underlies a wide belt west of the Stikine River. The rock is a massive, mineralogically and texturally homogeneous light grey rock, commonly well jointed. Megascopically it is coarse to medium grained, equigranular and composed of roughly equal proportions of plagioclase and potassium feldspar, each comprising about 10 per cent of the rock. Quartz averages 20 to 25 per cent. Biotite and lesser hornblende are interstitial to plagioclase and poikilitic feldspar and together comprise 5 to 10 per cent of the rock. Honey-coloured titanite is conspicuous to several per cent. Average composition of eleven thin sections (Kerr, 1948a) was: plagioclase, 58 per cent; orthoclase, 11 per cent; quartz, 20 per cent; biotite, 8 per cent; and hornblende, 3 per cent. Titanite, magnetite and apatite make up the accessories.

TERTIARY INTRUSIONS

Small stocks and plugs of biotite quartz monzonite **(Tm)** outcrop south of Sphaler Creek at its confluence with the

Porcupine River, and 10 kilometres further east, at Split Creek and northeast of Jack Wilson Creek (A. Panteleyev, personal communication, 1988). The rock is equigranular, medium grained and contains roughly equal proportions of plagioclase and potassium feldspar. Biotite averages 5 to 10 percent and quartz content varies to about 20 per cent.

A single potassium-argon date (recalculated to new decay constants) on biotite from the Sphaler Creek/Porcupine River stock gave 53.5 ± 1.6 Ma (Panteleyev, 1975), (Table 1-30-2).

Small plugs and dykes of plagioclase-phyric diorite **(Tp)** are intruded along north-trending faults within the South Scud River valley. The rocks are dense, green to grey coloured, with phenocrysts of zoned plagioclase (20 to 25 per cent) hornblende and quartz. Pyrite is ubiquitous and outcrops are limonite stained. These rocks are so fresh, they are thought to be Tertiary or younger.

Narrow dykes of inferred Tertiary age **(Tr, Tb)** are found in north-striking, steep-dipping fault zones. Rhyolite and lamprophyre/basalt are most common, but felsite, hornblende andesite and amphibolite dykes have been identified.

STRUCTURE

Complicated structures have resulted in part from polyform deformation (Paleozoic strata), but also from the contrasting competence of Triassic and Jurassic volcanic and sedimentary units. Four main sets of faults have produced a mosaic of fault-bounded blocks.

Three phases of deformation have been tentatively recognized for the oldest Paleozoic rocks and a single phase for Upper Triassic and younger strata. D_1 is pre-Permian to post-Mississippian; D_2 pre-Late Triassic "Tahltanian"; and D_3 post-Jurassic(?). Holbek (1988) has recognized four phases of folding within Stikine assemblage rocks to the east, and Panteleyev (1976) documented two generations in the Triassic rocks at Galore Creek.

Penetrative planar fabrics are ubiquitous in Paleozoic and Middle Triassic strata. Penetrative deformation of Upper Triassic and younger rocks is rare, restricted to north-trending zones of foliation.

FOLDS

PHASE 1 DEFORMATION

Paleozoic rocks between Sphaler Creek and Round Lake (Figure 1-30-2) contain a single bedding-parallel foliation. Flattened fragments in volcaniclastic units define a stretching lineation colinear with the foliation. Southwest of Round Lake, Permian and older purple tuff, volcaniclastics and plagioclase-phyric flows are folded into north-northwest-trending isoclinal folds. Bedding in these volcanics is truncated by a panel of moderately west-dipping Early Permian (Wolfcampian) limestones. It is uncertain whether this contact is a detachment fault or an angular unconformity. Neither fault gouge nor basal conglomerate are apparent.

PHASE 2 DEFORMATION

Permian limestones reflect the regional northerly-trend of D_2 folding. This phase is characterized by large, upright, tight to open folds above the Scud River. The axial traces trend north to north-northwest and folds verge westerly. The limestones are weakly to pervasively foliated, generally parallel to bedding. South of Scud River and east of Galore Creek, tight upright folds are characterized by ductile flow of limestone around chert boudins in strongly attenuated fold limbs. Souther (1972) reports thickened and detached fold crests in Permian limestones at the head of Sphaler Creek.

The Middle Triassic shale at Copper Canyon is assumed to lie below the Tahltanian unconformity (Souther, 1971) and had been folded (D_2) and regionally metamorphosed prior to deposition of the Upper Triassic Stuhini Group (Souther, 1972). At Copper Canyon the Middle Triassic sediments and Permian limestone are conformable and have been tightly folded as one unit (Jeffery, 1965). Tight isoclinal folds wholly within limestone are visible in cliffs above the thrust fault.

Metamorphism accompanied D_1 and D_2 and reached greenschist facies, culminating prior to D_3 (Souther, 1971; Monger, 1977; Holbek, 1988).

PHASE 3 DEFORMATION

The third phase of deformation is manifest as chevron folds and kink bands north of Round Lake. Fold axes have generally west or west-northwesterly trends and within the Stuhini Group the folds are upright box folds with chevron cores. The Jurassic sediments outcrop in a shallow westerly facing homocline onto which Upper Triassic porphyritic volcanics have been thrust eastward.

FAULTS

The most pronounced and longest-lived structures (active into the Quaternary) strike north (Souther, 1972). Vertical to steeply dipping faults occur on the western flank of the Hickman batholith and south of Sphaler Creek. Adjacent to the Hickman batholith is a zone of listwanite alteration, 15 to 20 metres wide, which hosts Tertiary(?) rhyolite and basaltic dykes. The fault zone juxtaposes Permian limestone with a narrow belt of Stuhini volcanic flows, tuffs and sediments intruded on the east by Hickman diorite. Souther (1972) has traced this fault south to Sphaler Creek where Permian and older metasediments and metavolcanics have been faulted against Upper Triassic volcanics.

A north-striking, east-dipping thrust fault at Copper Canyon places overturned Permian limestones and Middle Triassic shale on Upper Triassic volcanics (Figure 1-30-2). The hangingwall strata have dips of 30 to 50 degrees east. The contact with footwall rocks is sealed by Early to Middle Jurassic syenites at Copper Canyon (Table 1-30-2). South of the Scud River the thrust is truncated by a northwest-striking fault dipping steeply northeast. It is not known whether this is a splay of the thrust fault, or an unrelated structure. A parallel normal fault in the Scud River Valley also dips steeply northeast. It is pyritic and deeply weathered and can be traced 12 kilometres southward, almost to Copper Canyon.

A set of northwest-striking normal faults marks the boundary between the Upper Triassic and Paleozoic rocks between Scud River and Jack Wilson Creek. East-striking shear zones occur along the eastern margin of the Coast Complex.

The youngest faults in the map area strike north-northeast to northeast. The upper reaches of Sphaler Creek follow these steep to vertical structures and at the Sphal/Trek showing (MINFILE 104G 022, 029) one fault shows evidence of 1200 metres of left-lateral offset. Upstream, towards Round Lake, Paleozoic rocks have been uplifted along steep west-dipping reverse faults. A set of northeasterly striking shears and fractures on the Trophy claims is mineralized by quartz-carbonate veins. North-northeast-trending faults in the Galore Creek syenite complex postdate Early to Middle Jurassic mineralization.

GALORE ARCH

The attitudes of layered rocks around the Galore Creek complex indicate an arch-like structure, with its axis roughly coincident with the central zone of mineralization (Jeffery, 1965), interpreted to represent an eroded volcano (Allen *et al.*, 1976). North-northeasterly-trending breccia zones, syenite intrusives and faults occupy the central core in Galore Creek basin. Structures in this subvolcanic setting are predictably complex.

MINERALIZATION

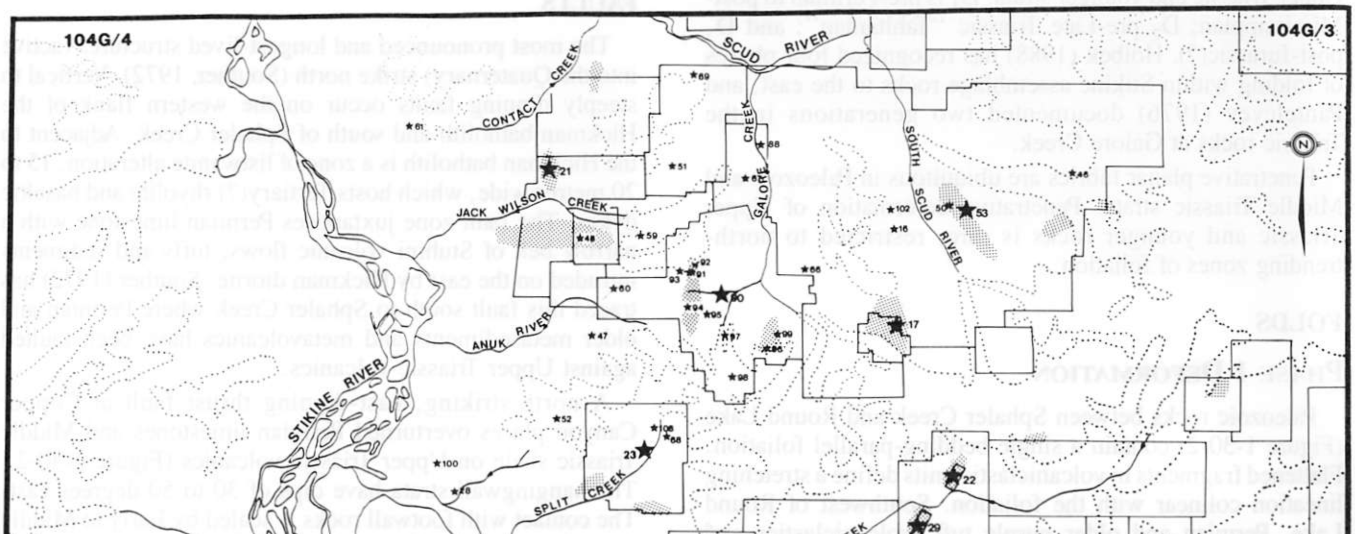
Mineral deposits in the Sphaler Creek–Scud River area can be subdivided into three groups: porphyry copper-silver-gold deposits associated with syenitic sills and monzonite plugs; mesothermal silver-gold and copper-zinc mineralization in quartz and carbonate veins; and massive polymetallic sulphides with or without gold and silver. Precious metal porphyry and vein deposits related to alkaline rocks are well documented (Mutschler *et al.*, 1985; Barr *et al.*, 1976) and important exploration models in northwestern British Columbia. Figure 1-30-4 shows the locations of mineral occurrences recorded in MINFILE as well as alteration zones and boundaries of mineral claims. Major occurrences and those subject to recent exploration activity are described below.

ALKALIC PORPHYRY DEPOSITS

Alkalic porphyry deposits occur throughout the length of the Intermontane Belt in Upper Triassic Nicola-Takla-Stuhini volcanic rocks and comagmatic alkaline plutons, forming a class distinct from calcalkaline porphyry deposits (Barr *et al.*, 1976). The deposits occupy brecciated and faulted sub-volcanic zones in the intrusions and country rocks which are overprinted by extensive potassium, propylitic and pyrometasomatic alteration zones. The deposits are characteristically enriched in gold and silver. In the Galore Creek camp Stuhini volcanics and comagmatic syenitic intrusives host more than ten of these coeval disseminated deposits.

GALORE CREEK (MINFILE 104G 091 TO 104G 099)

The Galore Creek deposits are located at the headwaters of Galore Creek in the centre of the map area. The first claims were staked in 1955. In 1963 Hudson Bay Mining and Smelting Company Limited, Kennco Explorations, (Western) Limited and Consolidated Mining and Smelting Com-



No.	MINFILE NAME	COMMODITIES	No.	MINFILE NAME	COMMODITIES	No.	MINFILE NAME	COMMODITIES
016	LOT	Cu,Au,Pb,Ag	052	SAL	Cu	092	GALORE CREEK-NORTH JUNCTION	Cu,An,Gy
017	COPPER CANYON	Cu,Au,Ag	053	PTARMIGAN	Au,Ag,Zn,Pb,Cu	093	GALORE CREEK-WEST RIM	Cu
021	JW	Cu,Ag	059	HORN	Cu	094	GALORE CREEK-BUTTE	Cu
022	SPHAL 17	Cu,Au,Ag	060	DEVILS CLUB	Cu,Ag,Au	095	GALORE CREEK-SOUTHWEST	Cu,Fe
023	ANN	Cu	061	PERELESHIN	Cu,Zn	096	GALORE CREEK-SADDLE	Cu
028	RM	Cu	066	STIKINE EAST	Cu	097	GALORE CK-WEST FORK GLACIER	Cu
029	SPHAL 27	Cu,Au	067	STIKINE NORTH	Cu	098	GALORE CREEK-SOUTH BUTTE	Cu
046	JAY	Cu	068	AC	Cu	099	GALORE CREEK-SOUTH 110	Cu
047	JOAN AND MB	Cu	069	OP	Cu	100	CAM	Cu
048	JACK	Pb,Zn,Ag,Cu	088	CW-EAST	Cu	102	GALORE CREEK LIMESTONE	Ls
050	HUMMINGBIRD	Cu,Au,Ag	090	GALORE CREEK-CENTRAL ZONE	Cu,Au,Ag,An,Gy,Zn,Mo	108	PAYDIRT	Au,Cu
051	CW	Cu,Au	091	GALORE CREEK-JUNCTION	Cu			

Figure 1-30-4. Mineral occurrence map showing MINFILE locations (large stars represent occurrences discussed in the text), mineral claims, and gossan zones (shaded areas).

pany of Canada Limited incorporated their respective interests to form Stikine Copper Limited. Between 1960 and 1969, 53 164 metres of diamond drilling and 807 metres of tunnelling in two adits were completed with Kennco as operator. An additional 25 352 metres of diamond drilling was completed in 111 holes between 1972 and 1973 under the direction of Hudson Bay Mining and Smelting Company. In 1987, Mingold reassayed all sample pulps for gold. Recent interest in the property stems from its future development possibilities (reserves contain 50 tonnes of gold) and its importance as a regional exploration model.

The Galore Creek syenite complex contains syenite intrusions, metavolcanics and minor sediments. Sedimentary and volcanic rocks close to the syenite complex are severely folded, sheared, faulted, brecciated and metasomatized to locally recrystallized. Mineralization is associated with four distinct phases of syenite; six other phases outcrop peripheral to the main ore zone.

Ten copper deposits are known at Galore Creek, in addition to a number of showings. They are hosted by potassium-altered (biotite and potassium feldspar addition) volcanics and pipe-like breccias adjacent to syenite porphyry dykes and stocks. The deposits are manto-shaped and trend north to northeast, following syenite contacts and structural breaks (Allen *et al.*, 1976).

Alteration and mineralization are contemporaneous and spatially overlap. Mineral zoning (Allen, 1966) is related in part to proximity to syenite bodies and breccia pipes but also reflects parent-rock composition. Potassium feldspar, biotite, garnets and anhydrite are ubiquitous and locally have replaced host rocks completely.

Chalcopyrite and bornite, in a ratio of 10:1, are the principal copper minerals. Disseminated pyrite is the most abundant sulphide; sphalerite and galena are associated within garnet-rich areas and trace amounts of molybdenite, native silver, native gold and tetrahedrite have been noted (Allen, 1966). Magnetite occurs in veinlets with or without chalcopyrite and often as a breccia matrix. Chalcocite, cuprite, native copper and tenorite are secondary copper minerals.

The largest deposit is the Central zone, which extends 1950 metres north-northeast, varies from 200 to 500 metres in width and averages 335 metres. It is centered on a steeply dipping breccia pipe. Reserves are estimated as 125 million tonnes grading 1.06 per cent copper, 0.40 gram per tonne gold and 7.7 grams per tonne silver (Allen *et al.*, 1976).

Copper Canyon (MINFILE 104G 017)

The Copper Canyon prospect is located approximately 8 kilometres due east of the Galore Creek deposit. Copper mineralization is associated with a syenite porphyry body and related dykes intruded along a major thrust fault. The syenite is sill-like and conformable with east-dipping Middle Triassic sediments and Upper Triassic volcanics. Textures vary from holocrystalline to sparsely porphyritic and are generally masked by alteration and weathering. Pseudoleucite phenocrysts form 10 per cent of the syenite along Doghouse Creek. An intrusive breccia phase or brecciated intrusive is developed locally. Sericitic and propylitic alteration and potassium metasomatism are widespread and pervasive. Pyritization and bleaching has produced an extensive gossan surrounding the intrusives and malachite and azurite stain cliffs in the canyon. Copper mineralization occurs as disseminations of chalcopyrite and bornite with minor gold and silver values. Other associated minerals include pyrite, magnetite, specularite, hematite, molybdenite and fluorite.

Ann/Sue and Paydirt (MINFILE 104G 023, 108)

The Ann/Sue and Paydirt showings are located north of Split Creek, a tributary of the Porcupine River.

The Ann/Sue showing is hosted by an intrusion of fine-grained porphyritic diorite to granodiorite within fine to medium-grained andesitic tuffs and altered greenstones. These rocks are so similiar in appearance that distinguishing intrusive from extrusive is difficult. Propylitic alteration has extensively affected both the intrusive and the host volcanics. Disseminated pyrite mineralization is ubiquitous and chalcopyrite sparse. Diamond-drill intersections assayed between trace and 0.32 per cent copper, with average values between 0.10 and 0.20 per cent copper (Jeffery, 1966). Panteleyev (1975) documents potassium-argon dates of 48.5 ± 1.7 Ma from biotites associated with pyrite mineralization (Table 1-30-2).

The Paydirt prospect is located within a large malachite-stained pyritic gossan 2 kilometres northeast of the Ann/Sue showing. The mineralization is hosted by massive andesitic tuffs, flows and crystal-lapilli tuffs with subordinate sediments. Jurassic to Tertiary monzonite to granodiorite outcrops in Split Creek and upslope from the main gold showing which is a silicified, sericitic and pyritic alteration zone in Upper Triassic andesitic tuffs. It strikes north and dips steeply east with a surface strike length of less than 100 metres and a maximum thickness of 25 metres. An unaltered andesite dyke follows the footwall of the mineralized zone. Drill-indicated reserves are 185 000 tonnes averaging 4.11 grams per tonne gold (Holtby, 1985). Longreach Resources Ltd. carried out exploratory drifting to intersect this zone in 1987.

JW (MINFILE 104G 021)

The JW claims are located on the north tributary of Jack Wilson Creek. They are underlain by a fine-grained, green, massive subvolcanic monzonite which intrudes Upper Triassic amygdaloidal volcanics of andesitic to basaltic composition. The monzonite is stongly magnetic and carries widespread pyrite as disseminations and fracture fillings. Sulphide mineralization occupies prominent northerly trending shear zones and vein systems marked by well-developed gossanous zones. Mineralization comprises chalcopyrite and pyrite in schistose propylitically altered greenstones and crystal tuffs. In the creek valley, gold values are associated with sericitized, pyritized and silicified zones in andesites. Gold-bearing quartz veins and silicified shear zones cut the monzonite (H. Awmack, personal communication, 1988).

Sphal 17 and Sphal 27 (MINFILE 104G 022, 029)

The Sphal 17 and Sphal 27 showings are located approximately 10 kilometres southeast of the Galore Creek deposit, north and south of Sphaler Creek. The area is underlain by Upper Triassic pyroxene-porphyry flows, andesitic breccias and crystal tuffs. Prominant north-northeast-trending faults have localized intrusions of Tertiary(?) monzonite and felsite bodies as well as mineralization.

On the Sphal 27 claim mineralization is hosted by northeast-trending faults and shear zones containing massive to disseminated pyrite and pyrrhotite, chalcopyrite and lesser magnetite, galena and sphalerite. Shear zones and subparallel structures carry gold and silver values (H. Almack, personal communication, 1988). Pervasive propylitic alteration and strong fracturing mark these mineralized shear zones.

North of Sphaler Creek, on the Sphal 17 claim, disseminated copper mineralization occurs in altered and brecciated zones in volcanics and felsite intrusives. The main mineralized zone is hosted by an intrusive breccia measuring 50 by 18 metres at surface; pyrite, chalcopyrite and magnetite fill the matrix. Faulting has broken the breccia into discontinuous sections. Samples over an area 18 by 20 metres assayed an average of 0.24 gram per tonne gold, 10.6 grams per tonne silver and 2.45 per cent copper (Folk, 1981).

MESOTHERMAL QUARTZ-CARBONATE VEINS

Hummingbird, Ptarmigan (MINFILE 104G 052, 050)

Exploration was begun in 1964 by Silver Standard Mines Limited which discovered the Hummingbird showing and outlined lead and zinc mineralization on the Ptarmigan showing containing up to 5.4 grams gold and 229 grams silver per tonne over 16 metres (Whiting, 1964). During 1988 Continental Gold Corporation carried out an aggressive program of geological mapping, sampling and diamond drilling (2735 metres in 16 holes).

The showings are underlain from west to east by Permian limestones, conformably overlain by Middle Triassic cherty siltstones and shale, in turn overlain by pervasively altered Stuhini Group massive andesite and flow breccia which are intruded by monzonite to monzodiorite **(eJHm)** along a northwest-trending faulted(?) contact. A Jurassic polymictic boulder conglomerate containing volcanic, sedimentary, granitic and rhyolite clasts outcrops in uncertain stratigraphic position nearby.

Northeast-striking faults and shear zones appear to crosscut older northwest-trending structures. Both structures contain mineralization, the younger are sulphide rich.

The Ptarmigan zone is a circular quartz-sericite-pyrite alteration zone, 50 metres in diameter, localized at the intersection of a northeast-striking fault (Ptarmigan shear) and a northwest-trending fault separating Triassic-Jurassic volcanic and sedimentary strata and Hickman monzonite. The monzonite is brecciated into angular blocks as large as 0.5 by 1.5 metres which are locally aligned and commonly dip southwestward into the zone. Within the Ptarmigan zone the monzonite is pervasively sericitized and bleached. Iron carbonate and pyrite occur as stockwork veinlets and matrix replacements. Away from the Ptarmigan zone the monzonite is coarse grained, massive and moderately chloritized. Adjacent to this intrusive breccia is an equally altered polymictic matrix-supported fault breccia containing well-rounded clasts of augite porphyry, monzonite, chert and feldspar porphyry. Angular blocks of altered monzonite, some veined by iron carbonate and pyrite are also present. The matrix is sericitized and locally completely replaced by pyrite. Clast lithologies are identical with those in the polymictic conglomerate overlying volcanics to the east. Continental Gold Corporation geologists have suggested the Ptarmigan zone represents a hydrothermal breccia pipe.

Precious metal mineralization occupies narrow and widely spaced fractures, veinlets and stockworks which crosscut the pyrite alteration zone. Vein mineralogy comprises disseminations of pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, minor arsenopyrite and electrum in a quartz carbonate gangue. Mineralization is silver-rich with silver:gold ratios averaging 80:1; the silver mineral has not been identified.

The Hummingbird zone is located 300 metres northwest of the Ptarmigan zone. Skarn mineral assemblages and weak associated mineralization have developed in Upper Triassic limestones adjacent to the northwest-trending Hummingbird fault. Sulphides include pyrite, chalcopyrite and pyrrhotite, skarn minerals are brown garnets and diopside.

Other Quartz Veins

These veins are made conspicuous by the rusty oxidation of iron carbonate alteration which envelopes them. The veins occupy north, northeast, northwest and west-striking structures. Alteration minerals include chlorite, ankerite and calcite. Sulphide mineralogy includes pyrite, sphalerite, chalcopyrite and arsenopyrite in concentrations up to 25 per cent of the quartz vein.

An east-striking vein at the headwaters of Hickman Creek is typical: the vein zone is composed of a medial 30-centimetre-wide quartz vein with a peripheral alteration envelope of bleaching, quartz carbonate veining and pyritization extending 40 centimetres on either side of the vein. Vein and alteration envelopes have been sampled for geochemical analysis.

Narrow quartz veins occur in two northwest-striking fault zones in the valley of the Scud River. The fault zones are up to 40 metres wide and host parallel quartz veins containing massive pyrite and traces of chalcopyrite.

MASSIVE SULPHIDES

Massive concentrations of pyrite, pyrrhotite and lesser chalcopyrite are present in Middle Triassic sediments on both sides of the South Scud River. These are irregular masses up to 20 by 30 metres in size. Mineralization is both conformable and transgressive. A lens of massive pyrite, pyrrhotite, chalcopyrite and arsenopyrite on the Trophy claims assayed 2.0 grams per tonne gold over 4.0 metres (Forster, 1988).

The potential for volcanogenic massive sulphide deposits in Paleozoic rocks is high. Pyroclastic sulphide fragments and small stratiform lenses of massive sulphides in Paleozoic felsic fragmental rocks located to the east have been reported by Holbek (1988), and massive sulphide deposits are known in correlative stratigraphy in the Tulsequah River area (Nelson and Payne, 1984).

AGES OF MINERALIZATION

At least two separate mineralizing events are postulated for the deposits within the map area. Middle Triassic sediments host conformable massive polymetallic sulphide occurrences. Adjacent to Hickman intrusions these are transgressive, suggesting some middle to Late Triassic remobilization.

Alkalic porphyry deposits are hosted by Late Triassic to Early Jurassic volcanics and subvolcanic intrusives. Four potassium-argon dates (recalculated to new decay constants) for hydrothermal biotite from the Galore Creek Central zone, range from 177 to 201 Ma., Early to Middle Jurassic (White *et al.*, 1968), (Table 1-30-2). Mesothermal vein deposits are peripheral to the volcanic-intrusive centers. Potassium-argon dating of chrome-bearing muscovite from a carbonate-sulphide vein (Mess Creek area) gave a 192 ± 7 Ma, Early Jurassic age for the mineralization (Holbek, 1988). At Schaft Creek, Panteleyev and Dudas (1973) report a 185 ± 5 Ma, Middle Jurassic age for mineralization (Table 1-30-2).

Lead isotope dating suggests a separate event in the Tertiary. Galena lead from the Ptarmigan zone has isotope ratios similar to Tertiary model-ages (J. Gabites, personal communication, 1988).

ACKNOWLEDGMENTS

David Rhys and Darren Bahrey provided capable and enthusiastic assistance throughout the field season. The cooperation of Douglas Forester and Gregory Dawson of Continental Gold Corporation was greatly appreciated. Thanks to Henry Almack and Equity Engineering Ltd. for the use of preliminary geological information, to E.T. Tozer for providing prompt fossil identifications, and to S. Carlow of the Surveys and Resources Mapping Branch for speedy delivery of air photographs. W.J. McMillan, A. Panteleyev and T.G. Schroeter are thanked for visiting our camp, and taking the only two days of sunshine in all of July.

REFERENCES

Aiken, J.D. (1959): Atlin Map-area, British Columbia, *Geological Survey of Canada*, Memoir 307, 89 pages.

Allen, D.G. (1966): Mineralogy of Stikine Copper's Galore Creek Deposits, Unpublished M.Sc. Thesis, *The University of British Columbia*, 38 pages.

Allen, D.G., Panteleyev, A. and Armstrong, A.T. (1976): Galore Creek *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*. Special Volume 15, pages 402-414.

Anderson, R.G. (1983): The Hotaihuh Batholith, Cry Lake, Spatsizi and Dease Lake Map-areas, North-central, B.C., Unpublished Ph.D Thesis, *Carleton University*, 646 pages.

——— (1984): Late Triassic and Jurassic Magmatism along the Stikine Arch and the Geology of the Stikine Batholith, North-central British Columbia, *Geological Survey of Canada*, Paper 84-1A, pages 67-73.

——— (1989, in press): A Stratigraphic, Plutonic and Structural Framework for the Iskut Map Area (104/B), Northwestern B.C; *in* Current Research, Part E, *Geological Survey of Canada*, Paper 89-1E

Barr, D.A., (1966): The Galore Creek Copper Deposit: *Canadian Institute Mining and Metallurgy*, Transactions, Volume 69, pages 251-263.

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A., (1976): The Alkaline Suite Porphyry Deposits: a Summary, *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume Number 16, pages 359-367.

Brown, D.A. and Gunning M. (1989): Geology of the Stikine River Area, North-western British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

de Rosen-Spence, A. (1985): Shoshonites and Associated Rocks of Central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1985-1, pages 426-442.

Folk, P.G. (1981): Report on Rock Chip Sampling of the Sphal 7-12, 19-33, Kim 1-10, 38, 40, 42, Sphal Fraction Claims; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 9614, 10 pages.

Forster, D.A. (1988): Trophy Gold Project – Geological and Geochemical Report, *United Mineral Services Limited*, Private Company Report, 63 pages.

Holbek, P.M. (1988): Geology and Mineralization of the Stikine Assemblage, Mess Creek Area, Northwestern British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 174 pages.

Holtby, M.H. (1985): A Geological, Soil Geochemical, Trenching and Diamond Drilling Programme on the Paydirt Claim Group, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 14980.

Jeffery, W.G. (1965): Galore Creek (Stikine Copper Limited), *B.C. Minister of Mines*, Annual Report, 1964, pages 19-40.

Kerr, F.A. (1948a): Lower Stikine and Western Iskut River Areas, British Columbia, *Geological Survey of Canada*, Memoir 246, 95 pages.

——— (1948b): Taku River Map Area, British Columbia, *Geological Survey of Canada*, Memoir 248, 84 pages.

Mamet, B.L. (1976): An Atlas of Microfacies in Carboniferous Carbonates of the Canadian Cordillera, *Geological Survey of Canada*, Bulletin 255, 131 pages.

Monger, J.W.H. (1970): Upper Paleozoic Rocks of the Stikine Arch, British Columbia, *in* Report of Activities, Part A, *Geological Survey of Canada*, Paper 70-1, Pt A, pages 41-43.

——— (1977): Upper Paleozoic Rocks of the Western Cordillera and their Bearing on Cordilleran Evolution, *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

Monger, J.W.H. and Ross, J.V. (1971): Distributions of Fusulinaceans in Western Canadian Cordillera, *Canadian Journal of Earth Sciences*, Volume 8, pages 259-278.

Mutschler, F.E., Griffin, M.E., Stevens, D.S. and Shannon, S.S. (1985): Precious Metal Deposits Related to Alkaline Rocks in the North American Cordillera – an Interpretive Review; *Transactions of the Geological Society South Africa*. Volume 88, pages 355-377.

Nelson, J. and Payne, J.G. (1984): Paleozoic Volcanic Assemblages and Volcanogenic Massive Sulphide Deposits near Tulsequah, British Columbia; *Canadian Journal of Earth Sciences*, Volume 21, pages 379-381.

Nixon, G.T. and Ash, C.H. (1989): Alaskan-type Ultramafic Rocks in British Columbia: The Hickman, Gnat Lakes and Menard Mafic-Ultramafic Complexes, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Panteleyev, A. (1975): Galore Creek Map Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1974, Paper 1975-1, pages 59-62.

——— (1976): Galore Creek Map Area, *B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork*, 1975, Paper 1976-1, pages 79-81.

——— (1977): GC, HAB, BUY(Stikine Copper), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology in British Columbia, 1976, pages 122-125.

Panteleyev, A. and Dudas, B.M. (1973): Schaft Creek, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration, and Mining in British Columbia, 1972, pages 527-528.

Pitcher, M.G. (1960): Fusulinids of the Cache Creek Group, Stikine River Area, Cassiar District, B.C., Unpublished M.Sc. Thesis, *Brigham Young University*, 64 pages.

Read, P. (1984): Geology Klastline River (104G/16E), Ealue Lake (104H/13W), Cake Hill (104I/4W), and Stikine Canyon (104J/1E), British Columbia, *Geological Survey of Canada*, Open File 1080.

Rigby, J.K. (1961): Upper Paleozoic Rocks of Central and Northern British Columbia, *Geological Society of America*, Special Paper 68, Abstracts, page 253.

Skinner, J.W. and Wilde, G.L. (1965): Permian Biostratigraphy and Fusulinid Faunas of the Lake Shasta Area, Northern California, *University of Kansas Paleontological Contributions, Protozoa* Article 6, pages 1-98.

Souther, J.G. (1971): Geology and Mineral Deposits of Tulsequah Map-area, British Columbia, *Geological Survey of Canada*, Memoir 362, 84 pages.

——— (1972): Telegraph Creek Map Area, British Columbia, *Geological Survey of Canada*, Paper 71-44, 38 pages.

——— (1977): Volcanism and Tectonic Environments in the Canadian Cordillera – a Second Look, Volcanic Regimes of Canada, *Geological Association of Canada*, Special Paper Number 16, pages 1-24.

Tipper, H.W., Richards, T.A. (1976): Jurassic Stratigraphy and History of North-central British Columbia; *Geological Survey of Canada*, Bulletin 270, 73 pages.

White, W.H., Harakal, J.E. and Carter, N.C. (1968): Potassium-argon Ages of some Ore Deposits in British Columbia, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 61, pages 1326-1334.

Whiting, K. (1964): Geological Report on the Mineral Claims Blk 87 to 116 Inclusive, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 623.

STRATIGRAPHY AND STRUCTURE IN THE TWIN GLACIER - HOODOO MOUNTAIN AREA, NORTHWESTERN BRITISH COLUMBIA (104B/14)

By Jeffrey A. Fillipone and John V. Ross
The University of British Columbia

KEYWORDS: Regional geology, Iskut River, stratigraphy, deformation, structure, greenschist metamorphism.

INTRODUCTION

The Iskut River area of northwestern British Columbia is underlain by a thick succession of upper Paleozoic and Mesozoic volcanic rocks which host a number of significant base and precious metal prospects. Near Bronson Creek, a tributary of the Iskut River, the Johnny Mountain deposit is currently being mined by Skyline Explorations Ltd. and the Snip deposit is being developed for production by Cominco Ltd.

During the summer of 1988, two weeks were devoted to mapping a sequence of volcanic and sedimentary rocks which outcrop on the north side of the Iskut River, north of Bronson Creek (Figure 1-31-1). An attempt was made to document all stratigraphic and structural features that might have bearing on the geologic evolution of nearby areas of economic interest.

PREVIOUS WORK

Regional geological maps cover overlapping areas but present many disparate descriptions of probably equivalent rocks comprising the Triassic and Jurassic successions (Kerr, 1948; Grove, 1986). Kerr mapped the area in the vicinity of the Iskut and lower Stikine rivers, and devised a generalized regional stratigraphy including upper Paleozoic sedimentary and volcanic rocks, Permian limestone, Triassic and Jurassic sediments and volcanics, and numerous, mostly Mesozoic intrusive rocks. Mapping in the Telegraph Creek area (104/G) by the Geological Survey of Canada (1957) as part of Operation Stikine, and later by Souther (1972) documents Triassic and Jurassic rocks exposed northeast of the study area, along the Iskut River valley. Lefebure and Gunning (1988) mapped the area south of the Iskut River near Bronson and Snippaker creeks, and compiled geochemical data on major gold properties and prospects. This study will complement mapping by the British Columbia Geological Survey Branch in the Unuk River and Sulphurets areas to the south (Britton and Alldrick, 1988; Britton *et al.*, 1989, this volume) and in the Scud river area to the north (Logan and Koyanagi, 1989; Brown and Gunning, 1989, both this volume).

Upper Paleozoic and Mesozoic rocks in the Iskut River area comprise part of the Stikine terrane of northwestern British Columbia (Wheeler and McFeely, 1987). Stratigraphic descriptions of the Mesozoic succession are limited to the work of Kerr (1948) and numerous mineral property assessment reports, which generally lack details of the age relationships and stratigraphy. Rocks mapped in this study are part of Kerr's Unit 11, which he described as intermediate to basic lavas, tuffs, clastic rocks and limestone, cut by a variety of intrusions.

Souther (1971) applied the term Stuhini Group to Triassic volcanic rocks in the Tulsequah map area which may be correlative with similar strata in the Stewart area (Grove, 1971, 1986). Recent geological compilation of the Canadian Cordillera includes rocks of the study area in the Stuhini Group (Wheeler and McFeely, 1987). This paper presents an interpretation of the detailed stratigraphy on the ridge separating Twin Glacier and a nearby area on the north flank of Hoodoo Mountain, a Quaternary volcano. Units are correlative across the extensive icefield separating these two areas (Figures 1-31-1 and 1-31-2).

STRATIGRAPHY

The map area is underlain by a package of interlayered intermediate to mafic volcanogenic sediments and volcanic flows. At Twin Glacier these rocks generally dip moderately to steeply southwest, with some northerly dips resulting from obvious macroscopic folds. In contrast, the same units near Hoodoo Mountain have steep to near-vertical dips to the north and south. Primary sedimentary structures were used to determine stratigraphic tops and they indicate most of the succession (Units 1 to 6) at Twin Glacier is overturned; the steeply dipping strata near Hoodoo Mountain are both right-way-up and overturned. The following descriptions of stratigraphic units are ordered from oldest to youngest, based on this interpretation.

UNIT 1

Unit 1, a sequence of well-layered basaltic to andesitic flows, basic to intermediate tuffs, minor limestone and argillite, at least 700 metres thick, crops out at the south end of Twin Glacier ridge. Compositional layering is laterally continuous and individual flows vary from 10 to 50 centimetres in thickness, with most between 20 to 30 centimetres thick. Light grey recrystallized limestone occurs as thin lenses, mostly within the basalt flows. At the extreme southern end of the ridge silty tuffs and poorly bedded siltstone become more abundant. Thinly laminated, light grey calcareous tuff with quartz phenocrysts occurs near the base of the unit.

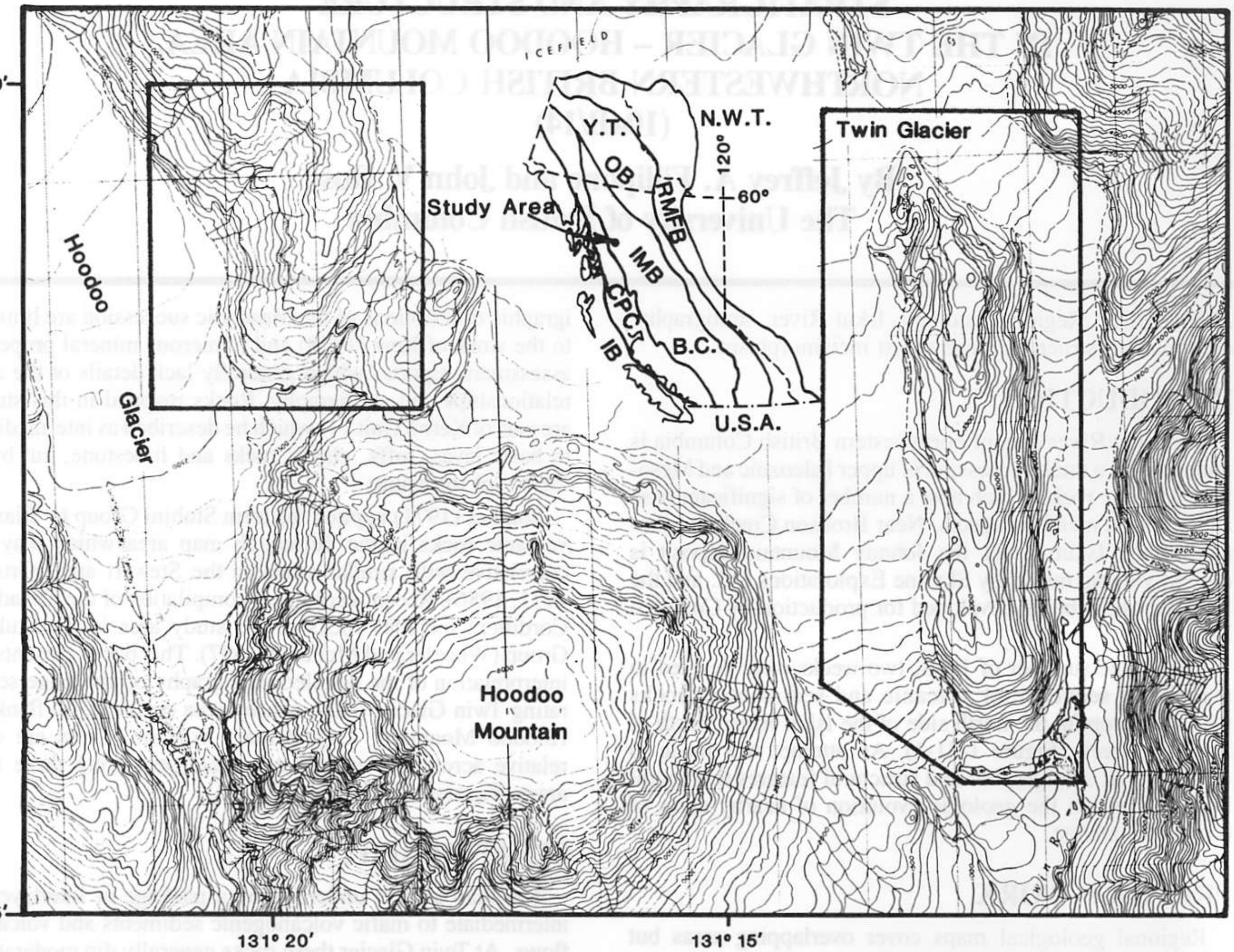


Figure 1-31-1. Location map of the Twin Glacier – Hoodoo Mountain area, northwestern British Columbia with boundaries of the individual map areas. Inset shows relationship to major tectonic belts of the Canadian Cordillera. Belt abbreviations are as follows: RMFB = Rocky Mountain fold and thrust belt; OB = Omineca Belt; IMB = Intermontane Belt; CPC = Coast plutonic complex; IB = Insular Belt.

Recrystallization and coarsening of micas has clearly taken place due to an apparent increase in metamorphic grade. Paleozoic rocks mapped by Kerr (1948) at the south end of Twin Glacier are probably the slightly higher grade(?) metamorphic equivalents of Unit 1.

UNIT 2

Unit 1 is followed, in continuous progression, by a sequence of interlayered basalt, rhyolite and rhyodacite at least 450 metres thick (Figure 1-31-2a). Interlayered basalt and carbonate of Unit 1 are succeeded by similar basalt with layers and pods of rhyolite and/or rhyodacite 1 to 5 metres thick. Light to dark grey, very fine-grained, strongly flow-banded siliceous volcanics, mainly flows, alternate with layers of basalt 1 to 3 metres thick, and minor lenses of recrystallized limestone (Plate 1-31-1). The siliceous volcanics locally form large flow-banded pods and "pillowed" zones. Globular "pillows", 5 to 15 centimetres thick, locally impart a "pinch-and-swell" texture to the rock. Toward the top of Unit 2 rhyolite flows become thinner and less abundant.

UNIT 3

Unit 3, approximately 150 metres thick, comprises basalt (40 per cent), almost identical to that of Unit 2 and the lower part of Unit 1, and graded beds of silty to fine-grained green and purplish tuff with minor argillite and lapilli tuff horizons. The silty tuffs are locally interlayered with discontinuous fine cherty bands 1 to 3 millimetres thick; the coarser tuffs contain diverse fragments of tuff, dark grey mudstone, light green fine-grained volcanic rocks and feldspar crystals. Individual grains range from less than 1 millimetre to 1 centimetre or more in diameter.

UNIT 4

The base of Unit 4 is defined by rusty weathering basalt in contact with bedded tuff of Unit 3. The unit comprises 600 metres or more of basalt and minor tuff passing upwards into

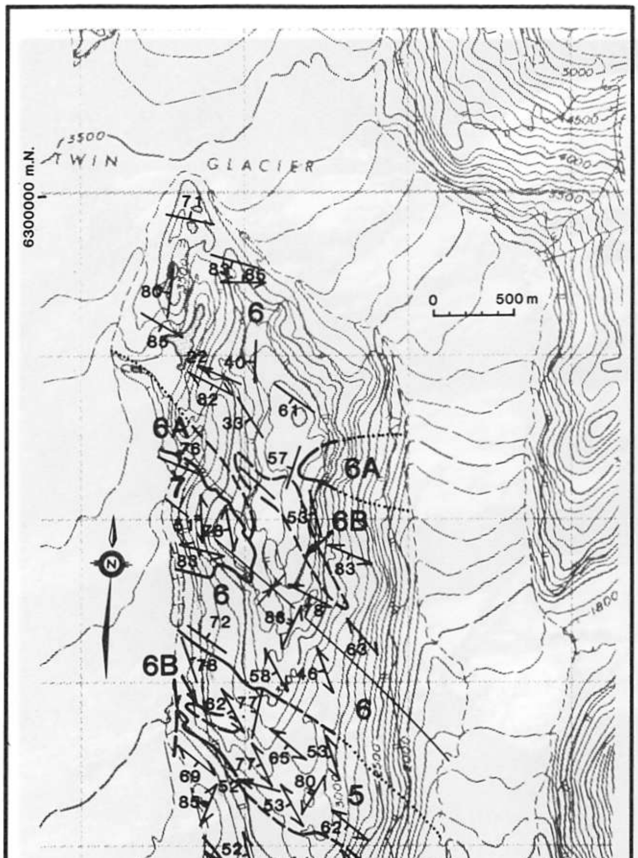


Figure 1-31-2 (a) Geologic map of the Twin Glacier area.

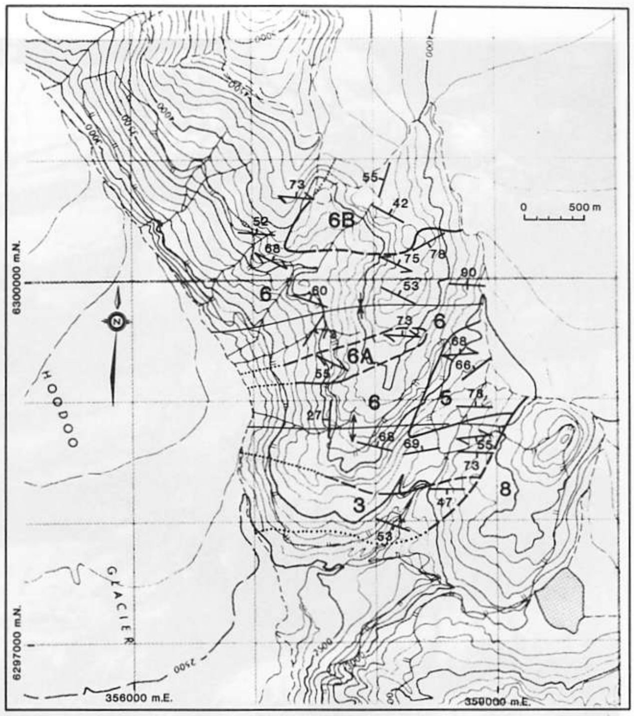


Figure 1-31-2 (b) Geologic map of the Hoodoo Mountain area.

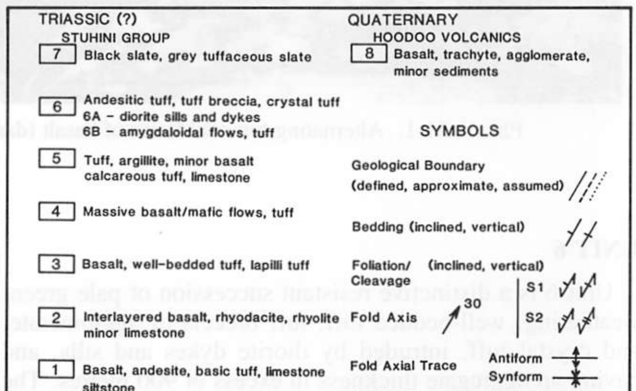


Figure 1-31-2 (c) Legend for geologic maps.

plagiophyric andesite and basalt flows; epidote alteration and carbonate veining are developed locally.

UNIT 5

Unit 5 is a structurally complex package of grey phyllite and slaty tuff, black argillite, and calcareous tuff, 450 or more metres thick. A thin discontinuous calcareous tuff at the base of the unit is overlain by fine-grained slaty tuff and a layer of dark grey plagiophyric basalt 1 to 1.5 metres thick. Locally, a thin sill of light brownish grey porphyritic rhyolite or rhyodacite occurs above the slaty tuff; it is very fresh and undeformed, and contains plagioclase laths a centimetre or more long. Above the sill is a zone of purple to grey phyllite overlain by very fine-grained, black sooty argillite or slate containing small pyrite grains preferentially developed along cleavage planes. The black slate contains thin layers of plagiophyric basalt almost identical to that above the slaty tuff lower in the section. Basalt flows are also intercalated with black slates within the calcareous tuff sequence that comprises the rest of the unit. The calcareous tuff is massive to slaty and contains fragmental zones where lapilli of tuffaceous material make up 20 to 30 per cent of the rock.

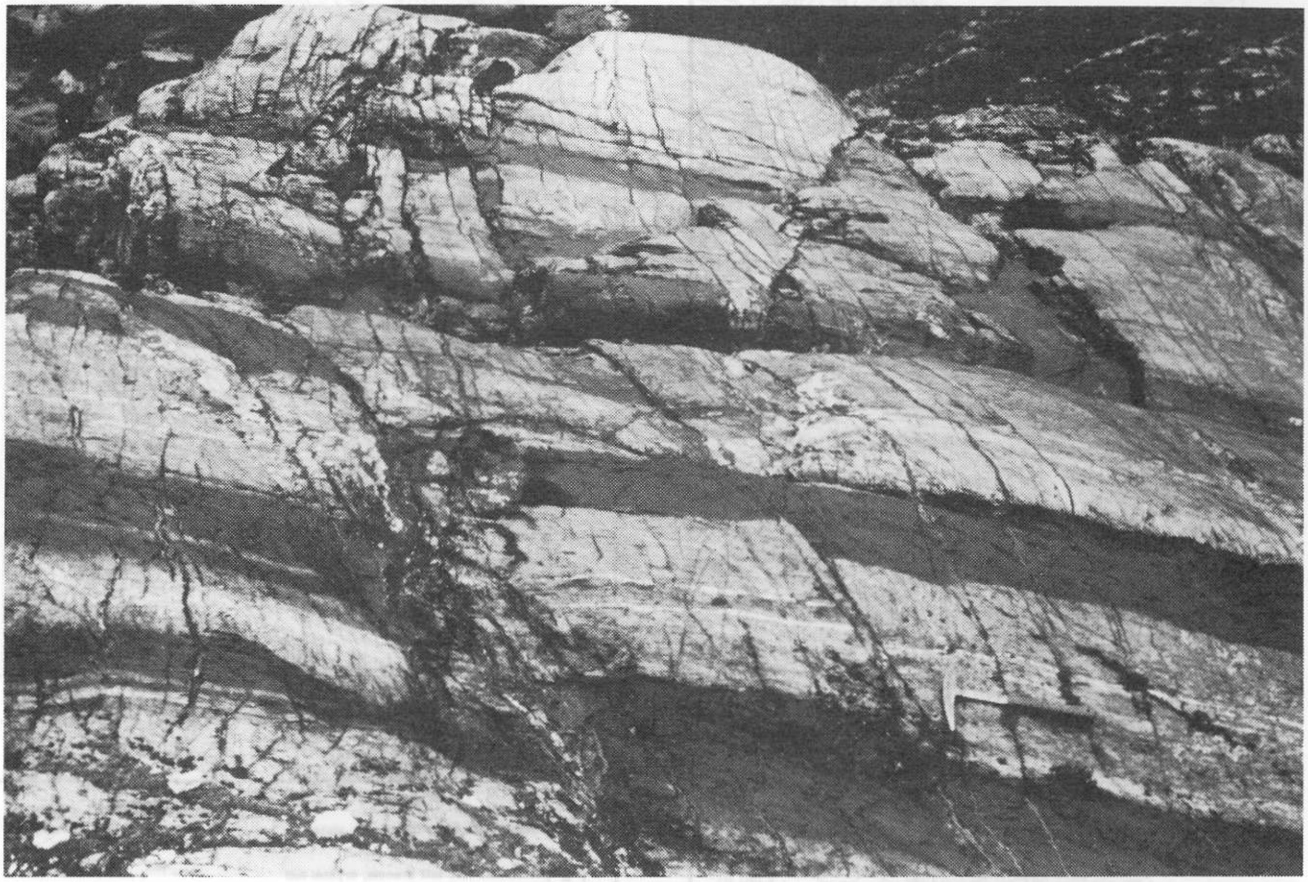


Plate 1-31-1. Alternating bimodal flows of basalt (dark layers) and plagiophyric siliceous volcanics (rhyodacite?).

UNIT 6

Unit 6 is a distinctive resistant succession of pale green-weathering, well-bedded tuff, tuff breccia or agglomerate, and crystal tuff, intruded by diorite dykes and sills, and having an aggregate thickness in excess of 900 metres. The contact with calcareous tuffs of Unit 5 is a low-angle unconformity. Massive, unfoliated hornblende crystal tuff, and what is interpreted to be coeval diorite (Subunit 6A), are commonly overlain by beds of medium to coarse-grained silty tuff and tuff breccia containing angular to subrounded fragments. The tuffs include well-developed graded beds indicating that this unit is right-way-up; both normal and reverse grading are observed. Augite is a major component of tuffs throughout Unit 6, especially in the finer grained rocks, occurring as phenocrysts, glomerophenocrysts and small lath-shaped grains in a fine-grained devitrified matrix. Feldspar is invariably altered to epidote, sericite and oxides. The breccias incorporate blocks of tuff and fine-grained volcanic rocks of similar composition to the matrix. Fragments are generally lapilli size but include subangular to subrounded blocks up to 25 centimetres long.

In the upper part of the unit ocassional beds of dark grey mudstone, 1 to 4 metres thick, occur in bedded tuffs and, north of Hoodoo Mountain, pale green tuff locally grades into thinly laminated to slaty, maroon lithic tuff.

Subunit 6B consists of zones of dark grey amygdaloidal flows near the base of the well-bedded tuffs. Large irregular bodies of diorite (subunit 6A) at the base of Unit 6 crosscut bedding in the underlying black slate and argillite of Unit 5; one diorite body lies wholly within Unit 5 (Figure 1-31-2a).

Convolute laminations are common where thinly bedded tuff is overlain by very coarse agglomerate and may indicate a base-surge origin for some of the finer grained pyroclastic material (Fisher and Schminke, 1984). Rare examples of small-scale load structures and channel scours have been observed at similar contacts where coarse clastic beds have been deposited on top of much finer grained material (Plate 1-31-2). Cross-stratification was not seen, although carefully looked for. These sedimentary structures are interpreted as evidence of deposition in a shallow marine environment close to a volcanic centre.

UNIT 7

Black slates and grey tuffaceous slates, 200 metres thick, comprise the youngest stratigraphic unit exposed in the study area. Bedding, manifest as colour bands several centimetres wide or as alternating beds of light coloured silly slate and black fine-grained slate 10 to 30 centimetres thick, is strongly folded throughout the unit but there is no evidence of discordance with underlying beds of Unit 6.

Plate 1-31-2. Graded beds in tuff breccia and well-bedded tuff in Unit 6, Twin Glacier.

Plate 1-31-3. F_2 minor folds in Unit 5 bedded tuff; view down plunge to the south-southwest (approximately 200° azimuth).

STRUCTURE

The study area covers only a small segment of the large fold structures which characterize the region (Kerr, 1948; Grove, 1986). Nevertheless, minor structures and stratigraphic top indicators can be used to interpret the major structural features of the area. Lower hemisphere equal-area projections of planar and linear structures at Twin Glacier and north of Hoodoo Mountain are presented in Figures 1-31-3 and 1-31-4. Structural data from the two areas, and from above and below the unconformity between Units 5 and 6, are plotted separately.

FOLDING

The plots presented in Figures 1-31-3 and 4 indicate two superimposed deformational events. The first phase of folding (F_1) and its related cleavage, are developed along a northwest trend. Best-fit girdles of deformed bedding indicate a trend of 280 to 300 degrees for F_1 fold axes (Figure 1-31-3a, 3c), except where modified by pre-existing unconformities or subsequent folding. F_1 minor folds are preferentially developed in the fine-grained clastic units such as black mudstone (slate). Axial planes are moderate to steeply dipping with hinge lines generally plunging gently to the northwest. Minor folds are open to tight, and exhibit asymmetry from which a general northeast sense of vergence is deduced. S_1 fabrics are generally nonpenetrative and in rare instances have an incipiently recrystallized mica fabric parallel to cleavage planes.

F_2 folds have an open, upright style, and steeply dipping axial surfaces with a trend almost orthogonol to F-1 structures (Figure 1-31-3e). A nonpenetrative spaced cleavage typifies the S_2 fabric (Plate 1-31-3). A possible interpretation of the significant change in the orientation of S_1 between the Twin Glacier and Hoodoo Mountain localities (Figure 1-31-4) is that large wavelength F_2 folds have refolded earlier structures about predominantly southwest-plunging fold axes – L_2. This is supported by the observation that F_2 folds distort L_1 linear structures at Twin Glacier. F_2 minor folds were not documented with certainty at Hoodoo Mountain.

A slaty cleavage striking 220 to 240 degrees and dipping 40 to 65 degrees northwest was observed at a few localities, in several different lithologies, however, its significance is not yet understood.

FAULTS

Few significant faults were recognized in the map area. One fault cuts bedding in Unit 5 at a shallow angle (Figure 1-31-2a) and appears to ramp up-stratigraphy within the unit, producing a minimum offset of 10 metres reverse movement (hangingwall up to the southwest). The fault has been distorted by F_2 folds and is probably related to the earlier deformation event. Younger, north-trending, steeply dipping faults with small offsets, mapped on the west side of Twin Glacier ridge, cut bedding at a high angle and are probably related to F_2 deformation.

VEINS

Brittle structures related to post-F_1 deformation are common throughout the area. Extension gashes, some of which are sygmoidal in shape, are filled with calcite, or rarely quartz, and are especially abundant in basalt and well-indurated tuff of Units 3 through 7. Sigmoidal gashes record progressive deformation of complex geometry. Many extension fractures, with or without vein fillings, are subparallel to the S_2 cleavage (Figure 1-31-3f). Syntaxial calcite veins in

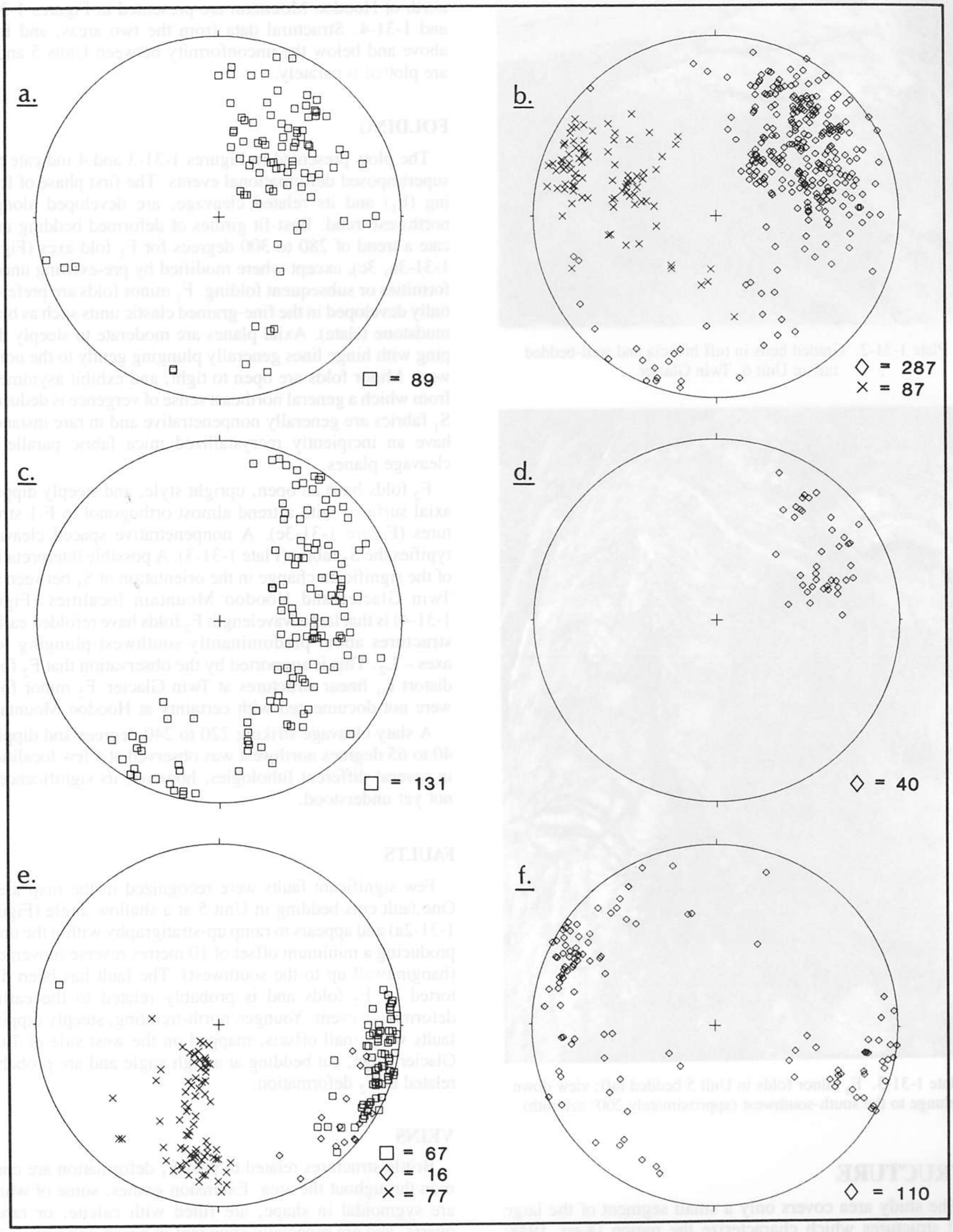


Figure 1-31-3. Twin Glacier area – lower hemisphere, equal-area projections of poles to bedding (S_0), poles to foliation planes/ minor fold axial plants (S_1, S_2) and F_1 fold axes/intersection lineations (L_1, L_2). Symbols are as follows: boxes = bedding; diamonds = foliation (except for (f) which represent poles to fractures); X = fold axes. (a) S_0 data, Units 1-5; (b) F_1 data, Units 1-5; (c) S_0 data, Units 6, 7; (d) S_1 data, Units 6, 7; (e) F_2 data, all units, undivided, (f) extension fractures/gashes (diamonds = poles).

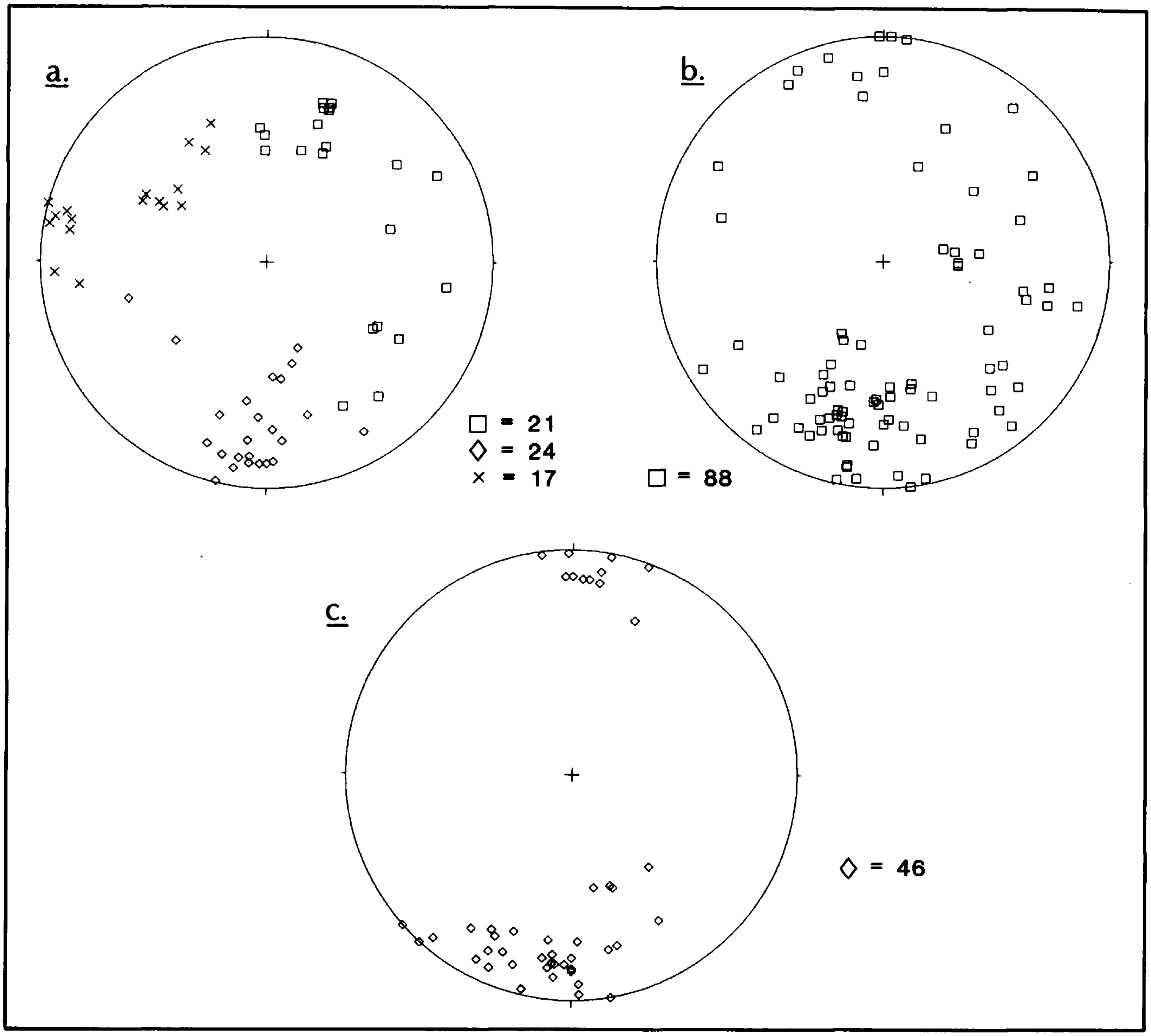


Figure 1-31-4. North of Hoodoo Mountain – lower hemisphere, equal-area projections of poles to bedding (S_0), poles to foliation planes/minor fold axial planes (S_1) and F_1 fold axes/intersection lineations (L_1). Symbols are as follows: boxes = bedding; diamonds = foliation; X = minor fold axes. (a) S_0, S_1 and L_1 data, Units 3-5; (b) S_0 data, Unit 6; (c) S_1data, Unit 6.

basalt and calcareous tuff frequently show crack-seal textures (Ramsay, 1980) and locally carry small amounts of pyrite.

METAMORPHISM

Lower greenschist metamorphism synchronous with F_1 deformation has affected all units. Fine-grained phyllite contains a muscovite-chlorite-albite-epidote metamorphic assemblage; original calcite, quartz, hornblende and iron oxides are preserved in many of the volcanic rocks. Patches of very fine-grained biotite are developed in phyllite of Units 4 and 5. In places the rims of calcite amygdules in basaltic lavas are altered to chlorite and/or epidote. Fine-grained schists, metagreywackes and basic to intermediate volcanic rocks at the Snip property exhibit biotite-grade metamorphism, implying increasing metamorphic grade south of the Iskut River. Mineralization at Snip is probably early synmetamorphic as the ore zones are deformed by F_1 folds.

ACKNOWLEDGMENTS

Financial support for this study by a British Columbia Geoscience Research Grant to J.V. Ross and J. Fillipone is gratefully acknowledged. We thank Dr. R.G. Anderson of the Geological Survey of Canada for his interest in the project and for logistical support in the field. Sincere thanks are also extended to Dr. Alan Patterson, Ron Nichols and the staff at Cominco's Snip property for their hospitality and the heli-

copter support without which the fieldwork would not have been possible.

REFERENCES

Britton, J.M. and Alldrick, D.J. (1988): Sulphurets Map Area (104A/05, 12W; 104B/08E, 09E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987-1, Paper 1988-1, pages 199-209.

Britton, J.M., Webster, I. and Alldrick, D.J. (1989): Unuk Map Area (104G/5, 6), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Brown, D.A. and Gunning, M.H. (1989): Geology of the Scud River Area, Northwestern British Columbia (104G/5, 6), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Fisher, R.V. and Schmincke, H. U. (1984): Pyroclastic Rocks, *Springer-Verlag*, 472 pages.

Geological Survey of Canada (1957): Stikine River Area, Cassiar District, British Columbia, Map 9-1957.

Grove, E.W. (1971): Geology and Mineral Deposits of the Stewart Area, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 58, 219 pages.

——— (1986): Geology and Mineral Deposits of the Unuk River – Salmon River – Anyox Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 63, 152 pages.

Kerr, F.A. (1948): Lower Stikine and Western Iskut River Areas, British Columbia, *Geological Survey of Canada*, Memoir 246, 94 pages.

Lefebure, D.V. and Gunning, M.H. (1988): Gold Lithogeochemistry of Bronson Creek Area, British Columbia (104B/10W, 11E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia, 1987, pages B71-B77.

Logan, J.M. and Koyanagi, V.M. (1989): Preliminary Geology and Mineral Deposits of Sphaler Creek and Flood Glacier (104G/3, 4), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Ramsay, J.G. (1980): The Crack-seal Mechanism of Rock Deformation, *Nature*, Volume 284, pages 135-139.

Souther, J.G. (1971): Geology and Mineral Deposits of the Tulsequah Map-area, British Columbia, *Geological Survey of Canada*, Memoir 362, 84 pages.

——— (1972): Telegraph Creek Map-area, British Columbia, *Geological Survey of Canada*, Paper 71-44, 38 pages.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America, *Geological Survey of Canada*, Open File Report 1565.

THE GEOLOGY OF THE TAGISH LAKE AREA (FANTAIL LAKE and WARM CREEK) (104M/9W and 10E)

By M.G. Mihalynuk, L.D. Currie and R.L. Arksey

KEYWORDS: Regional geology, Boundary Ranges metamorphic suite, Nisling terrane, Stuhini Group, Laberge Group, Coast Complex, Llewellyn fault, Teepee Mountain, skarn, gold veins.

INTRODUCTION

This report is an update on the regional mapping project begun in 1987 in the Tutshi Lake map area in northwestern British Columbia (Mihalynuk and Rouse, 1988a and b). Mapping over the past field season centred on the Tagish Lake area between Atlin, British Columbia and Skagway, Alaska (Figure 1-32-1). Fieldwork was completed between early June and mid-September. A regional geochemical program including moss-mat and stream-sediment sampling was run in concert with geological mapping at 1:25 000 scale (800 square kilometres, compiled at 1:50 000).

Lithologies in the 1988 map area do not vary significantly from those within the 1987 study area. During the past season emphasis was on subdivision of the existing gross lithologic units shown in their regional geologic setting in Figure 1-32-2. The simplified geology of the 1988 study area is portrayed in Figure 1-32-3 and regional correlations with the 1987 map area are shown in Figure 1-32-4.

Lithologies represented in Figures 1-32-2, 3, and 4 range from metamorphic rocks of probable Proterozoic marine clastic protoliths to Mesozoic volcanics and coarse clastic marine sediments. Layered rocks are crosscut by three granitoid suites loosely constrained as Late Triassic (*circa* 215 Ma), Early Cretaceous (*circa* 130 Ma) and Late Cretaceous through Paleocene (*circa* 90 to 65 Ma; *see* Table 1-32-1). A large fault zone (known as the Llewellyn fault; Bultman, 1979) transects the area diagonally and marks the western boundary of the metamorphic terrain. Stream sediment and lithogeochemical analyses indicate that the metamorphic terrain, and in particular the fault zone, are anomalous with respect to both arsenic and gold, and are thus significant mineral exploration targets.

ACCESS AND PHYSIOGRAPHY

The 1988 study area is most conveniently reached by charter float-plane or helicopter; both stationed 40 kilometres to the east at Atlin. At high water (late July through September) the Atlin River, which joins the Atlin and Tagish Lake systems, can be negotiated by powerboat, however, this route is not recommended for the uninitiated.

Approximately 20 per cent of the map area is easily reached from major lakes that follow the eastern margin (Tagish) and central east-west axis (Fantail) of the map sheet. These lakes are at 650 metres and 690 metres elevation respectively, treeline is about 1250 metres, and the major peaks exceed 2150 metres elevation. Nearly 5 per cent of this mountainous area is covered by glaciers that are presently in recession. Both permanent and fresh snow may cover much of the alpine areas throughout the summer.

REGIONAL GEOLOGIC SETTING

The map area encompasses a small segment of the north-northwest-trending boundary between the Intermontane and Coast crystalline belts; the structural fabric of three distinct lithotectonic domains within the area reflects this orientation. In the west (Domain I; Figure 1-32-5) rocks of the Coast crystalline belt intrude the Proterozoic to Paleozoic Boundary Ranges metamorphic suite of the Nisling terrane, (Domain II; Figure 1-32-5) which are in fault contact with the Upper Triassic Stuhini Group or the Lower Jurassic Inklin overlap assemblage (Wheeler *et al.*, 1988) together forming the easternmost Domain III. Plutonic bodies east of Domain I

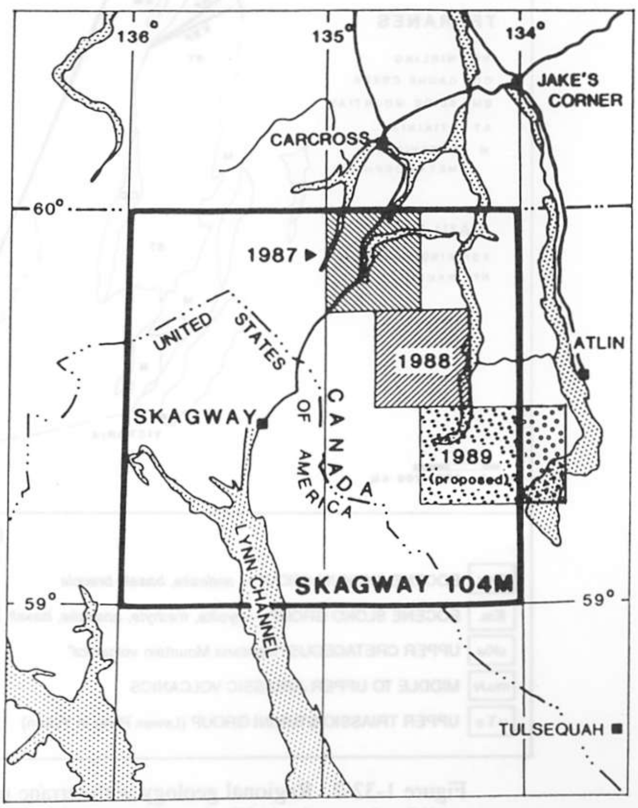


Figure 1-32-1. Location map showing 1987, 1988 and proposed 1989 field areas.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

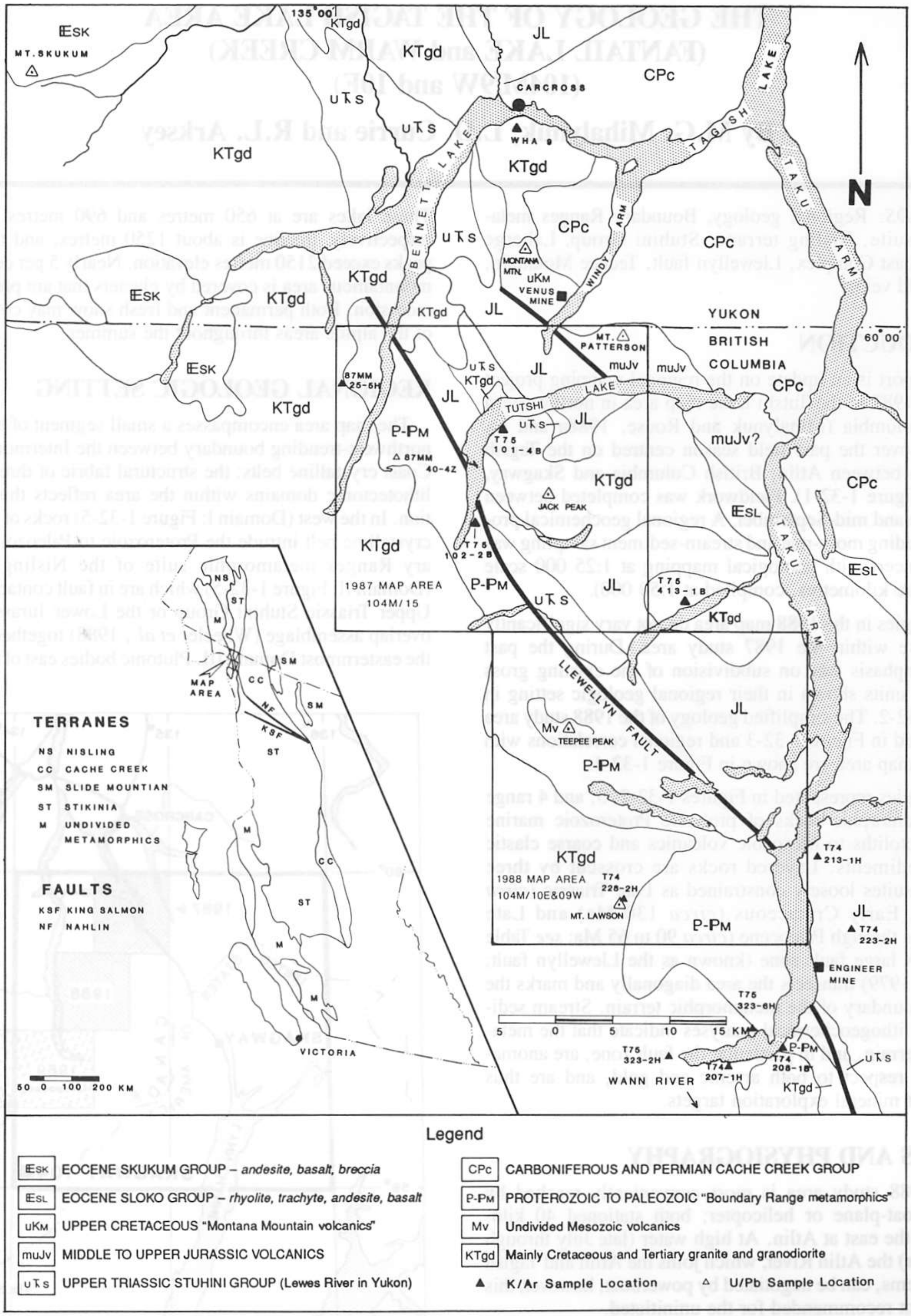


Figure 1-32-2. Regional geology with terrane map inset (Modified after Christie, 1957; Wheeler, 1961; Wheeler *et al.*, 1987). Isotopic age information from the sites indicated are listed in Table 1-32-1.

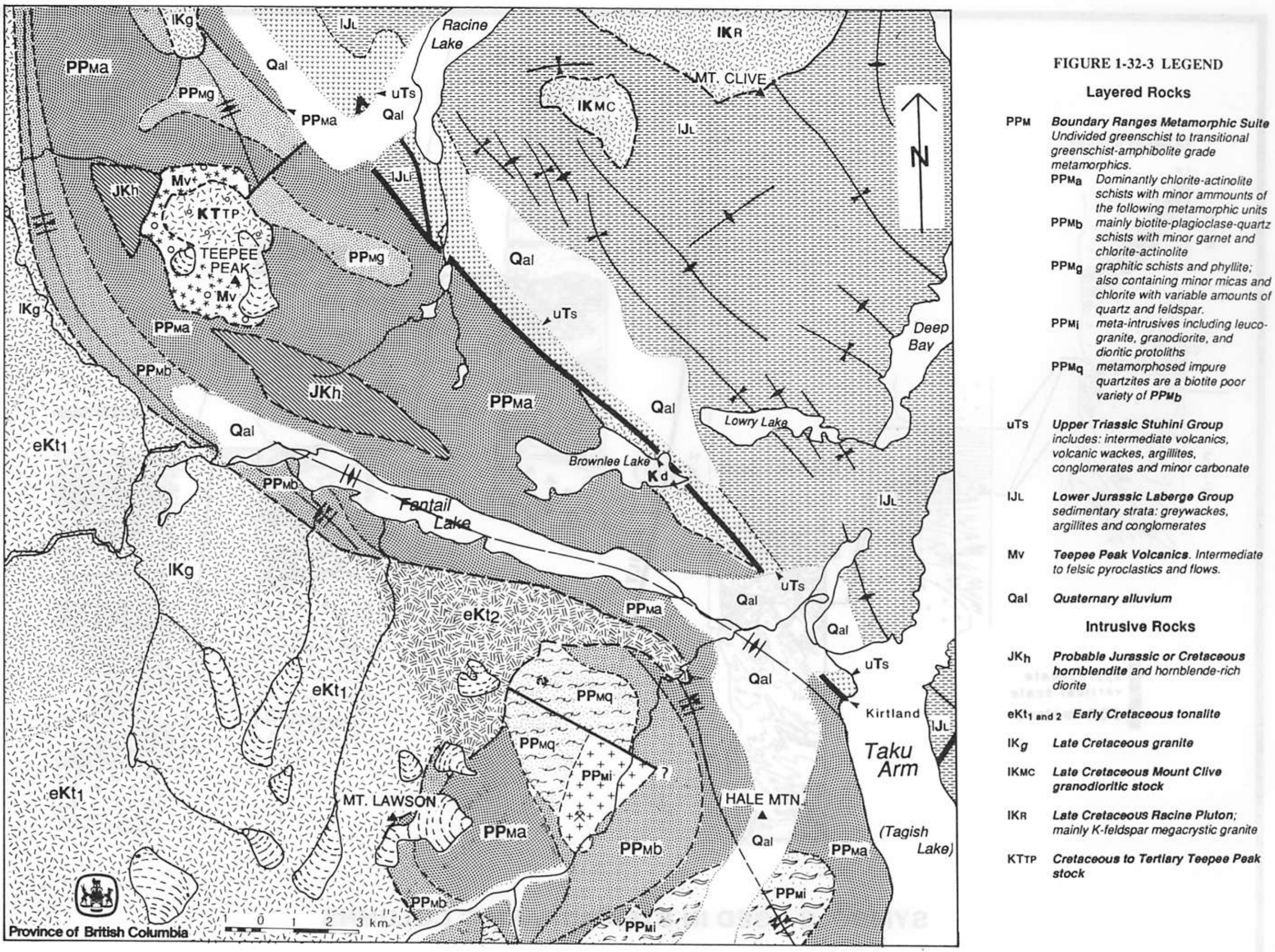


Figure 1-32-3. Simplified geology of the Tagish Lake area (*see* text for a description of the units). Unit PPM_a is primarily, but not exclusively, chlorite-actinolite schists; narrow zones of other lithologies, including marbles, are common. Hinge traces shown within units of PPM are interpreted as those of large scale F_3 folds (denoted by two ticks).

crosscut all layered rocks and represent the youngest lithologies, aside from minor late crosscutting dykes, and yield potassium-argon dates of 131 to 65 Ma (Bultman, 1979; Table 1-32-1).

Nisling rocks wrap around a small salient of slightly foliated hornblende diorite/tonalite thought to be part of a 131 Ma suite (Bultman, 1979; Mt. Lawson; Figure 1-32-2; Table 1-32-1). Older meta-intrusives are deformed and/or infolded with the metasediments to various degrees. A potassium-argon age determination on one such body on the southern border of the Tagish Lake area yielded 215.3 ± 5 Ma (Bultman, 1979), this represents the oldest of the three intrusive suites postdating regional metamorphism of the Boundary Ranges metamorphic suite. Extensive uranium-lead isotopic dating of foliated intrusive rocks will likely yield ages older than 215 Ma as structural and textural evidence suggests that they have been subjected to a longer deformational history than have the 215.3 ± 5 Ma intrusives.

LAYERED ROCKS

PROTEROZOIC TO PALEOZOIC(?) BOUNDARY RANGES METAMORPHICS (PPM)

Mihalynuk and Rouse (1988) termed low-grade metamorphic rocks in the Tutshi Lake area, previously called Yukon Group (Christie, 1957), the Boundary Ranges metamorphic suite. Templeman-Kluit (1976) suggests that the term "Yukon Group" may be misleading since juxtaposed metamorphic rocks within this package may have widely varying protolith ages. The name "Boundary Ranges metamorphics" is suitable for rocks south of the British Columbia –Yukon border as these rocks underlie the Boundary Ranges. On the other hand, as these rocks have been included in the Nisling terrane (Wheeler and McFeely, 1987), a name like "Nisling metamorphic suite" is also apt, but perhaps not recommended due to the youth and presently poorly defined character of the Nisling terrane.

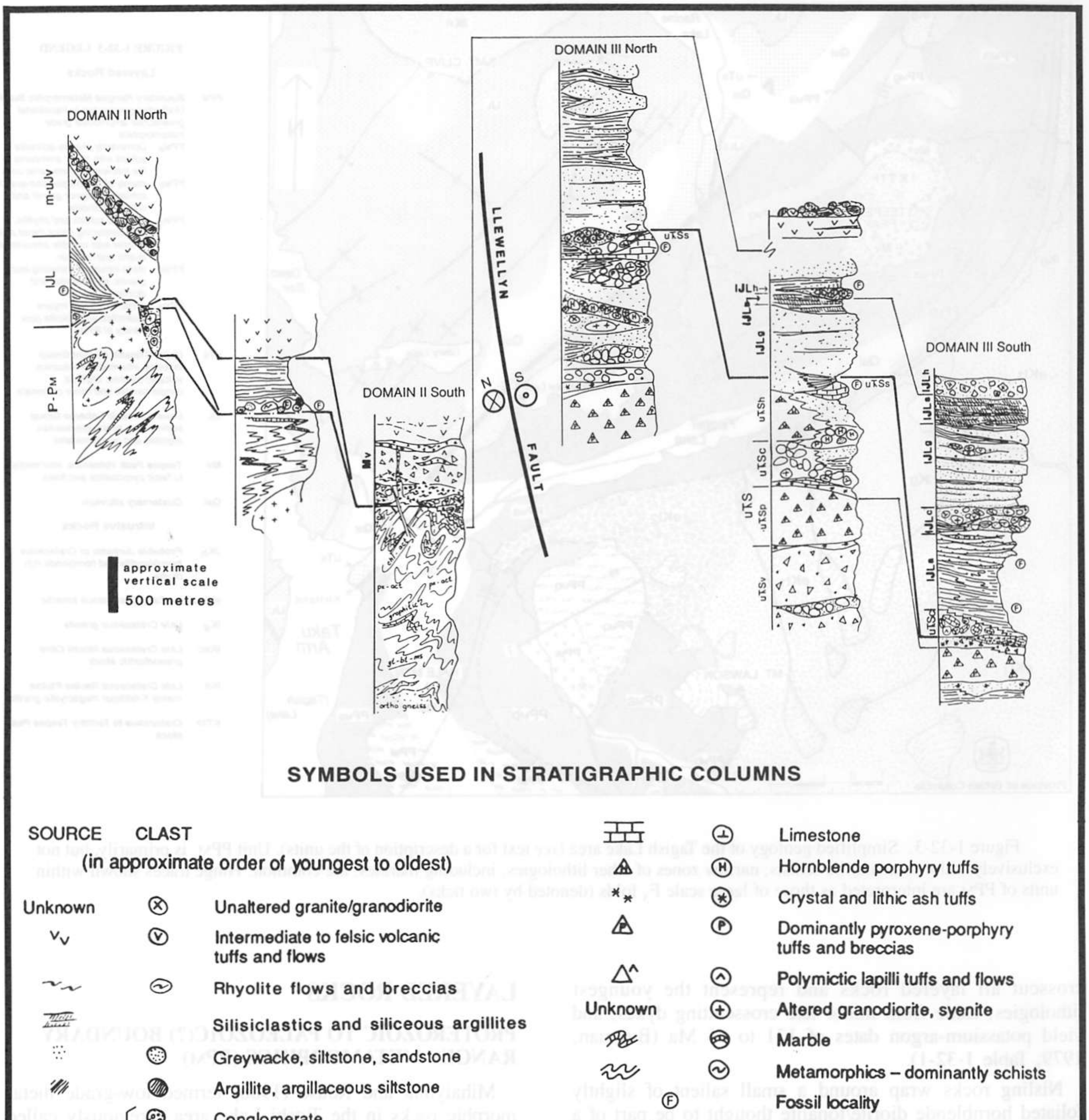


Figure 1-32-4. Stratigraphic correlation chart showing both 1987 and 1988 map areas. Unit UTsh is comprised of hornblende-rich tuffs and epiclastics (Mihalynuk and Rouse, 1988a, b). Unit muJv, defined in the Tutshi Lake map area, is tentatively correlated with Unit Mv (*see* "Hornblendite" section for age argument). See text and Figure 1-32-3 legend for description of units.

TABLE 1-32-1
K-Ar ISOTOPIC AGE DATA
(Locations Shown on Figure 1-32-8)

Sample No.[a]	Location Latitude	Location Longitude	Rock Type	%K	$^{40}Ar^{b}$ 10^{-7} cc/g	$\%\,^{40}Ar^{c}$ $-^{40}Ar_{total}$	Age, error,[d] Ma[e]
T74-101-4b	104M/15 59°55′20″	134°42′31″	biotite granite	6.09 (n=3)	22.30	40	90±3 92±3
T74-207-1h	104M/8 59°24′45″	134°22′43″	granodiorite	2.54 (n=2)	6.49	53.7	64±1.3 66±1.3
T74-208-1b	104M/8 59°25′25″	134°17′10″	granodiorite	6.37 (n=3)	31.56	79.2	120±2 123±3
T74-208-1h	104M/8 59°25′25″	134°17′10″	granodiorite	0.85 (n=1)	4.98	36.0	142±4 145±4
T74-213-1h	104M/9W 59°34′45″	134°15′20″	granodiorite	0.45 (n=2)	3.41	38.3	181±5 185±5
T74-223-2h	104M/9W 59°30′35″	134°10′31″	hornblende tonalite	0.39 (n=2)	1.27	34.1	80±3 83±3
T74-228-2h	104M/10E 59°33′00″	134°31′52″	hornblende tonalite	0.60 (n=2)	3.23	41.1	131±3 133±3
T75-102-2b	104M/15 59°51′50″	134°46′15″	granodiorite	7.10 (n=3)	22.48	81.3	78±1.6 80±1.6
T75-323-2h	104M/8 59°25′20″	134°26′12″	hornblende diorite	0.38 (n=2)	1.83	40.4	117±3 120±3
T75-323-6h	104M/8 59°26′00″	134°18′52″	hornblende gneiss	1.14 (n=2)	7.89	43.9	166±3 170±3
T75-413-1b	104M/15 59°47′25″	134°24′31″	biotite granite	5.74 (n=3)	19.21	39.4	82±2.1 84±2.1
87MM-25-5h	104M/15 59°57′38″	134°57′38″	hornblendite	0.39 (n=3)	20.57	79.7	— 150±6

[a]b refers to biotite analysis; h to a hornblende analysis.
[b]Radiogenic ^{40}Ar.
[c]Radiogenic as percentage of total ^{40}Ar; all samples from Bultman (1979) except 87MM-25-5h.
[d]Error expressed as 1 standard error of the mean.
[e]First date tabulated is derived using decay constants 4.72/.584/1.19; second using 4.96/.581/1.16.

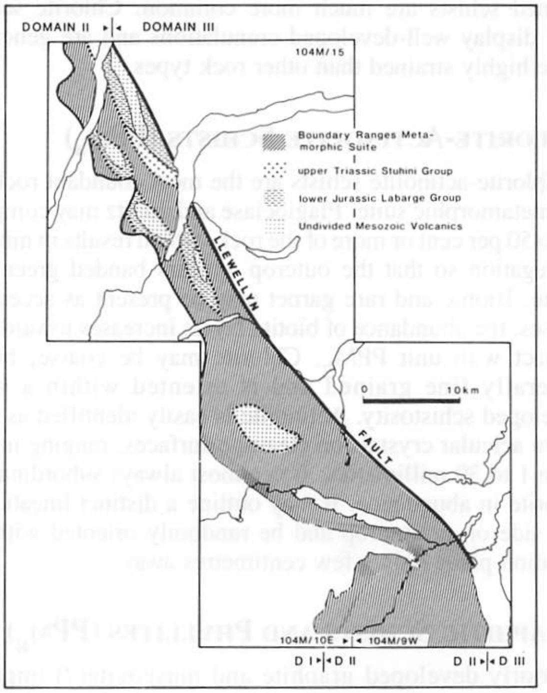


Figure 1-32-5. Distribution of Mesozoic strata overlying Boundary Ranges metamorphic rocks.

Metamorphic rocks form a polydeformed belt (Domain II, Figure 1-32-5; Plate 1-32-1) bounded on the east by the Llewellyn fault and on the west by mainly intrusive rocks of the Coast crystalline belt. Evidence exists for a variety of protoliths: quartzose to pelitic, carbonaceous and calcareous marine sediments to tuffaceous strata; small lenses to large bodies (several kilometres diameter) of ultramafic, gabbroic, dioritic, granodioritic and granitic intrusives. This lithologic variability is similar to that described by Wheeler (1961) suggesting a correlation with the metamorphic rocks in the Whitehorse map area. Thicknesses are exceedingly difficult to estimate due to the high degree of deformation, and in particular, non-coaxial folding and interstratal slip. These same factors make it impossible to trace specific layers more than a few 100 metres in outcrop.

Doherty and Hart (1988) map quartz-mica schists just north of the British Columbia–Yukon border which they correlate with the biotite schist unit of Tempelman-Kluit (1976). The only significant difference between metamorphic rocks north and south of the border seems to be the increase in metavolcanics to the south (although these do not appear to persist as far south as 104M/8; Werner, 1977, 1978). Within 104M/8, however, metamorphic rocks display characteristics that are identical to those described for the biotite schist unit.

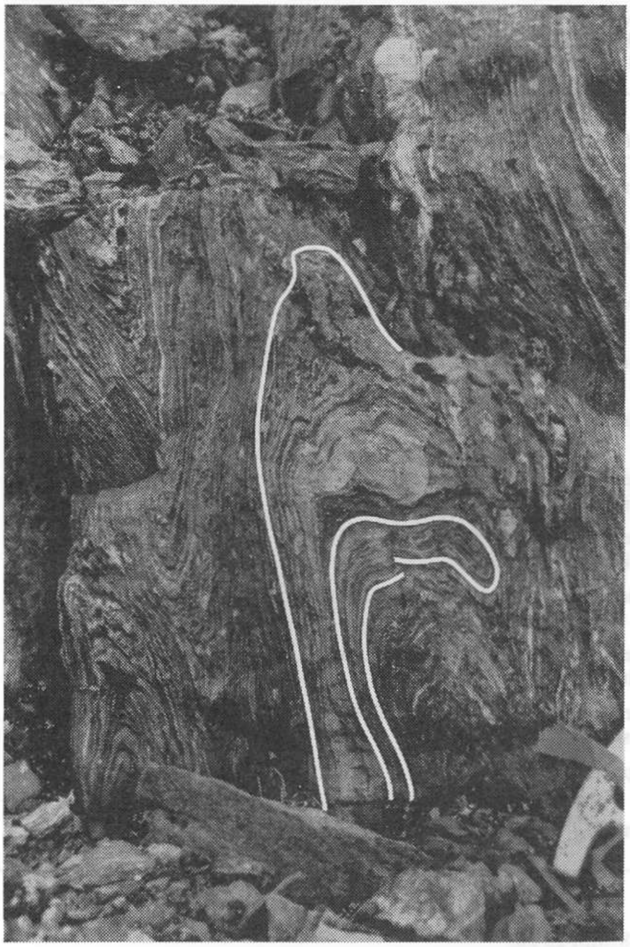


Plate 1-32-1. Folded fold within metamorphic rocks displaying typical irregular, tight to isoclinal folds (*i.e.* folded S_{0+1} surface is highlighted in white).

The age of Unit PPM is based on rubidium-strontium isotopic model age determinations on rocks correlated to the north and south which are: 1170 Ma (Wasserburg *et al.*, 1963); Late Proterozoic (less than 770 Ma; Armstrong *et al.*, 1986); 1200 Ma (Watson *et al.*, 1981), and a similar age for equivalent rocks immediately south of the map area in 104M/8 (Werner, unpublished data; Armstrong, personal communication, 1988). Aleinikoff *et al.* (1987) interpret an Early Proterozoic age based on uranium-lead and samarium-neodynium isotopic data for similar rocks in the Yukon-Tanana upland in eastern Alaska. Existing isotopic dating will be extensively tested in the Tagish area as part of a Ph.D. thesis at Carleton University by L. Currie using uranium-lead isotopic techniques.

META-INTRUSIVES (PPM$_i$)

Investigating the age of meta-intrusives within the PPM suite is the easiest way to determine the **minimum** age for these metamorphic rocks. At this time, isotopic dates exist only for the youngest of these intrusions which are Late Triassic in age 215 ± 5 Ma (Table 1-32-1) and probably should not be included as a component of the Nisling terrane *sensu stricto*. Other types of early intrusives (porphyritic granodiorites, fine to medium-grained granites, among others) may be infolded with the metasediments to various degrees, and are probably older than Late Triassic. One of these bodies, located on the south flank of Hale Mountain, is a large, foliated, chlorite (12 per cent) and epidote (2 per cent) altered hornblende biotite granodiorite.

BIOTITE PLAGIOCLASE QUARTZ SCHISTS (PPM$_b$)

The biotite schists form a belt along the western edge of Domain II. The proportion of minerals is normally biotite less than plagioclase less than quartz, although nearly pure biotite layers up to 10 centimetres thick are common. These schists may contain sparse garnet porphyroblasts typically 1 to 3 millimetres in diameter, but rarely up to several centimetres. Both muscovite and actinolite are normally subordinate phases, but can be found in amounts subequal to biotite in confined layers.

Biotite schists are well foliated and this foliation is commonly folded. Despite their compact nature in outcrop they are most abundant in the lowlands. Outcrops are rusty, dark grey weathering.

IMPURE METAQUARTZITES (PPM$_q$)

These rocks can be regarded as quartz-rich biotite schists as they are texturally indistinguishable from Unit PPM$_b$, but typically contain less than 10 percent biotite and less than 20 per cent feldspars. The contact between this unit and Unit PPM$_b$, although somewhat arbitrary, is mappable.

CHLORITE SCHISTS (PPM$_c$)

These schists are not extensive but underlie a significant area north of Fantail Lake. Chlorite porphyroblasts are well developed (up to 2 centimetres diameter) in places but fine-grained schists are much more common. Chlorite schists may display well-developed crenulations and are generally more highly strained than other rock types.

CHLORITE-ACTINOLITE SCHISTS (PPM$_a$)

Chlorite-actinolite schists are the most abundant rocks of the metamorphic suite. Plagioclase and quartz may comprise up to 50 per cent or more of the rock, which results in mineral segregation so that the outcrop appears banded green and white. Biotite and rare garnet may be present as accessory phases; the abundance of biotite layers increases towards the contact with unit PPM$_b$. Chlorite may be coarse, but is generally fine grained and is oriented within a well-developed schistosity. Actinolite is easily identified as dark green acicular crystals on cleavage surfaces, ranging in size from 1 to 30 millimetres. It is almost always subordinate to chlorite in abundance. It may outline a distinct lineation at one side of an outcrop and be randomly oriented within a foliation plane only a few centimetres away.

GRAPHITIC SCHISTS AND PHYLLITES (PPM$_g$)

Poorly developed graphite and muscovite(?) impart a silver sheen to these rocks which generally form rubbly to blocky outcrops depending on the degree of induration. They may grade into Unit PPM_a and commonly contain calcareous interlayers. Quartz, chlorite and feldspar content varies but black graphitic folia are diagnostic.

Pyroxene-Plagioclase Schists (PPM_p)

Pyroxene-plagioclase schists with lesser chlorite and actinolite are common, although volumetrically minor within chlorite-actinolite schists. Pyroxenes are typically 0.5 to 1 centimetre in diameter within a matrix of chlorite, actinolite and plagioclase. The latter minerals tend to wrap around the more competent pyroxene crystals. Proportions of pyroxene in a given sample vary from a few per cent to about 50 per cent. Protoliths of these rocks are not known, but basic tuffs or intrusives are most likely. In 104M/15 very similar schists are seen to grade into a weakly foliated gabbroic body.

Marble (PPM_m)

Yellow, orange and tan-weathering, medium-grained, resistant carbonate layers up to 200 metres thick are the best marker units within the metamorphic package. Unfortunately, like all other rocks within the polydeformed metamorphic domain, these units are discontinuous and difficult to follow. Where they do crop out persistently, they clearly outline structures (*see* Figure 1-32-6).

STUHINI GROUP VOLCANICS (uTs)

The Stuhini Group in the Tagish Lake area may be represented by less than 500 metres of strata. Near the south end of Racine Lake the apparent thickness exceeds 3 kilometres, but much of this succession is strongly foliated and its correlation

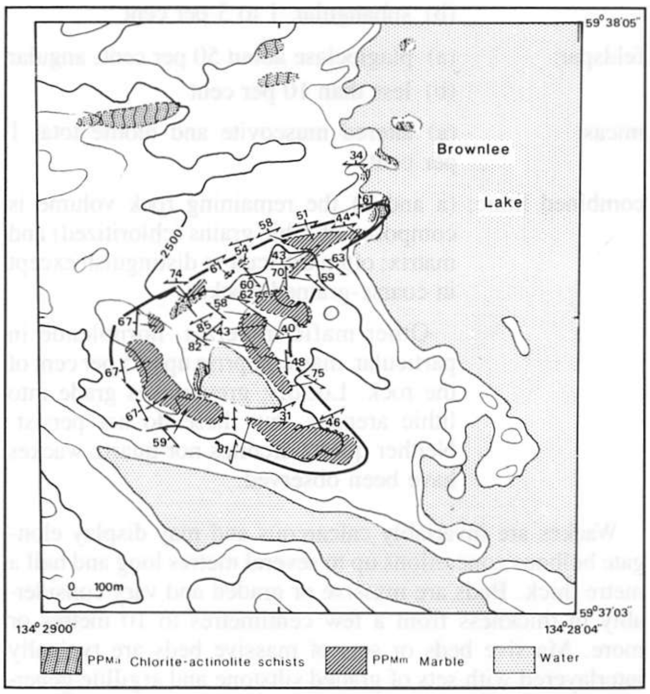


Figure 1-32-6. Outcrop distribution and structural data are shown for an F_3 interference structure west of Brownlee Lake, outlined by a massive carbonate band within dominantly chlorite-actinolite schists.

with Stuhini Group strata is largely conjectural. Protoliths for part of the foliated strata were rhyolite lapilli tuffs – unlike any *bona fide* Stuhini Group lithologies within either the 1987 or 1988 map areas, adding further to the uncertainty of this correlation.

Contacts between units in the Stuhini Group are rarely exposed in the Tagish Lake area and are often faulted, particularly where adjacent to the Llewellyn fault. As a result it is difficult to map contacts within these rocks with a high degree of confidence. A stratigraphic succession can, however, be developed based upon the same relative position of strata for more than half the exposed length of the belt. Tops are inferred to a large degree from the general eastward younging of lithologies. The stratigraphy appears to be: argillites, volcanic wackes and/or arenites followed by fetid, scoria-rich carbonate, which is succeeded by varicoloured, heterolithic, lapilli tuffs, augite porphyry pyroclastic breccias, and finally conglomerates comprised mainly of carbonate and volcanic cobbles.

Augite Porphyry Breccias (uTs_p)

This lithology is characteristic of the Stuhini Group and is best displayed just east of the Llewellyn fault on the ridges south of Brownlee Lake, where its apparent thickness exceeds 300 metres. The breccias are resistant, rounded to blocky weathering, dark green and monolithologic, composed dominantly (50 to 80 per cent) of blocks and bombs(?). Idiomorphic pyroxene phenocrysts (20 to 40 per cent, up to 1.5 centimetres diameter) are conspicuous within both clasts and matrix. Plagioclase occurs as subhedral phenocrysts of lesser, but variable abundance and size. Matrix and phenocryst alteration includes chlorite and lesser epidote.

Argillites and Volcanic Litharenites/ Wackes (uTs_a)

This sedimentary package is best exposed near Brownlee Lake where it is involved in the Llewellyn fault zone. Massive argillites are maroon, green and brown and weather to angular gravel-sized fragments. These argillites are easily mistaken for aphanitic intrusives except that in rare instances weathered surfaces preserve original sedimentary layering. Immediately adjacent to the fault these rocks are transformed to chlorite schists which may be tectonically mixed with fault material derived from other lithologies.

Argillites grade "upwards" (tops uncertain) and eastwards into volcanic wackes and arenites. Volcanic sandstones and wackes (wacke herein indicating at least 15 per cent clay minerals in the matrix), are brown to grey, recessive weathering, calcareous, fissile and common throughout the meagre Stuhini stratigraphy. On the ridges northwest of Brownlee Lake wackes sit "above" (east of) the augite porphyries, but south of Brownlee Lake the opposite relationship is observed. Foliation of this unit generally increases towards the Llewellyn fault with zones of high strain, 1 to 2 metres across, existing several hundred metres away from the main fault trace.

Heterolithic Lapilli Tuffs (uTs_v)

Dark green to grey (less commonly maroon), angular, scoriaceous fragments to rounded volcaniclasts comprise 20 to 80 per cent of the rock. Fragments are aphanitic or porphyritic (crystals less than 3 millimetres), although phenocrysts may be replaced by chlorite. Rare fragments have trachytically aligned plagioclase phenocrysts and microlites.

Limestone-Boulder Conglomerate and Fetid and/or Volcaniclast-rich Carbonate (uTs_c)

This conglomerate is orange to yellow weathering, clast supported and varies from a conglomerate with 100 per cent limestone boulders to one with a large proportion of intrusive and volcanic clasts (clasts other than limestone increase in abundance to the east). The conglomerate may be several hundred metres thick and is persistent laterally. In places, however, it is not developed. For example, at the same statigraphic level at Kirtland there is instead a dark grey, orange-weathering, foliated carbonate with scoria-rich layers (less than 10 metres thick) overlain by epiclastics. The lithologies and succession at Kirtland are identical to a section in 104M/15 on the ridges southwest of Moon Lake. It is not known if this conglomerate is Late Triassic or Early Jurassic in age as it sits between strata of Late Triassic Stuhini Group affiliation and Laberge Group argillites of Pliensbachian age.

LABERGE GROUP

The contact between the Upper Triassic Stuhini Group and the Lower Jurassic Laberge Group is probably not exposed within the map area unless it is represented by the conglomerate (Unit uTs_c) at the top of the Stuhini succession. A broad covered interval between the Stuhini and Laberge Group rocks exists along most of the contact region. In rare outcrops within this interval, lithologies are fine grained – normally argillites and/or wackes (similar to the Upper Triassic–Lower Jurassic transition mapped in 104M/15). The oldest age determination for rocks immediately to the east of this zone comes from an ammonite suite (identified by H.W. Tipper, Geological Survey of Canada) of Pliensbachian age. The top of the Laberge Group stratigraphy has not been identified within the map area. Youngest fossils from these strata are Toarcian.

Many of the units within the Laberge Group sediments have a limited facies-dependent distribution which results from their depositional environment – interpreted as one of coalescing subaqueous turbiditic fans (Bultman, 1979).

Argillites (lJL_a)

Laberge Group argillites are of two major types: rhythmically bedded (2 to 5 centimetre beds, showing good internal normal grading) and irregularly, thinly bedded.

Rhythmically bedded argillites form successions 10 to 100 metres or more thick. A typical graded bed consists of a light grey base of fine-grained wacke to siliceous argillite, grading upwards to a dark grey to black argillite; individual beds lack internal sedimentary structures (Plate 1-32-2a). Bedding tops may display bioturbation and feeding trails; these are especially prominent in calcareous beds which may attain a thickness of 10 centimetres. The beds generally have slightly irregular tops and bottoms. Very sparse cobbles (less than 1 per cent) of a variety of protoliths are not uncommon.

Irregularly and thinly bedded argillites are typically found as sets between massive wacke beds. They are dark brown to black and have thicknesses ranging from a few millimetres to several centimetres. Individual layers may display good normal grading, but this is not a feature of most beds. The grain size and composition ranges from siltstone to argillite, with common interbeds of lithic wacke. The argillites are typically recessive and rusty weathering.

Greywackes (lJL_g)

The term greywacke is herein used to denote a rock dominated by sand-sized grains, but containing 15 to 75 per cent muddy matrix. Greywackes are by far the dominant rock type within the Laberge Group. Feldspathic wackes are generally subordinate to lithic wackes; grain sizes vary significantly from very fine sand to granules, with medium to coarse sand being the estimated modal grain size. An example of compositional and textural variations between two widely spaced outcrops (a and b) follows:

quartz:	(a) subrounded, 10 to 15 per cent (b) subangular, 1 to 5 per cent
feldspar:	(a) plagioclase about 50 per cent, angular (b) less than 10 per cent
micas:	(a) altered muscovite and biotite total 1 per cent
combined lithic:	(a and b) the remaining rock volume is composed of lithic grains (chloritized) and matrix; often difficult to distinguish except in coarse-grained wackes.
	Other mafic minerals, hornblende in particular, may comprise up to 5 per cent of the rock. Locally, greywackes grade into lithic arenites, but these do not persist. Neither quartz arenites nor quartz wackes have been observed.

Wackes are invariably calcareous and may display elongate bulbous concretions up to several metres long and half a metre thick. Beds are massive or graded and vary considerably in thickness from a few centimetres to 10 metres or more. Massive beds or sets of massive beds are typically interlayered with sets of graded siltstone and argillite generally less than 2 metres thick. Greywackes are grey to green and orange weathering and are resistant compared to adjacent argillites. In several isolated localities they occur as discordant dykes, probably dewatering structures.

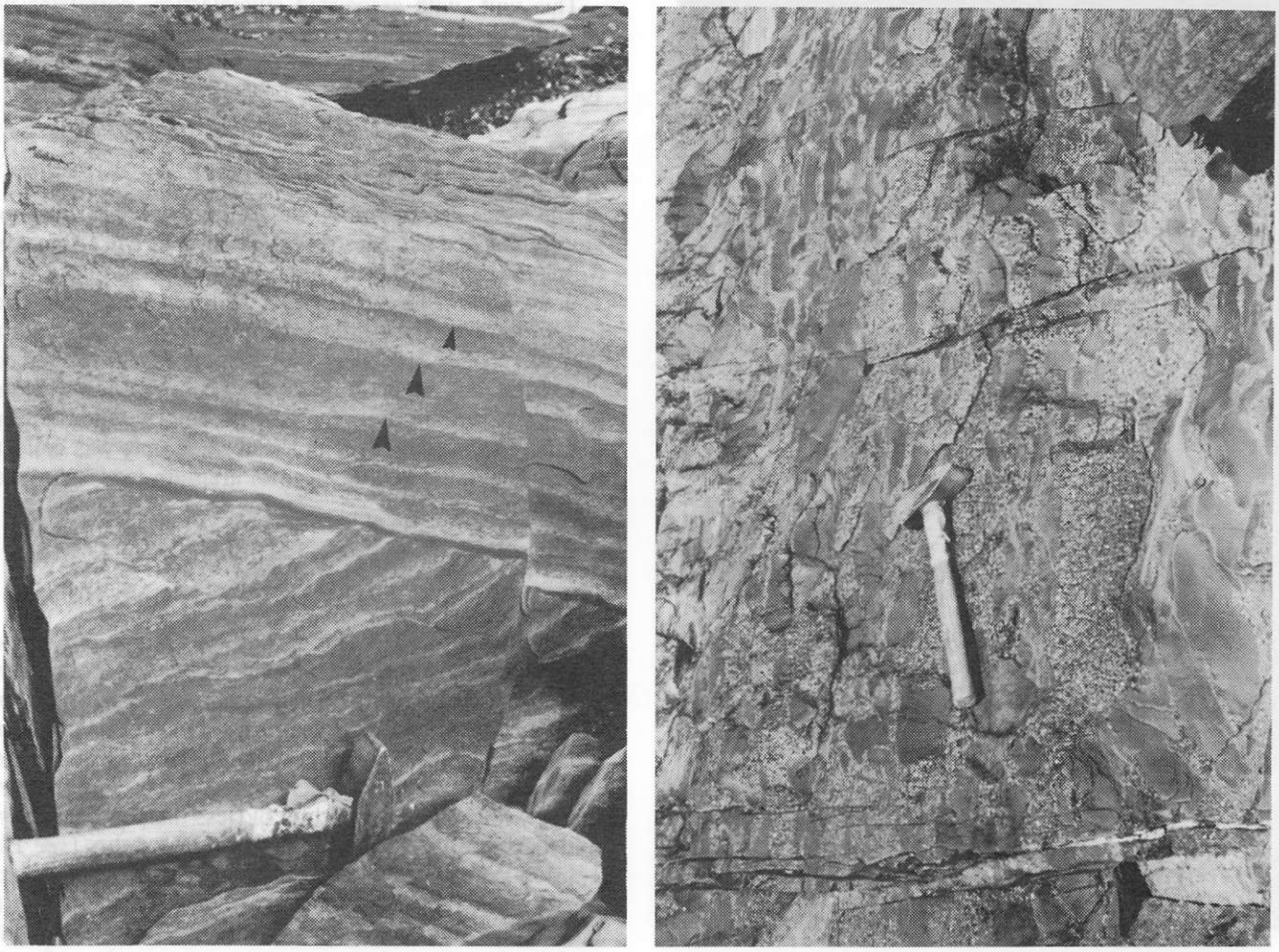


Plate 1-32-2. Fine-grained facies of the Lower Jurassic Laberge Group: (a) angular intraformational unconformity in rhythmically bedded argillites (the grading and tops of three beds are indicated by the arrows) and (b) associated intraformational conglomerate derived from argillites (note granule pebble conglomerate matrix).

CONGLOMERATES (lJL$_c$)

Conglomerates are common as minor units within a stratigraphic succession dominated by argillites and wackes. Mappable conglomerate units, however, are uncommon. Conglomerate units exceed 200 metres in thickness only in the lower parts of the Laberge Group. Both clast and matrix composition are variable. Clasts may include volcanic, sedimentary and intrusive lithologies. Volcanic clasts range in composition from pyroxene and hornblende feldspar porphyries, feldspar porphyries, and aphanitic mafic to felsic rocks. Intrusives vary from syenites through leucogranites, generally medium grained, altered and rarely foliated. North of Whitehorse, boulders of intrusives within the Laberge Group have been potassium-argon dated at 199, 179 and 174 Ma (Tempelman-Kluit, 1976). Sedimentary clasts are dominated by light and dark grey, rarely fossiliferous, carbonates (probable upper Norian Sinwa Formation equivalent; Unit uTss on Figure 1-32-4) with lesser wacke and argillite. There appears to be a gross change from volcanic-clast dominated to intrusive/carbonate-clast dominated conglomerates higher in the Laberge section, however, certain horizons may be more than 90 per cent intraclasts (Plate 1-32-2b). Conglomerates are typically clast supported with a coarse wacke matrix, but varying percentages (generally 1 to 2 per cent, rarely up to 30 per cent) of clasts floating within an irregularly bedded argillite matrix are also common.

Conglomerates are conspicuous in outcrop due to the contrast between clasts of light-coloured carbonate and intrusive rock and the dark wacke (or argillite) matrix. Boulders of intrusive rock may attain a diameter of 1.2 metres, however, both intrusive and limestone clasts are most commonly less than 15 centimetres in diameter.

The most likely source for many of the conglomerates is the Upper Triassic Stuhini Group (including the reefal Sinwa Formation). Clasts of intrusives are probably derived from Late Triassic bodies within the Boundary Ranges metamorphics (*see* "Meta-intrusives" above).

SILICICLASTICS (lJL$_s$)

Indurated siltstones to quartz-rich lithic wackes are included within the siliciclastic subdivision. They commonly display small-scale trough cross-stratification (Plate 1-32-3) and very good internal layering (unlike massive wackes) and

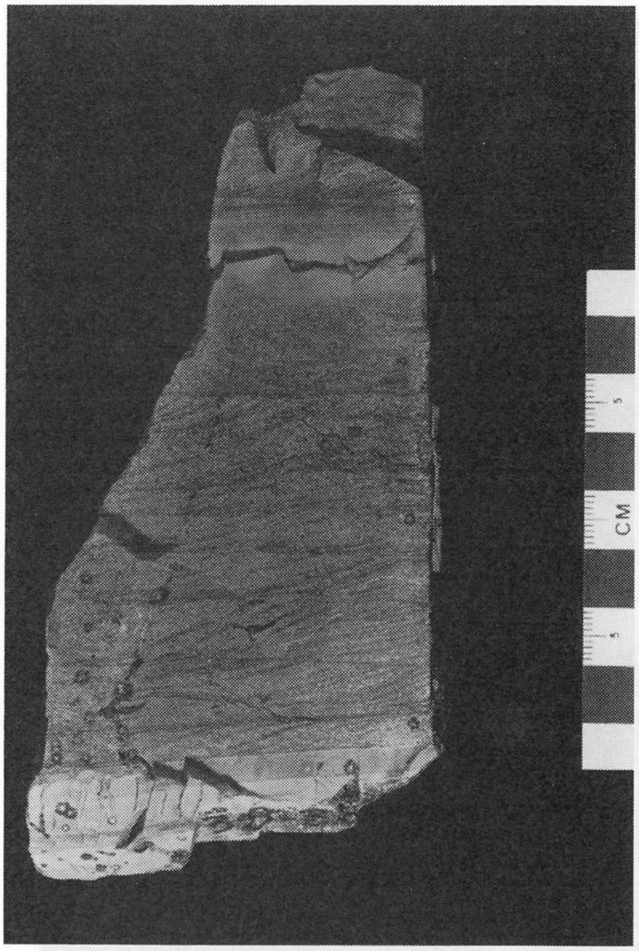


Plate 1-32-3. Sample of Laberge Group siliciclastics. Note small-scale trough cross-stratification, truncation of ripple foresets, and sequences of graded beds. Tops are towards the top of the plate.

are rusty weathering. A conchoidal fracture and surprisingly high hardness are also diagnostic.

These strata are probably over 100 metres thick and form the northeastern dip-slope to the northwest-trending belt of high peaks in central Domain III. They sit relatively high in the stratigraphic succession and, because of their uniqueness and continuity, are a useful marker within the Laberge Group (Figure 1-32-4).

Hornblende-Feldspar-Porphyry Conglomerate (lJL_h)

These rocks occur both above and below the siliciclastics and superficially look like coarse lithic and feldspathic wackes except for the abundance of hornblende feldspar porphyry granules and pebbles, and crystals derived from them (moderately fresh hornblende may comprise several per cent of the rock). Clasts may be subangular to rounded and rare cobbles are matrix supported within a quartz-feldspar-rich wacke. In rare instances the conglomerate is clast supported, and, except for minor intraclasts, the clasts are monolithologic.

This unit, with associated siliciclastics, correlates well with the section exposed on the peaks due east of Mount Brown in 104M/15, where they are found together with Toarcian fossil fauna (Figure 1-32-4).

TEEPEE PEAK VOLCANICS (Mv)

The volcanic succession at Teepee Peak has been previously mapped as "Mesozoic Volcanics of Uncertain Age" (Christie, 1957) and lately has been included with the Upper Triassic Stuhini Group (Lhotka and Olsen, 1983). These rocks, however, have little in common with Stuhini Group lithologies; they are conspicuously more felsic, and the conglomerates and augite porphyries so common in the Stuhini Group are absent, as is the epidote-chlorite alteration and folding displayed by Stuhini rocks. A sample was collected from a spherulitic rhyolite flow for uranium-lead isotopic age determination.

Basal Breccia/Conglomerate (Mvb)

A conspicuous basal conglomerate is present at most places where the Teepee volcanics are seen in contact with probable Upper Proterozoic metamorphic rocks. It is best developed on the south and eastern contacts. The most common components are angular to subrounded blocks of well-foliated metamorphics (generally less than 25 centimetres) mixed with a lesser proportion of (less than 20 centimetres) feldspar and quartz-phyric rhyolite fragments (*see* Plate 1-32-4). Minor constituents include intermediate volcanic fragments and, in one instance, a large transported boulder of the breccia contained a fragment of horneblendite identical to an intrusive phase that appears to crosscut the volcanics.

Dyke-like breccia bodies that are lithologically very similar to the basal breccia, except for the higher degree of chlorite alteration and their discordant nature, crosscut the metamorphic rocks.

Hornblende Feldspar Porphyry Breccias (Mvh)

These volcanic breccias are typically dark grey-green to brown-black, monolithologic, blocky weathering and indurated. Fragmental textures are obscured on all but the cleanest weathered surfaces. Polymictic coarse ash and lapilli tuffites are occassionally interbedded with the breccias. These strata sit relatively low in the volcanic succession in the southeast and west-central parts of the Teepee Peak exposures.

Rhyolite Flows, Domes and Pyroclastic Breccias (Mvr)

These rocks appear stratigraphically equivalent to Unit Mvh. Sparsely feldspar-phyric, pink, grey and white-banded spherulitic flows are interlayered with pyroclastic breccias containing a large proportion of clasts of the same rock together with intermediate fragments and ash. Subvolcanic

Plate 1-32-4. Outcrop of breccia at base of Teepee Peak volcanics. Dark, banded blocks are biotite-chlorite-actinolite-quartz-albite schists of probable Late Proterozoic age; white and light grey fragments are rhyolite and intermediate volcanics.

(?) intrusives (or very thick non-brecciated and poorly banded flows) form a continuum with the extrusive rocks. Some of these may attain thicknesses of more than 500 metres. Feeder dykes to rhyolites crosscut the basal breccia/conglomerate. Younger felsic dykes may display flow banding and crosscutting relationships with the entire exposed volcanic sequence. These rhyolites are generally not quartzphyric.

Heterolithic Lapilli Tuff (Mv_v)

A cliff-forming vitrophyric, crystal and heterolithic lapilli tuff underlies Teepee Peak. It contains variable proportions of lithic fragments (green, brown and grey, sparsely feldsparphyric to white and grey aphanitic rhyolite) in a black vitric matrix displaying eutaxitic texture. Euhedral and fragmented plagioclase comprises up to 15 per cent of the rock. Weathered surfaces are tan, red or maroon.

INTRUSIVE ROCKS

Foliated Granodiorite/Tonalite (eKt_1)

This body is blocky and tabular grey-green weathering, grey to white on fresh surfaces. It is typically medium grained with sparce hornblende megacrysts (xenocrysts?). Abundant hornblende and hornblende-biotite xenoliths are conspicuous as aligned plate-like inclusions less than 30 centimetres long. Hornblende most commonly occurs as glomeroporphyritic patches (10 per cent, single grains less than 4 millimetres in diameter), black when fresh, but often chlorite-altered to a greenish colour. Biotite may comprise 5 to rarely 7 per cent of the rock as glomeroporphyritic and subidiomorphic booklets up to 3 millimetres in diameter. Feldspars comprise 60 per cent of the rock, but only plagioclase can be readily identified in hand sample. Quartz is xenomorphic, generally less than 4 millimetres in diameter and comprises 20 per cent of the rock. Sphene is conspicuous as an abundant accessory with subidiomorphic grains up to 3 millimetres long.

These rocks are radiometrically dated by potassium-argon as 131.2 ± 3.2 Ma (using hornblende; Bultman, 1979).

Mildly Foliated Hornblende Diorite/ Tonalite (eKt_2)

This unit is probably a fine to medium-grained equivalent of Unit eKt_1. Although the contact relationships between these two tonalitic bodies are far from unequivocal, most evidence points to this unit being the younger of the two. It is generally more mafic than Unit eKt_1 with hornblende occurring as partly aligned 12-millimetre laths up to 18 per cent; medium-grained biotite, 0.5 to 4 per cent; and quartz 15 per cent. In hand sample biotite appears fresh; hornblende moderately so. Plagioclase is generally the only feldspar identified comprising 65 per cent of the rock; but potassium feldspar may rarely comprise up to 5 per cent, especially in coarser zones. Sphene and lesser pyrite are conspicuous accessory phases.

Late Cretaceous Granite (lKg)

Its pink colour and non-foliated character provide striking contrast to Unit eKt_1 which it cuts. It is medium to coarse grained, containing 1 to 5 per cent potassium-feldspar megacrysts up to 5 centimetres long. Total potassium feldspar is generally about 40 to 45 per cent; grains are perthitic, zoned, and less than 1 centimetre in diameter. Plagioclase occurs as white-weathered or fresh translucent hypidiomorphic grains less than 6 millimetres long, comprising 10 to 15 per cent of the sample. Xenomorphic quartz occurs interstitially (40 per cent). Biotite is fine to less commonly medium grained, occurring as euhedral booklets (2 to 3 per cent); macroscopic sphene is generally absent. Outcrops are rounded to blocky weathering and resistant.

Teepee Peak Stock (KT_{TP})

This body is a medium-grained granodiorite to tonalite. Near its northern contact it displays a mineralogy of biotite, 10 per cent; hornblende, 15 per cent; quartz, 30 per cent;

altered plagioclase, 40 per cent; potassium feldspar, 5 per cent. On its eastern contact a chilled margin 20 centimetres wide, hosts veins of pyrophyllite and 2 per cent coarse molybdenite rosettes. At this locality the modal composition is quartz, 60 per cent; feldspar, 35 per cent (propylitically altered plagioclase?), muscovite, 5 per cent; and altered biotite(?).

Racine Pluton (lK_R)

This is a homogeneous pluton of slightly potassium feldspar porphyritic, medium to coarse-grained granite with 20 to 40 per cent potassium feldspar (commonly mantled by plagioclase), 20 to 40 per cent quartz, 30 to 40 per cent plagioclase, 3 to 6 per cent hornblende, and 3 to 8 per cent chloritized biotite. It is lithologically very similar to the Jack Peak body (104M/15) dated as 89.5±2.6 Ma (Bultman, 1979; Table 1-32-1).

Mount Clive Stock (lK_{MC})

The Mount Clive stock, 3.5 kilometres long, crops out over an ovoid area only 1.5 kilometres southwest of the Racine pluton. It is a medium-grained granodiorite with a composition of quartz, 30 to 40 per cent, rarely coarse grained; plagioclase, 30 to 50 per cent; potassium feldspar, 15 to 25 per cent, white, up to 1.5 centimetres long; biotite, 10 to 15 per cent; and minor magnetite. A chilled apophysis of this body thins to 5 metres thick but persists for over 1.5 kilometres through the thin wedge of Laberge strata separating it from the Racine pluton. The apophysis may be the surface expression of a link between the two bodies bnt unfortunately its point of entry into the Racine pluton is obscured by glacial drift, so that a definite age relationship could not be ascertained in the field.

Altered Diorite (K_d)

On the eastern shores of Brownlee Lake is an elongate, altered dioritic body with an intrusive western margin and a probable faulted eastern margin. The mineralogy is difficult to determinc due to alteration, but is approximately 70 to 90 per cent white argillically altered feldspars (plagioclase?); up to 10 per cent chloritized mafic minerals; and, in more severly altered zones, 3 to 10 percent pyrite, and 10 per cent epidote. Outcrops display localized foliation and are white, green and pink (potassium metasomatism?) weathering and have blocky jointing.

Hornblendite (JKh)

Black hornblendites, veined by epidote and feldspar, are strung out along the central axis of Domain II. These bodies intrude into and assimilate the metamorphic rocks, hornfelsing them, in some cases over 1 kilometre from the main body. Hornfelsing may result in a "dioritized" host rock where feldspar and chlorite clots produce a medinm to fine-grained igneous texture often crosscut by a plexus of irregular, green (chlorite and actinolite?) veinlets and clots. Assimilation is selective, with more refractory units, such as carbonate bands, preserved at the margins and several hundred metres inside the intrusive body. Alternatively, the contact may be highly silicified (multiple quartz and much lesser carbonate stringer/breccia events) hackley, and bright red weathering, in a zone tens of metres thick, best displayed along the northern margin of the largest body (Figure 1-32-3). Internally it is an inhomogenous, very coarse to fine-grained hornblendite to hornblende diorite, in which multiple intrusive/eanibalistic events preceded its final emplaeement.

The age of these bodies is poorly constrained. They clearly crosscut the metamorphic rocks and also appear to thermally affect the Teepee Peak volcanic rocks, however, hornblendite fragments have been observed in boulders of Unit Mvb. A new potassium-argon age determination on green hornblendite bodies within Unit PPm near the Yukon border (Figure 1-32-2, Table 1-32-1) indicates an age of 150±6 Ma. Considering the proximity of this sample locality to the large intrusive mass of Domain I, thermally induced argon loss is a distinct possibility and this age should be regarded as a minimum. In the Tagish area similar hornblendites crosscut and occur as clasts within the Teepee Peak volcanics suggesting that they are of about the same age. If the age of the hornblendites in the Tagish area is similar to those of the Tutshi Lake area then the Teepee Peak volcanies must be of Late Jurassic age. Such an age would be consistent with their correlation with the Middle to Upper Jurassic volcanics of the Tutshi Lake mapsheet with which they share many characteristics (*see* correlation between Units Mv and muVv on Figure 1-32-4).

Dykes

Tabular-feldspar porphyry dykes: brown to green-brown-weathering tabular-feldspar porphyry dykes are particularly abundant within Lower Jurassic Laberge Group strata. They most commonly trend northeast as bodies 0.5 to 20 metres thick, in places comprising 10 to 20 per cent of the section. Feldspars (10 to 30 per cent) are generally tabular, 0.5 to 2 centimetres long, and may be trachytically aligned within a fine-grained to aphanitic brown-green matrix. Hornblende is a rare accessory phase. Contacts are invariably chilled. The age of these dykes is constrained by the age of their hosts and that of the Racine pluton which crosscuts them.

Pyroxenites: crosscutting the metamorphic suite are northwest-trending pyroxenite dykes up to 25 metres thick (one body is intermittently exposed over a width of more than 120 metres). These dykes pinch and swell along their length and have an internal fabric parallel to the foliation of the enclosing metamorphic rocks. They are highly compact, ringing when struck, charcoal grey, and reddish weathering. Pyroxenes are medium grained and pristine, comprising in excess of 85 per cent of the rock, with magnetite (10 per cent, variable) and phlogopite (or biotite?; 0 to 7 per cent) forming the remainder. Their age is unknown but they crosscut the thermal aureole of the hornblendite. This crosscutting relationship suggests that they are younger than 150±6 Ma, if an extrapolation of the hornblendite age date from northern 104M/15 to north-central 104M/10E is correct.

STRUCTURE

FOLD STYLES WITHIN METAMORPHIC ROCKS

Folds at an outcrop-scale give the impression of an incoherent mess; however, on a regional scale, elongate synforms and antiforms are resolved as shown by the interpreted fold hinge traces on Figure 1-32-3. These structures represent the third deformational phase (F_3, *see* below) which is roughly coaxial with structures within the Laberge Group which are crosscut and modified by Cretaceous intrusions. Such folds tend to be open to tight, upright, and subhorizontal to gently plunging. This phase of folding is at least in part non-coaxial with earlier phases as evidenced by an interference fold pattern near Brownlee Lake illustrated by Figure 1-32-6.

Phase 1 folds (F_1) are invariably isoclinal and display axial planar schistosity. Phase 2 folds (F_2) are open to isoclinal, developed on both mesoscopic and megascopic scales. Orientations of F_2 hingelines and mineral lineations (mostly actinolite) are shown in Figure 1-32-7. This figure presents a preliminary structural analysis of a small dataset from the north, central and southern parts of Domain II (Domain II divisions are shown in Figure 1-32-8). F_2 hingelines and mineral lineations form vague girdles with approximate, subhorizontal axes of 020° and 045° produced in Domain II_{N+C} during a Phase 3 deformational event. Dispersion of lineation orientations and rotation of girdles occurs in Domain II_S as F_3 folds are wrapped around the intrusive salient to produce a Phase 4 fold. A summary of the deformational history of the metamorphic rocks is briefly outlined in Table 1-32-2.

DEFORMATIONAL HISTORY OF THE LABERGE GROUP

Deformation of the Laberge Group sediments began in the early depositional stages as evidenced by intraformational angular unconformities and associated conglomerates (Plates 1-32-2a and 2b) in strata of probable Pliensbachian age. Slump folds are common on the scale of hand-sample to hillside. Later axial-surface cleavages bear no relation to these early-formed slump folds (Plate 1-32-5).

The most apparent deformational event affecting the Laberge sediments occurred following the deposition of overlying volcanics (in 104M/15) and predates late Cretaceous intrusions. Folds produced during this deformation have axial planar (or near planar) surfaces that consistently trend northwest and most commonly dip steeply both to the east and west. Axial cleavages are well developed in argillites, but are rare in massive wackes. Major folds are upright, gentle to close, and gently plunging.

Smaller east-northeast-trending structures also deform the stratigraphy, apparently postdating the northwest-trending structures. This age relationship is based on folded axial planar cleavages in central Domain III and an apparently folded axial trace in the northeast corner of the map area. However, an interference structure in south-central Domain III suggests the opposite relationship.

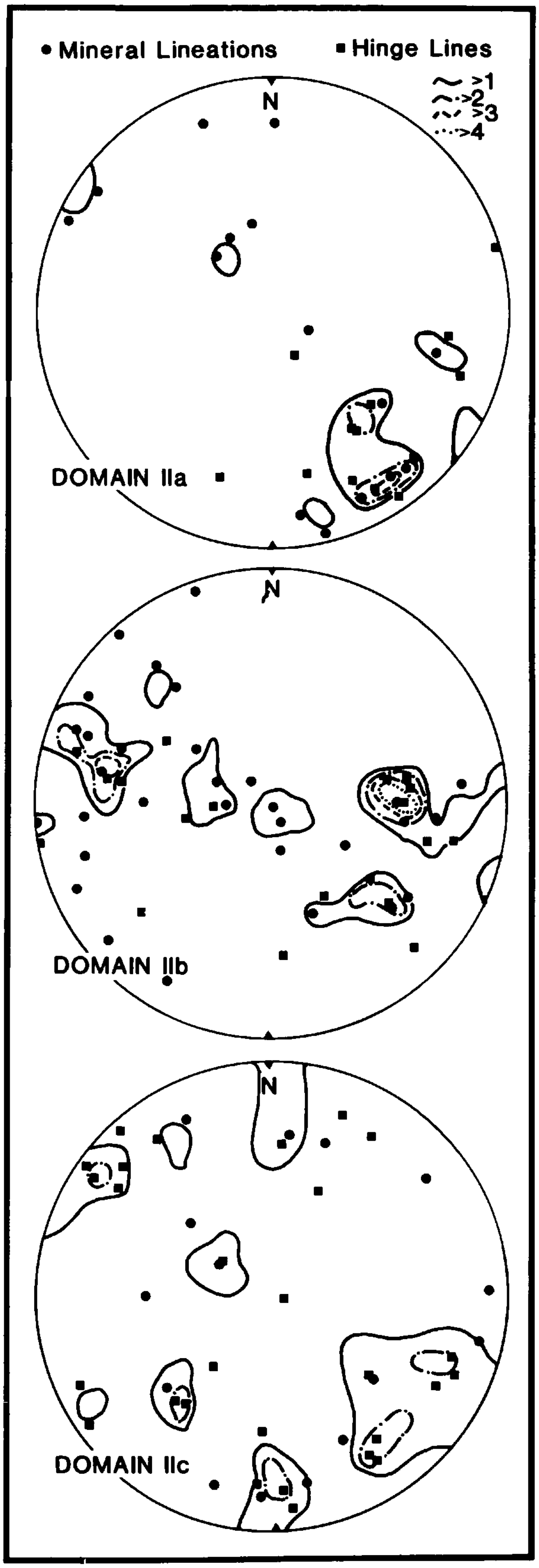


Figure 1-32-7. Three contoured stereoplots showing the change in structural style from north to south in Domain II, mainly resulting from F_4 warping of F_3 folds.

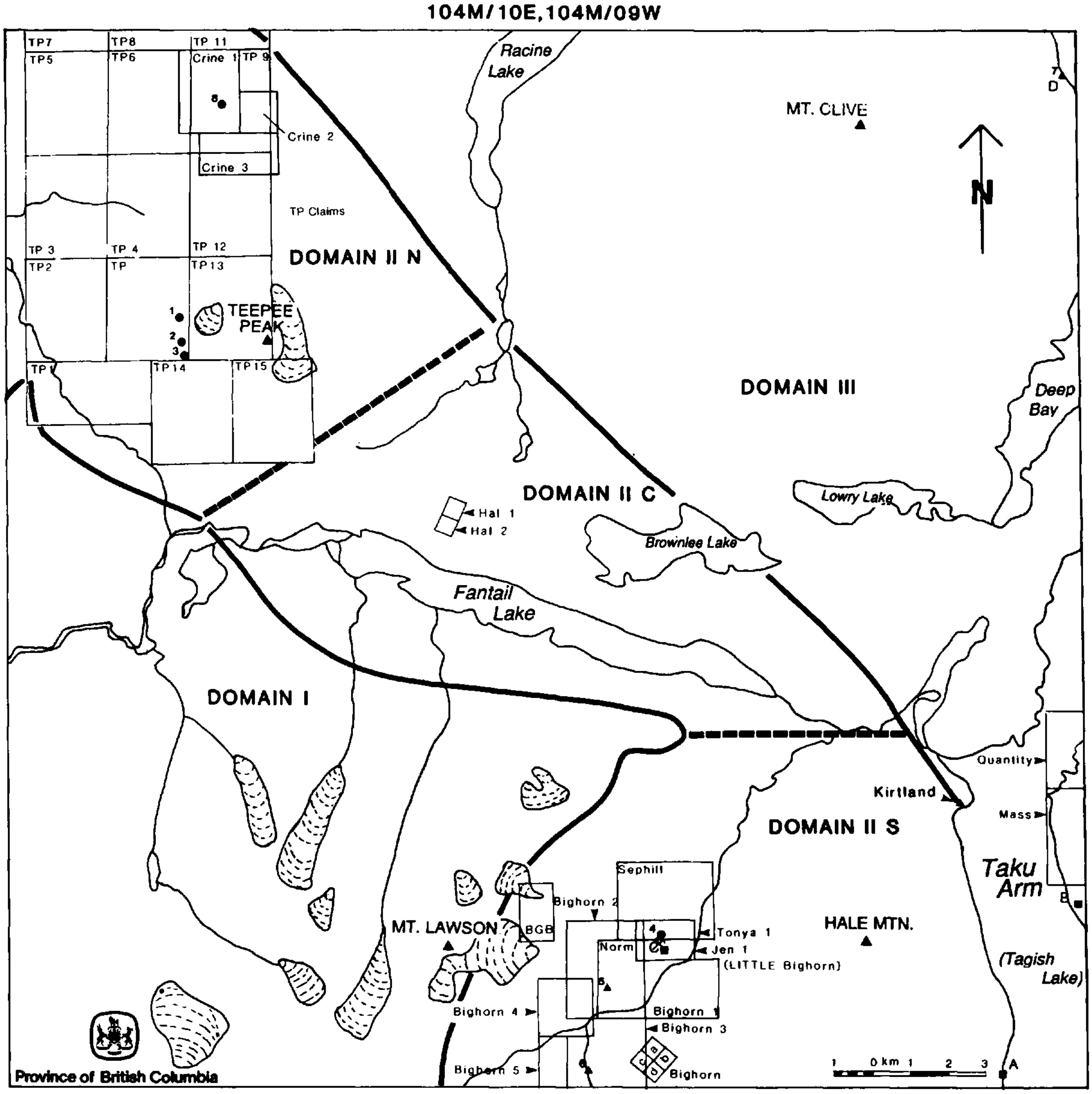


Figure 1-32-8. Claim map and domains of the Tagish map area including MINFILE occurrences and locations of assay samples listed in Tables 1-32-2 and 1-32-4 respectively.

MINERALIZATION

Three distinct styles of mineralization are present within the Tagish area including the Teepee gold-cobalt skarn; Bighorn, Red Rupert and Crine gold-bearing quartz veins; and the Lakefront antimony-silver veins. The Teepee property received a large share of exploration activity in 1988 with Cypress Gold (Canada) Limited conducting a major program from mid-July to September.

GOLD-COBALT-BEARING SKARNS

The successful application of the gold-enriched skarn model at places such as Hedley has brought the Teepee prospect into prominence. The Teepee Peak gold-bearing skarn occurs within bands of carbonate (several metres combined thickness) or at their contact with chlorite-actinolite schists (both are lithologies of the Boundary Ranges metamorphic suite). Visible gold occurs in one trench at the principal Teepee Peak showing where an amphibole-rich skarn is developed near the hinge of a fold involving the carbonate. The host rocks are extensively crosscut by a variety of predominantly intermediate to felsic dykes and are overlain unconformably by Teepee Peak volcanics. Youngest dykes crosscut both the metamorphic and volcanic rocks, while older ones terminate at the unconformity, but no phase of late (post unconformity) dyking appears to be extensively affected by thermal metamorphism. Nearby, two large intrusive bodies, a hornblendite, and the Teepee Peak stock, crosscut the unconformity. This combination of geologic elements is repeated at several localities north and northeast

TABLE 1-32-3
MINERAL OCCURRENCES-104M/10E & 9W

Map No.	Name (MINFILE No.)	Commodity	Assay (reference)	Sample width	Description
1	TP Main (104M/048)	Au Ag Co	22.7 g/t <10 g/t 3.91% (AR 11300)	grab grab grab	Skarn zones within the pre-Permian metamorphics display erythrite-cobaltite-arsenopyrite; mineralization develops near a quartz feldspar porphyry stock.
2	TP Central (104M/050)	Au Ag Co Cu	10.8 g/t 147.4 g/t 0.02 % NA (AR 11300)	grab grab grab	Pyrrhotite-chalcopyrite-arsenopyrite mineralization is hosted in a magnetite and calc-silicate skarn zone.
3	TP Camp (104M/049)	Fe	NA (AR 11300)		Pyrrhotite and massive magnetite occur in a northwesterly trending skarn within the pre-Permian metamorphics.
4	Spokane (104M/006)	Au Ag Zn Cu Pb	23.3 g/t 6.2 g/t NA NA NA (AR 1933-79)	grab grab	Pre-Permian metasediments host an east-trending 1.1-metre sulphide-bearing quartz vein.
5	Lawsan (104M/007)	Au Ag Pb Cu	NA NA NA NA (AR 5910, AR 10069)		A narrow quartz vein contains small amounts of sphalerite, galena and native gold.
6	Red Rupert (104M/024)	Au Ag	34.3 g/t 13.7 g/t (AR 1933-80)	0.6 m 0.6 m	A 30 to 60-centimetre quartz vein is hosted within the pre-Permian metamorphics.
7	Lakefront (104M/005)	Sb Pb	6.48% 6 g/t	grab grab	A 1.0 metre conformable vein composed mostly of quartz and stibnite is hosted within the Jurassic Labarge Group.
8	Crine Vein (new)	Au	NA		Discovered during the 1988 regional mapping program. Assay of 2 grab samples in progress. A 0.5-2.0-metre-wide northwest-trending, brecciated and sheared silicified quartz veined zone hosts stibnite, pyrite and arsenopyrite up to 15% combined. A faulted western margin is in some places well defined. Total strike length may be 1 km or more.

of the main showing. However, it is not known if the main control on ore formation is intrusive activity, the proximity of the profound unconformity, host rock related, structural, or some combination of these possibilities. Hence, the potential for discovery of more gold-enriched skarns in areas north of the main showing is difficult to assess. Controls on mineralization will be addressed by a petrology-based B.Sc. thesis at the University of Calgary by K. Mountjoy.

GOLD-QUARTZ VEINS

Gold-bearing quartz veins have historically been the mainstay of mine development in the region. The old Engineer mine, 2 kilometres outside the southeast corner of the map area, produced approximately 560 kilograms of gold during its 40-year production history (1913 to 1952). Ore at the Engineer was within a series of narrow quartz and carbonate veins cutting Lower Jurassic Laberge Group strata.

Sulphide-poor veins on the Spokane, Lawsan and Red Rupert (?) claims crosscut Units PPM_i and PPM_b. Spokane (Tonya) and Lawsan (Bighorn) claims have had significant development work. The mineralogy of these veins is galena, chalcopyrite and sphalerite with native gold. The Lawsan showing is a shear zone containing brecciated quartz-vein material. Veins on the Tonya claims are continuous and have been drifted along on three levels with a vertical separation of 460 metres. Assay values obtained from both showings are listed in Table 1-32-3; new assay data are listed in Table 1-32-4.

The Crine vein (Locality 8 on Figure 1-13-8), was discovered during the 1988 regional mapping program. Hosted within Unit PPM_g, the vein is a concordant, 0.5 to 2.0-metre-wide quartz-veined zone that intermittently displays a sheared and brecciated fabric, particularly along its western margin. Sulphide mineralogy includes pyrite and arsenopyrite (up to 15 per cent). The vein was traced for 200 metres, but its full length is unknown. Assay data are not available, however, anomalous gold values in stream sediments and soils were found by Dupont of Canada Exploration Limited (Copeland and Neelands, 1983) downslope from this vein, and can probably be attributed to it. The Crine claims were staked on the basis of geochemical results over the vein (Figure 1-32-8), but the vein itself was not discovered. Several arsenic-gold-silver soil anomalies (Dupont survey) that are uphill from the Crine vein, suggest the possibility of more veins of this type.

A similar vein is exposed in an overgrown trench on the west shore of Tagish Lake near the southern border of the map area (Locality A′ on Figure 1-32-8). The vein is a drusy-quartz-flooded shear and breccia zone within Unit PPM. A sample of vein material assayed 35 grams per tonne gold (Table 1-32-4).

ANTIMONIAL VEINS (LAKEFRONT PROSPECT)

Layered veins containing stibnite, minor galena, and crustiform quartz were observed to have an *in situ* thickness of 15 centimetres, although reported vein thicknesses are up to 1.2 metres. On the wall of a partly caved adit the vein strikes 350° with a 63° dip to the east within strongly foliated argillites and argillaceous siltstones of the Lower Jurassic Laberge Group. At the showing, (Locality D′ on Figure 1-32-8) approximately 40 tonnes of high grade material are reported by Schroeter (1986) to be scattered just above the shore of Tagish Lake.

TABLE 1-32-2
DEFORMATION AND METAMORPHISM OF BOUNDARY RANGES METAMORPHIC SUITE

Deformation I

S_0 original bedding/layering is visible but thicknesses are distorted – both thickened and thinned. Competent layers are boudinaged.

S_1 generally seen coplanar with S_0 and defined by growth of chlorite, muscovite, actinolite, biotite and rare garnet. Only rarely are F_1 folds observed, but in these S_1 distinctly crosscuts the hinge. They are typically close to isoclinal and pervasively affect the original strata.

Deformation II

Two fold styles are apparent depending upon lithologic competency:

F_{2A} hinge-line orientations are variable. Sheath folds indicate differential strain along hinge-lines, typically within chlorite schists.

F_{2B} occurs in more competent units. Fold-styles are open to closed and commonly chevron in nature (Plate 1-32-1).

S_2 is only locally developed as a crenulation cleavage. Crenulations may fold actinolite, biotite, chlorite and muscovite.

Deformation III

F_3 is observed on kilometre-scale as refolding of closed F_2 folds within the chlorite schist/marble succession (see Figure 1-32-6).

S_3 is parallel to limbs of refolded F_2 folds and may be seen decapitating F_2 folds on an outcrop scale.

Deformation IV

F_4 is developed as F_3 is warped around the intrusive salient seen in Figures 1-32-3 and 7.

GEOCHEMICAL DATA

A regional stream sediment geochemical survey in the Tutshi Lake area in 1987 (Rouse *et al.*, 1988) indicated that anomalously high arsenic and gold values correlated well with a belt of rocks underlain by Unit PPM, and bounded to the east by the Llewellyn fault (Figure 1-32-9). The highest stream-sediment gold anomalies plot adjacent to this major structure. Although the results of the 1988 stream sediment survey of the Tagish Lake area are not yet available, it is expected that high gold and arsenic geochemical values will again correlate with the Unit PPM and the Llewellyn fault.

Plate 1-32-5. Slump folds within Laberge argillites have an irregular form displaying no logical relationship to cleavage. The strongest cleavage, probably related to regional structures, trends parallel to the plane of the plate.

TABLE 1-32-4
NEW ASSAY DATA FOR THE TAGISH AREA

Location on Figure 1-32-8	Sample Number	Au* ppm	Au† ppm	Ag ppm	Cu ppm	Pb ppm	Zn ppb	Hg ppm	As ppm	Sb ppm
A SW Tagish Lk.	88MM-05-06	41	35	20	215	30	9	183	118	10
B E of Kirtland	88MM-06-03	5	5	19	19	0.15%	380	30	0.7%	270
C Bighorn mine	88MM-28-3-2	11	9	13	131	0.18%	0.1%	70	<50	6
C Bighorn mine	88MM-28-3-6	8	9	11	21	250	26	23	<50	3
D Lakefront	88MM-07-05	0.07	N/A	1	9	6	6	37	160	6.48%

Au analyses performed at both private sector (*) and Ministry (†) labs.

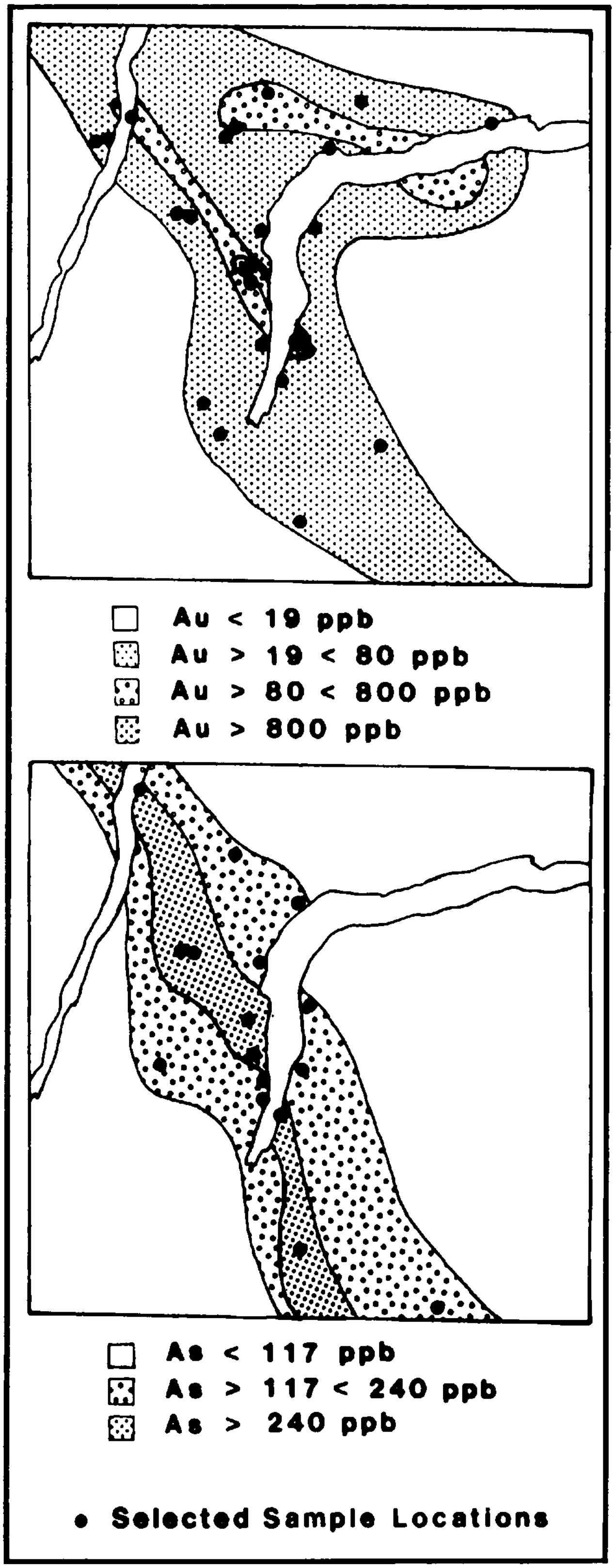


Figure 1-32-9. Contoured anomalous gold and arsenic values from the 1987 regional stream sediment sampling program.

ASSESSMENT OF MINERAL POTENTIAL

Four geologic environments appear most prospective for precious metals; these are:

(1) Veins hosted in Laberge Group strata that are associated with splays off the Llewellyn fault zone as at the old Engineer mine. A possible splay is inferred east-southeast of Kirtland where brecciated argillite and drusy quartz occur within a linear steep-walled valley with slickensided walls. A grab sample from Locality B′ on Figure 1-32-8 returned assays of 5.35 and 4.74 grams per tonne gold (Table 1-32-4).

(2) Both concordant and discordant veins and breccia zones within the Unit PPM. Large numbers of barren quartz veins and "sweats" require that careful prospecting and/or geochemistry be used to focus in on precious metal-bearing veins.

(3) Sheared and altered/silicified rocks within and immediately adjacent to the Llewellyn fault zone are shown to yield anomalous, albeit sporadic gold assays (Mihalynuk and Rouse, 1988b; Rouse *et al.*, 1988).

(4) Skarns within the Unit PPM, particularly those that are related to ultramafic and/or granodioritic bodies and/or extensive dyking have precious metal potential.

SUMMARY

Mapping was conducted with an emphasis on subdividing the poorly understood Laberge and Stuhini Groups, Boundary Ranges metamorphic and Coast Crystalline rocks which generally conform to three northwest trending belts. The recognition of distinctive units within the Laberge Group has enabled correlations to be made with strata 20 to 30 kilometres away to the northwest. Mapping separate lithologies within the metamorphic suite has permitted a more comprehensive understanding of fold styles and the recognition of four phases of deformation.

The Llewellyn fault diagonally bisects the area from southeast to northwest, separating probable Upper Proterozoic Boundary Ranges metamorphics in the west from Mesozoic strata of the Whitehorse trough to the east. One exception is the Teepee Peak volcanic outlier, possibly of Late Jurassic age, which sits unconformably above the metamorphic rocks. A previously unmapped hornblendite body crosscuts this unconformity near the Teepee Peak gold-cobalt skarn locality and may be genetically related to it. Skarn zones at other places within Unit PPM may also have precious metal potential. The potential of two other exploration targets within the map area is indicated by the assay results presented in Table 1-32-4. These include: (1) sulphide-bearing quartz veins, both concordant and discordant, within Unit PPM; and (2) inferred splays off the Llewellyn fault. Both the belt of Unit PPM, and the Llewellyn fault zone, have previously been shown to be anomalous with respect to gold and arsenic in the 1987 regional geochemical survey in the Tutshi Lake map area.

ACKNOWLEDGMENTS

This study has benefitted from the capable assistance, persistent smiles and fortitude of both Keith Mountjoy and Carol Wallace. Dr. H.W. Tipper (Geological Survey of Canada) provided remarkably prompt fossil identifications which helped to direct field research. The cooperation and generosity of Cyprus Gold (Canada) Ltd. is greatly appreciated. Finally, a heartfelt thanks to Norm Graham, Haley and crew of Capitol Helicopters, Atlin, for their hospitality and impeccable service.

REFERENCES

Aleinikoff, J.N., Dusel-Bacon, C., Foster, H.L. and Nokleberg, W.J. (1987): Lead Isotopic Fingerprinting of Tectono-stratigraphic Terranes, East-central Akaska, *Canadian Journal of Earth Sciences*, Volume 24, pages 2089-2098.

Armstrong, R.L., Harakal, J.E., Forbes, R.B., Evans, B.W. and Thurston, S.P. (1986): Rb-Sr and K-Ar Study of Metamorphic Rocks of the Seward Peninsula and Southern Brooks Range, Alaska, *Geological Society of America*, Memoir 164, pages 185-203.

Bultman, T.R. (1979): Geology and Tectonic History of the Whitehorse Trough West of Atlin, British Columbia, Unpublished Ph.D. Thesis, *Yale University*, 284 pages.

Christie, R.L. (1957): Bennett, British Columbia, *Geological Survey of Canada*, Map 19-1957 with Descriptive Notes.

Copeland, H.J. and Neelands, J.T. (1982): Geological and Geochemical Report on the Crine Claims, Atlin Mining Division (104M/10E. *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 10426, 10 pages with Appendix and Map.

Doherty, R.A. and Hart, C.J.R. (1988): Preliminary Geology of the Fenwick Creek (105D/3) and Alligator Lake (105D/6) Map Areas, *Indian and Northern Affairs Canada*, Open File 1988-2, 65 pages plus Maps and Appendices.

Lhotka P.G. and Olsen, R.A. (1983): TP Mineral Claim, Atlin Mining Division, British Columbia, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 11300, 17 pages plus Appendices and Maps.

Mihalynuk, M.G. and Rouse, J.N. (1988a): Preliminary Geology of the Tutshi Lake Area, Northwestern British Columbia (104M/15), *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, Paper 1988-1, pages 217-231.

——— (1988b): Geology of the Tutshi Lake Area (104M/15), *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-5, Sheet 1, 1:50 000.

Rouse, J.N., Mihalynuk, M.G., Moore, D. and Friz, P.(1988): 1987 Stream Sediment and Lithogeochemical Survey Results for the Tutshi Lake Map Area, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-5, Sheet 2 1:50 000.

Schroeter, T.G. (1986): Bennett Project, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 184-189.

Tempelman-Kluit, D.J. (1976): The Yukon Crystalline Terrane: Enigma in the Canadian Cordillera, *Geological Society of America*, Bulletin, Volume 87, pages 1343-1357.

Wasserburg, G.J., Eberlein, U.S. and Lanphere, M.A. (1963): Age of the Birch Creek Schist and some Batholithic Intrusions in Alaska, *Geological Society of America*, Special Paper, 73, pages 258-259.

Watson, P.H., Godwin, C.I. and Armstrong, R.L. (1981): Geology, Mineralization and K-Ar Isotopic Study of the RAM Pb-Zn-Ag Property, Yukon Plateau, Southwest Yukon Territory (105D/4), Yukon Exploration and Geology 1979-80, *Indian and Northern Affairs Canada*, pages 123-127.

Werner, L.J. (1977): Metamorphic Terrane, Northern Coast Mountains West of Atlin Lake, B.C., *in* Report of Activities, Part A, *Geological Survey of Canada*, Paper 77-1A, pages 267-269.

——— (1978): Metamorphic Terrane, Northern Coast Mountains West of Atlin Lake, B.C., *in* Current Research, Part A, *Geological Survey of Canada*, Paper 78-1A, pages 69-70.

Wheeler, J.O. (1961): Whitehorse Map-area, Yukon Territory, (105D), *Geological Survey of Canada*, Memoir 312, 156 pages.

Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W. and Woodsworth, G.J. (1988): Terrane Map of the Canadian Cordillera, *Geolgical Survey of Canada*, Open File 1894, 9 pages and 1:2 000 000 Map.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera, *Geological Survey of Canada*, Open File 1565.

GEOLOGY AND MINERALIZATION OF THE ATLIN AREA, NORTHWESTERN BRITISH COLUMBIA (104N/11W and 12E)

By M.A. Bloodgood, C.J. Rees and D.V. Lefebure

KEYWORDS: Regional geology, Atlin, Cache Creek Group, Cretaceous intrusions, stratigraphy, structure, lode gold, placer gold.

INTRODUCTION

A regional mapping project was begun in the Atlin area during the 1988 field season, following a compilation project started by D.V. Lefebure and M.H. Gunning in 1987. An area of 780 square kilometres was mapped at a scale of 1:50 000 during this first year of a proposed 4-year program. The map area is underlain by a thick succession of Paleozoic sedimentary and volcanic rocks of the Cache Creek Group which are intruded by Cretaceous granodiorite to granite. Placer mining has been ongoing in the Atlin area since 1898 and continues to be a major component of the local economy. Current exploration is focused on lode gold sources of the placer deposits.

PREVIOUS WORK

Gold in the Atlin camp was first discovered in 1898, by Miller and McLaren, on Pine Creek. Geological work in the early part of the century was conducted by both the Geological Survey of Canada and the Bureau of Mines, and is summarized by Gwillim (1901) and Cairnes (1913). During the 1950s and 1960s the Geological Survey of Canada conducted mapping in northwestern British Columbia and completed a 1:250 000-scale map of NTS sheet 104N and an accompanying memoir (Aitken, 1959). Several other publications also resulted from this work (Aitken, 1953; Gabrielse and Wheeler, 1961; Monger, 1966, 1967, 1968).

Several studies have addressed the stratigraphic problems within the Cache Creek Group (Link, 1965; Monger, 1975). Monger examined the Cache Creek Group in specific locations within the Atlin terrane, to better understand its stratigraphic relationships and tectonic framework. Lithogeochemical studies have focused on the Surprise Lake batholith, with which a significant uranium anomaly is associated (Ballantyne and Littlejohn, 1982). Recent geological investigations have focused on the lode gold mineralization of the area (Andrew, 1985; Lueck, 1985; Newton, 1985). Morphological and chemical characteristics of the placer gold have been examined (MacKinnon, 1986) and characteristics of placer and lode gold within the Atlin terrane have been compared (Ballantyne and MacKinnon, 1986).

REGIONAL SETTING

The map area is largely underlain by Mississippian to Upper Triassic rocks of the Cache Creek Group intruded by Cretaceous batholiths. The Cache Creek terrane (Monger *et al.*, 1982) is an important element in the Intermontane Belt, and outcrops almost continuously throughout the length of British Columbia (Figure 1-33-1). In northern British

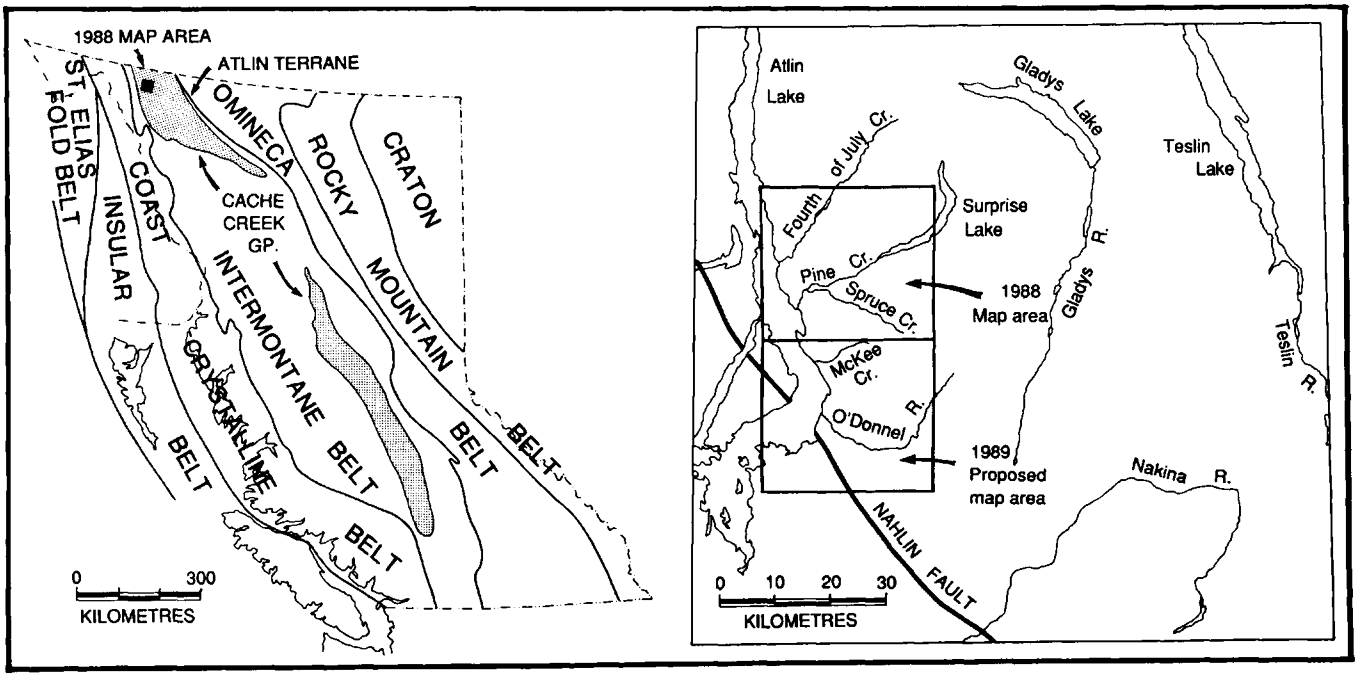


Figure 1-33-1. Location of the Atlin project and the distribution of the Cache Creek Group rocks throughout British Columbia (modified after Wheeler and McFeely, 1987).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

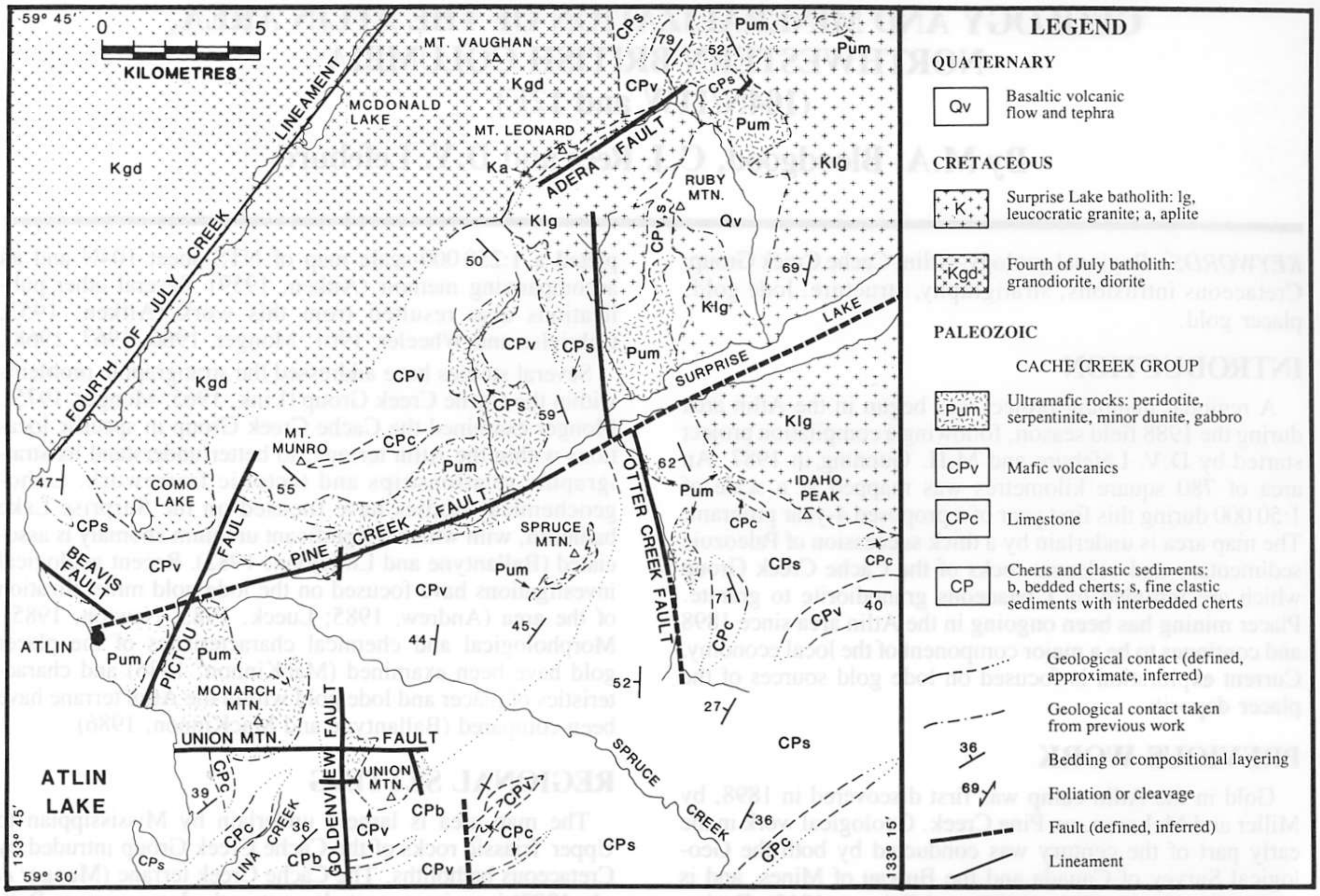


Figure 1-33-2. Geology map (104N/11W, 12E).

Columbia and the southern Yukon it is referred to as the Atlin terrane. The Atlin terrane is bounded to the west and southwest by the Stikine and Nisling terranes (Mihalynuk and Rouse, 1987), onto which it was thrust in the Middle or Late Jurassic (Monger, 1984), mostly along the Nahlin fault (Figure 1-33-1). The eastern boundary of the terrane is the subvertical Thibert Creek fault, which trends northwestwards into the Teslin lineament. It separates the Atlin terrane from deformed and metamorphosed Paleozoic and Mesozoic rocks to the northeast (Monger, 1975).

The main lithologies in the Atlin terrane are radiolarian chert, argillite, carbonate, submarine tholeiitic basalts and alpine-type ultramafic rocks. They are typically metamorphosed to subgreenschist grade (Monger, 1984). Cache Creek rocks are intercalated on all scales, although there is greater stratigraphic continuity in the Atlin terrane than in southern British Columbia.

In the Atlin terrane, Mississippian to Pennsylvanian basalt of the Nakina Formation represents the basal unit of the stratigraphic sequence (Monger, 1975). It is overlain by radiolarian chert and clastic sediments with lesser carbonate and volcanics of the Kedahda Formation. Interfingering of these two units is characteristic of the sequence. They are gradationally overlain by Upper Mississippian to Upper Permian Horsefeed Formation, a carbonate sequence 2000 metres thick, which in turn is unconformably overlain by clastic rocks of possible Mesozoic age (Monger, 1975).

Mafic and ultramafic rocks, mainly serpentinized peridotite and less common dunite and gabbro, range from linear bodies many tens of kilometres long, to pods and slivers a few metres in length. These rocks were called the "Atlin Intrusions" by Aitken (1953, 1959), and interpreted as coeval with the Nakina Formation basalts because of their close spatial association. Monger (1977) suggested that the large Nahlin ultramafic body may represent oceanic basement upon which the Nakina Formation was deposited.

LITHOLOGY

Rock exposure is best on the ridges above treeline (1370 metres), although felsenmeer is extensive and contacts are rarely exposed. Elsewhere outcrop is poor due to extensive glacial overburden except where creeks and placer mining have exposed bedrock.

CACHE CREEK GROUP

Clastic Sediments and Cherts (Unit CP):

Argillaceous sediments (CPs) underlie much of the southeastern part of the map area (Figure 1-33-2). The sediments are very siliceous, dark grey to black in colour, and very fine grained. They are almost always interbedded with some chert and contain thin, pale grey-weathering siltstone beds (Figure 1-33-3) which may comprise a significant component of the

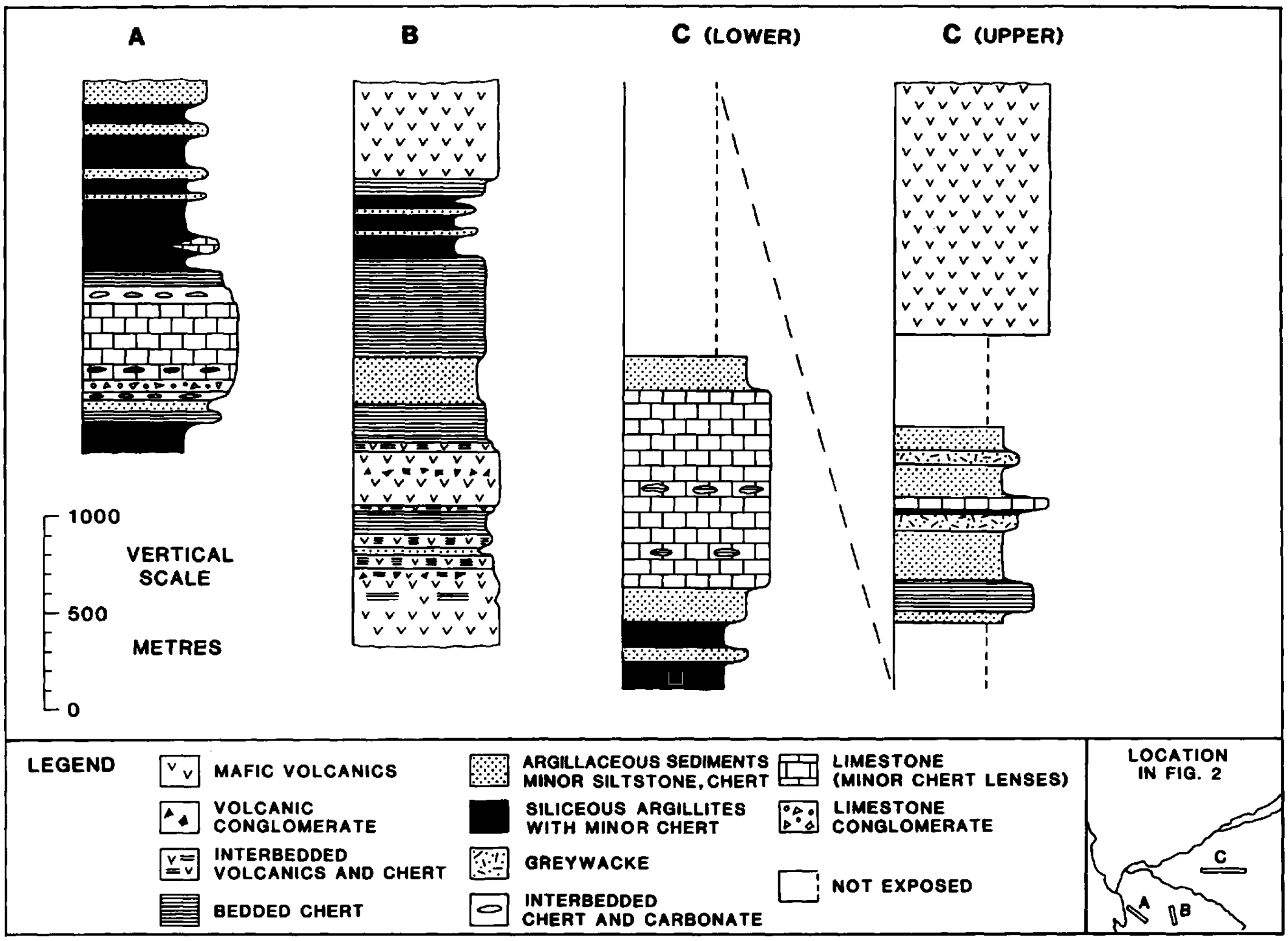


Figure 1-33-3. Stratigraphic columns emphasizing the relationships observed within the Cache Creek sediments.

section. The chert occurs as centimetre-scale discontinuous lenses and discrete beds, and may comprise up to 30 per cent of the unit. Locally, the fine-grained siliceous sediments have a flinty parting resembling cherts despite the significant clastic component.

Pure bedded cherts (CPb) are relatively rare except in the vicinity of Union Mountain and Lina Creek (Figure 1-33-3); they are microcrystalline, pale to dark charcoal-grey or rarely reddish brown in colour, and weather grey to off-white. The cherts are regularly bedded (ribbon bedded) with beds 2 to 10 centimetres thick, intercalated with thin beds of argillaceous sediments (Plate 1-33-1) and less commonly associated with the coarser, silty sediments. At Lina Creek, the chert is locally calcareous and is in gradational contact with limestone. The transition is marked by repetitive interbedding of discontinuous lenses and beds of both chert and limestone (Column A, Figure 1-33-3).

Greywacke is widespread though not abundant in Unit CP. It is a distinctive pale, buff-orange weathering, fine to medium-grained rock, usually interbedded with chert or silty argillite, and has a distinctive flaggy parting. On a ridge east of Spruce Mountain, the greywacke overlies finer clastics and contains clasts of the underlying sediments. It is gradationally overlain by limestone and becomes distinctly calcareous near the contact. These relationships are interpreted as facies transitions between the lithologies.

Limestone/Dolostone (Unit CPc):

Throughout the area, carbonate rocks are in contact with all other Cache Creek lithologies. Typical carbonates are mottled grey to white, fine to medium-grained limestones. Rare buff-weathering carbonate, which reacts poorly with 10 per cent hydrochloric acid, is interpreted as dolostone. Macrofossils are very rare but include shell and crinoid debris and a gastropod. The limestone is usually massive and bedding is obscure. Small limestone bodies are locally foliated at their contacts, larger bodies generally lack foliation. Gradational contacts are locally marked by limestone conglomerates and breccias (Figure 1-33-3). The limestone frequently occurs as large lensoid bodies, that stand out in the landscape due to their distinctive pale weathering colour (Plate 1-33-2).

Recrystallization and skarn alteration of limestone is common near the Surprise Lake batholith. Recrystallized limestone is medium to coarse grained, medium to dark grey in colour and weathers pale grey to white. It contains

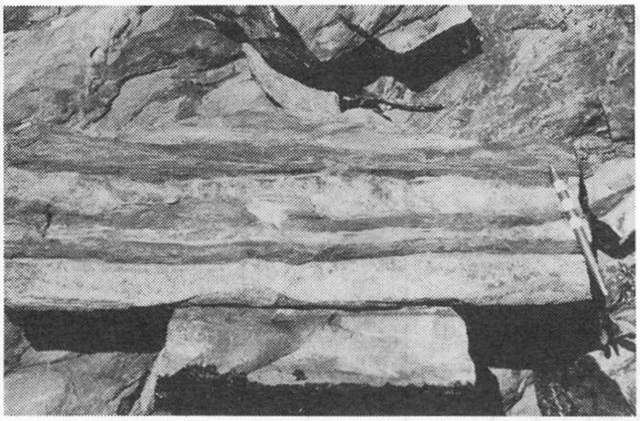


Plate 1-33-1. Outcrop photograph of the typical association of cherts interbedded with fine argillaceous sediments.

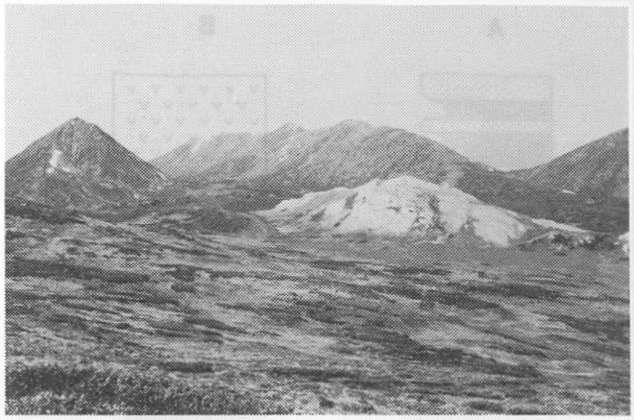


Plate 1-33-2. Larger bodies of limestone frequently have a lensoid geometry and are prominent features on the landscape due to pale weathering characteristics.

centimetre-scale beds or pods of green to brown-weathering, fine-grained calc-silicate. These are most common near contacts with clastic sediments and cherts or volcanics, and locally contain disseminated pyrite.

VOLCANICS (UNIT CPV):

Massive mafic flows with lesser volcanic breccia and tuff comprise the volcanic assemblage. These lithologies underlie much of the central part of the map area; the best exposures are on Union Mountain and Spruce Mountain.

Textural rather than compositional variations seem to characterize the volcanic succession. The massive flows are pale to medium green on fresh and weathered surfaces, aphanitic to fine grained, and homogeneous. They are rarely porphyritic and, when present, phenocrysts of pyroxene and chalky weathering feldspar rarely exceed 1 millimetre in size. Pillow structures have been recognized on Sentinel Mountain (Monger, 1975) immediately south of the map-area, but no definite pillow structures have been observed within the flows of the Atlin area, except in talus at the southeastern boundary of the map area.

Fine-grained, irregular colour laminations within the flows are interpreted as primary flow banding. Individual laminations vary in colour from pale to medium green and range in thickness from 2 to 50 millimetres. They are generally discontinuous and have diffuse to wispy terminations along strike. A very mottled fragmental texture on the weathered surface is characteristic.

Volcanic breccias within the flows typically contain rounded to subrounded clasts ranging in size from 3 to 30 centimetres. The clasts appear to be compositionally equivalent to the surrounding matrix, but are coarser grained and more porphyritic. Boundaries vary from sharp to diffuse, and may represent autobrecciation of the flow.

At Union Mountain lenses of chert (up to 1 metre in length) interfinger with the volcanics at the base of the sequence, suggesting a gradational contact between the sediments and volcanics. Also at Union Mountain, the base of the volcanic assemblage is locally marked by a thin tuff unit containing small vitric and lithic fragments.

ULTRAMAFIC ROCKS (UNIT PUM):

Peridotites, dunites and serpentinites comprise the ultramafic assemblage. Ultramafites occur as lensoid bodies, concordant with the stratigraphy (Figure 1-33-2). Contact relationships are obscured by shearing. On Monarch Mountain there is near continuous exposure of relatively unserpentinized ultramafic rocks in excess of 1 kilometre thick.

Peridotites dominate the unit and are typically khaki-brown to orange-weathering and green to black in colour. Texturally the peridotites vary from fine grained to moderately coarsely crystalline. Large pyroxene grains, ranging from 1 to 2 centimetres in length, are more resistant to weathering than the olivine-rich groundmass and form prominent knobs on weathered surfaces. Locally, glomeroporphyritic masses of pyroxene form large resistant clusters up to 15 centimetres in diameter. The best exposures of this texture occur on the ridge west of Boulder Creek.

Along the summit ridge, and to the west and north of Monarch Mountain, the pyroxenes occur in planar concentrations, defining a distinctive banding which may be interpreted as cumulate layering or a tectonite fabric (Plate 1-33-3). Individual layers vary in thickness from 1 to 50 centimetres, averaging 5 centimetres. Magnetite is locally abundant, occuring as fine segregations and individual grains up to 3 millimetres across.

Dunite has been mapped at the summit of Monarch Mountain where it occurs in sharp and conformable contact with the banded peridotites (Plate 1-33-4). The dunite is distinctively pale-weathering, very equigranular and dark green on the fresh surface. Small chromite grains, 1 to 3 millimetres in size, are evident on the weathered surface. The dunite occurs as a lens 10 metres wide and several tens of metres in length.

Discrete planar segregations of magnetite, commonly rimmed by fibrous serpentine, are an interesting textural variation. They are observed on Monarch Mountain, Mount Munro and Mount Barham, but are not continuous along strike. The segregations are generally less than 5 millimetres in thickness, usually with a preferred planar orientation, but are often crosscut by subparallel segregations of the same composition.

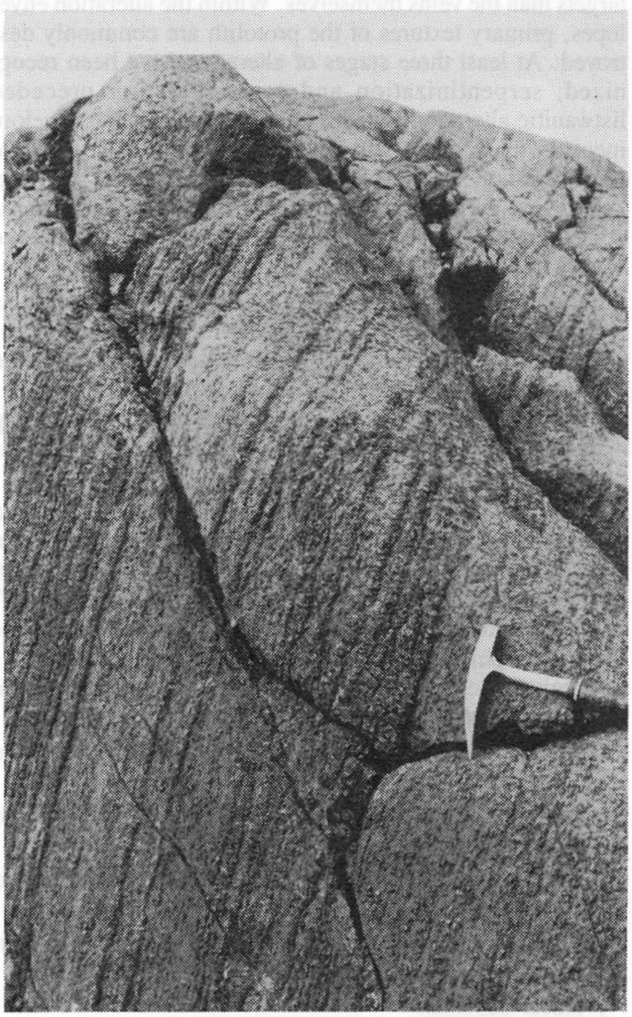


Plate 1-33-3. Large pyroxene crystals define a prominent banding within the peridotites, and may represent either cumulate layering or a tectonite fabric.

Serpentinization of the ultramafics is pervasive within fault zones and along lithologic contacts. It has resulted in a penetrative anastomosing fabric and complete retrogression of the primary mineralogy to serpentine minerals.

CRETACEOUS INTRUSIONS

Fourth of July Batholith (Unit KGD):

The Fourth of July batholith is a multiphase Cretaceous intrusion (Aitken, 1959). It underlies the northwestern quadrant of the map area where it varies from biotite hornblende diorite to granodiorite; its eastern limit is north and east of Mount Leonard. Aitken correlated the Fourth of July batholith with the Coast intrusions; Christopher and Pinsent (1979) obtained potassium-argon ages of 73.3 ± 2.6 Ma and 110 ± 4 Ma from biotite and hornblende, respectively.

The eastern phase is most typical of the Fourth of July batholith within the map area. It is well exposed north of Mount Leonard and in the Mount Vaughan area. North of Mount Leonard the batholith comprises coarse-grained hornblende diorite; elsewhere it is characterized by coarse-grained, equigranular hornblende biotite granodiorite.

Plate 1-33-4. A sharp contact between dunites and peridotites on Monarch Mountain. The dunites, in the foreground, weather a pale blonde colour in contrast to the overlying peridotites.

Hornblende is ubiquitous. Xenoliths occur locally and consist of fine to medium-grained diorite up to 10 centimetres in size.

North of Como Lake the batholith consists of dull pink to grey-weathering megacrystic granite. Euhedral potassium feldspar megacrysts, up to 5 centimetres in size, comprise approximately 20 per cent of the rock volume, surrounded by the coarse-grained quartz and plagioclase-rich groundmass. Fine-grained biotite-rich mafic dykes are prevalent in this phase of the batholith and range from 5 centimetres to 150 centimetres in width.

Finer grained equivalents of the megacrystic granite have been recognized along the eastern shore of Atlin Lake. This variation is typically pale grey to pink-weathering, with small, acicular, black hornblende crystals. It occurs both as a minor phase within the batholith, and as dykes crosscutting the Cache Creek rocks along its southwestern margin.

Surprise Lake Batholith (Units Klg, Ka):

The Surprise Lake batholith underlies the northeast quadrant of the map area. Leucocratic granite (Klg) characterizes the batholith and is well exposed on Idaho Peak. Christopher and Pinsent (1979) report an average biotite potassium-argon age of 70.6 Ma. The granite is generally coarsely crystalline and equigranular, composed of smokey quartz, chalky plagioclase, potassium feldspar and accessory biotite. The presence of very smokey quartz is unique to the Surprise Lake batholith.

Satellitic to the main body is the Mount Leonard stock, within which several different phases have been mapped. The main granitic phase has similar weathering characteristics to the granite in the Idaho Peak area, but is not as coarsely crystalline. A granitic aplite phase (Ka) marks the contact between the Surprise Lake and Fourth of July batholiths. This marginal phase is traceable over a strike length of approximately 2.5 kilometres, from the summit of Mount Leonard to west of Boulder Creek (Figure 1-33-2). The aplite is grey to white on fresh and weathered surfaces, and is characterized by a very sugary equigranular texture. Smokey grey quartz-eyes up to 5 millimetres in size are locally developed. Plagioclase is present as small lath-shaped crystals up to 1 centimetre in length. Minor amphibole occurs as green, bladed crystals, immediately east of the Mount Leonard summit. This occurrence of hornblende is anomalous within the Surprise Lake batholith.

Quartz-eye porphyry dykes are also present in the Mount Leonard area and range from 1 to 5 metres in width. The dykes are typically grey to rusty weathering and grey on the fresh surface, with an aphanitic to phaneritic groundmass supporting smokey quartz-eyes up to 1 centimetre in diameter.

STRUCTURE

FAULTING

The dominant structures in the Atlin area are characteristic of brittle deformation. Faults and fractures are recognized throughout the area, and occur in all lithologies. The truncation of lithologic units, localization of intense brittle deformation, imbrication of diverse lithologies and linear physiographic features comprise the field evidence supporting fault traces. Fault movement along lithologic contacts is indicated by the pervasive shearing along many contacts. Shearing and serpentinization are characteristic of all ultramafic contacts. Reactivation of the fault zones is indicated by crack-seal textures within associated vein systems, crosscutting relationships of veins of differing composition, and zones of repeated brecciation.

Two major fault systems have been mapped (Figure 1-33-2). A series of east-northeast-trending faults occurs throughout the area, represented by the Pine Creek, Union Mountain and Adera faults, as well as many minor structures not shown on the map. A north-trending fault system is represented by the Golden View and the Otter Creek faults. A complimentary system of shears is developed parallel to the east-northeast structural trend on the Atlin Ruffner property. The Beavis and Pictou faults are oblique to the major trends. The Fourth of July Creek lineament also trends oblique to the major trends and is a prominent topographic feature.

FOLDING

The structural trends indicate that the stratigraphic sequence has been deformed into a broad northwesterly plunging synform. Mesoscopic fold structures are weakly developed and are generally absent. They are manifest as broad, open warps of bedding. Where a sense of asymmetry is observed, it is compatible with a regional synformal geometry. An axial-planar cleavage is locally developed within the argillaceous sediments, striking northwest and dipping moderately to the west. An intersection lineation, defined by the intersection of cleavage on the bedding surface, plunges shallowly northwest.

ALTERATION AND MINERALIZATION

Mineralization and alteration are often concentrated along the fault zones which may have acted as a pathway for hydrothermal fluids. Alteration envelopes are associated with virtually all known lode gold deposits in the Cache Creek rocks and provide larger and more obvious exploration targets than the veins themselves. Within the alteration envelopes, primary textures of the protolith are commonly destroyed. At least three stages of alteration have been recognized; serpentinization and carbonitization preceded lisrwanitic alteration, intense silicification and the development of quartz veins and stockworks which host the gold mineralization. Ballantyne and MacKinnon (1986) have suggested that the gold is introduced during a post-listwanitic stage, which is compatible with relationships observed elsewhere.

Serpentinization of the ultramafic rocks is manifest as veinlets, arcuate fractures and massive replacements. Hydration of olivine has resulted in the development of magnetite and serpentine; the serpentine minerals include chrysotile, antigorite and lizardite. The magnetite produces a strong magnetic response which can be used to trace the serpentinites in areas of thick overburden.

Carbonate alteration is widespread in the ultramafics and associated Cache Creek rocks. The ultramafics have been altered to ferroan magnesite or breunerite (Newton, 1985). Talc and mariposite occur within elongate orange to buff-weathering zones of carbonate alteration related to faulting or shearing. This is interpreted as listwanitic alteration, although pyrite is less abundant than in the classic Russian localities (Ballantyne, personal communication, 1987).

The mineral deposits in the Atlin area can be divided into four groups:

(1) lode gold deposits hosted by the Cache Creek Group and associated ultramafic rocks;
(2) vein-hosted silver-lead systems with associated copper, lead and gold;
(3) skarns, veins and porphyry systems related to the Surprise Lake batholith; and,
(4) placer deposits.

Auriferous quartz veins containing the elemental association of gold, silver, lead, zinc, bismuth, antimony, tellurium, arsenic, nickel, cobalt and carbon dioxide (Ballantyne and MacKinnon, 1986) are found only within the Cache Creek Group. Silver-lead systems such as Atlin-Ruffner are relatively rare, but may have a gold association. Skarns, veins and porphyry deposits containing diverse suites of elements (W, Sn, U, F, Zn, Pb, Co, Cu, Mo and Ag) occur within or adjacent to the Surprise Lake batholith. Placer deposits are derived from both groups of deposits.

LODE GOLD DEPOSITS

The Imperial, Yellowjacket, Lakeview, Surprise, Golden View, Pictou, and Beavis are some of the numerous auriferous quartz vein and stockwork prospects in the Cache Creek rocks (Figure 1-33-4). Many of the veins are located near contacts between the ultramafic and volcanic rocks. Veins vary from a few centimetres up to 2 metres wide and pinch and swell along strike. Individual veins can sometimes be traced for hundreds of metres; they contain quartz, carbonate and coarse gold with disseminations of pyrite, sphalerite, galena and chalcopyrite. Ore microscopy studies have identified the following metallic minerals: electrum to argentiferous gold, galena, sphalerite, gersdorffite, bismuthinite, tetrahedrite, hessite and tetradymite (Ballan-

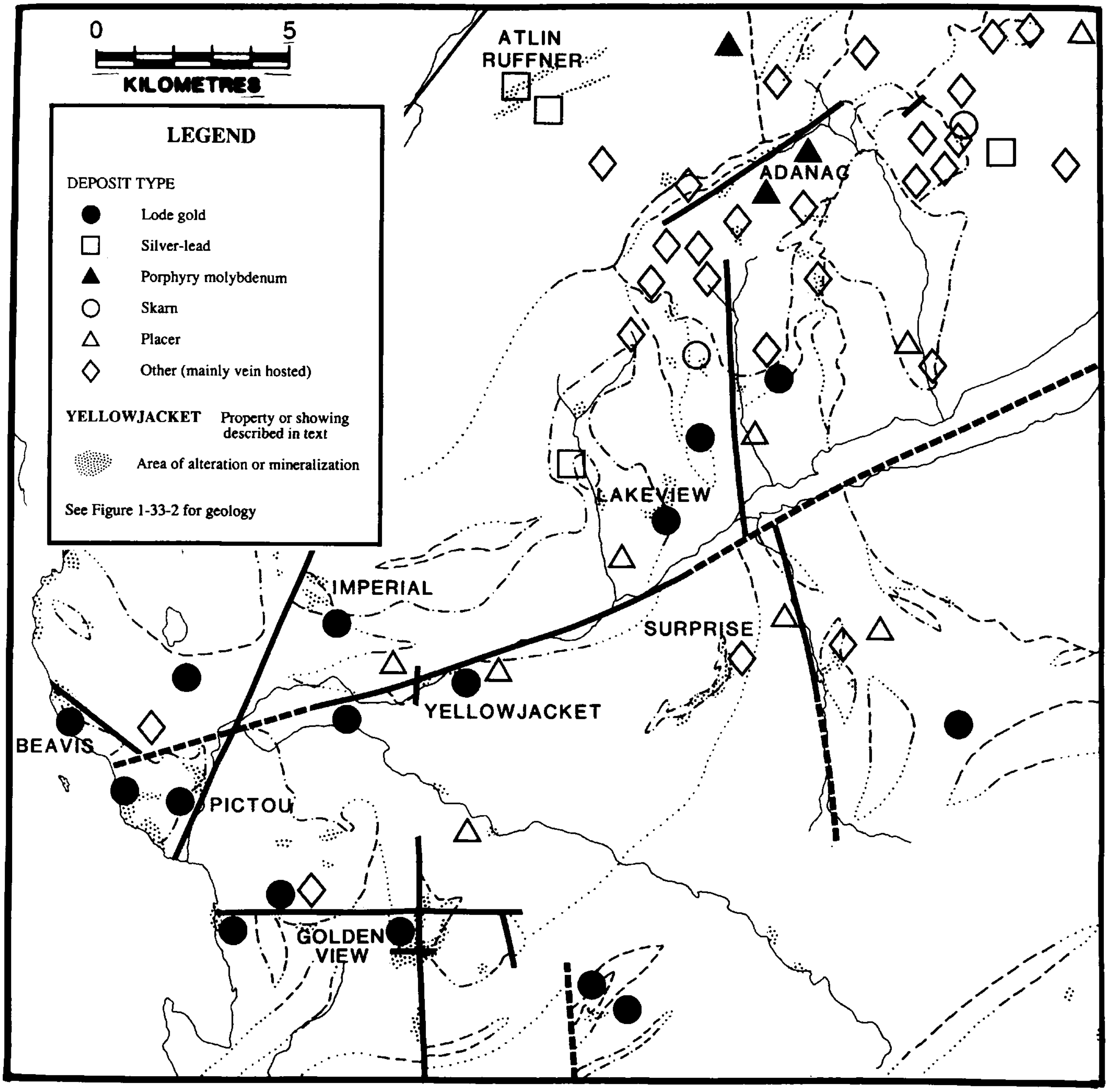


Figure 1-33-4. Mineralization and alteration within 104N/11W, 12E.

tyne and MacKinnon, 1986; Ballantyne, personal communication, 1987).

The age of mineralization for the lode deposits is younger than the host Cache Creek Group rocks, and is presumed to be older than the Fourth of July and Surprise Lake batholiths. Typically the batholiths contain a suite of elements significantly different from the Cache Creek hosted mineralization. Preliminary lead isotope data (Andrew, 1985) has been interpreted to give a Triassic age for mineralization at Surprise, Lakeview, Discovery and Golden View.

Imperial Property (MINFILE 104N 008)

The Imperial mine is on the southwestern flank of Mount Munro, approximately 8 kilometres northeast of Atlin. The ground was first claimed in 1899 and two adits were driven, with a total of 144 metres of underground development. Average grades of 13.7 and 5.1 grams per tonne gold respectively, were recovered from 245 tonnes of ore mined on the upper level, and 23 tonnes from the lower level. This is the only recorded lode gold production from the Atlin camp.

Mineralization is vein hosted, fault controlled, strikes northwest and dips moderately south. The wallrocks are serpentinized peridotites. Carbonatization of the host rock and local development of talc-carbonate schist are typical of the alteration along the fault zone. Gossanous patches are developed in areas a few centimetres across where pyrite is concentrated. Mariposite occurs within the carbonate alteration and is usually associated with millimetre to centimetre-scale quartz veinlets and stockworks. There is little visible sulphide mineralization but galena, chalcopyrite and pyrite have been recorded.

Yellowjacket Property (MINFILE 104N 014)

The Yellowjacket prospect is on Pine Creek, 9 kilometres east-northeast of Atlin. The lode gold was originally discovered by placer miners in 1899; a 30-metre shaft sunk at the turn of the century intersected an alteration zone containing quartz veins carrying visible gold. The shaft has since been covered by placer tailings and its location is unknown. No further work was done on the property until 1983 when Canova Resources Ltd. optioned the claims from local prospectors. Homestake Mineral Development Company acquired the property in 1986, and has completed a comprehensive exploration program including more than 10 000 metres of drilling which has delineated a zone 5 to 10 metres wide, extending 200 metres along strike and up to 90 metres down dip.

The Yellowjacket zone is located along the southern contact of a major ultramafic body with mafic volcanic rocks, and is coincident with the Pine Creek fault. Within the fault zone, numerous lenses of volcanic and serpentinized ultramafic rock are cut by dykes of diorite, gabbro and diabase. Rocks within the fault zone are intensely altered to carbonate, talc, chlorite, sericite and mariposite. Coarse electrum occurs in quartz veins 1 to 2 centimetres wide which form stockworks with grades of 3 grams per tonne gold or better over significant widths (Ronning, 1986; Lefebure and Gunning, 1988). Sparse arsenopyrite, pyrite and gersdorffite are also present in the veins.

Lakeview Property (MINFILE 104N 009)

The Lakeview property is approximately 16 kilometres northeast of Atlin, between Birch and Boulder creeks. Development in 1902 involved driving a 25-metre adit in the Lakeview quartz vein. Exploration did not resume until 1981 when Yukon Revenue Mines Ltd. acquired the property and obtained low-grade gold values in altered volcanics and quartz veins. Between 1982 and 1987 Cream Silver Mines Ltd. completed diamond drilling, detailed geological mapping, geochemical and geophysical surveys, trenching, blasting and bulk sampling.

The mineralization is hosted by quartz veins cutting carbonate-altered Cache Creek mafic volcanics, close to the contact with ultramafic rocks. The Lakeview vein occurs within a 30-metre-wide shear zone; it is at least 1.5 metres wide at the adit and has been traced for 800 metres along strike. The veins contain pyrite, galena, green chromium mica, gold, argentite and sphalerite.

Surprise Showing (MINFILE 104N 076)

The Surprise showing is on the northeastern flank of Spruce Mountain, 3 kilometres southwest of Surprise Lake. There is little recorded work history for the property, although it is briefly described in a 1925 Geological Survey of Canada Summary Report and several theses (Andrew, 1985; Newton, 1985).

Carbonatized ultramafic and volcanic rocks host the main quartz vein which is 3.5 metres wide. Talc-carbonate and silica-carbonate alteration are concentrated close to the contact between the two lithologies. Veins and stockworks contain disseminations of mariposite, galena and minor pyrite. Several mafic dykes occur parallel to the vein, trending south and dipping moderately to the west.

Golden View (MINFILE 104N 042)

The Golden View property is on the western flank of Union Mountain approximately 6 kilometres southeast of Atlin. Work on the property has been sporadic since it was first staked in 1899, and has involved some underground development and trenching (Newton, 1985). Descriptions of the property are included in Minister of Mines Annual Reports for the periods 1902-1938 and 1950-1971.

The property is underlain by Cache Creek mafic volcanic and ultramafic rocks. Quartz veins and stockworks host the mineralization which occurs within discrete lensoidal zones of quartz-earbonate (listwanite) alteration, along the trace of the Golden View fault. Mariposite, associated with listwanitic alteration, is frequently concentrated within thin bands while minor chalcopyrite, pyrite and malachite occur primarily as disseminations in veins and host rock.

Pictou Property (MINFILE 104N 044)

The Pictou prospect is west of Pine Creek, at the southern end of the new airstrip, 3 kilometres northeast of Atlin. A 20-metre adit and 7-metre shaft were excavated in 1900. In 1987 and 1988, Homestake Mineral Development Company conducted geophysical and geochemical surveys, surface trenching and diamond drilling. Gold assays as high as 13.5 grams per tonne gold have been obtained from quartz veins.

The mineralization is hosted by ultramafic rocks which have been extensively brecciated during carbonatization and silicification (Plate 1-33-5). Talc is a minor constituent of the carbonate alteration and quartz veins occur as stockworks, breccia veins and veinlets 2 to 10 millimetres wide. Coarse euhedral crystals frequently occur along vein margins, indicating open space filling. Gold mineralization is related to intense silicification associated with abundant green chromium mica, fine-grained chalcopyrite, pyrite and tetrahedrite.

Beavis Property (MINFILE 104N 011)

The Beavis property is 2 kilometres north of Atlin and 1 kilometre east of Atlin Lake. The property geology has been described in Minister of Mines Annual Reports between 1902 and 1933. Recent trenching has increased exposure dramatically.

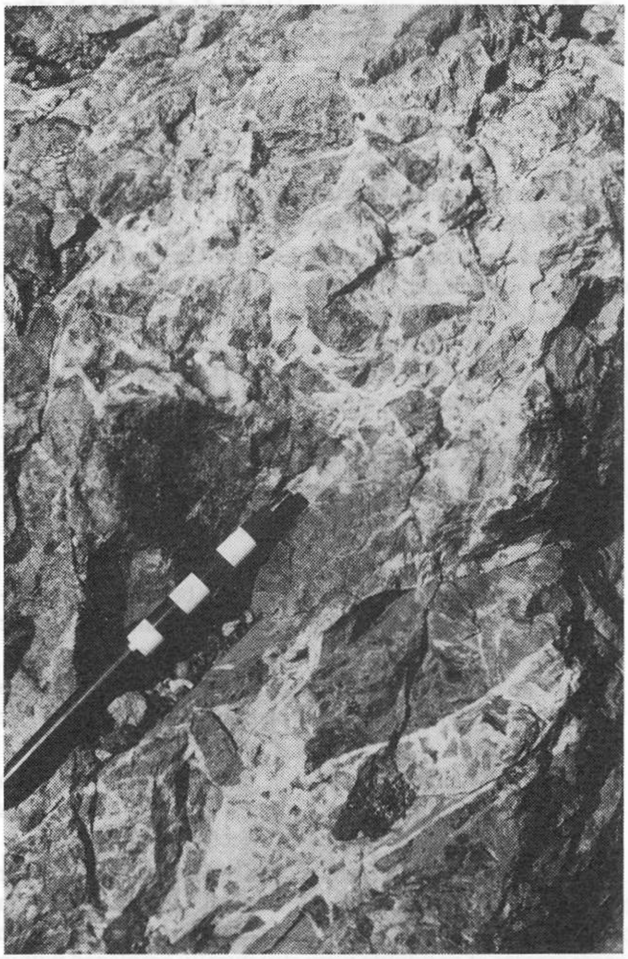


Plate 1-33-5. Intense brecciation of the host rock resulting from silica flooding following carbonate alteration on the Pictou prospect.

The mineralization is hosted within Cache Creek sediments and minor volcanics, close to the contact between volcanics and ultramafics. The contact is faulted and characterized by brecciation and intercalation of diverse Cache Creek lithologies. Gold is concentrated along this contact and is associated with carbonate-silica alteration, quartz stockworks and open space vein filling. Green mica and pyrite are disseminated within strongly silicified zones. Numerous crosscutting mafic and felsic dykes, believed to be related to the Fourth of July batholith, have been affected by the alteration and mineralization.

SILVER-LEAD SYSTEMS

Atlin Ruffner Mine (MINFILE 104N 011)

The Atlin Ruffner mine is south of Mount Vaughan, approximately 23 kilometres northeast of Atlin. The property was initially explored as a silver-lead-zinc prospect, with minor gold and copper. It has been described in numerous Minister of Mines Annual Reports from 1900 to 1968, and has had an extensive work history. Between 1974 and 1976, Atlin Silver Corporation milled approximately 1610 tonnes of ore and an additional 1082 tonnes were mined by Trident Resources Inc. (now Trident Industries Limited) during 1981. In 1988, Homestake Minerals commenced detailed geologic mapping and sampling of the property.

The mineralization is vein-hosted and confined to dioritic to diabasic dykes which crosscut granodiorite to quartz monzodiorite of the Fourth of July batholith. There are six mineralized dykes striking consistently east-northeast and dipping steeply northwest. They range in width from 1 to 8 metres, and one has been traced over a strike length of at least 2500 metres. The contacts of the dykes with the surrounding rock are sharp, but strongly sheared. They are characterized by intense brecciation and the development of quartz and quartz-carbonate stockworks within which massive galena, sphalerite and aresenopyrite are the principal sulphide minerals. Minor chalcopyrite, pyrite, tetrahedrite, bornite and molybdenite are also present in the stockworks. Crack-seal textures and open-space fillings are common in the veins.

MINERALIZATION RELATED TO THE SURPRISE LAKE BATHOLITH

The Surprise Lake batholith is a texturally varied leucocratic granite with biotite granite and granite porphyry phases, and is similar to other granites with associated tin-tungsten-uranium-molybdenum mineralization. The presence of roof pendants of Cache Creek volcanics near Ruby Creek and a down-faulted block of Cache Creek volcanics along the Trout Lake valley (Aitken, 1959) suggest the western part of the batholith is not deeply eroded. Typically the roof zone and apophyses of volatile-rich intrusions are favorable locations for mineralization. In the Surprise Lake batholith, wolframite, scheelite and cassiterite veins and minor greisen, often with associated fluorite, occur in the roof zone. The veins are best developed in the Mount Leonard stock, and on Mount Weir, outside of the current map area.

Skarn deposits are developed in the Cache Creek limestones immediately adjacent to the Surprise Lake batholith. Pyrite, pyrrhotite, chalcopyrite, galena, sphalerite and fluorite replace the recrystallized limestone in relatively small pods or lenses.

Uranium (14.6 ppm) and thorium (45.6 ppm) contents in the Surprise Lake batholith are high compared to most low-calcium granite bodies. The primary uranium minerals are believed to be syngenetic in origin, crystallizing at the same time as the major rock-forming minerals, but circulating magmatic and meteoric waters have remobilized and concentrated uranium in new locations within the batholith and adjacent country rocks (Ballantyne and Littlejohn, 1982). In the Mount Weir area the mineralization is derived from late magmatic fluids and is related to metasomatic alteration and enrichment of uranium. Kasolite, metazeunerite and wulfenite occur along fractures and fluorite, sphalerite and magnetite with minor cassiterite and niobium-bearing ilmenite are vein-hosted. Springs with an unusually high radon content are associated with faults in the batholith and may reflect hydrothermal fluids generated by convection cells driven by radiogenic heat. Buried, postmagmatic hydrothermal uranium concentrations may be developed along these faults. Ballantyne and Littlejohn (1982) have identified near-surface deposition of kasolite and metazeunerite on fractures in the batholith and anomalous concentrations of uranium in stream waters and sediments on and around the batholith, suggesting that leaching and redeposition of the uranium has occurred.

Adanac Mine

The Adanac molybdenum deposit is in a porphyry setting in the multi-phased Mount Leonard stock, satellitic to the Surprise Lake batholith. First discovered in 1967, the deposit was being prepared for production in the early 1980s when a drop in molybdenum prices brought the project to a halt. Open-pit resetrves are 152 million tonnes grading 0.063 per cent molybdenum (Christopher and Pinsent, 1979).

The Adanac mineralized zone consists of molybdenite as coatings on fractures and in quartz veins. Pyrite and rare chalcopyrite are restricted to the veins and fractures (Christopher and Pinsent, 1979). Wolframite, arsenopyrite, scheelite and fluorite occur in some veins within and peripheral to the mineralized zone which is hosted by quartz monzonite intruded by a weakly mineralized quartz monzonite porphyry. The Adera fault truncates the ore zone to the north. Propylitic to argillic alteration is indicated by chloritization of biotite, and plagioclase altèred to sericite, clay and carbonate (White *et al.*, 1976). Locally potassic alteration extends up to 5 centimetres from fractures.

PLACER DEPOSITS

Placer deposits occur in river gravels deposited in channels up to 12 metres thick and 400 metres wide (MacKinnon, 1986). Gold, cassiterite, chromite, scheelite, and wolframite are concentrated in the channels. Formed during the Pleistocene, these placer gravels are a distinctive rusty or reddish colour, decomposed and cemented by clay, iron oxides or wad. During the Wisconsin glaciation the placer gravels were first buried by lacustrine sediments, then morainal debris and finally glaciofluvial and till deposits up to 100 metres thick (Milner, 1983). In some localities creeks have cut down through the former channels and have concentrated gold in the present creek bed. Comparison of placer nuggets and gold grains from lode deposits in the same area has proved the placer gold is derived from the lodes (MacKinnon, 1986; Ballantyne and MacKinnon, 1987).

The Atlin camp is among the largest producers of placer gold in British Columbia, with production of more than 19 000 kilograms since its initial discovery in 1898 (Debicki, 1983). Virtually all placer production has focused on the recovery of gold except for an attempt to recover wolframite on Boulder Creek during the early 1950s. Chromite, scheelite and wolframite were identified in significant concentrations; minor osmium, iridium and ruthenium alloys with minor platinum and palladium were also found in the placer concentrates (MacKinnon, 1986).

CONCLUSIONS

Field mapping has identified the following characteristics of the Cache Creek Group.

- A generalized stratigraphy can be defined for the entire map area.
- All sedimentary units occur interbedded with each other at scales from centimetres to hundreds of metres.
- Gradational contacts are observed between limestones and clastic sediments, cherts and clastic sediments, and cherts and volcanics.
- Hybrid lithologies such as limy ehert, limy greywacke and intraformational breccias are typical of gradational contacts.

These observations suggest the Cache Creek Group rocks were deposited under similar conditions, near a source of clastic material and probably in a shallow oceanic basin or a back-arc setting. Previously the Cache Creek terrane has been interpreted as a tectonic mélange (Monger, 1984; Price *et al.*, 1985) although significant, faulting has not obliterated stratigraphic continuity in the Atlin area. As there is less structural disruption the Atlin terrane may provide a unique study area for the Cache Creek Group.

Field examination of the ultramafic rocks has shown that:

- Ultramafic bodies vary greatly in size.
- There is a close spatial relationship between the ultramafic and volcanic rocks, although smaller ultramafic bodies also occur in sedimentary sequences.
- Ultramafic contacts are sheared or faulted, with no chilled margins or contact metamorphism of adjacent rocks.
- Relatively pristine textures, such as pyroxene-rich bands and dunite layers, suggest that the ultramafics represent primary cumulate or tectonite features.

The ultramafic rocks were probably formed in the lower oceanic crust and subsequently tectonically emplaced into an oceanic-basin assemblage of volcanics and sediments. The larger masses of peridotite were structurally emplaced within the volcanics, and were obducted as a coherent wedge. Imbrication of the package created slivers of ultramafics which occur in contact with all Cache Creek lithologies.

Auriferous quartz veins have been shown to be the source of the placer gold deposits in the Atlin area (MacKinnon, 1986; Ballantyne and MacKinnon, 1986). Lode gold is almost exclusively restricted to quartz veining and stockworks associated with fault zones, anomalous geochemistry and intense listwanite alteration. Faults are common at ultramafic-volcanic rock contacts. Listwanites may grade inwardly to a talc-carbonate-mariposite-rich core, and these intense alteration envelopes are a common signature of major faults. The gold mineralization appears to be later than the listwanite alteration.

ACKNOWLEDGMENTS

The authors would like to express their thanks to Michael Gunning, Ingrid Gertz, Trevor Misfeldt and William Motherwell for their competent and enthusiastic assistance in the field. Linda Dandy of Mark Management helped with the orientation phase of the project in 1987, and her knowledge and enthusiasm are much appreciated. Geological maps provided by the Hughes-Lang Group and Homestake Mineral Development Company proved most helpful. The staff of Homestake, especially Darcy Marud and Duncan McIvor are gratefully acknowledged for their willingness to share information and discuss the geology of the Atlin area. Thanks are also due to Bruce Ballantyne for the time and information he contributed and his enthusiastic support of the project. Special thanks are due to Norm Graham of Capitol Helicopters for reliable and safe service, Fred Jenkins for logistical assistance and Geoff Collins for providing comfortable accomodations.

REFERENCES

Aitken, J.D. (1953): Greenstones and Associated Ultramafic Rocks of the Atlin Map-area, British Columbia, Unpublished Ph.D. Thesis, *University of California*, Los Angeles.

——— (1959): Atlin Map-area, British Columbia, *Geological Survey of Canada*, Memoir 307, 89 pages.

Andrew, K.P.E. (1985): Fluid Inclusion and Chemical Studies of Gold-quartz Veins in the Atlin Camp, Northwestern British Columbia, Unpublished B.Sc. Thesis, *The University of British Columbia*, 117 pages.

Ballantyne, S.B. and Littlejohn, A.L. (1982): Uranium Mineralization and Lithogeochemistry of the Surprise Lake Batholith, Atlin, British Columbia, *Geological Survey of Canada*, Paper 81-23, pages 145-155.

Ballantyne, S.B. and MacKinnon, H.F. (1986): Gold in the Atlin Terrane, British Columbia, Abstract *in* Gold '86, An International Symposium on the Geology of Gold Deposits. A.M. Chater, Editor, *Geological Association of Canada*, pages 16-17.

Cairnes, D.D. (1913): Portions of the Atlin District, B.C.: with Special Reference to Lode Mining, *Geological Survey of Canada*, Memoir 37, 129 pages.

Christopher, P.C. and Pinsent, R.H. (1979): Geology of the Ruby Creek and Boulder Creek Area near Atlin (104N/11W) (Adanac Molybdenum Deposit), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map No. 52.

Debicki, R.L. (1983): Placer Mining Industry in Yukon and Atlin Mining Division, Yukon River Basin Project Report: Placer No. 1., *Indian and Northern Affairs Canada*, 197 pages.

Gabrielse, H. and Wheeler, J.O. (1961): Tectonic Framework of Southern Yukon and Northwestern British Columbia, *Geological Survey of Canada*, Paper 60-24.

Gwillim, J.C. (1901): Report on the Atlin Mining District, British Columbia, *Geological Survey of Canada*, Annual Report, Volume 12, pages 5B-48B.

Lefebure, D.V. and Gunning, M.H. (1988): Yellowjacket. *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, Part B, Pages B87-B95.

Link, P.K. (1965): Stratigraphy of the Mount White – Eastern Little Atlin Lake Area. Unpublished Ph.D. Thesis, *University of Wisconsin*.

Lueck, B.A. (1985): Geology of Carbonatized Fault Zones on the Anna Claims and their Relationship to Gold Deposits, Atlin, B.C. Unpublished B.Sc. Thesis, *The University of British Columbia*.

MacKinnon, H.F. (1986): Examination of Concentrates from Atlin, B.C. Placers: Economic Implications, Unpublished B.Sc. Thesis, *Carleton University*, 199 pages.

Mihalynuk, M.G. and Rouse, J.N. (1987): Preliminary Geology of the Tutshi Lake Area, Northwestern British Columbia (104M/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 217-231.

Milner, M.W. (1983): The Klondike, Atlin and Cariboo Goldfields in a Progression of Glacial Involvement and Lode Gold Production, *Geological Association of Canada and Mineralogical Association of Canada*, Annual Meeting, Victoria, Program with Abstracts, Volume 8, page A47.

Monger, J.W.H. (1966): Atlin Horst Project, Report of Activities, *Geological Survey of Canada*, Paper 67-1, Part A, pages 76-77.

——— (1967): Atlin Horst, British Columbia (104 J,K,N), Report of Activities, *Geological Survey of Canada*, Paper 68-1, Part A, pages 34-36.

——— (1968): Late Paleozoic Rocks of the Atlin Horst, Northwestern British Columbia and South-central Yukon (104M,N and 105C,D). Report of Activities, *Geological Survey of Canada*, Paper 69-1, Part A, pages 23-27.

——— (1975): Upper Paleozoic Rocks of the Atlin Terrane, *Geological Survey of Canada*, Paper 74-47, 63 pages.

——— (1977): Upper Paleozoic Rocks of the Western Canadian Cordillera and their Bearing on Cordilleran Evolution, *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

——— (1984): Cordilleran Tectonics: a Canadian Perspective, *Bulletin Societ Geologique France*, Volume 26, No. 2, pages 255-278.

Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J. (1982): Tectonic Accretion and the Origin of the Two Major Plutonic Welts in the Canadian Cordillera, *Geology*, Volume 10, pages 70-75.

Newton, D.C. (1985): A Study of Carbonate Alteration of Serpentinites around Au and Ag-bearing Quartz Veins in the Atlin Camp, British Columbia. Unpublished B.Sc. Thesis, *The University of British Columbia*.

Price, R.A., Monger, J.W.H. and Roddick, J.A. (1985): Cordilleran Cross-section; Calgary to Vancouver, *in* Field Guides to Geology and Mineral Deposits *in* the Southern Canadian Cordillera, D.J. Templeman-Kluit, Editor, *Geological Society of America*, Cordilleran Section, Annual Meeting, Vancouver, pages 3-1 to 3-85.

Ronning, P.A. (1986): Summary Report, Diamond Drilling and Geophysical Work, Arent 1, Arent 2, Beama and adjacent Claims, North and South Claim Groups. Yellowjacket Property, Atlin Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 15683, 15 pages.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera (1:2,000,000). *Geological Survey of Canada*. Open File Map 1565 (2 sheets).

White, H.W., Stewart, D.R. and Ganster, M.W. (1976): Adanac (Ruby Creek), Porphyry Molybdenum Deposits of the Calc-alkalic Suite, *in* Porphyry Deposits of the Canadian Cordillera, A. Sutherland-Brown, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume, Paper 47, Part D, pages 476-483.

GEOLOGY AND MINERAL DEPOSITS OF THE CASSIAR AND McDAME MAP AREAS, BRITISH COLUMBIA* (104P/3, 5)

By JoAnne L. Nelson and John A. Bradford

KEYWORDS: Regional geology, Cassiar platform, Sylvester allochthon, tectonic history, gold veins, asbestos, sedex deposits.

INTRODUCTION

Mapping at 1:25 000 scale of the Cassiar map area and the northwest quarter of the contiguous McDame sheet was completed during the summer of 1988. This concluded a 3-year program of mapping from the Yukon border north of the Midway silver-lead-zinc deposit to the Erickson gold mine, about 13 kilometres southeast of Cassiar (Figure 1-34-1). The northeast quarter of the Needlepoint Mountain map sheet (104P/4), including the Erickson mine area, was mapped by T. Harms in association with the Cassiar mapping program (Harms, 1989, this volume). The town of Cassiar is near the southwestern corner of the Cassiar map area, about 15 kilometres from the junction with the Stewart-Cassiar highway, which crosses the southern boundary of the map sheet.

Objectives of the Midway-Cassiar program are:

- To map the geology in detail and determine the settings and controls of known mineral deposits.
- To map the Sylvester allochthon in terms of significant lithotectonic units, to identify the units and structures within it that are favourable for Erickson-type gold-quartz occurrences, and to evaluate the asbestos potential of Sylvester ultramafic bodies.
- To identify structural-stratigraphic settings that are likely to host Midway-type manto deposits.
- To investigate other potential metallic and nonmetallic resources.

GEOLOGICAL SETTING

The main elements of the geology of the map area (Figures 1-34-1, 2 and 3) are identical to those described previously in the Blue Dome (104P/12) and Midway (104O/16) map areas (Nelson *et al.*, 1988a; Nelson and Bradford, 1987). Displaced North American strata of the Cassiar terrane, ranging in age from Hadrynian to Early Mississippian, are structurally overlain by the Sylvester allochthon, which occupies the core of the McDame synclinorium (Gabrielse, 1963). In the Cassiar and McDame map areas, components of the Sylvester allochthon range at least from Early Mississippian to Late Triassic age, and include marginal basin and arc volcanic-sedimentary sequences, and subcrustal ultramafite-gabbro complexes.

Middle to Late Cretaceous granitic stocks intrude miogeoclinal strata along the western margin of the Cassiar map area. The Eocene Mount Haskin stock lies in the southeast corner. High-angle faults occur near the western and eastern margins of the Sylvester allochthon, with the Marble Creek fault to the west cutting both autochthonous and allochthonous strata. This structure is a probable control for asbestos mineralization in the Cassiar mine as well as silver-lead-zinc replacement deposits of the Marble Creek system. The Blue Dome fault, recognized in the Blue Dome map area in 1987 (Nelson *et al.*, 1988b), has been traced southward through the Cassiar and McDame sheets, and is inferred to extend into the Cry Lake (104J) area. This is a high-angle fault system with probable lateral displacement, associated with lenses of serpentinite-matrix mélange. It truncates thrusts bounding lithotectonic units within the Sylvester allochthon, but is not known to cut underlying autochthonous strata.

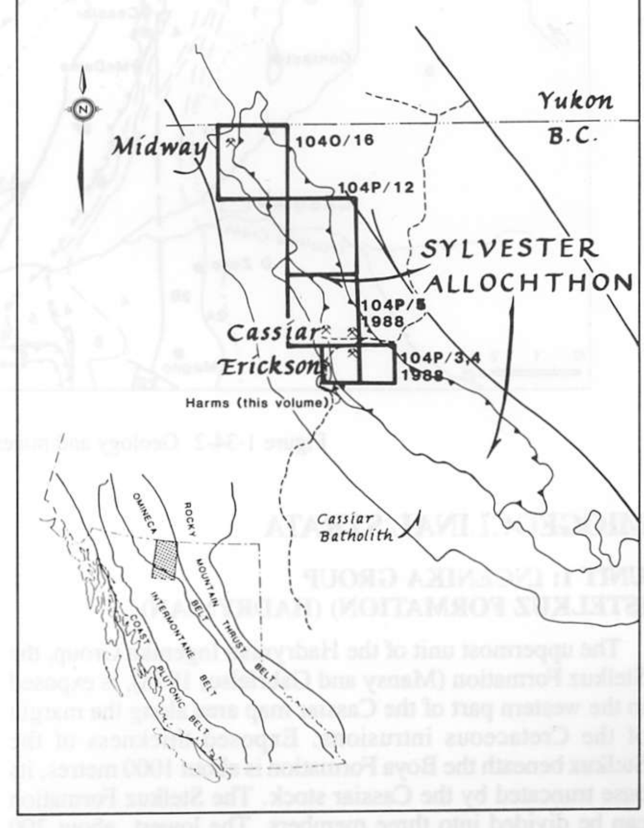


Figure 1-34-1. Location of the Cassiar and Needlepoint Mountain and McDame map areas (104P/3, 4, 5).

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

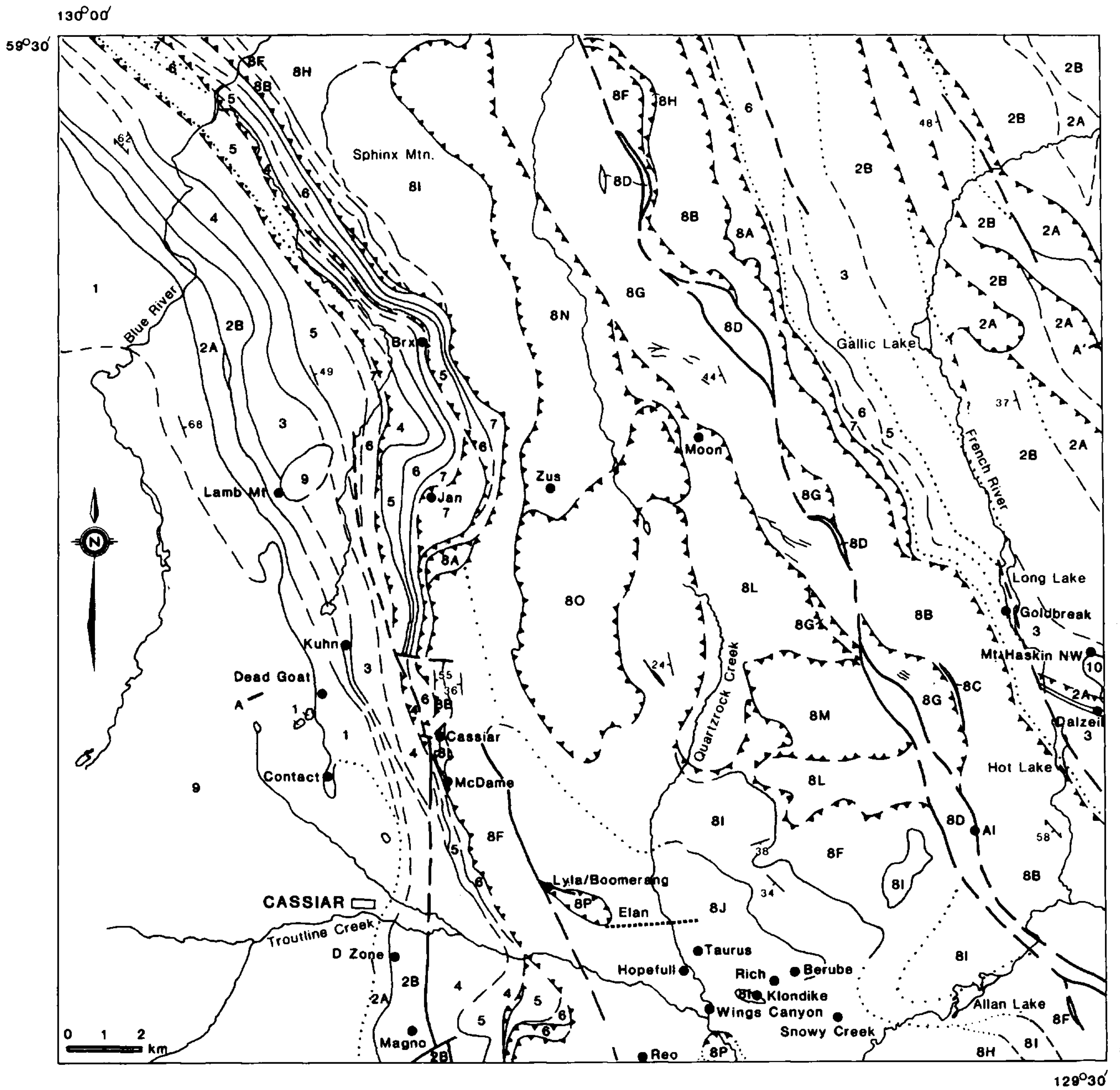


Figure 1-34-2. Geology and mineral occurrences of the Cassiar map area.

MIOGEOCLINAL STRATA

UNIT 1: INGENIKA GROUP (STELKUZ FORMATION) (HADRYNIAN)

The uppermost unit of the Hadrynian Ingenika Group, the Stelkuz Formation (Mansy and Gabrielse, 1978), is exposed in the western part of the Cassiar map area along the margin of the Cretaceous intrusions. Exposed thickness of the Stelkuz beneath the Boya Formation is about 1000 metres, its base truncated by the Cassiar stock. The Stelkuz Formation can be divided into three members. The lowest, about 200 metres thick, contains phyllite with minor interbedded quartzite, green phyllitic argillite and dolomitic sandstone. A middle member, about 350 to 400 metres thick, consists of siltstone with intercalated medium-bedded limestone, interbedded slate and limestone and minor massive limestone. The unit is characterized by two prominent ribs of laminated to medium-bedded limestone 5 to 10 metres thick. The upper member, about 400 metres thick, contains mainly green to olive-brown-weathering phyllite with minor quartzite. The contact with overlying Cambrian strata is gradational, with a gradual increase in quartzite upsection.

UNIT 2: ATAN GROUP (LOWER CAMBRIAN)

The Atan Group is exposed along both limbs of the McDame synclinorium on the eastern and western sides of the Cassiar map area. In the northeastern corner it forms a major duplex structure beneath a décollement in the overlying Kechika Group. The Atan Group includes the lower siliciclastic Boya Formation and overlying carbonates of the

LEGEND

EOCENE
10 Mt. Haskin stock: monzogranite

MID(?) AND LATE CRETACEOUS
9 Cassiar stock: monzogranite

DEVONIAN TO TRIASSIC
8 Sylvester allochthon

Division I

8A = IPsv: chert, argillite, basalt

8B = IMsi: argillite, chert, calcarenite, greywacke, exhalite, diabase

Division II

8C = Diabase, gabbro

8D = IIs: serpentinite, amphibolite, gabbro, basalt, ophicalcite

8E = IIMs: argillite, chert, calcarenite, greywacke

8F = IIMvs: basalt, diabase, chert, argillite, calcarenite, greywacke, conglomerate

8G = IIMPvsu: basalt, chert, argillite, diabase, serpentinite, ophicalcite

8H = IIMPsi: chert, tuff, diabase

8I = IIPvs: basalt, tuff, chert, quartz sandstone, rhodonite

8J = IIb: basalt

8K = IIPsi: black chert, argillite, diabase

8L = IICum: harzburgite tectonite, ultramafic cumulates, serpentinite

8M = IIP(?)Cgb: gabbro

8N = IIZMum: dunite, harzburgite tectonite, serpentinite

8O = IIPZMgb: gabbro

8P = IITrtms: slate, calcareous siltstone, limestone

Division III

8Q = IIIPPvs: augite (hornblende, plagioclase) porphyry, lapilli tuff, tuffaceous sandstone, limestone

8R = IIIPPs: limestone, tuffaceous sandstone, chert, volcanic breccia

8S = IIIP(?)t: tonalite

8T = IIIvs: tuff, limestone, quartz arenite, slate, variolitic basalt, chert

DEVONIAN TO MISSISSIPIAN
7 Earn Group: slate, siltstone, sandstone, exhalite

MIDDLE DEVONIAN
6 McDame Group: limestone, dolostone

LOWER DEVONIAN
5 Tapioca sandstone: dolomitic quartz arenite, quartzite, dolostone

ORDOVICIAN TO SILURIAN
4 Road River Group: black slate, calcareous mudstone, argillaceous limestone

CAMBRIAN TO ORDOVICIAN
3 Kechika Group: calcareous slate, siltstone, limestone

LOWER CAMBRIAN
2B Rosella Formation: limestone, dolostone, calcareous shale
2A Boya Formation: quartzite, siltstone

HADRYNIAN
Ingenika Group
1 Stelkuz Formation: phyllite, quartzite, limestone

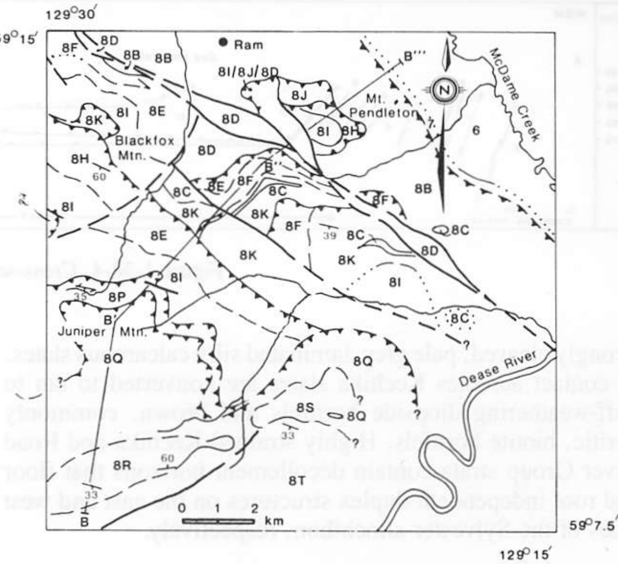


Figure 1-34-3. Geology and mineral occurrences of the McDame NW¼ (104P/3) map area.

Rosella Formation. The Boya Formation contains two members. The lower member consists of clean, well-sorted, white, green and pinkish quartzite, locally micaceous and commonly crossbedded, and minor quartz-pebble conglomerate. The upper member consists of rhythmically interbedded, grey-weathering, thin-bedded siltstone and brown-weathering medium-bedded sandstone. It is not always present, but where seen, appears to be gradational into interbedded siltstone and limestone of the overlying Rosella Formation. Thickness of the Boya Formation is about 200 metres.

The Rosella Formation consists mainly of well-bedded to massive blue-grey limestone and interfingering orange-weathering secondary dolomite. Sections measured by M. Pope (personal communication, 1988) in the eastern half of the map area contain thicknesses up to about 270 metres. A lower member contains interbedded siltstone and thin to medium-bedded limestone with archaeocyathids and trilobite fragments. This is overlain by thin to thick-bedded limestone which locally contains abundant oolitic and intraclastic horizons. Crosslaminated calcarenites are present locally, and a silty calcareous shale member occurs near the middle of the section.

The Rosella Formation is host to molybdenum-tungsten skarns and silver-lead-zinc mineralization adjacent to the Cassiar and Mount Haskin stocks. Molybdenum and tungsten mineralization is associated with metasomatic actinolite-garnet skarn, while silver-lead-zinc replacement bodies generally occur in unskarned marble.

UNIT 3: KECHIKA GROUP (CAMBRO-ORDOVICIAN)

The Kechika Group crops out in the western part of the Cassiar map area where it is strongly hornfelsed by the Troutline stock, and in similar exposures near Mount Haskin. Elsewhere it underlies valleys where it is covered by glacial and alluvial deposits. Where not hornfelsed, it consists of

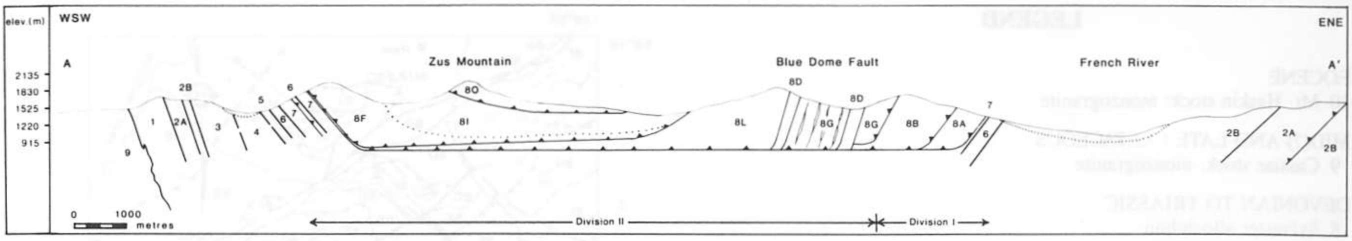


Figure 1-34-4. Cross-section A-A', Cassiar map area.

strongly cleaved, pale grey, laminated silty calcareous slates. In contact aureoles Kechika slates are converted to tan to buff-weathering diopside hornfels and brown, commonly pyritic, biotite hornfels. Highly strained Kechika and Road River Group strata contain décollement horizons that floor and roof independent duplex structures on the east and west sides of the Sylvester allochthon, respectively.

UNIT 4: ROAD RIVER GROUP (ORDOVICIAN – SILURIAN)

The Road River Group consists of brown to black, friable calcareous mudstone, black slate and lesser black argillaceous limestone. Graptolites are common in well-cleaved slates and mudstones. It is well exposed on the western limb of the McDame synclinorium, but was not seen on the eastern limb. In the Blue Dome map area, north of the Cassiar sheet, only one exposure of Road River Group was noted east of the Sylvester allochthon (Nelson *et al.*, 1988a). This suggests that the allochthon conceals an east-to-west facies change, with shallow-water, fine-clastic and carbonate-shelf sedimentation to the east and deeper basins with fine black clastic off-shelf sediments to the west.

The duplex west of the allochthon floors well within the Road River Group, as graptolitic slates are found at the base of some thrust panels. Near the Cassiar mine, graptolitic slates are complexly imbricated with Tapioca or McDame dolomite, directly below the cherts that comprise the footwall to the serpentinite hosting the orebodies.

UNIT 5: TAPIOCA SANDSTONE (LOWER DEVONIAN)

Pale grey to buff well-bedded dolostone, dolomitic quartz arenite and quartzite of the Tapioca sandstone occur along both limbs of the McDame synclinorium. Its thickness appears to vary abruptly, and in places it is absent from the section. This may be due to block faulting and local uplift of the carbonate platform in Early Devonian time, with erosional removal of the Tapioca sandstone in places. This is consistent with observations made in the Blue Dome map area (Nelson *et al.*, 1988a).

UNIT 6: McDAME GROUP (MIDDLE DEVONIAN)

The McDame Group is conspicuously exposed on both limbs of the McDame synclinorium as resistant pale grey bands underlying recessive black clastic sediments of the Earn Group and Sylvester allochthon. Lithologies include well-bedded, laminated, dark grey fetid dolostone, thin to thick-bedded micritic limestone, and very fossiliferous wackestone and packstone. Highly fossiliferous exposures, including pelecypod and amphipora-rich beds, occur just east of the Sylvester allochthon near the northern boundary of the Cassiar map area. On the west side of the map area, calcite-healed solution breccias containing angular blocks up to a metre across occur locally. At the base of the McDame Group along the eastern side of the Sylvester allochthon, a breccia zone up to tens of metres thick extends several kilometres along strike. This zone is locally chaotic, with mixed pale grey, buff and dark grey unfossiliferous dolostone and limestone clasts, from millimetres to tens of centimetres across, in a white calcite matrix. It also contains graded breccias to coarse calcite sands. The linear nature and sorted material in this zone suggests that it may be related to a submarine fault scarp or tidal channel. Underlying dolostone of the Tapioca sandstone unit appears to be unbrecciated, but it is not certain whether Tapioca clasts occur in the breccias.

UNIT 7: EARN GROUP (UPPER DEVONIAN – LOWER MISSISSIPIAN)

The Earn Group forms part of several imbricates in a duplex structure on the west limb of the McDame synclinorium, but is poorly exposed on the eastern limb. Contrasting suites of lithologies vary along strike in different thrust panels, suggesting the interaction of north-south facies changes and variable amounts of shortening along different thrusts. The dominant lithology is black, rusty weathering graphitic slate. Coarser clastics are generally absent, but massive, dark grey, medium-grained quartzitic sandstone occurs in places south of the Cassiar mine, and greywacke crops out sporadically in sections near the north edge of the map area. Thick sections of very even, thin to medium-bedded rusty weathering siliceous and baritic exhalites occur in two thrust panels north of the Cassiar mine. These are associated with abundant quartz veins and local pyrite, chalcopyrite and tetrahedrite mineralization. Black slates and mudstones with nodular to lensoidal white barite, and black, pyritic, thin to medium-bedded porcellanite are associated with exhalite-bearing sections. Blue-grey weathering "Gunsteel" slates occur locally in all thrust panels.

SYLVESTER ALLOCHTHON

In the Cassiar map area the Sylvester allochthon occupies a flat-bottomed synclinorium flanked by autochthonous rocks (Figure 1-34-4). The northeastern limb of this structure underlies most of the northwest quarter of the McDame map area (Figure 1-34-5). The Blue Dome fault cuts the

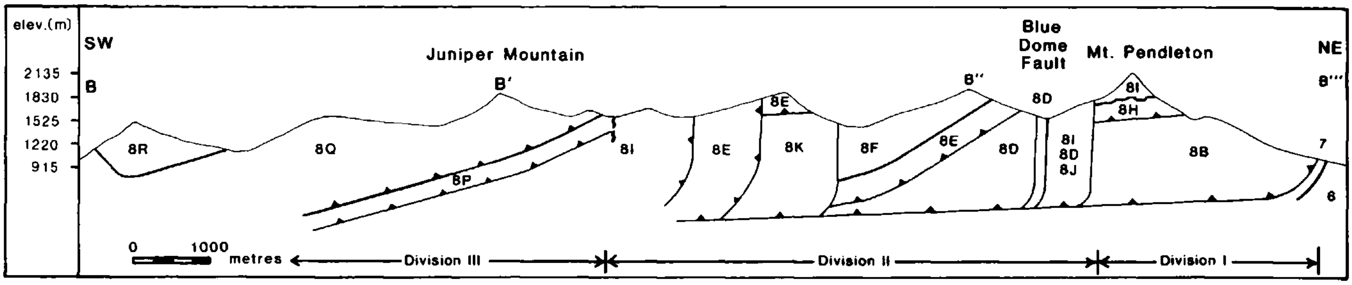


Figure 1-34-5. Cross-section B-B'-B''-B''', McDame map area.

allochthon approximately parallel to its strike (Figures 1-34-2 and 3). This major high-angle fault extends from the western edge of the Blue Dome map area at least to the Dease River (Nelson *et al.*, 1988b).

Exposures in the McDame map area reach higher structural levels in the allochthon than do those in the Cassiar map area. The two cross-sections (Figures 1-34-4 and 5) show that the tripartite structural division developed in the allochthon in the Blue Dome and Midway map areas (Nelson *et al.*, 1988a) is also seen here. The three divisions form consistent structural/lithologic packages extending at least from the Yukon border to the Dease River, a total strike length of 120 kilometres. The following discussion focuses on the three divisions and their component slivers.

Sylvester unit designations include both those appearing on Figures 1-34-2 and 3 and in parentheses, those that appear on Open File maps for example, 8B(IMsi).

DIVISION I

Division I was defined in the Blue Dome and Tootsee Lake map areas as consisting mainly of pelagic and hemipelagic sedimentary sequences (Nelson *et al.*, 1988a). It is structurally the lowest unit in the allochthon, occurring in thrust contact directly above the autochthonous Earn Group. It thickens dramatically to the east, with thicknesses exceeding 500 metres east of the Blue Dome fault. On the western edge of the allochthon, Division I sedimentary slivers are generally less than 50 metres thick and never more than 150 metres. Figure 1-34-4 shows an abrupt thickness transition across the Blue Dome fault.

Mapping in 1988, and conodont data now available for the Blue Dome map area, suggest the presence of two major stratigraphic or pseudostratigraphic map units within Division I, one of Mississippian and one of Late Pennsylvanian(?) to Early Permian age.

Unit 8B(IMsi) consists of black argillite, black and green chert, bedded grey calcarenite which tends to be partly to wholly replaced by black blobby chert, sandstone, siltstone, a few diabase/diorite sills and rare quartz-pyrite-barite bedded exhalites. These lithologic associations occur both in the Blue Dome and Tootsee Lake map areas, for which precisely located conodont ages are now available, and from lithologically identical, so far undated sequences in the Cassiar and McDame map areas. All conodont ages are from the calcarenite. The most complete conodont assemblages are Late Tournaisian (Early Mississippian) age. Two samples give Late Mississipian ages and one an Early to Middle Pennsylvanian age. The sandstones have been discussed elsewhere (Nelson *et al.*, 1988a, 1988b; Nelson and Bradford, 1987). Major clasts include chert, radiolarian chert and protoclastic quartz. Trace minerals – muscovite, tourmaline and zircon – indicate a continental, metamorphic source for the sands. Similarity of ages and lithologies suggests that these rocks are facies equivalents of the autochthonous Earn Group, or black clastic group. We refer to them as "black clastic equivalents", to emphasise this similarity. Black clastic equivalents occur throughout the Slide Mountain terrane (Nelson *et al.*, 1988c).

Unit 8A(IPs) contrasts strongly with Unit 8B(IMsi). It consists mostly of green, red, maroon, grey and tan chert-argillite interlayers. A minor but characteristic component of IPsv is well-bedded chert-chip breccia, consisting of highly angular but well-sorted chert clasts identical to the bedded cherts that make up most of the unit. Graded hedding is a common feature of the chert-chip breccias. Highly vesicular green and maroon basalts form a minor part of Unit 8A west of Gallic Lake on the northern border of the Cassiar map area.

In the Cassiar map area, these two sequences occur in inverted structural order, with Unit 8A(IPs) at the base of the allochthon and Unit 8B(IMsi) in presumed thrust contact above it.

On the west side of the allochthon, Division I consists of thin slivers of Unit 8B(IMsi) and a variety of bedded cherts, including black chert, "salmon-and-green" chert and green chert. In many areas it is entirely absent and basalts of Division II form the base of the allochthon.

DIVISION II

Division II in the Blue Dome and Tootsee Lake map areas was defined as a set of basalt-diabase-sediment packages and ultramafite-gabbro-amphibolite slivers, structurally higher than Division I (Nelson *et al.*, 1988a). An identical structural succession is seen in the Cassiar and McDame map areas. Except in the Blue Dome fault zone, Division II consists of four major lithotectonic units. In ascending structural order, they are:

(1) Cassiar ultramafic-mafic sheet [8L(IICum), 8M(IIP?Cgb)].
(2) A panel consisting of volcanic-sedimentary sequences of Early Mississippian to Early Permian age [8E(IIMs), 8F(IIMvs), 8H(IIMPsi), 8I(IIPvs), 8J(IIb), 8K(IIPsi)].
(3) Zus Mountain ultramafic-mafic sheet [(8N(IIZMum), 8O(IIPZMgb)].

(4) Table Mountain sediments [8P(IITrtms)].

The Blue Dome fault zone, comprising Units 8D and 8G, is a discrete structural entity and will be discussed separately.

Volcanic-sedimentary Sequences

Volcanic-sedimentary sequences form the bulk of Division II and also of the allochthon. They consist of basalt, basalt breccia, tuff and diabase interbedded or intercalated as sills with a variety of sedimentary packages. Variations in the nature and inferred age of the component sediments have been used to define most of the subunits. Original contacts, either depositional or intrusive, are key to the interpretation of these units and their mutual relationships. The absence of such contacts, or their rarity in comparison to tectonic contacts, defines a finely slivered structural style. However, original contacts – for instance interbedded pillow basalt, tuff, and argillite, or diabase sills cutting chert – are very common. On this basis we interpret these units as depositional sequences which, although they may be repeated by thrusts, are largely intact.

Unit 8F is a seqnence in which, basalt, pillow-basalt breccias and tuff are interbedded with black clastic equivalents – black argillite, chert, grey calcarenite in part or wholly replaced by black chert, sandstone, siltstone, chert-pebble conglomerate, and possibly exhalite (the Lang Creek showing, MINFILE 104P 008, in a part of the Needlepoint Mountain map area not included in 1988 mapping). The relative volume of basalt and black clastic sediments varies from 80:20 in the southeast quadrant of the Cassiar map area to 5:95 in some thrust panels in McDame map area. A few purely sedimentary parts of this sequence are large enough to be mapped separately as unit 8E (IIMS). The character of the sediments exactly parallels that of Unit 8B except for the presence of coarser clastic rocks and, in some panels, a much higher percentage of siliciclastics. Sandstone comprises over 80 per cent of the section in one panel northeast of Juniper Mountain. Chert-pebble conglomerate is restricted to Unit 8F on the western side of the allochthon, from Mount McDame south to Table Mountain. Sandstones contain tuffaceous material, and in some cases basalt fragments. Conodont ages from Unit 8F on Mount McDame and Lang Creek are Early Mississippian (M. Orchard, unpublished data). The identity of age and character of these sediments with Unit 8B suggests that the two are facies equivalents representing increasing volcanism to the west. Southwards in the McDame map area, increasing sill volumes in Unit 8B and decreasing volcanic material in Unit 8F blurs the distinction between them. The comparative abundance and coarseness of the siliciclastic rocks in Division II raises the intriguing possibility of a western source terrane.

Unit 8I is a mafic extrusive package interlayered with mainly bedded chert/argillite. Diabase feeder complexes developed in chert and argillite (8H) underlie Unit 8I north of Sphinx Mountain in the Cassiar map area, and on Mount Pendleton in the McDame map area. They are considered to be feeder complexes to the overlying extrusive packages – the basalts, basalt breccias, and aquagene dust tuffs. The cherts and argillites of Unit 8I are generally green and maroon or red, but may also be grey, black and tan. Their colorful aspect associates them with the varicoloured cherts of Unit 8A. The basalts and tuffs are drab green or bright green and maroon. Chert-chip breccias are present locally. Chert clasts in them are mixed with fragments of basalt; the matrix is generally tuffaceous. Coarse volcaniclastic layers are interbedded with basalt, tuff, quartz sandstone and green chert of Unit 8I on Blackfox Mountain and north of Snowy Creek. They contain clasts of local basalt, green and red chert, as well as coarse-grained gabbro, tonalite, trondjhemite and amphibolite. Bedded rhodonite occurrences are common, generally within undated grey, green and black chert below the brightly coloured cherts, but well above the black clastic equivalents. Conodont and radiolarian ages from green and red cherts interbedded with basalts in the Blue Dome and Tootsee Lake map areas are Late Pennsylvanian to Early Permian (M. Orchard, T. Harms, personal communication). Like the 8B-8F correspondence, the parallel age and character of the sediments in Units 8A and 8I suggest that they are two facies within the same basin.

North of Snowy Creek, Unit 8I overlies Unit 8F along 8 kilometres of strike length. The contact between the two is bedding-parallel and mapped as transitional because it lies within basalt and diabase sills. Across it, the argillites, sandstones and limestones of Unit 8F disappear upwards and are replaced first by black chert with scattered bedded rhodonite, and then by the green and maroon cherts and argillites that characterise Unit 8I. No single thrust contact could be outlined, although sheared contacts are seen, as everywhere in the allochthon. The Mississippian-Permian contact is considered depositional. This relationship shows that, at least in part, Permian volcanism succeeded Mississippian and stratigraphies can be constructed which span a major part of the Sylvester age range.

Unit 8K is restricted to the McDame map area. It consists of very well-bedded, uniformly dark grey to black, rarely pink, cherts and argillites, intruded by widely spaced but continuous diorite and diabase sills. The intrusive rocks do not exceed 10 per cent of the section, and extrusive equivalents – basalts and tuffs – were seen only in a single exposure. An Early Permian conodont age was obtained from the cherts by Gordey *et al.* (1982). This package, although equivalent in age to Unit 8I, contrasts strongly with it in the colour of the cherts and the lack of extrusive rocks. The structural proximity of the two units on Blackfox Mountain shows tectonic juxtaposition of apparently unrelated facies. Southwest of Mount Pendleton, Unit 8K structurally and perhaps depositionally overlies Unit 8F.

Unit 8J underlies most of the lowlands near the confluence of Quartzrock and Troutline Creeks. It is defined strictly on lithologic grounds. It consists almost exclusively of massive and pillowed basalt with extremely rare chert intercalations. The basalt is drab green to apple green where altered. In the Snowy Creek area it overlies the varicoloured chert-argillite of Unit 8I; but east of Mount McDame it overlies black argillite, tuff and sandstone of Unit 8F. This sort of disorderly structural succession characterises the tectonic style of the Sylvester allochthon (Harms, 1984); it may in part be due to rapid facies changes in the small rift-generated sub-basins where the volcanic-sedimentary sequences accumulated, as well as to later tectonic slivering.

The Ultramafic-mafic Sheets

Two major ultramafic-mafic sheets occur in Division II in the Cassiar and McDame map areas. They are disparate in character and occupy different structural levels. The lower Cassiar sheet outcrops extensively east of upper Quartzrock Creek. It dips below the volcanic-sedimentary sequences and reappears on the western limb of the synclinorium as the small serpentinite body that hosts the Cassiar asbestos deposit. East of Quartzrock Creek this sheet consists of block to mountain-sized slivers of gabbro, ultramafic cumulates, harzburgite tectonite, basalt and sediments, with serpentinite along tectonic contacts and internal shears. No internal order is apparent. The largest knocker is mapped separately as Unit 8M. This coarse-grained gabbro is commonly layered and includes more felsic differentiates – diorites and quartz gabbros. A zircon uranium-lead analysis is in progress.

The Zus Mountain sheet, including Units 8N and 8O, lies at the centre of the synclinorium in the Cassiar map area. To the north it projects across the Blue River valley into the Blue River ultramafite (Nelson *et al.*, 1988a). To the south, east of Mount McDame, it pinches rapidly to a set of small serpentinites and listwanites that structurally underlie the Triassic Table Mountain sediments (Unit 8P). These listwanites are an important component of the Erickson-Taurus gold-quartz system.

The ultramafic part of the Zus Mountain sheet, Unit 8N, is a fairly intact cumulate body containing abundant screens of harzburgite tectonite. Dunite is the most common cumulate lithology. Chromite grains are scattered within it. In places, for instance the northern slopes of Sphinx Mountain, the dunite contains fine chromite layers. Peridotite layers in the dunite consist of varying amounts of clinopyroxene and orthopyroxene. Because of extensive subsolidus deformation of the body, some of the orthopyroxene-rich layers are indistinguishable in appearance from harzburgite tectonites. The harzburgite tectonites themselves occur as screens a few metres to several hundred metres in areal exposure. They consist of large harzburgite grains, arranged individually or in trains and schleiren in a dunite matrix. Flaser and augen textures visible in hand samples attest to the very strong subsolidus deformation that these rocks have undergone. We follow the interpretations of Nicholas *et al.* (1980) in assigning the harzburgite tectonites to oceanic upper mantle and the cumulates to a magma chamber located near the crust-mantle interface. Here, the cumulates interfinger intimately with the harzburgitic primary mantle. This suggests a complicated geometry for the magma chamber; perhaps the Zus Mountain–Blue River body represents a level near or at its base.

The Zus Mountain gabbro body (Unit 8O) lies structurally above the ultramafite. It is sporadically well layered. It ranges from coarse-grained gabbro to, locally, trondjhemite. A Permian uranium-lead zircon date has been obtained from this body (H. Gabrielse, personal communication, 1987). It represents the upper levels of an oceanic magma chamber, probably the chamber whose base is represented by the Zus Mountain ultramafite.

Table Mountain Sediments

The structurally highest unit in Division II is Unit 8P, the Table Mountain sediments. They occur as klippen in the Cassiar map area southeast of Mount McDame and south of Wing's Canyon, and immediately below Division III in McDame map area. They include lustrous grey to black slate, thin-bedded, well-laminated calcareous siltstone, and grey limestone. Their Late Triassic age is established by a conodont collection from the Plaza pit at the top of Table Mountain (M. Orchard, unpublished data), and by collections of halobia near the Cusac vein (Harms, 1989, this volume). The presence of halobia limestone in this unit suggests that it is a facies variation of the halobia limestone that occurs at the structural top of Division II in the Blue Dome map area (Nelson *et al.*, 1988a), dated as Ladinian to Late Triassic by conodonts and macrofossils. The basal contact of the unit is everywhere sheared. Its structural position above independantly imbricated Late Paleozoic packages hints at an unconformable relationship, although the roof of a duplex involving Division II panels is also located within it.

DIVISION III

In the Blue Dome (104P/12) and Tootsee Lake (104O/16) map areas Division III occupies the highest structural level in the Sylvester allochthon (Nelson and Bradford, 1987; Nelson *et al.*, 1988). There, it is an Early Permian package of mainly intermediate volcanic rocks, shallow-water limestones with chert interbeds, and a zoned hornblende gabbro to granodiorite pluton (Nelson *et al.*, 1988a). This high structural level was eroded from the Cassiar area. South of Table Mountain, in the Huntergroup massif, Division III reappears, structurally overlying the Table Mountain sediments (Harms, 1989, this volume). Its lowest unit is informally termed the Huntergroup volcanics which extend southeastward into the McDame map area around Juniper Mountain (Figure 1-34-3). They are overlain by the limestones, cherts and epiclastic rocks of Unit 8R(IIIPPs). A northeast-trending fault at least partly separates this sequence from a second Division III package, which includes Units 8T(IIIvs) and 8S(IIIP?t).

The Huntergroup volcanics Unit 8Q (IIIPPvs), are equivalent to Unit 4 of Diakow and Pantaleyev (1981) and Unit 2 of Gordey (1982). Gordey collected Early Pennsylvanian conodonts from thin limestone intervals near the base of the sequence. The unit is dominated by augite porphyry flows but also includes polymictic epiclastic and tuff breccias that contain felsic as well as intermediate clasts, hornblande and plagioclase porphyries, crystal and lapilli tuffs and tuffaceous sandstones, and scattered limestone pods. The overall unit is about 1000 metres thick. Its contact with the overlying Unit 8R is certainly depositional, but ranges from abrupt to transitional. At some points the contact involves intercalation of augite porphyries and highly fossiliferous calcareous volcanic sandstones over as much as 100 metres of section. Elsewhere, nearly pure, thick-bedded limestone (Unit 4 of Gordey *et al.*, 1982) directly overlies massive augite porphyry.

Unit 8R – corresponding to Gordey's Units 3 and 4, which are part of a single unit – is a mixed carbonate-chert-epiclastic sequence. Its two end-members are thick-bedded limestone, and polymictic volcanic breccia and sandstone with graded bedding. Intermediate between these are thick to

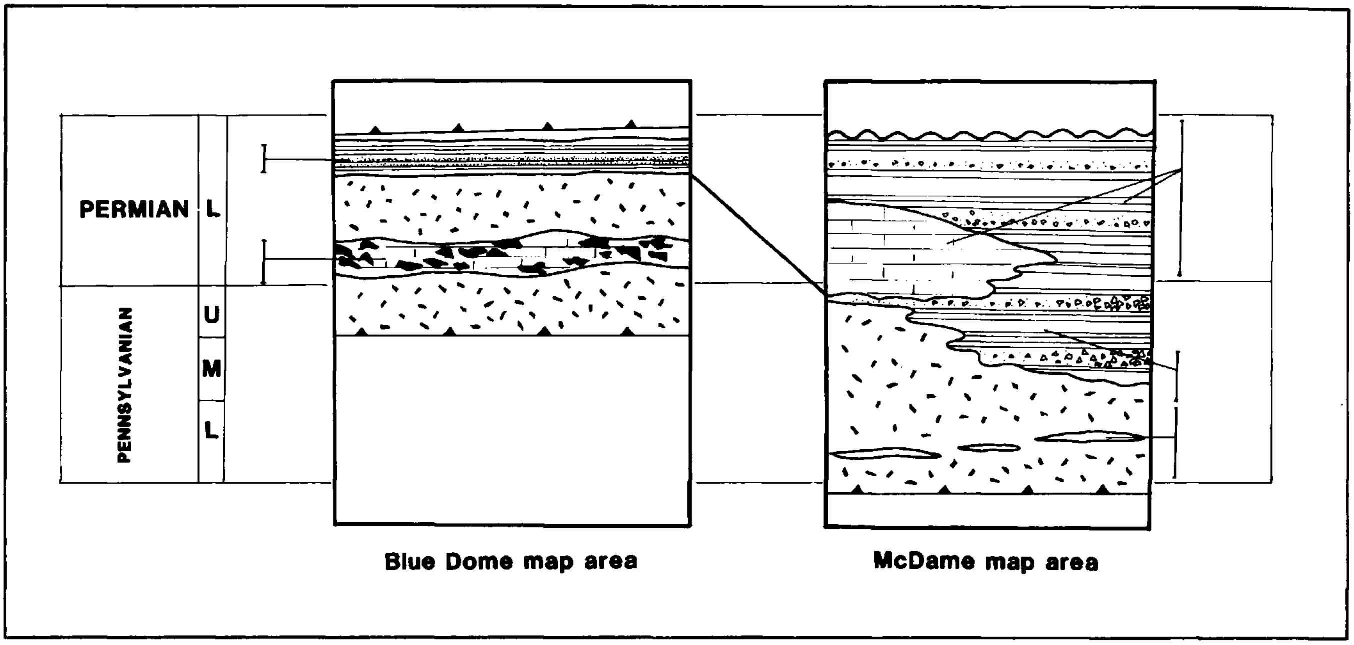


Figure 1-34-6. Comparative partial Division III stratigraphy, McDame and Blue Dome map areas.

medium-bedded limestone breccias that contain a variety of volcanic clasts. The clasts are identical to those in the volcanic breccias. They are red and green, and include basalt, andesite, quartz-phyric dacite, and uncommon intermediate intrusives and quartz sandstone. Augite porphyry clasts are notably absent, except near the base of the sequence. It is likely that the volcanic breccias were derived from contemporaneous bimodal volcanic areas. Green and red cherts are interbedded with the limestones. Gordey obtained Middle Pennsylvanian and Early Permian conodont ages from the unit. Our macrofossil collections include brachiopods, horn corals, crinoids and fusilinids. The richest faunas come from the calcareous tuffaceous sandstones that are interbedded with augite porphyries near the base of the unit.

The Pennsylvanian to Early Permian volcanic-sedimentary succession of Units 8Q and 8R shows a striking resemblance to Division III in the Blue Dome map area (Nelson *et al.* 1988a), although they differ in some details and the Blue Dome package is structurally complex. Figure 1-34-6 compares the two sequences. The augite porphyries in the Blue Dome area are latest Pennsylvanian to Early Permian, somewhat younger than the Huntergroup volcanics. They are structurally succeeded, probably in sheared depositional contact, by Early Permian limestone turbidites and interbedded sea-green chert (Unit IIIG). The limestones contain volcanic clasts, crinoid fragments and horn corals. Unit IIIG is almost certainly a distal equivalent of Unit 8R. It is structurally overlain by more augite porphyries and dacites. This may be a thrust repetition, or the resumption of Huntergroup-type volcanism.

Unit 8T(IIIvs) is separated from the Huntergroup volcanics in part by a northeast-trending fault, and in part by the tonalite body of Unit 8S(IIIP?t). Unit 8T includes Gordey's Units I to III. It contains a variety of volcaniclastic and sedimentary lithologies – thin-bedded green tuff and lapilli tuff, commonly with limestone pods and beds; quartz arenite; thin to medium-bedded limestone, subarkosic sandstone and grit; maroon and green slate; variolitic basalt; chert; argillite; and small diorite bodies. The fine intercalation of these units makes further subdivision impossible at 1:25 000 scale. The unit is so far undated.

Petrographic examination of the sandstones shows that they consist of protoclastic quartz and minor, equally deformed plagioclase; the trace mineral suite includes muscovite, tourmaline and zircon. The sandstones range from quartzites to matrix-supported greywackes with abundant sericite. They lack chert clasts, although their trace mineral suite indicates a metamorphic source like that of the sandstones in Divisions I and II. Quartzite clasts in the limestone breccias of Unit 8R are identical to these sandstones. In spite of the fault relationship between the two, this may indicate early proximity.

The tonalite body, Unit 8S is sheet-like in overall morphology. It is a homogeneous, coarse-grained intrusion consisting of plagioclase, quartz, about 10 per cent potassium feldspar, and chloritized mafic minerals. It contains inclusions and rafts of green tuff with thin limy beds, lithologies typical of Unit 8T. Although the present contact between the two units is sheared, it was probably originally intrusive. Limestones near the intrusion are converted to marble. The contact between the tonalite and the Huntergroup volcanics is strongly sheared and rocks in Unit 8Q adjacent to the tonalite are not hornfelsed. However the geometry of the tonalite suggests that it fills the fault between Units 8Q and 8T. A similar relationship between a Late Permian tonalite and a sliver-bounding fault is found in northeast Cry Lake map area (Harms, 1986). A uranium-lead zircon date for unit 8S(IIIP?t) is in progress by the Geological Survey of Canada.

The Blue Dome Fault and Fault Zone

The Blue Dome fault is a moderately to steeply dipping fault that trends northwesterly and lies, within the limits of present mapping, entirely within the Sylvester allochthon. It extends from the western edge of the Blue Dome map area, across the summit ridge of Blue Dome (Nelson *et al.*, 1988a), into the Cassiar and McDame map areas (Figures 1-34-2 and 3). It may continue through Mount Sylvester south of the Dease River. The fault contains large pods of serpentinite, Unit 8D(IIs). Unit 8G occurs as two elongate slivers next to the Blue Dome fault. These are considered part of the Blue Dome fault zone because of their structural style.

Unit 8D resembles serpentinites in other structural locations within the allochthon; for instance, in general aspect it resembles parts of the Cassiar ultramafic sheet. Blocks of texturally intact ultramafic rocks, gabbro, gabbro mylonite, amphibolite and basalt float within it. However, it also contains blocks and slivers of several types of breccia that do not occur in the Cassiar sheet: shear-brecciated serpentinite, ophicalcite and argillite-matrix polymictic breccias, and polymictic breccias like the "fanglomerates" that occur in the Blue Dome map area near the Blue Dome fault (Nelson *et al.*, 1988a). These breccias show a diversity of textures and clast compositions and may have formed at several different times. The ophicalcites are either monolithologic serpentinite breccias, or serpentinite-basalt-chert, both in a calcareous matrix. In a few occurrences they pass into sedimentary limestone. Similar ophicalcite-limestone associations have been described from dredge hauls of oceanic fracture zones (Lemoine *et al.*, 1987; Bernoulli and Weissert, 1985). We infer that these breccias formed in such a fracture zone, perhaps the precurser of the Blue Dome fault, while the supracrustal parts of Division II accumulated around it. The basement clasts in breccias in Unit 8I are further evidence for early surface exposure of mantle material. Definite interpretation of the ophicalcites awaits conodont ages. The "fanglomerates", on the other hand, contain a variety of clasts, including plagioclase and augite porphyries whose source is presumably the Huntergroup volcanics in Division III. Nelson *et al.* (1988a) argued that, because juxtaposition of Divisions II and III involved the Upper Triassic limestone, these breccias must be of Early Jurassic or younger age.

Unit 8G occurs as two slivers next to the Blue Dome fault (Figure 1-34-2). Its contacts against the Blue Dome fault, and also against other Sylvester units, dip moderately to steeply west. Lithologies in it – basalt, diabase, green, grey and red chert, black argillite and very minor sandstone – are indistinguishable from the volcanic-sedimentary sequences; structural style defines this unit. By contrast with the volcanic-sedimentary sequences, which exhibit an overall structural coherence and stratigraphic integrity, Unit 8G is internally slivered on a 10-metre to 100-metre scale. It is cut by numerous steeply dipping shear zones, with prominent flaser fabrics and gently plunging slickensides that define a dextral sense of motion. They are marked by discontinuous pods of highly sheared serpentinite, serpentinite breccia, ophicalcite, and argillite-matrix mixed-clast breccias including clasts of basalt, serpentinite, chert and gabbro. These faults mimic the Blue Dome fault on a smaller scale. Their trends, about 125 degrees on average, intersect it at a low angle. The presence of ophicalcite suggests an early history (Permian?) for these faults.

The possibility that breccias in the Blue Dome faults and in the sliver-bounding faults in Unit 8G range in age from syndepositional (Permian?) to syntectonic (Jurassic?), coinciding with the emplacement of the allochthon, suggests a long and complex history for this major fault zone. It may have been initiated as a transform fault in the basin where the volcanic-sedimentary sequences accumulated. At present, however, the Blue Dome fault crosscuts Sylvester thrust faults in the Blue Dome map area (Nelson *et al.*, 1988a), implying motion on it after, or at least during, the compressional event that telescoped the allochthon. Its apparent confinement to the Sylvester allochthon suggests that it does not penetrate the Cassiar platform, and thus developed prior to final emplacement. Later movement on the Blue Dome fault may be a result of transpressional tectonics during the assembly and transport of the allochthon towards its eventual resting place on the Cassiar platform. This interpretation follows the model proposed by Hansen (in press).

The Blue Dome fault projects southwards towards Sylvester Peak, and more tentatively along a zone of ultramafites south of the Rapid River in the Cry Lake map area (Gabrielse *et al.*, 1977). Significantly, the southern border of the Sylvester allochthon is not offset by this fault.

Although the magnitude of displacement on the Blue Dome fault is unknown, it is a major, through-going, probably transcurrent fault. Such faults can juxtapose related but differing facies: for instance the Tintina fault separates platformal and slope-basin facies of the North American margin. Facies juxtaposition across the Blue Dome fault may in part explain differences between the higher structural levels in the allochthon. For instance, the Nizi limestone (Gabrielse, 1963) only occurs east of the Blue Dome fault as projected; the Four Mile batholith (Harms, 1986) only to the west.

THE SYLVESTER ALLOCHTHON: SYNTHESIS AND HISTORICAL SUMMARY

Terrigenous sandstones are interbedded with other sediment types and, where present, with volcanic rocks in all three divisions of the Sylvester allochthon in the Cassiar and McDame map areas. This relationship establishes that all of the sandstone-bearing units, (IMs, IIMvs, IIPvs on Blackfox Mountain, IIIvs, and IIIPPs,) accumulated within the reach of turbidity currents from continental sources. Further, rocks that lie in depositional contact with these units – Unit 8I in Cassiar map area, 8I, and 8K – must represent prior or subsequent history of the same crust, not tectonically juxtaposed primary oceanic crust. These observations favour the depiction of the Sylvester allochthon as a strongly telescoped package of marginal basin and island arc elements that developed on the fringes of the ancestral North American continent. The basic geometry of the original Sylvester involved, from east to west, a subsiding sedimentary basin (Division I) that passed westward into a volcanic-sedimentary rift basin (Division II) with locally exposed subcrustal mantle, and furthest west, an arc founded on a rifted continental sliver (Division III). Only Divisions I and II belong to the Slide Mountain terrane as defined by Monger and Berg (1987). Division III, although minute, may merit separate terrane status.

Devono-Mississippian events – Radiolarian ages from the Cry Lake map area range as old as Late Devonian (Harms, 1986). The oldest conodont assemblages in the allochthon are Early Mississippian. Thus the subsidence that initiated accumulation of the supracrustal rocks of Divisions I and II began at the Devonian-Mississippian boundary. Black clastic equivalents, ubiquitous in both Division I and II, link these sequences to the autochthonous black clastic group, which has been tied to rift tectonics in the Selwyn basin and Kechika trough (Gordey *et al.*, 1987). Divisions I and II represent a rift trough that differs from these only in degree: in it, centres of basaltic volcanism developed early, and rifting continued until mid-Permian time. Westward-coarsening of the black clastic equivalents suggests that they sourced to the west, possibly in a thermally-uplifted basement sliver that later would be the foundation of the Huntergroup volcanic arc.

Pennsylvanian – Well-defined Pennsylvanian conodont ages are extremely rare in Divisions I and II, so Pennsylvanian history within them is a cipher. The Huntergroup volcanics may record the inception of the volcanic arc in Division III, which continued to be active through Early Permian time.

Permian – Permian sedimentary accumulations in Divisions I and II show a close resemblance. Both lack the siliciclastic rocks that characterise Mississippian sequences. Both consist mainly of green or colourful red and green cherts and argillites. They contain distinctive bedded chert-chip breccias, which are probably the result of synsedimentary faulting and submarine slumps of lithified material. Interbedded basalts in Division II also tend to be colourful; they provide a likely source for the iron in the ferruginous cherts. The bedded rhodonites record exhalitive activity. The black cherts in Unit 8K are intercalated with minor sills, but contain scanty evidence of extrusive events. They may represent a deep, euxinic sub-basin.

The association of Permian sediments with Mississippian sediments in Division I; and Permian basalts and sediments with Mississippian rocks in Division II suggests that the locus of rifting remained fairly stationary throughout the evolution of the basin. The chert-chip breccias reflect small fault scarps, while the gabbro and amphibolite clasts both in the Blue Dome fault zone and within the basalt-sedimentary sequence reflect the presence of more major structures.

The relationship documented by Harms (1986), in which a 276 ± 6 Ma tonalite seals a thrust fault that juxtaposes Mississippian and mid-Pennsylvanian units, may be indicative of a major tectonic event that affected the Sylvester allochthon as a whole. The youngest radiolarian ages obtained from volcanic-sedimentary sequences in Division II are at the boundary between Early and Middle Permian (Harms 1986 and unpublished data from Tootsee River and Blue Dome map areas); this suggests a cessation of basin development and rifting at this time.

Triassic – The Middle to Late Triassic history of the Sylvester allochthon is recorded solely by the carbonates and siliciclastics of the Table Mountain sediments. A conodont assemblage from this unit strongly resembles Selwyn basin fauna (Orchard, personal communication, 1988). Although its base is strongly sheared everywhere, the fact that it overlies a variety of Mississippian to Permian supracrustal and mantle slices over a minimum strike length of 50 kilometres suggests an unconformable relationsbip, remobilized into a décollement.

Jurassic – Jurassic compressional tectonics stacked the three divisions into their present order along easterly-directed thrusts, with the Table Mountain sedimenrs in their depositional(?) position above Division II. Some of the transcurrent component of relative motion during this event was localized along the Blue Dome fault. The total amount of coastwise translation is unknown. Black clastic equivalents are found in the para-autochthonous Kootenay terrane at least as far south as Barriere (Schiarizza and Preto, 1987); the Sylvester assemblage may have developed outboard of the Eagle Bay assemblage, not the Cassiar Platform. In this, as in all Cordilleran studies, latitudinal pins are problematic.

STRUCTURE

During the Jurassic compressional event, the autochthonous strata of the Cassiar platform in the Cassiar map area formed duplex stacks with multiple repetitions. Décollement surfaces that divide the duplexes are located in the Road River–Kechika Group and in the Earn Group near the base of the Sylvester allochthon. Independant stacking of sub-Kechika; and Road River-Tapioca-McDame-Earn horses is beautifully demonstrated. A set of Rosella-Boya horses outcrops in the mountains in the northeast corner of the map area, east and north of the French River. Atan strata are not repeated west of the allochthon; instead, there are up to three repetitions of Road River–Tapioca–McDame–Earn strata. Both of these are anticlinal stacks; individual frontal ramps are not exposed except for one in the valley 7 kilometres north of Cassiar mine. Here, the Road River–Tapioca contact in the hangingwall appears to dip more gently eastward than the thrust itself; this relationship implies westward vergence.

The formation of anticlinal stacks on either side of the Sylvester allochthon in large part explains its synclinal geometry. In addition, the consistent northeastward dip of the Early Cambrian and Precambrian strata against the Cassiar batholith suggests that the batholith uplifted the stratigraphic pile during its emplacement. The Marker Lake batholith in map areas 105B/6, 7, 10 and 11 created a similar structural dome (Murphy, 1988).

Major post-Jurassic structures in the Cassiar map area are north-northwest to north-trending high-angle faults. The Marble Creek fault extends from the headwaters of Marble Creek to the vicinity of the Cassiar mine. Another fault trends north-northwest from the lowlands west of the Reo showing, through the saddle on the ridge west of the Boomerang vein. These faults parallel the Erickson Creek fault (Boronowski, 1988) on Table Mountain in the Needlepoint map area.

MINERALIZATION

The mineralization of the Cassiar-Erickson camp is the subject of an extensive and still-growing literature. Excellent descriptions of different types of mineralization can be found in Diakow and Pantaleyev (1981), Sketchley, *et al.* (1986), O'Hanley (1988), Cooke and Godwin (1984), and Gower *et* *al.* (1985). In this paper we emphasise systematics and the inter-relationships of the deposit types.

As shown in Table 1-34-1, mineralization in the Cassiar-Erickson camp can be divided into the following categories:

(1) Early Mississippian sedex deposits; minor massive sulphide volcanogenic exhalites; bedded Permian(?) rhodonite.

(2) Early Cretaceous mesothermal gold-quartz and related veins: the Erickson-Taurus system.

(3) Early Cretaceous(?) asbestos stockworks: the Cassiar and McDame mines.

(4) Late Cretaceous and Eocene skarns, replacements and veins associated with the Cassiar and Mount Haskins stocks, respectively.

SYNGENETIC MINERALIZATION

Siliceous and baritic exhalite horizons with associated silver, lead and zinc soil anomalies are widespread in the Earn Group west of the Sylvester allochthon, from the Blue claims in the Blue Dome map area (Nelson *et al.*, 1988a) south to within 7 kilometres of the Cassiar mine (Kuran, 1983). Blind targets may exist in the lowlands between Sphinx Mountain and the Blue River, where outcrop is very poor.

A new silica-barite exhalite was discovered in Unit 8B west of Hot Lake. This is the second occurrence of Mississippian sedex-type mineralization seen in Division I of the Sylvester allochthon. Unit 8F hosts the Lang Creek massive sulphide showing (104P 008) in 104P/4. This occurrence has been interpreted as volcanogenic and stratabound by Panteleyev (1978). It is of early Mississippian age (M. Orchard, unpublished data) and thus contemporaneous with the sedex exhalites of Division I. A small massive sulphide occurrence, chalcopyrite-sphalerite-pyrite-galena, located in the hangingwall of the Cassiar serpentinite on the east wall of the Cassiar pit, apparently parallels bedding in Unit 8F. It may be volcanogenic. Quartz-sericite schist and a diffuse silica-pyrite replacement body occur in Unit 8F in the cirque southeast of Mount McDame. These also bear a volcanogenic stamp: the silica-pyrite body may be a feeder. In general, the contrast of silica-barite-pyrite exhalites in Unit 8B with more sulphide-rich systems in Unit 8F represents a zoning of mineralization types, from sedex to volcanogenic, that matches the facies change from purely sedimentary to volcanic-sedimentary host rocks.

Locally continuous rhodonite beds occur in association with grey to black cherts near the base of Unit 8I. They are commonly impure and contain cherty silica, adularia, siderite, stilpnomelane and an unidentified brittle mica(?). Modern manganese-rich exhalites occur in the Red Sea and the northern Gulf of California. The Sylvester rhodonites may therefore indicate more significant exhalitive systems, perhaps like those that generated the Chu Chua massive sulphide deposit (Schiarizza and Preto, 1987), in equivalent rocks of the southern Slide Mountain terrane.

MESOTHERMAL GOLD: THE ERICKSON-TAURUS SYSTEM

The Erickson-Taurus system comprises a set of east-northeast-trending veins and vein swarms with accompanying strong carbonate alteration, that extends at least from Mount McDame in the north to Juniper Mountain in the southeast, a distance of 23 kilometres. A partial concentric zoning is seen in the area mapped, in that the northernmost veins – Elan, Boomerang and Lyla – and the Ram occurrence near Mount Pendleton southeast of the main showings, contain argentiferous tetrahedrite and little gold, while gold predominates in the central part of the system. Veins occur in the uppermost level of the volcanic-sedimentary package, directly below the Triassic Table Mountain sediments. The base of the sediments acted as a very effective physical and chemical barrier that localized the veins. There are two types of veins (Diakow and Pantaleyev, 1982). Type I veins (Jenny, Taurus) occupy steep fractures in basalts below the base of the sediments, with gold contents increasing toward the contact. Type II veins (Vollaug) follow the base of the sediments. Discontinuous listwanite bodies along this horizon seem to associate with higher gold values in the veins (A. Boronowski, personal communication, 1988). The listwanites, by association and texture, formed from primary serpentinite slivers. Slices of talc schist occur with listwanites above the Lyla and Boomerang trenches. These ultramafic scraps occupy the same structural level as the Zus Mountain body; they may be erosional remnants preserved under the Table Mountain sediments.

The Erickson-Taurus system is strongly elongate in a north-south direction, parallel to the set of late, high-angle faults. These faults terminate veins and are thus considered to be postmineral (M. Ball, personal communication, 1988). This relationship may be the result of their last motion, however. Their close proximity to the vein fractures suggests a genetic relationship. In a similar way, the Marble Creek fault further west intersects the eastern termination of the Magno massive sulphide replacement trend, and passes along the western side of the Cassiar pit. These north-trending faults may provide a structural link between the various modes of mineralization found in the camp.

The orientation of the stress field that gave rise to the Erickson-Taurus structures is problematic. The pattern of easterly vein trends in a overall northerly elongate swarm does not fit the configuration of an *en echelon* fracture set developed during dextral motion on a northwest-trending master fault or faults: according to theoretical and experimental models (for example Wilcox *et al.*, 1973) and field observations (Abbott, 1984), extension fracture sets in such a system should consist of north or north-northeast trending fractures arranged *en echelon* in a northwest-trending array. This, clearly, is not Erickson. Simple compression could generate joints as A-C joints and/or conjugate fractures (Wei, 1982), however, the Erickson-Taurus mineralization, dated at 125 Ma (Sketchley *et al.*, 1986), is much later than the main compressional deformation, and earlier than the tightening caused by emplacement of the 100 Ma Cassiar batholith. Continuing detailed structural studies by M. Ball are aimed at solving this problem.

The heat source for the Erickson-Taurus system has also been unclear, particularly as the mineralization predates the cooling of the Cassiar batholith by 10 to 15 Ma (Sketchley *et al.*, 1987). During 1988 fieldwork, granite inclusions were found in a lamprophyre dyke cutting a carbonate-altered zone north of Snowy Creek. Granite clasts have also been ob-

TABLE 1-34-1. MINERAL OCCURRENCES, 104P/5, 104P/3 (NW ¼)

Type	Names(s)	MINFILE	Economic Minerals	Description
1. Sediment-hosted exhalite	Jan	new showing	barite, chalcopyrite	Fine-grained, pale grey, bedded barite and irregular nodular to lensoidal white barite occur in a sequence of siliceous exhalites with disseminated pyrite and chalcopyrite in black rusty slates and porcellanites. (Earn Group).
2. Volcanogenic	—	new showing	chalcopyrite, sphalerite	On east wall of Cassiar asbestos pit, a small (1 m) lens of finely layered massive chalcopyrite-sphalerite-pyrite is hosted in fine tuffs with interbedded argillite.
3. Mesothermal Au (Ag) quartz veins	a. Taurus	104P 012	gold, tetrahedrite, arsenopyrite	East-trending, moderately to steeply dipping auriferous quartz veins are hosted in massive and pillow basalts. Veins have large carbonate-sericite-clay-pyrite alteration halos and pyrite-tetrahedrite selvages. An easterly trending lamprophyre dyke with granitic xenoliths occurs in the mine area. Production (1988): 4000 tonnes milled, production suspended in March. Reserves (June 1987): 42 600 tonnes, 6.4 g/t Au; 13 600 tonnes, 8.2 g/t Au (Taurus Resources).
	b. Hopefull Mack	104P 011 104P 010	gold, tetrahedrite	East-trending vertical to steeply south-dipping quartz veins in massive and pillow basalts occur in an extensive quartz-carbonate alteration zone. Recent I.P. surveys, trenching and diamond drilling indicate significant potential for open-pit reserves (Taurus Resources).
	c. Wing's Canyon (Red Rock)	104P 015	gold, tetrahedrite	An extensive zone of en echelon quartz veins and carbonate alteration trending 070/60S occurs in massive basalt. A selected sample of oxidized material contained 5.1 g/t Au (MINFILE).
	d. Rich Snow Creek	104P 014	gold, tetrahedrite	Quartz veins to about 80 cm in width with quartz-carbonate alteration halos cut massive basalt. Veins trend 045.
	e. Berube (Bozo)	104P 076	gold, tetrahedrite	En echelon 045-trending quartz veins with quartz-carbonate alteration cut massive and pillow basalt near a contact with underlying chert/argillite.
	f. Snowy Creek	none	gold, tetrahedrite	Intensely faulted and quartz-carbonate-altered basalt is cut by northeast-trending quartz veins and sningers.
	g. Klondike Fr.	104P 013	gold, tetrahedrite	A 2 m wide quartz knot occurs at the contact between strongly folded chert/argillite and overlying basalt or diabase. A sample across 1 m ran 5.47 g/t Au (MINFILE).
	h. Al (Dekalb)	104P 041	gold	Swarms of quartz veins cut very pyritic altered basalt and metasediments next to the Blue Dome fault zone.
	i. Reo (including Blueberry Hill)	104P 009	gold, tetrahedrite	Quartz veins to 5 m wide occur in a northeast-trending zone 180 m wide in basalt. Both 090 and 045 trending veins are present. A grab sample of graphitic quartz contained 1.02 g/t Au and 52 g/t Ag.
	j. Elan	104P 075	tetrahedrite	An easterly trending quartz vein with locally abundant tetrahedrite extends about 4 km in massive basalt. The vein is 1 to 3 m wide, with a strong quartz-carbonate alteration halo.
	k. Lyla Boomerang	new showing tetrahedrite		Tetrahedrite-bearing quartz veins are hosted in basalts immediately below Table Mountain sediments on the ridge north of the Elan vein.
	l. Ram	104P 042	tetrahedrite	An intensely fractured zone in argillite and chert contains tetrahedrite-bearing quartz veins.
4. Polymetallic vein	a. Brx	new showing tetrahedrite	chalcopyrite	Quartz-stockwork zones in black slate and porcellanite, blebs and disseminated pyrite-tetrahedrite-chalcopyrite (Earn Group).
	b. Goldbreak	104P 096	chalcopyrite	Irregular quartz veins up to 25 cm wide in Tapioca sandstone quartzite host disseminated chalcopyrite-pyrite. Twelve samples averaged 5.8 g/t Ag, 0.33% Cu. (MINFILE).
	c. unnamed	new showing azurite	malachite	Quartz veins in McDame Group limestone have selvages of malachite and azurite; about 2 km south of the Cassiar open pit.

TABLE 1-34-1. MINERAL OCCURRENCES, 104P/5, 104P/3 (NW ¼) — *Continued*

Type	Names(s)	MINFILE	Economic Minerals	Description
5. Replacement	a. Contact	104P 004	galena, sphalerite, chalcopyrite, tetrahedrite, molybdenite, dyscrasite, pyrargyrite, bismuthinite	Galena-sphalerite pods have replaced a marble bed in a screen of Hadrynian Stelkuz Formation hornfels. Garnet-diopside(-scapolite?) skarn is developed in marble near the showing. 25 tonnes milled (1956) produced 10 451 grams Ag, 25 kg Cu and 1947 kg Pb.
	b. D Zone including Lower, Middle and Upper zones and Granite Creek	104P 044 104P 080 104P 088	galena, sphalerite	Magnetite-galena-sphalerite pods occur in Rosella Formation marble and dolomite. In the Middle D Zone, 90 000 t grading 3.3% Pb, 6.3% Zn, and 70 g/t Ag have been outlined. A 7.6 m intersection in the Upper D Zone ran 4.73% Pb, 4.74% Zn, 240 g/t Ag, and 0.069 g/t Au. Tin values up to 0.12% have been obtained.
	c. Magno (Marble Creek, Silver Queen)	104P 006	galena, sphalerite	Irregular galena-sphalerite-magnetite-pyrrhotite pods occur along an easterly trending fracture system, about 1 km long, west of the north-trending Marble Creek fault. Drill-indicated reserves for the West, Middle West and East zones total 426 417 tonnes grading 5.92% Pb, 4.15% Zn, 192 g/t Ag (MINFILE).
	d. Mt. Haskin NW (A Zone)	104P 059	sphalerite, galena	Two pyrrhotite-sphalerite-galena-chalcopyrite lenses occur in skarn in the Rosella Formation.
	e. Dalziel	none	sphalerite	A massive pyrrhotite-diopside(?)-sphalerite lens occurs in Rosella Formation marble.
6. Skarn	a. Dead Goat (Balsam)	104P 079	scheelite, chalcopyrite, sphalerite	Massive pyrrhotite with sphalerite, chalcopyrite, scheelite and fluorite occurs as lenses in layered garnet-diopside skarn containing tremolite/actinolite, hosted by Stelkuz metasediments. Drill-indicated reserves include 100 900 tonnes grading 0.49% WO_3 and 27 600 tonnes grading 0.39% WO_3 and 0.16% Cu.
	b. Kuhn	104P 071	scheelite, molybdenite, chalcopyrite, sphalerite	Rosella Formation zebra dolomite and marble is replaced by garnet-diopside skarn with pods and veins of massive magnetite and massive pyrrhotite containing disseminated scheelite, chalcopyrite and molybdenite. Drill indicated and inferred reserves for the Kuhn North zone include 409 300 tonnes grading 0.48% WO_3 and 0.134% MoS_2) and an additional 78 700 tonnes grading 0.50% WO_3.
	c. Lamb Mountain	104P 003	molybdenite, scheelite, chalcopyrite	Rosella Formation marbles are replaced by magnetite-garnet-diopside and retrograde actinolite skarn adjacent to the Lamb Mountain stock. Disseminated scheelite occurs in magnetite skarn and pyrrhotite lenses with abundant molybdenite rosettes in actinolite skarn. Massive pyrrhotite-chalcopyrite pods occur further from the stock.
7. Ultramafite-hosted	a. Cassiar	104P 005	asbestos, jade	A crescent-shaped, moderately east-dipping and south-plunging stockwork of cross-fibre asbestos veins is developed in serpentinites of the Cassiar ultramafic sheet near the basal thrust of the Sylvester allochthon. This body has been mined since 1952.
	b. McDame	104P 084	asbestos	A stockwork of long-fibre asbestos veins is developed in serpentinite of the Cassiar ultramafic sheet, near the base of the Sylvester allochthon. At present, drill-indicated reserves are 16 Mt at 5.6% mill yield.
	c. Zus	104P 002	asbestos	Widely scattered cross-fibre asbestos veinlets occur in serpentinized ultramafic cumulates of the Zus Mountain ultramafic sheet.
	d. Moon	104P 036	asbestos	Chrysotile veins up to 0.6 cm wide cut serpeminite of the Cassiar ultramafic sheet.

served in postmineralization lamprophyres on the Erickson property (M. Ball, personal communication, 1988). These hint at the presence of cryptic intrusive bodies below the system.

ASBESTOS: CASSIAR AND McDAME OREBODIES

Both of the asbestos orebodies are located within a kilometre of each other, within serpentinite of the thin western edge of the Cassiar ultramafic-mafic sheet. The structural matrix of asbestos development was studied in detail by O'Hanley (1988), who concluded that asbestos formation occurred during a change from normal to dextral-reverse motion on the "45-degree shear", a north-trending fault that transects the Cassiar serpentinite. Pre-ore, magnetite-bearing fibre veinlets trend generally northwest, while ore veinlets trend northeast.

Regional mapping indicates that the Cassiar pit occupies a zone of anomalous structure. The Marble Creek fault outcrops in several benches above the main garage northwest of the pit. It juxtaposes bedded black and possibly salmon-and-green chert and argillite to the east, against black graptolitic Road River slate and calcareous slate to the west. Several thin dolomite slivers, located west of, and structurally lower than, the Road River slates, represent a Tapioca sandstone and McDame section that is anomalously thin and discontinuous compared to any other such section in the region. Moreover, the lower adit into the McDame deposit shows a similar lack of a well-developed Tapioca/McDame unit. Normal and/or transcurrent faulting at a low angle to bedding is required to thin the carbonate section to this degree. Further mapping in the vicinity of the mine is required to delineate the structural geometry of the faults around it.

PORPHYRY, SKARN AND CARBONATE-HOSTED SULPHIDE DEPOSITS

Intrusions of both Late Cretaceous and Eocene age have generated mineralized systems ranging from porphyry deposits within the intrusions, outward through skarns to veins and mantos in the surrounding carbonate rocks. The western edge of the Mount Haskins system is exposed east of Hot Lake. The skarns here, including the Mount Haskins A zone (MINFILE 104P 059) were studied by Gower *et al.* (1985). The Goldbreak vein (MINFILE 104P 096) is part of this system, which also shows a lively geochemical signature in stream sediments, with four anomalous samples ranging up to 2.6 ppm silver, 2300 ppm zinc, and 995 ppm lead (RGS 104P).

Late Cretaceous intrusions along the western side of the Cassiar map area have generated a suite of deposits, including porphyries (Lamb Mountain, Storie Moly; 0.5 kilometre south of the map area), skarns (Lamb Mountain, Contact, Kuhn) and silver-lead-zinc replacement deposits (D showings, Magno, Pant showing in 104P/4). The replacement deposits show the interaction of fluid source and flow-path controls. They are all located in Rosella or Stelkuz marbles close to the Cassiar stock; they also lie next to or along the Marble Creek fault. The D showings and the Magno massive sulphides form discontinuous bodies aligned in easterly trends that abut the northerly trending Marble Creek fault. The Pant tin-bearing massive sulphide showing occurs within the extension of the Marble Creek fault south of the Cassiar map area. The matrix of this system – Late Cretaceous intrusion and high-angle fault – is similar to the Midway manto deposit (Bradford and Godwin, 1988), except in this case the intrusion is well exposed and closer to the deposits.

MINERAL POTENTIAL

This paper has emphasised the broad extent of the Erickson-Taurus system. The strong fracture-controlled carbonate alteration and listwanite slivers that characterize it extend, below the base of the Table Moutain sediments, from Mount McDame in the north, through the Taurus and Erickson properties, and southeast past Juniper Mountain into a heavily forested valley that drains into the Dease River. This area is of particular regional interest because it contains the structural level in the Sylvester allochthon defined as favorable for Erickson-type gold-quartz veins, well-developed carbonate alteration and listwanites, but no known vein occurrences.

Although the silver-lead-zinc(-tin) bodies that have been found in the Marble Creek system are individually small, the overall size of the system – 5 kilometres from the Pant to the D showing – is encouraging to further exploration.

Although rhodonite has been known in the Sylvester allochthon (I. Lyn, personal communication), this study has shown bedded rhodonite to be a common occurrence in Unit 8I. It has potential both as a source of artistic material to small-scale craftsmen and as an indicator of exhalitive environments in the Slide Mountain terrane to large-scale metallogenetic modellers.

CONCLUSIONS

The Cassiar and McDame map areas contain a thrust-repeated miogeoclinal succession structurally overlain by the Sylvester allochthon. Fieldwork in 1988 has confirmed that the allochthon consists of: a Late Paleozoic North American marginal basin in Divisions I and II, partly underlain by oceanic crust; and a roughly coeval island arc in Division III. The latter should be excluded from the Slide Mountain terrane. The youngest Sylvester unit, the Middle to Late Triassic Table Mountain sediments, may have an unconformity-turned-décollement at its base.

Patterns of mineralization include Early Cretaceous asbestos and gold-quartz mineralization controlled by north-trending faults, and Late Cretaceous and Eocene porphyry-skarn-replacement systems created by the interaction of intrusions, high-angle faults and Paleozoic carbonates.

ACKNOWLEDGMENTS

Field mapping was aided by the excellent prior work of Gordey *et al.* (1982), Diakow and Pantaleyev (1981, 1982 and unpublished data), Ian Lyn (unpublished compilation), and Chris Bloomer (Assessment Report 9548). Mary Maclean and Louise Maddison co-authored the Open File maps; like the proverbial postman, they delivered in spite of the "summer" of 1988.

Our thanks for thought-provoking discussions go to Tekla Harms, Mike Pope, Alex Boronowski, Matt Ball, Peter Fischer, Roger Tyne, Andre Panteleyev, Dave Lefebure, Don McIntyre, Ron Smyth, Graham Nixon, Chris Ash, Jim Sears and Bill Storie. Grant Overton and Yves Venini marshalled the field assistants and provided TLC for the crew. Claude Marchand of Frontier Helicopters was his usual reliable self under grim flying conditions.

REFERENCES

Abbott, J.G. (1984): Silver-bearing Veins and Replacement Deposits of the Rancheria District, *Department of Indian Affairs and Northern Development*, 1984, Yukon Geology and Exploration 1983, pages 34-44.

Bernoulli, D. and Weissert, H. (1985): Sedimentary Fabrics in Alpine Ophicalcites, South Pennine Arosa Zone, Switzerland, *Geology*, Volume 13, pages 755-758.

Boronowski, A. (1988): Erickson Gold Camp, Cassiar, B.C., NTS 104P/4 and 5, Abstract, in Smithers Exploration Group – *Geological Association of Canada, Cordilleran Section*, Geology and Metallogeny of Northwestern British Columbia Workshop, Program With Abstracts, page A10-A21.

Bradford, J.A. and Godwin, C.I. (1988): Midway Silver-lead-zinc Manto Deposit, Northern British Columbia (104O/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 353-362.

Cooke, B.J. and Godwin C.I. (1984): Geology, Mineral Equilibria, and Isotopic Studies of the McDame Tungsten Skarn Prospect, North-central British Columbia, *Economic Geology*, Volume 79, pages 826-847.

Diakow, L.J. and Panteleyev, A. (1981): Cassiar Gold Deposits, McDame Map-area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1980, Paper 1981-1, pages 55-62.

Gabrielse, H. (1963): McDame Map-area, Cassiar District, British Columbia, *Geological Survey of Canada*, Memoir 319, 138 pages.

Gabrielse, H., Anderson, R.G., Leaming, S.F., Mansy, J.L., Monger, J.W.H., Thorstad, L. and Tipper, H.W. (1977): Geology of Cry Lake (104I) Map-area, *Geological Survey of Canada*, Open File 610.

Gordey, S.P., Abbott, J.G., Tempelman-Kluit, D.J. and Gabrielse, H. (1987): "Antler" Clastics in the Canadian Cordillera, *Geology*, Volume 15, pages 103-107.

Gordey, S.P., Gabrielse, H. and Orchard, M.J. (1982): Stratigraphy and Structure of Sylvester Allochthon, Southwest McDame Map Area, Northern British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 82-1B, pages 101-106.

Gower, S.J., Clark, A.H. and Hodgson, C.J. (1985): Tungsten–molybdenum Skarn and Stockwork Mineralization, Mount Reed–Mount Haskin District, Northern British Columbia, Canada, *Canadian Journal of Earth Sciences*, Volume 22, pages 728-747.

Hansen, V.L. (*in press*): A Working Model for Terrane Accretion and Continental Expansion: Yukon-Tanana and Slide Mountain Terranes, submitted to *Geology*, April, 1988.

Harms, T.A. (1984): Structural Style of the Sylvester Allochthon, Northeastern Cry Lake Map Area, British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 84-1, pages 109-112.

——— (1986): Structural and Tectonic Analysis of the Sylvester Allochthon, Northern British Columbia: Implications for Paleogeography and Accretion, Unpublished Ph.D. Thesis, *The University of Arizona*.

——— (1989): Geology of the Needlepoint Mountain Map Area, Northeast Quarter (104P/4), *B.C. Ministry of Energy, Mines and Petroleum Resources*, This volume.

Kuran, V.M. (1983): Assessment Report on the ELO 2-7 and BRX 3-5 Claims, Liard Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 11151.

Lemoine, M., Tricart, P. and Boillot, G. (1987): Ultramafic and Gabbroic Ocean Floor of the Ligurian Tethys (Alps, Corsica, Appenines): In Search of a Genetic Model, *Geology*, Volume 15, pages 622-5.

Mansy, J.L. and Gabrielse, H. (1978): Stratigraphy, Terminology and Correlation of Upper Proterozoic Rocks in Omineca and Cassiar Mountains, North-central British Columbia, *Geological Survey of Canada*, Paper 77-19.

Monger, J.W. and Berg, C. (1987): Lithotectonic Terrane Map of Western Canada and Southeastern Alaska. *United States Geological Survey*, Miscellaneous Field Studies, Map 1874-B.

Murphy, D.C. (1988): Geology of Gravel Creek (105B/10) and Irvine Lake (105B/11) Map-areas, Southeastern Yukon, *Indian and Northern Affairs Canada*, Yukon Region, Open File 1988-1, 61 pages.

Nelson, J. and Bradford, J. (1987): Geology of the Area Around the Midway Deposit, Northern British Columbia (104O/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 181-192.

Nelson, J., Bradford, J.A., Green, K.C. and Marsden, H. (1988a): Geology and Patterns of Mineralization, Blue Dome Map Area (104P/12), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 233-243.

Nelson, J.L., Harms, T.H., Bradford, J.A., Green, K. and Marsden, H. (1988b): Blue Dome Map Area, 104P/12, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-10.

Nelson, J.L., Ferri, F. and Schiarizza, P. (1988c): Emplacement of the Slide Mountain Terrane: Obduction or Shortening?, (Abstract), *in* Proceedings, *American Geophysical Union*, 35th Annual Meeting, Victoria, B.C., page 6.

Nicholas, A., Boudier, F. and Bouchez, J.L. (1980): Interpretation of Peridotite Structures from Ophiolitic and Oceanic Environments, *American Journal of Science*, Volume 280-A, pages 192-210.

O'Hanley, D.S. (1988): The Origin of Alpine Peridotite-hosted, Cross Fiber, Chrysotile Asbestos Deposits, *Economic Geology,* Volume 83, pages 256-265.

Panteleyev, A. (1978): Cassiar Map Area (104P), *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork, 1977, Paper 1978-1, pages 51-60.

Schiarizza, P. and Preto, V.A. (1987): Geology of the Adams Plateau–Clearwater–Vavenby Area, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1987-2, 88 pages.

Sketchley, D.A., Sinclair, A. and Godwin, C.I. (1986): Early Cretaceous Gold-silver Mineralization in the Sylvester Allochthon, near Cassiar, North-central British Columbia, *Canadian Journal of Earth Sciences,* Volume 23, pages 1455-1458.

Wei, M. (1982): Geology of the Glen Hope Property, Cassiar, B.C., Unpublished B.Sc. Thesis, *The University of British Columbia,* 51 pages.

Wilcox, R.E., Harding, T.P. and Seely, D.R. (1973): Basic Wrench Tectonics, *American Association of Petroleum Geologists Bulletin,* Volume 57, pages 291-313.

GEOLOGY OF THE NORTHEAST NEEDLEPOINT MOUNTAIN AND ERICKSON MINE AREAS, NORTHERN BRITISH COLUMBIA*
(104P/4)

By Tekla A. Harms
Amherst College

KEYWORDS: Regional geology, Needlepoint Mountain, Erickson mine, Sylvester allochthon, veins, structural controls.

INTRODUCTION

As part of a 3-year program of geologic mapping from the Yukon border south through the Midway, Cassiar and Erickson mining camps (Nelson and Bradford, 1987a; 1987b; 1989, this volume; Nelson *et al.* 1988a; 1988b), 1:25 000-scale mapping was conducted in the northeast quarter of the Needlepoint Mountain (104P/4) map area during the 1988 field season (Figure 1-35-1). Since Gabrielse's (1963) original 1:250 000-scale McDame map, excellent but schematic geologic maps by Diakow and Panteleyev (1981), Gordey *et al.* (1982), and Panteleyev and Diakow (1982), have served as the only available detailed maps of this area. Consequently, the objectives of this project are:

- To map the geology of the study area in detail.
- To identify, map, and date significant lithotectonic units within the Sylvester allochthon.
- To examine the structural and stratigraphic setting of the Erickson deposit in the context of the geology and geologic history of the study area.

REGIONAL GEOLOGY

The Sylvester allochthon is a vast, composite klippe of middle to late Paleozoic, to earliest Mesozoic oceanic rocks that rests entirely on top of the Cassiar terrane, which is a northward-displaced fragment of the western North American Paleozoic miogeoclinal continental margin. Lithologies of the Sylvester allochthon are, in part, coeval with but distinctly different in nature from the North American strata against which they are juxtaposed (Harms, 1986). On this basis the Sylvester has been included as part of the Slide Mountain terrane, an accreted suspect terrane (Monger and Berg, 1987).

In the study area, this relationship can be seen on the west side of the base of Needlepoint Mountain (Figure 1-35-2). Cherts and basaltic rocks of the Sylvester allochthon overlie North American carbonate and clastic strata across a planar, layer-parallel basal fault that dips steeply east-northeast. This fault is part of the terrane boundary of the Sylvester allochthon; the basal Sylvester fault has the same planar, layer-parallel character, and is generally gently dipping, under the entire allochthon (Nelson and Bradford, 1987b).

Above and below this boundary, the distinctive assemblages of the North American Cassiar terrane and the Sylvester allochthon are each deformed separately by different characteristic suites of structures. Late Paleozoic North American miogeoclinal strata are telescoped within a duplex structure between roof and sole faults along the basal Sylvester/Earn Group contact and within the top of the Road River/Kechika Group respectively. These structures are interpreted to be the result of shortening associated with emplacement of the Sylvester allochthon (Harms, 1986). At least two panels of McDame and Earn group strata occur within the map area. Exposure is insufficient to unequivocally deter-

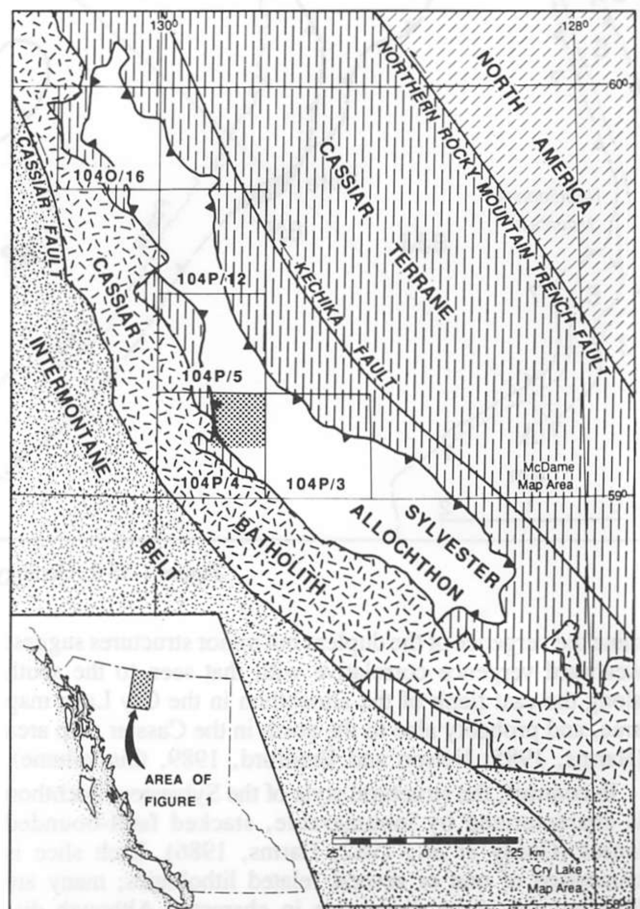


Figure 1-35-1. Location of Needlepoint Mountain (104P/4) map area (shown in stipple).

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

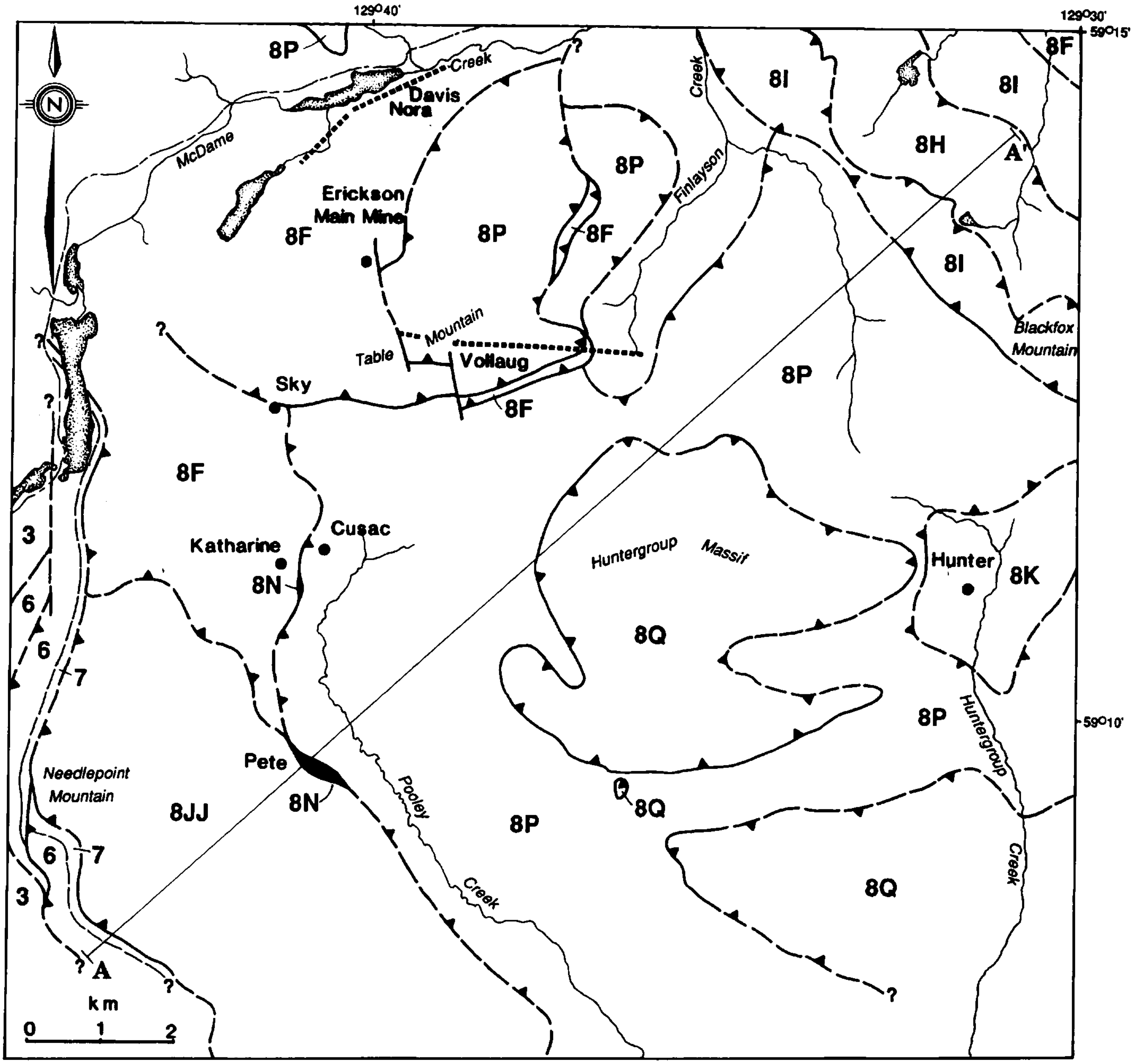


Figure 1-35-2. Geology of 104P/4 NE ¼ map area.

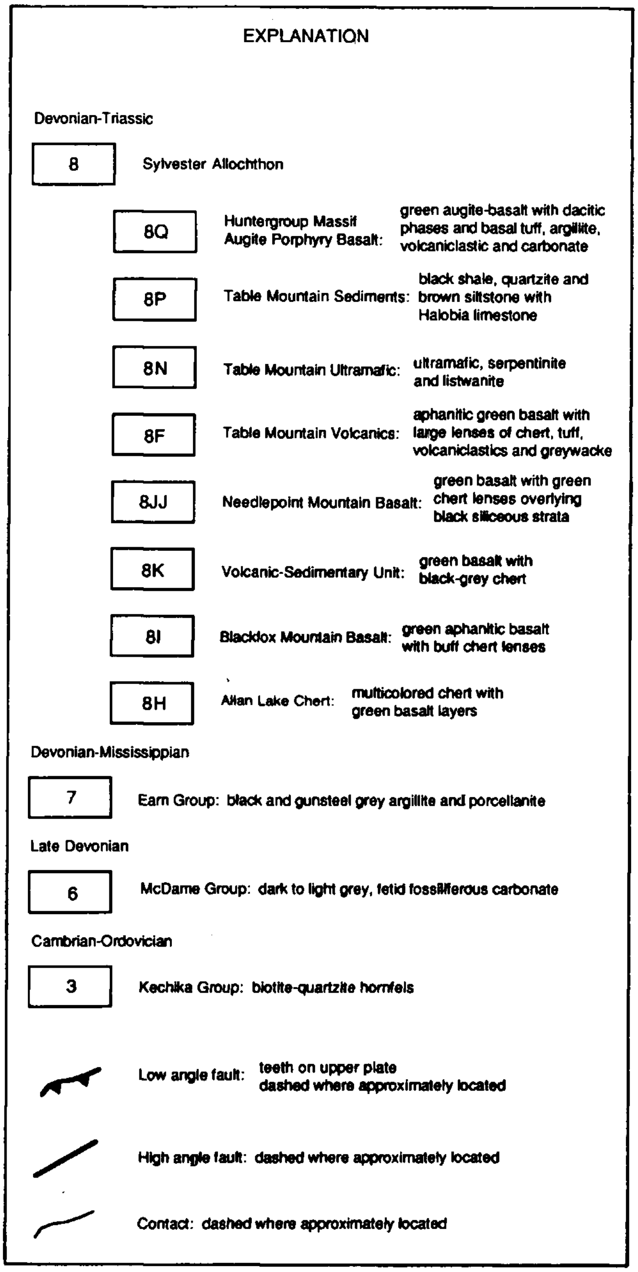
mine the vergence of the duplex, but minor structures suggest westward vergence correlative with that seen to the south along the east flank of the allochthon in the Cry Lake map area, and probably also to the north in the Cassiar map area (Harms, 1985; Nelson and Bradford, 1989, this volume).

In contrast, the structural style of the Sylvester allochthon is characterized by innumerable, stacked fault-bounded lenses (Gordy *et al.*, 1982; Harms, 1986). Each slice is comprised of one or several related lithologies; many are lithologically quite distinctive in character. Although distinctive lithologic suites may be repeated in several discontinuous tectonic slices, most of the fault-bounded lithotectonic units seem geologically unrelated and have coeval but contrasting, or even incompatible, characters and histories. These lithotectonic slices appear to have been derived from a number of different oceanic environments. Telescoping and amalgamation of the various units in the Sylvester happened in part well prior to, and in part coevally with, obduction or accretion of the allochthon.

NEEDLEPOINT MAP AREA

NORTH AMERICAN UNITS

North American miogeoclinal strata are exposed beneath the west side of the Sylvester allochthon along the west edge of the map area. The sequence dips moderately to steeply (up to 60°) northeast below the basal Sylvester fault. The characteristics of the North American units, as they occur in the Needlepoint Mountain area are consistent with the general



descriptions found in Gabrielse (1963). Only the uppermost units of the sequence are exposed within the map area. A high-angle fault along the western edge, extending south from the Cassiar area (Nelson and Bradford, 1989, this volume), may disrupt the North American sequence; the Road River Group and Tapioca sandstone, which elsewhere occur between the Kechika and McDame groups, are missing. The Cassiar batholith lies immediately west of the map area; portions of the North American sequence are metamorphosed by it.

Unit 3: Kechika Group

Rocks which may be part of the Kechika Group crop ont along the Stewart-Cassiar Highway on the western edge of the map area. They are dark, rusty, biotite quartzites, probably the result of contact metamorphism associated with the Cassiar batholith.

Unit 6: McDame Group

Light to dark grey, fetid micritic limestone of the mid-Devonian McDame Group, locally *Amphipora* and *stringocephalus*-bearing, crops out along the western base of Needlepoint Mountain and includes a small area of limestone breccia several metres long. The McDame and the overlying Earn argillites are involved in two thin, thrust-duplex panels below the base of the Sylvester allochthon.

Unit 7: Earn Group

The Devono-Mississippian Earn Group, in this area, consists of black argillite, black porcellanite and gunsteel-grey shale. It is relatively thin (approximately 30 metres), but as the top of the unit is at the basal Sylvester fault, this may be an incomplete section. Nevertheless, regionally, the stratigraphic thickness of the unit is known to increase dramatically northward from the southernmost McDame map area to the northern tip of the Sylvester allochthon (Harms, 1986).

SYLVESTER ALLOCHTHON LITHOTECTONIC UNITS

Unit 8: Sylvester Allochthon

The Sylvester allochthon consists of a varied assemblage of oceanic lithologies: banded radiolarian chert, argillite, carbonate, ultramafite, gabbro, and basic and intermediate volcanics; and probable distal continentally derived lithologies: greywacke and quartz sandstone, and relatively more felsic intrusive rocks. Previous work (Gordey *et al.*, 1982; Harms, unpublished data) has shown these lithologies to occur in every age ranging from Late Devonian through Triassic. Each lithology, either singularly, or within a suite of a few genetically related lithologies, occurs as a fault-bounded lens or slice. These lenses together comprise the large-scale structural and tectonostratigraphic framework of the allochthon (Figure 1-35-3). Because of this distinctive internal character, the lithotectonic slices themselves constitute the most accurate and descriptive map unit for the Sylvester and have been used as such in this report. Consequently, contacts between all Sylvester map units in this area are faults.

Wherever possible by direct correlation, units of the Sylvester allochthon in this report have been named in conformity with informal names used by Nelson and Bradford (1989, this volume). However, Divisions I, II and III of Nelson *et al.* (1988a), are not distinguished in this study area; accordingly those designations do not appear in unit symbols. Microfossil dating is in progress on samples collected from most of the units of this map area. Therefore, unless a unit age is known from previous work, the designation "PzTr" is temporarily assigned based on the known age range of the allochthon.

Unit 8Q (lIPHapb): Huntergroup Massif augite-porphyry basalt. The Huntergroup Massif in this map area, together with the Juniper Mountain region to the east, is underlain by an extensive, distinctive volcanic suite. This volcanic unit corresponds to Unit 2 of Gordey *et al.* (1982), and Unit 4 of Diakow and Panteleyev (1981). The unit

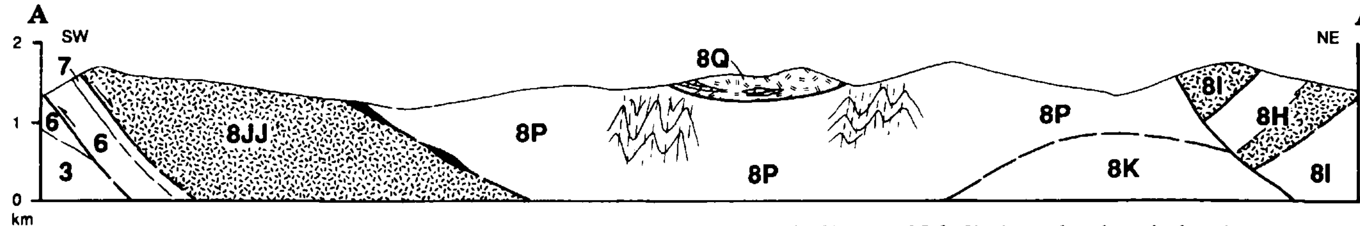


Figure 1-35-3. Cross-section across the study area. Line of section shown in Figure 1-35-2. Horizontal and vertical scale equal.

consists largely of homogeneous augite-porphyry basalt with an aphanitic sea-green groundmass. Small (1 to 2 millimetres or less) subhedral to round, black augite phenocrysts constitute up to 10 per cent of the rock. Locally abundant pale green plagioclase phenocrysts also occur. The unit becomes much more heterogeneous at its base, where it may include coarse volcaniclastic breccia, interbedded green tuff and black siliceous argillite, and minor medium-grained andesitic to dacitic intrusive phases. Black argillite at the base of the unit is, in places, faulted against black shales at the top of Unit 8P, the Table Mountain sedimentary unit. Unit 8Q sediments are distinguished by their siliceous character, lack of uniform bedding or slaty cleavage, and the presence of interbedded tuff. The base of the Huntergroup Massif volcanic suite is also characterized by a band of discontinuous, large (up to hundreds of metres in length) carbonate pods approximately 10 metres thick. The distribution of the carbonate suggests they are primary reefs and interflow deposits. However, the carbonate is commonly pervasively recrystallized, and only rare crinoid stems are preserved. Gordey *et al.* (1982), recovered Early Pennsylvanian conodonts from one of these carbonate lenses. On this basis the volcanic suite is considered Pennsylvanian in age. The Huntergroup volcanic unit is at least 600 metres thick.

Unit 8P (TrTMs): Table Mountain sedimentary unit. The Table Mountain sedimentary unit is remarkably uniform over its significant outcrop area. It consists of homogeneous black shale with thin, brown, commonly carbonaceous siltite horizons, and minor massive black, fine-grained quartzite beds. It is distinguished by a pervasive, well-developed slaty cleavage that parallels bedding. Bedding and cleavage are commonly steeply dipping to vertical as they have been folded on the outcrop scale and/or finely crenulated by a second phase of deformation. Weakly developed axial planar cleavage locally accompanies second phase folds. This folding is disharmonious with, and truncated by, the subhorizontal tectonic base of overlying units. Outside the map area (Nelson and Bradford, 1989, this volume) the Table Mountain sedimentary unit includes rare carbonate interbeds; these were not observed in exposures in this study area. However, a distinctive *Halobia*(?)-bearing carbonate occurs locally at the base of the unit on the south side of Table Mountain. Unit 8P corresponds to Unit 1 of Gordey *et al.* (1982) and Unit 3 of Diakow and Panteleyev (1981).

Unit 8N (TMum): Table Mountain ultramafic unit. This unit includes serpentinite, listwanite, ultramafic and altered ultramafic rocks which occur in small (most too small to be mapped) discontinuous lenses that decorate the fault surface at the tectonic base of the Table Mountain sedimentary unit (Unit 8P). Listwanite in this unit commonly shows relict ultramafic texture that suggests it is the result of pervasive alteration of serpentinite and ultramafic bodies. Unit 8N listwanites host the higher concentrations of mineralization in the Erickson deposit.

Unit 8F (PzTrTMvs): Table Mountain volcanic-sedimentary unit. Aphanitic green basalt volumetrically dominates this unit. However, large lenses of various sedimentary rocks, which are either inclusions or interlayers, occur within the basalt. The sedimentary members include green and black chert, siliceous argillite, coarse volcaniclastic rocks and poorly sorted greywacke. Black siliceous argillite, volcaniclastics and greywacke of Unit 8F occur along the crest of Table Mountain, in direct juxtaposition with overlying Unit 8P, the Table Mountain sedimentary unit. Unit 8F sediments can be distinguished by the lack of slaty cleavage and siliceous nature of the argillite, and by the poor compositional sorting of the coarser clastics; characteristics which are not true of the consistently homogeneous Table Mountain sedimentary unit. Whether the several sedimentary lithologies which occur within the basalts of Unit 8F represent one coherent stratigraphic sequence may be determined from microfossil dating in progress.

Unit 8F volcanic-sedimentary rocks and structurally overlying Unit 8P sedimentary strata, with discontinuous ultramafic pods between, make up the tectonically layered, subhorizontal sequence which underlies Table Mountain. This sequence has been thrust over itself along a shallow to moderately north-northwest-dipping fault which nearly circumscribes Table Mountain. The interaction of these two fault surfaces produces the complex outcrop pattern of the two lithotectonic units.

Unit 8JJ (PzTrNMb): Needlepoint Mountain basalt unit. The Needlepoint Mountain basalt unit is largely composed of aphanitic green basalt with ubiquitous chlorite stringers. Locally it includes small (less than 50 metres in length) lenses of recrystallized white to grey bedded chert, which appear to be large country rock inclusions in the igneous body. Southwest of Needlepoint Mountain the basalts are intimately intruded by fine to medium-grained gabbro or diorite bodies which gradually become the dominant lithology through the southern half of the unit. On Needlepoint Mountain, the basalt rises steeply to the east, forming the 60° dip-slope of the east flank of the castellated peak. The west side of the peak is underlain by an east-tapering wedge of sedimentary strata that is approximately 150 metres thick at its thickest, and consists of bedded black siliceous argillite with minor interbedded grey siltstone and carbonate. The contact between these sediments and the overlying basalt is demonstrably intrusive, albeit nearly planar. The sediments are included in Unit 8JJ for this rea-

TABLE 1-35-1
MINERAL OCCURRENCES, NEEDLEPOINT MOUNTAIN, NE

Type	Name(s)	MINFILE Number	Economic Minerals	Description
Mesothermal Au (-Ag)	(a) Erickson (Jennie, Maura)	104P 029	gold, tetrahedrite	Steeply dipping multiphase quartz veins in sheared basalts contain free gold and gold disseminated within pyrite and tetrahedrite. Total production from Erickson, Vollaug and Cusac veins since production began in 1978 has been 490 000 tonnes grading 15.6 g/t Au and 11.3 g/t Ag (Boronowski, 1988).
	(b) Vollaug	104P 019	gold, tetrahedrite	An easterly striking ribbon-quartz vein dips 30° along the contact between footwall listwanites and overlying Triassic sediments. A strike length of 2.7 metres is exposed. About 107 000 tonnes grading 10.5 g/t Au have been mined (Boronowski, 1988).
	(c) Cusac (Eileen, Katherine)	104P 070	gold, tetrahedrite	A quartz vein trending 060-070/60N has been mined along a strike length of 300 metres. Mineralization occurs in listwanite zones bounding the upper contact of basalt-sediment sequences. Gold grades average 30 g/t (MINFILE).
	(d) Sky	104P 078	gold, tetrahedrite	A quartz vein 4 metres wide lies along an east-trending fault dipping 75N. Listwanite occurs along the hangingwall between the vein and Triassic sediments. Erratic gold assays up to 36 g/t have been reported (MINFILE).
	(e) Pete	104P 025	gold, tetrahedrite	East to northeast-trending quartz veins up to 1.8 metres wide carry tetrahedrite and minor gold.
	(f) Hunter	104P 034	gold, tetrahedrite	A wide north-trending shear zone contains northeasterly trending quartz veins up to 1 metre wide. Erratic gold values up to 6.9 g/t have been reported (MINFILE).
	(g) Rocky Ridge Gold Hill Nora	104P 016 104P 017 104P 018	gold, tetrahedrite	A zone with quartz veins trending 040-050 and 070 can be traced for 2.5 kilometres. Erratic gold assays up to 35 g/t over 0.6 metre have been reported (MINFILE).

son. Needlepoint Mountain basalts are overlain by Unit 8P along a largely concealed east-dipping fault contact in the Pooley Creek drainage.

Unit 8I (PzTrBMb): Blackfox Mountain basalt unit. The crest of the easternmost ridge of Blackfox Mountain is underlain by Unit 8I. Within the study area, Unit 8I is a green aphanitic basalt with minor phaneritic, fine-grained gabbroic phases. It includes numerous, small (approximately 30 metres in length) lenses of strongly recrystallized, honey-coloured bedded chert as rafts within the basalt. Elsewhere (Nelson and Bradford, 1989, this volume), Unit 8I has more variable characteristics.

Units 8F, 8JJ and 8I together comprise most of Unit ii of Gordey *et al.* (1982). In the course of this work the three units have been separated firstly on the basis of differences in included sedimentary lithologies, and secondly on the basis of differences in structural setting. In contrast to Gordey *et al.*, in this study the Table Mountain sedimentary unit (8P) is mapped as overlying Blackfox Mountain basalt (Unit 8I) along a moderately to steeply east-dipping fault.

Unit 8H (PzTrch): Allan Lake chert unit. A well-bedded, multicoloured chert sequence, including green, white, black and brick-red cherts occurs in the northeast corner of the study area, along the ridge south of Allan Lake, and continues onto Blackfox Mountain. This distinctive chert package has been mapped as Units 8H and 8A by Nelson and Bradford. The Allan Lake chert unit includes layers of green fine-grained basalt at its base and so is here correlated with Unit 8H. Unit 8H is overlain by Unit 8I basalts across a west-dipping fault that roughly parallels bedding in the cherts.

Although there is no outcrop, Units 8I and 8F are shown as repeated below Unit 8H cherts across the extreme northeast corner of this map area. They have been extrapolated from along-strike exposures mapped by Nelson and Bradford in immediately adjacent areas.

Unit 8K (PzTrsi): Unit 8K occurs in a tectonic window through Unit 8P in the headwaters of Huntergroup Creek. There, it is a massive, green aphanitic volcanic suite including minor amounts of black to grey chert. The chert is moderately recrystallized and displays only relict bedding.

STRUCTURE

A network of slice-bounding faults within the Sylvester allochthon is the main set of structures in the study area. The nested, low-angle, layer-parallel nature of these structures is consistent with that in the Sylvester allochthon regionally. Together they constitute a very large-scale structural fabric. Additionally, within and around the study area, other structure sets are superimposed on this fundamental pattern. Several through-going, steep north to north-northwest-trending faults have been mapped immediately north of this study area, in the Cassiar map area (Nelson and Bradford, 1989, this volume). One of them, the Marble Creek fault, may continue south along the extreme western border of 104P/4, and may truncate the North American section mapped there (Gabrielse, 1963). Closely spaced sets of northeast-trending fractures with negligible offset occur in several places within the map area. The southeast flank of Needlepoint Mountain is cut by these fractures as is Table Mountain, where the set is associated with alteration and mineralization in the Erickson system. Mineralized veins and fractures in the Erickson mine are also cut by north-trending faults with minor offsets, most too small to be mapped at the scale used in this study (M. Ball, personal communication, 1988). These faults may be related to the large north to north-northwest-trending faults, like the Marble Creek fault, that occur in the surrounding region.

MINERALIZATION

The Erickson mineralized system is described in Nelson and Bradford (1989, this volume). Table 1-35-1 shows the veins of this system in 104P/4 NE ¼. Total production to date from the Erickson, Cusac and Vollaug veins has been about 490 000 tonnes grading about 15.6 grams per tonne gold and 11.3 grams per tonne silver (Boronowski, 1988). Erickson mineralization can be placed in the context of the pattern of the structures described above. The mineralization is localized at the base of Unit 8P, the Table Mountain sedimentary unit, which appears to have acted as an effective barrier to migration of fluid due to its inability to sustain fractures. Mineralization is further concentrated along the base of the sedimentary unit in listwanite bodies that are the altered equivalents of ultramafic lenses of Unit 8N. Veins either parallel the basal contact of Unit 8P, or are developed in the east-northeast-trending fracture system that abuts the basal contact. These veins suffer minor offset along the north-trending fracture system.

In this way, important structural controls on the Erickson mineralization system stem from both Sylvester allochthon structural patterns, and from younger sets of structures superimposed on the Sylvester. The advantageous juxtaposition of host lithologies and subhorizontal tectonic layering result from processes inherent to the Sylvester allochthon. Younger (126 Ma, Sketchley *et al.*, 1986), fracture sets controlled circulation of mineralizing fluids within the allochthon.

SUMMARY AND CONCLUSIONS

Fieldwork in 1988 has shown that North American miogeoclinal strata and Sylvester allochthon lithotectonic units in the northeast Needlepoint Mountain map area are consistent with the regional character of those assemblages. Devono-Mississippian carbonate and clastic strata at the top of the miogeoclinal sequence occur in at least two, probably west-vergent, duplex panels below the basal Sylvester fault. The Sylvester assemblage includes fine-grained clastic (8P), dominantly chert (8H), ultramafite (8N), intermediate volcanic (8Q) and several basalt-sedimentary (8F, 8JJ and 8I) lithotectonic units in a nested stack of fault-bounded slices. Superimposed on this Sylvester framework is a set of mineralized northeast-trending fractures and a set of minor and locally through-going north-trending faults. The Erickson mineralization appears to be controlled by both the large-scale distribution of Sylvester lithotectonic units and subhorizontal structures, and localized, crosscutting steep structures.

ACKNOWLEDGMENTS

The author would like to acknowledge the generous and essential co-operation of the staff of Total Erickson Gold Mines Ltd.; Jim Lehtinen, Matt Ball and Marthe Archambault were extremely helpful, as was Peter Fischer. Juliet Crider's enthusiastic and able assistance in the field is also gratefully acknowledged.

REFERENCES

Boronowski, A. (1988): Erickson Gold Camp, Cassiar, British Columbia (104P/4, 5), *in* Geology and Metallurgy of Northwestern British Columbia, Workshop, *Geological Association of Canada - Smithers Exploration Group*, Program with Abstracts, pages A10-A21.

Diakow, L.J. and Panteleyev, A. (1981): Cassiar Gold Deposits, McDame Map-area (104P/4, 5), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1980, Paper 1981-1, pages 55-62.

Gabrielse, H. (1963): McDame Map Area, British Columbia, *Geological Survey of Canada*, Memoir 319, 138 pages.

Gordey, S.P., Gabrielse, H. and Orchard, M.J. (1982): Stratigraphy and Structure of Sylvester Allochthon, Southwest McDame Map Area, Northern British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 82-1B, pages 101-106.

Harms, T.A. (1985): Cross-sections through Sylvester Allochthon and underlying Cassiar Platform, Northern British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 85-1B, pages 341-346.

——— (1986): Structural and Tectonic Analysis of the Sylvester Allochthon, Northern British Columbia: Implications for Paleogeography and Accretion, Unpublished Ph.D. Thesis, *University of Arizona*, 80 pages.

Monger, J.W.H. and Berg, H.C. (1987): Lithotectonic Terrane Map of Western Canada and Southeastern Alaska, *United States Geological Survey* Map MF-1874-B.

Nelson, J. and Bradford, J. (1987a): Geology of the Area around the Midway Deposit, Northern British Columbia (104O/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 181-192.

——— (1987b): Geology of the Midway Area, Northern British Columbia (104O/16), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-5.

——— (1989): Geology and Mineral Deposits of the Cassiar and McDame Map Areas, British Columbia (104P/3, 5), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This Volume.

Nelson, J., Bradford, J.A., Green, K.C. and Marsden, H. (1988a): Geology and Patterns of Mineralization, Blue Dome Map Area, Cassiar District (104P/12), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 233-243.

Nelson, J., Bradford, J., Harms, T., Green, K. and Marsden, H. (1988b): Geology and Mineral Occurrences of Blue Dome Map Area (104P/12), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-10.

Panteleyev, A. and Diakow, L.J. (1982): Cassiar Gold Deposits, McDame Map Area (104P/4, 5), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1981, Paper 1982-1, pages 156-161.

Sketchley, D.A., Sinclair, A.J. and Godwin, C.I. (1986): Early Cretaceous Gold-silver Mineralization in the Sylvester Allochthon, near Cassiar, North-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, pages 1455-1458.

NOTES

STRUCTURE AND METAMORPHISM IN THE HORSERANCH RANGE, NORTH-CENTRAL BRITISH COLUMBIA (104P/2,7,10)

H.E. Plint and P. Erdmer
University of Alberta, Edmonton

KEYWORDS: Regional geology, Horseranch Range, Cassiar terrane, Ingenika Group, schist complex, structural geology, metamorphism.

INTRODUCTION

Detailed geological mapping of a Proterozoic and/or Cambrian high-grade schist complex in the Horseranch Range of north-central British Columbia was initiated to investigate its structure and metamorphic history, and to contribute to the understanding of basement tectonics in the northern Cordillera. This report presents the results of the second season of a 2-year field study. Several questions raised by the first field season's work (Plint and Erdmer, 1988) are addressed.

LOCATION AND ACCESS

The area is located in the Cassiar Mountains, approximately 65 kilometres southeast of Watson Lake, Yukon Territory (Figure 1-36-1), and is covered by NTS map sheets 104P/2, 104P/7 and 104P/10. Mapping was conducted during June and July, 1988 from fly camps positioned and supplied by helicopter from Watson Lake.

REGIONAL SETTING AND PREVIOUS WORK

The Horseranch Range lies within the Cassiar terrane (Monger and Berg, 1984), which comprises Upper Proterozoic and Paleozoic miogeoclinal and platformal strata that were displaced northwards by several hundred kilometres along the Tintina–Northern Rocky Mountain Trench fault system (Gabrielse, 1985).

Gabrielse (1963) documented the major rock types and the structure of the Horseranch Range, and correlated its geology with the Upper Proterozoic Windermere Supergroup and the Lower to Middle Paleozoic Atan, Kechika, Sylvester and Sandpile groups. The range is underlain by a thick sequence of metasedimentary schists, by orthogneiss, and by post-tectonic ultramafic, mafic, and felsic intrusions (Gabrielse, 1963; Plint and Erdmer, 1988). Proterozoic uranium-lead ages (2.2 Ga) for detrital zircon indicate that the schists have a Proterozoic provenance (Erdmer and Baadsgaard, 1987). The dominant structure of the range is that of a northerly trending, doubly plunging anticlinorium bounded to the east and west by the Horseranch and Deadwood faults respectively. At least 2 kilometres of vertical uplift is postulated along these faults (Gabrielse, 1985).

The central schist complex consists of interlayered pelitic to psammitic schist, quartzite, marble and minor amphibolite, intruded by granitic and mafic to ultramafic rocks. The eastern contact of the schist complex is drift-covered; to the west, the schists are separated from low-grade homogeneous quartzite by a moderately west-dipping mylonite zone. Kinematic indicators in the mylonite zone indicate top-down-to-the-northwest movement, suggesting the mylonite is related to tectonic denudation. Chloritic phyllite, overlain by unmetamorphosed dolomitic limestone, overlies quartzite at the western margin of the Horseranch Range. The Horseranch fault (Gabrielse, 1963, 1985) separates the dolomitic limestone from rocks to the east.

Three fold phases have been identified in the map area: F_1 tight to isoclinal folds, commonly defined by quartz veins, with axial surfaces parallel to the schistosity in the schist complex; F_2 passive folds in the mylonite which deform mylonitic layering; and F_3 upright to steeply inclined, gently northwesterly or southeasterly plunging folds which refold F_1 and F_2 folds and are congruent with the overall antiformal structure of the Horseranch Range. In addition, tight to isoclinal, horizontal folds occur in fine-grained calcareous layers in the phyllite. These folds are northwesterly trending with moderately southwesterly dipping axial surfaces and are cut by an axial planar cleavage. This cleavage is deformed by west-southwesterly trending, gently westerly plunging kinks and chevron folds. Fine crenulation lineations, mineral stretching lineations defined by quartz and feldspar and locally by hornblende, and fine rodding in quartz veins and quartzites in the schist complex are parallel to the hinge lines of F_3 folds. Rodding and stretching lineations in the mylonite are parallel to those in the schist complex (Plint and Erdmer, 1988).

ROCK UNITS

No new rock types have been identified in the southern part of the schist complex. Staurolite is common in the southwestern and northern parts of the range, and kyanite is present in at least one outcrop on its eastern flank (Figure 1-36-1).

A tan-weathering, biotite-bearing, grey to white marble is exposed at the north end of the range, structurally overlying the schist complex. Resistant siliceous layers 1 to 5 centimetres thick are commonly parallel to a biotite-defined foliation. Minor white quartzite and mica schist are locally interlayered with the marble. Structurally overlying the marble is a muscovite-chlorite-garnet schist, locally containing layers of hornblende-garnet calc-silicate schist, two-mica

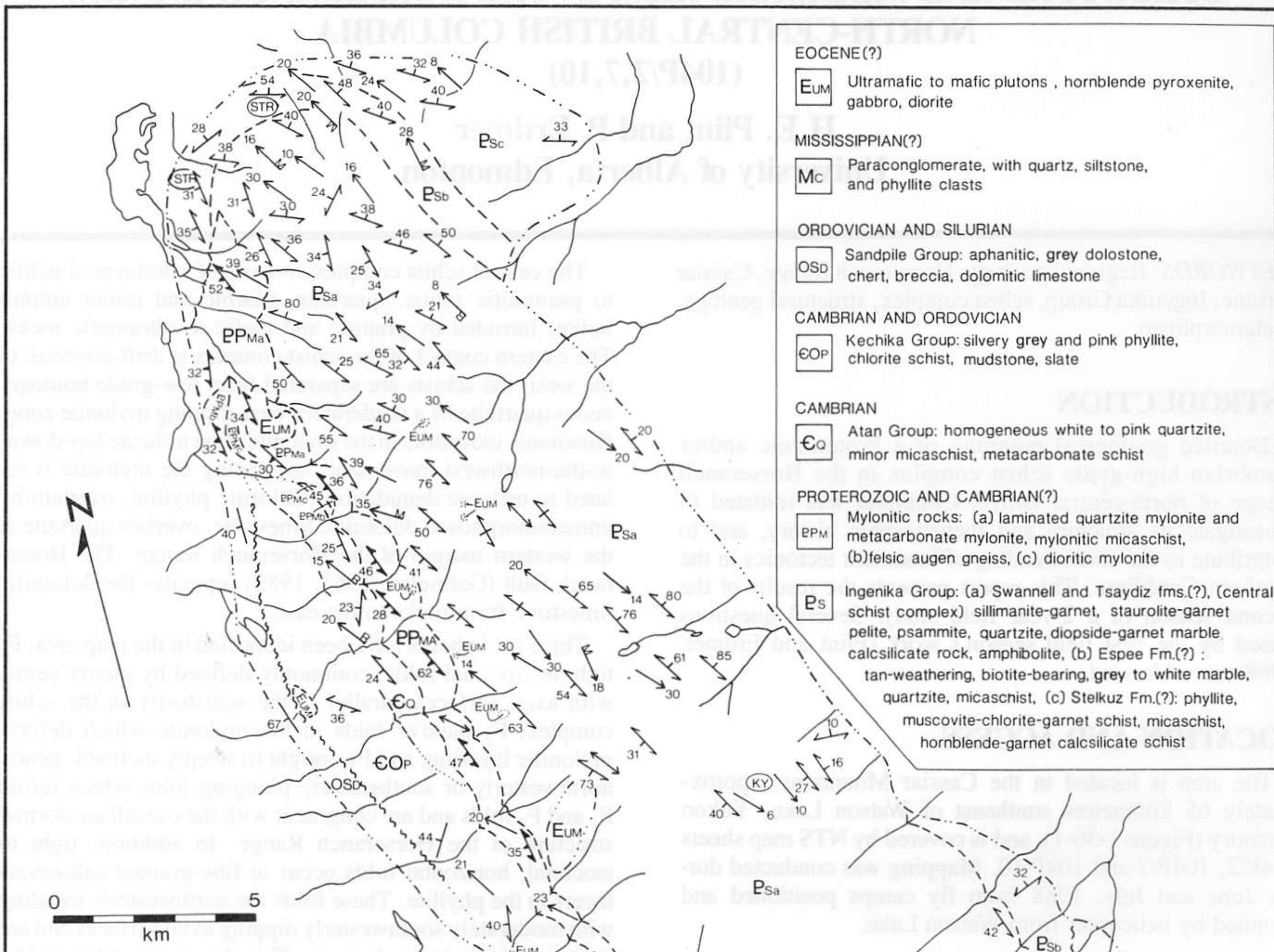


Figure 1-36-1: Geology of the Horseranch Range. Inset shows index map and regional geology.

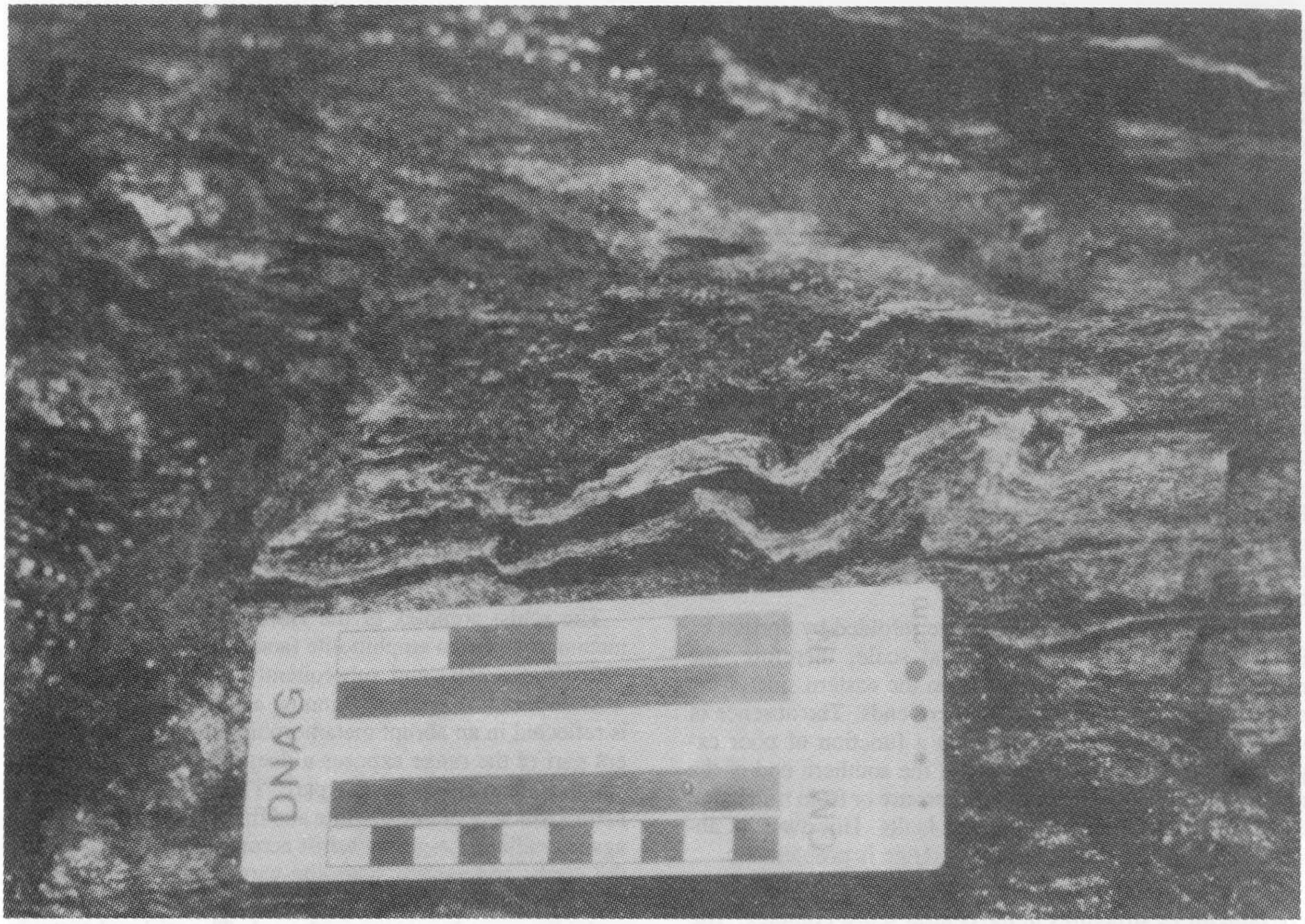


Plate 1-36-1: Isoclinal F_2 fold in mylonitic metacarbonate schist deforms the mylonitic foliation and is refolded by tight, F_3 folds.

semipelitic to psammitic schist, grey to white quartzite, and grey marble 1 to 5 metres thick. Along the northwestern side of the range, these units are deformed in a mylonite zone and are more highly metamorphosed.

The "phyllite unit" (Plint and Erdmer, 1988) is expanded here to include silvery grey calcareous phyllite, pink to white siliceous phyllite, silvery green-grey chloritic phyllite, chloritic schist, grey, locally fossiliferous mudstone, and calcareous black slate. Minor paraconglomerate containing clasts of quartz, phyllite and siltstone exposed west of the phyllite may be of Mississippian age (Gabrielse, 1963).

Along the west and southeast flanks of the Horseranch Range a unit of tan to grey-weathering dolostone, locally with chert beds 1 to 3 centimetres thick, dolostone breccia and dolomitic limestone structurally overlies the phyllite unit. Calcite veins, 1 millimetre to 10 centimetres thick, commonly cut this unit. Fossils of rugose coral occur in the dolostone on the southeast flank of the range (Figure 1-36-1). Identification of these fossils is in progress.

REGIONAL CORRELATIONS

We have previously correlated the homogeneous quartzite unit structurally above the mylonite with the Boya Formation (Atan Group) and suggested that the absence of overlying Rosella Formation may result from a local hiatus. In keeping with this correlation and the local stratigraphy, mylonitic rocks, tan-weathering marble, chlorite-muscovite-garnet schist, and the central schist complex are correlated with the Proterozoic Ingenika Group (compare Mansy and Gabrielse, 1978). On the basis of descriptions of the Ingenika Group (Mansy and Gabrielse, 1978; Evenchick, 1985; Ferri and Melville, 1988), the tan-weathering resistant marble unit and muscovite-chlorite-garnet schist are correlated with the Espee and Stelkuz formations respectively. Therefore, the central schist complex may correlate with the Swannell and Tsaydiz formations. The phyllite and dolostone-dominated units are correlated with the Cambro-Ordovician Kechika Group and Ordovician-Silurian Sandpile Group respectively (compare Gabrielse, 1963; Plint and Erdmer, 1988).

STRUCTURE

Data collected this season allow comment on the regional extent of the mylonite zone, the relative timing of mylonitization and of late upright folding, and the relationship of strain in the low-grade Paleozoic units to the central schist complex.

Figure 1-36-1 shows that the mylonite zone thins rapidly towards the northern and southern ends of the range. In the north, northwesterly trending stretching lineations in the mylonite zone plunge moderately northwestward and kinematic indicators reflect top-down-to-the-northwest shear. Near the central part of the range, along its western flank, stretching lineations in the mylonite zone are horizontal, and C-S planes developed in granitoid rocks indicate dextral shear such that rocks structurally overlying the shear zone have moved north relative to those beneath it. An abrupt change in metamorphic grade from amphibolite facies (sillimanite zone) to greenschist facies (biotite zone) occurs across the mylonite zone (over approximately 100 to 600 metres horizontal distance) suggesting that tectonic thinning has occurred (compare Plint and Erdmer, 1988). East-west transects farther south reveal a similar change in metamorphic grade across approximately 200 metres (horizontal distance), in which biotite phyllite and fine-grained biotite schist are juxtaposed against staurolite-garnet schist. However, no mylonite is exposed in this area, suggesting the mylonite zone probably pinches out southwards. No change in fabric attitude or rock type accompanies the abrupt transition in metamorphic grade.

Mesoscopic mylonitic F_2 folds are refolded by upright F_3 folds (Plate 1-36-1). On a regional scale, therefore, the mylonite zone should be exposed on the eastern side of the range and at its northern and southern ends. The absence of mylonite on the east flank may be a function of poor exposure. The absence of mylonite at the southern end of the range may result from the lack of exposure or from truncation by the Horseranch and Deadwood faults. However, its absence from the northern end of the range is problematic.

Northwesterly trending folds in the Kechika Group may be coeval with F_3 structures in the central schist complex. The later, west-southwesterly trending, gently westerly plunging kinks and chevron folds in this unit have no apparent equivalent in the schist complex.

METAMORPHISM

Diagnostic metamorphic minerals in the schist complex include sillimanite (commonly as fibrolite), kyanite, or staurolite in pelitic and semipelitic schist, and diopside, grossular, and locally, hornblende or tremolite in marble. The widespread partial replacement of muscovite by potassium-feldspar and sillimanite in pelitic schist suggests that peak metamorphic temperature exceeded that of the muscovite-out equilibrium (650 to 700°C) in most of the schist complex. The presence of staurolite and kyanite in some of the schists places a lower pressure-temperature limit on metamorphism of approximately 500°C and 400 megapascals (4 kilobars). Assuming that pressures corresponding to peak metamorphic temperatures in sillimanite schist were higher than those in the structurally overlying staurolite and kyanite schists, a minimum pressure of 500 to 700 megapascals (5 to 7 kilobars) is plausible for the sillimanite schist.

Sillimanite, kyanite, and staurolite overprint the foliation or are randomly oriented on schistosity surfaces in the schist complex. This indicates that metamorphism outlasted foliation development. In the mylonite zone, sillimanite is folded by mylonitic (F_2) folds, and diopside commonly occurs as porphyroclasts. Retrogression is minor and is characterized by minor chlorite after biotite, white mica after feldspars, hornblende after diopside and chlorite, and biotite after igneous hornblende. Mylonitization, therefore, postdated peak regional metamorphism, and took place at high temperatures and/or under dry conditions.

Little or no new mineral growth is present in the axial surface region of late F_3 folds. This suggests that F_3 folding postdates regional metamorphism. A similar relationship has been documented in the Ingenika Group in the Deserters and Sifton ranges (Evenchick, 1985) and in the Wolverine complex (Parrish, 1976; Ferri and Melville, 1988). If F_3 folds postdate regional metamorphism, isograds should be folded. The distribution of staurolite in outcrop suggests the staurolite isograd is folded. However, field occurrences of staurolite, kyanite and sillimanite are too few to allow delineation of isograds in the absence of detailed petrographic data.

DISCUSSION AND CONCLUSIONS

The schist complex of the Horseranch Range has been metamorphosed to amphibolite facies (650 to 700°C, 500 to 700 megapascals) and subsequently mylonitized along its western margin. Tectonic thinning across the mylonite zone is reflected in an abrupt metamorphic transition. The northern part of the range exposes a deeper section of the schist complex than the southern part. This is reflected by the juxtaposition of biotite phyllite and fine-grained biotite schist against sillimanite-garnet schist across the mylonite zone in the north, and against staurolite-garnet schist in the south. Therefore, tectonic thinning and displacement across the mylonite zone decreases southward. The regional tectonic significance of the mylonite zone is still unclear. The absence of mylonite at the northern end of the range (around which all other units can be traced) is problematic. The continuity of the other units precludes the offset of the mylonite zone by a fault. Therefore, the zone must thin severely or pinch out entirely.

The absolute timing of regional metamorphism is unknown. However, on the basis of estimates of the age of metamorphism in the Sifton Range and the Wolverine complex (Evenchick, 1985; Parrish, 1976), metamorphism may be as young as Cretaceous. Regional metamorphism and mylonitization were followed by folding about an upright, northwesterly trending regional axis parallel to mesoscopic F_3 folds. Uplift along the Horseranch and Deadwood faults postdates F_3 folds.

Continuing work, including petrography, geothermobarometry, macroscopic and microscopic structural analysis, and uranium-lead and $^{40}Ar-^{39}Ar$ isotopic dating, will address the following:

- The pressure and temperature conditions of metamorphism;
- The "absolute" timing of regional metamorphism and metamorphic cooling;
- The regional tectonic significance and "absolute" timing of mylonitization;
- The rate and mechanism(s) of uplift.

ACKNOWLEDGMENTS

This study forms part of the senior author's Ph.D. research at the University of Alberta. Financial support by the British Columbia Ministry of Energy, Mines and Petroleum Resources and Natural Sciences and Engineering Research Council is gratefully ackowledged. Field assistance provided by K. Krey is sincerely appreciated.

REFERENCES

Erdmer, P. and Baadsgaard, H. (1987): 2.2 Ga Age of Zircons in Three Occurrences of Upper Proterozoic Clastic Rocks of the Northern Cassiar Terrane, Yukon and British Columbia, *Canadian Journal of Earth Sciences*, Volume 24, pages 1919-1924.

Evenchick, C. (1985): Stratigraphy, Metamorphism, Structure, and Their Tectonic Implications in the Sifton and Desserters Ranges, Cassiar and Northern Rocky Mountains, Northern British Columbia, Unpublished Ph.D. Thesis, *Queen's University*, 191 pages.

Ferri, F. and Melville, D.M. (1988): Manson Creek Mapping Project (93N/09), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 169-180.

Gabrielse, H. (1963): McDame Map-area, Cassiar District, British Columbia, *Geological Survey of Canada*, Memoir 319, 139 pages.

——— (1985). Major Dextral Transcurrent Displacements along the Northern Rocky Mountain Trench and Related Lineaments in North-central British Columbia, *Geological Survey of America*, Bulletin, Volume 96, pages 1-14.

Parrish, R.R. (1976): Structure, Metamorphism, and Geochronology of the Northern Wolverine Complex near Chase Mountain, Aiken Lake Map-area, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 89 pages.

Plint, H.E. and Erdmer, P. (1988): Geological Studies in the Horseranch Range (104P/7, 10), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 254-260.

Mansy, J.L. and Gabrielse, H. (1978): Stratigraphy, Terminology and Correlation of Upper Proterozoic Rocks in Omineca and Cassiar Mountains, North-central British Columbia, *Geological Survey of Canada*, Paper 77-19, 17 pages.

Monger, J.W.H. and Berg, H.C. (1984): Lithotectonic Terrane Map of Western Canada and Southeastern Alaska, Part B, *in* Lithotectonic Terrane Maps of the North American Cordillera, N.J. Siberling and D.L. Jones, Editors, *United States Geological Survey*, Open File Report 584-523, 104 pages.

NOTES

Mineral Deposit Studies

METALLOGENIC STUDIES OF LODE GOLD-SILVER OCCURRENCES IN SOUTH-CENTRAL BRITISH COLUMBIA: A PROGRESS REPORT (82E, 82L)

By R.E. Meyers and W.A. Taylor

KEYWORDS: Economic geology, metallogeny, lode gold-silver, epithermal, mesothermal, Okanagan.

INTRODUCTION

The recent success experienced by the exploration industry in newly discovered mining camps in northwestern British Columbia, combined with new discoveries and the successful regeneration of historical mining camps of the Canadian Shield and in the Western United States has encouraged industry re-assessment of the potential for precious metal lode deposits in southern British Columbia.

The objective of this study is to provide the explorationist with a review of precious metal occurrences in south-central British Columbia, their geologic setting and their character. Attention is drawn to the nature and potential of current exploration targets and the contrasts between them, and the type of deposits that have been historically exploited. The initial focus is in the Okanagan region, specifically on map sheets 82E/W and 82L/SW (Figure 2-1-1), where two recent epithermal discoveries have prompted a substantial increase in exploration activity.

This preliminary report summarizes the results of field observations and compilation of data from 127 precious metal lode occurrences in the Okanagan region. Other types of gold occurrences, such as copper-gold porphyries and gold-bearing skarns are not dealt with in this study, although a few skarn-related vein deposits are included.

SOURCES

Information has been compiled from 31 property visits, property descriptions researched from British Columbia Minister of Mines Annual Reports, MINFILE, assessment reports, Geological Survey of Canada publications and district property files, as well as from some earlier compilations (Dawson *et al.*, 1984). Occurrences were selected on the basis of having a "reasonable" tenor of mineralization. Very small, isolated veins with only geochemically anomalous values were avoided. In most cases the historic property names have been used in preference to more recent claim names. All properties are tabulated and plotted at 1:250 000-scale in Open File 1989-5 (Meyers *et al.*, 1989).

The geology of the Okanagan region is presented in the context of new interpretations by Parrish *et al.* (1988) and others. Geological information for the Penticton map sheet (82E/W) has been primarily derived from Tempelman-Kluit (in press) and for 82L/SW from Wheeler and McFeely (1987).

REGIONAL GEOLOGY

The Okanagan region is underlain by a diverse assemblage of rocks, ranging in age from late Paleozoic to early Cenozoic (Bostock, 1941; Jones, 1959; Little, 1961). The region is bisected by the Okanagan Valley, which represents a major tectono-stratigraphic break separating high-grade metamorphic rocks of the Okanagan metamorphic complex to the east from lower grade Carboniferous to Triassic metasedimentary and metavolcanic rocks to the west. The fault system is projected from Washington State along the full length of the Okanagan Valley to north of Shuswap Lake (Tempelman-Kluit and Parkinson, 1986; Parrish *et al.*, 1988).

The Okanagan metamorphic complex occupies the western flank of the Omineca Belt and includes amphibolite-grade orthogneiss and paragneiss intruded on a broad scale by deformed granitoid plutonic rocks of the middle Jurassic Nelson suite and the Jura-Cretaceous Valhalla suite. The age of the gneiss complex was previously thought to be as old as Precambrian (Bostock, 1941; Little, 1961; Okulitch and Woodsworth, 1977), however, studies by Medford (1975), Mathews (1981), Parkinson (1985) and Parrish *et al.* (1988) have produced fission-track, uranium-lead and potassium-argon isotopic ages as young as late Eocene.

On the west side of the Okanagan Valley, late Paleozoic to middle Mesozoic sedimentary and volcanic rocks of island arc and oceanic derivation have preserved Mesozoic penetrative deformation and are metamorphosed to greenschist facies. As on the eastern side, these rocks are intruded by Nelson and Valhalla plutonic rocks but contrast dramatically in their metamorphic history.

Pre-Tertiary rocks on both sides of the Okanagan Valley are unconformably overlain, in places, by thick accumulations of Eocene volcanic and sedimentary rocks that are generally unmetamorphosed. Church (1982) and Tempelman-Kluit (in press) have correlated outliers of the Eocene sequence, and Parrish *et al.* (1988) interpret them as remnants of a continuous depositional basin that covered the southern Okanagan.

Recently presented evidence (Parrish *et al.*, 1988, Tempelman-Kluit and Parkinson, 1986, Bardoux, 1985) indicates that the Okanagan fault system formed as a series of low-angle, west-dipping normal faults with east to west movement, placing lower grade rocks to the west against higher grade rocks to the east.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

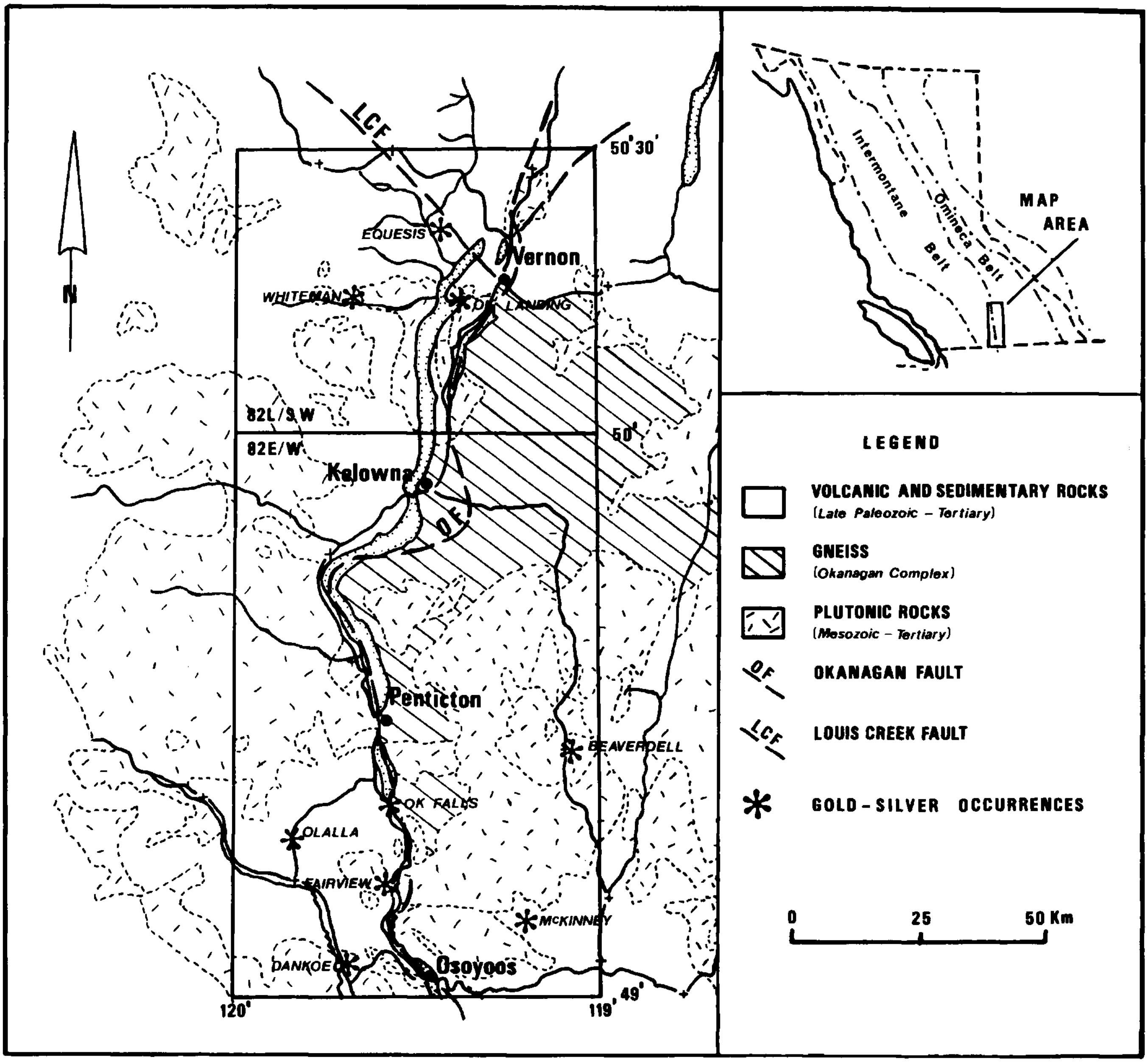


Figure 2-1-1. Okanagan region showing location of study area and main localities of lode gold-silver occurrences. Geology simplified after Wheeler and McFeely (1987) and Parrish *et al.* (1988).

DISTRIBUTION, SETTING AND CHARACTER OF PRECIOUS METALS DEPOSITS

NORTHERN OKANAGAN

In the northern Okanagan region (82L/SW) most occurrences are centred around Vernon, at Okanagan Landing, Equesis Creek and the Whiteman Creek – Terrace Mountain area. The majority of these prospects occur in greenschist facies, Upper Triassic to Lower Jurassic Nicola Group volcanic and sedimentary rocks and in metasedimentary rocks of the Upper Triassic Slocan Group (Okulitch, 1979), while comparatively few occurrences have been discovered in Tertiary rocks.

Okanagan Landing and Vernon

Mineralized veins in this area are mesothermal in character and associated with north, northwest and west-trending structures that may be splays of the northern Okanagan fault system or the Louis Creek fault. The veins are gold-bearing with secondary silver, copper, lead and zinc. Some veins occur in fractures oriented oblique to foliation (Plate 2-1-1). Alteration is graphitic, with clay and limonite. On the east shore of Okanagan Lake, near the Ruby Gold prospect, the stratified rocks have a strong northwest-dipping penetrative fabric that is distinctly mylonitic in texture.

Equesis Creek

Several precious metal bearing qnartz-vein prospects occur in chloritic volcanic rocks and phyllitic sedimentary

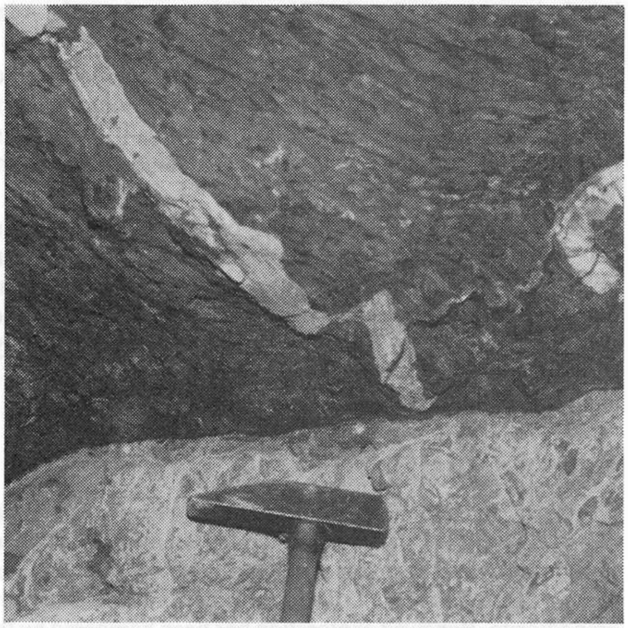


Plate 2-1-1. Imperial property. Deformed quartz vein and felsic dyke in schistose, chloritized metasedimentary rocks, which are truncated by lower grey breccia zone.

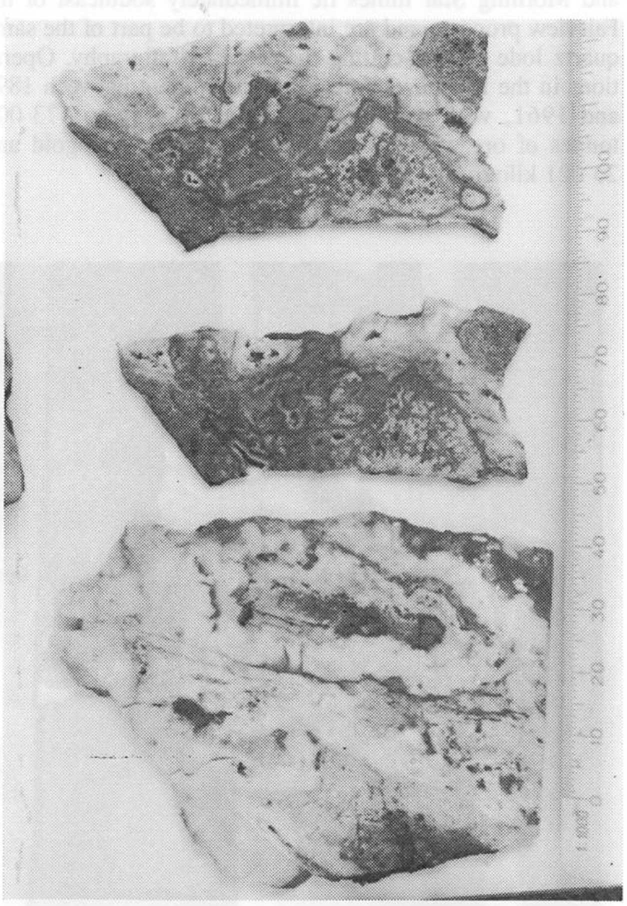


Plate 2-1-2. Brett property. Banded, vuggy and brecciated quartz veins. Wallrock material is silicified and clay (illite) altered; Trench No. 1, Main Shear Zone.

rocks of the Nicola and Slocan groups, between Equesis Creek and the Salmon River. The veins are subparallel to host-rock foliation and are mainly gold-rich with low silver values. A minority, however, are silver-rich, gold-poor veins that contain galena and sphalerite. Alteration is variable and generally not well defined over large areas. Chlorite, limonitic carbonate, sericite and weak graphitic alteration are the most common.

Whiteman Creek

In contrast to the areas described above, gold-silver mineralization in the Whiteman Creek – Terrace Mountain area occurs within, or close to relatively unmetamorphosed volcanic rocks of the Eocene Kamloops Group. The most notable occurrence is the Brett property, which is characterized by bladed and vuggy, epithermal gold and silver-bearing quartz veins (Plate 2-1-2) associated with illite, sericite and silica alteration (Meyers, 1988a). The veins occur in northwest striking, highly fractured fault zones, which tend to coincide with feldspar porphyry dykes. A broad silicified breccia zone (Plate 2-1-3) northeast of the mineralized areas is believed to represent a major epithermal system. Recent drill-hole data indicate that silicification and gold mineralization in the main shear zone may extend laterally into porous tuff units, where they are intersected by the steeply dipping, mineralized fault zones. Southeast of the mineralized area, the volcanic sequence is intruded by a syenitic stock dated at 50.3 Ma (Church, 1980a).

The White Elephant property which was exploited briefly in the 1920s and 1930s, is several kilometres south of Whiteman Creek. Precious metals occur in fractured and faulted

Plate 2-1-3. Brett property. Silicified and pyritized breccia, Gossan Zone.

quartz-rich and sulphide-rich veins that are hosted in propylitically altered middle Jurassic granodiorite. The deposit is exposed a few hundred metres east of Eocene volcanic rocks and the veins are cut by basaltic dykes.

SOUTHERN OKANAGAN

Occurrences in the southern Okanagan region (82E/W) are grouped in several well-known mining camps, where a number of past producers are still being explored. The Fairview Camp, Orofino Mountain, Olalla, Camp McKinney and Beaverdell are of particular note. In most areas, mesothermal veins occur in deformed late Paleozoic to Mesozoic sedimentary-volcanic sequences. At Okanagan Falls, however, Eocene volcanic rocks of the Marama and White Lake formations host epithermal gold mineralization.

OKANAGAN FALLS

At the south end of Skaha Lake epithermal mineralization at the Dusty Mac mine occurs in quartz-vein breccia in laharic deposits of the Eocene White Lake Formation (Church, 1969, 1973). The geology of the area is dominated by a northwest-trending fault system and dissected locally by numerous normal and reverse faults. Fracture-controlled veins are commonly banded (Plate 2-1-4), or exhibit cockscomb quartz intergrowths. The deposit was mined briefly between 1969 and 1975 and is currently undergoing further exploration.

Several kilometres southeast, at the Venner property, gold-silver mineralization is related to quartz-carbonate breccia and veining within Eocene Marama andesitic breccias, rhyolitic flows and crystal tuffs. This unit underlies the White Lake Formation.

A new epithermal gold-silver prospect has been discovered recently northwest of Okanagan Falls, at the Vault property. Mineralization is characterized by crustiform-banded chalcedonic quartz veining (Plate 2-1-5) and widespread silicification in brecciated and tuffaceous trachyandesites of the lower Marama Formation. Normal faulting is a complicating structural feature.

FAIRVIEW CAMP

At the Fairview mine, deformed gold-silver veins (Plate 2-1-6) occur in refolded and faulted Kobau metaquartzites of Carboniferous to Permian age (Okulitch, 1969, 1973) that are wedged between Oliver granite and the Fairview granodiorite. Renewed exploration has been hampered by the structural complexities of early polyphase folding and superimposed normal and reverse faulting (Meyers, 1988b). Veins are typically mesothermal, with precious metals associated with iron, lead, zinc and copper sulphides. The Stemwinder and Morning Star mines lie immediately southeast of the Fairview property and are interpreted to be part of the same quartz lode system cutting the Kobau stratigraphy. Operations in the Fairview camp were intermittent between 1895 and 1961, with total production amounting to 473 000 tonnes of ore which yielded 1944 kilograms of gold and 23 021 kilograms of silver.

Plate 2-1-4. Dusty Mac property. Multiple banding in quartz vein in laharic breccia.

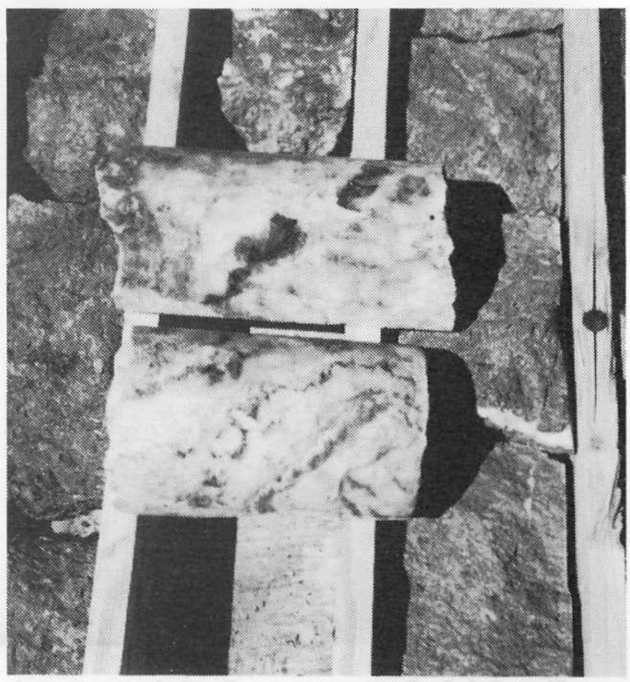


Plate 2-1-5. Vault property. Banded gold-bearing quartz vein in tuffaceous trachyandesite. Core is 4.5 cm in diameter.

Plate 2-1-6. Fairview mine. Cleavage development in quartz vein, oriented parallel to S_1 foliation in wallrocks. Crossfracturing is subperpendicular to cleavage; No. 6 level.

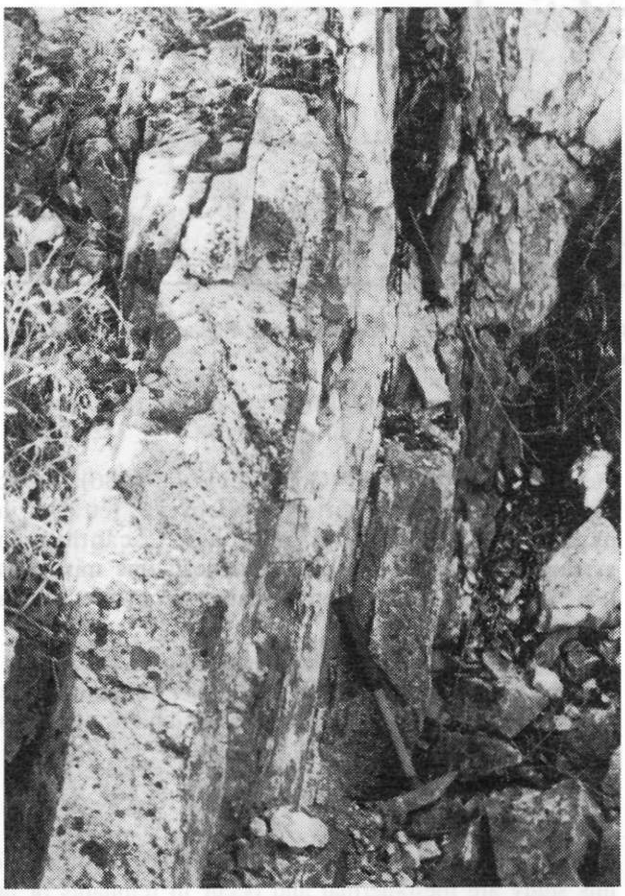


Plate 2-1-7. Standard property. Steeply dipping quartz vein enclosed in granodiorite (Jog) adjacent to adit portal.

A similar setting exists at Orofino Mountain where the host rocks are greenschist metasedimentary rocks of the Upper Triassic Old Tom and Shoemaker groups, intruded by dioritic and gabbroic rocks. Northeast and northwest-trending quartz veins carry gold and silver associated with polymetallic sulphides and chlorite-sericite alteration. The host strata and mineralization are cut by a number of northeast-oriented normal faults.

Other deposits in the same area, such as the Suzie mine and Standard prospect, occur in northeast and northwest-trending dilatent fracture zones within the granitoid rocks of the Oliver intrusion (Plate 2-1-7).

Olalla

Veins in the Olalla area occur within or peripheral to the mid-Jurassic Olalla pyroxenite and related syenitic rocks, where they intrude hornfelsed Upper Triassic Shoemaker Group metasedimentary rocks. Most structures trend east-northeast and are sheared or brecciated. Gold-silver mineralization is associated with base metals in quartz veins, quartz breccia zones and weakly mineralized gold and copper-bearing skarns. Alteration is variable, but predominantly silica, carbonate, clay and minor sericite. At least two properties (Sunrise, Juniper) are associated with skarn mineralization.

Dankoe

In the Dankoe (Horn Silver) mine area, south of Mount Kobau, flat-lying quartz veins are generally oriented east-west subparallel to shearing. They occur within the Kruger syenites, monzonites and related pegmatites (Plate 2-1-8). Precious metals occur with pyrite, chalcopyrite, galena and tetrahedrite. Native silver, argentite, pyrargyrite and silver halides have also been reported from this deposit. Some veins display banded and bladed sulphides and quartz, suggesting open-space filling. Alteration is strongly propylitic in character. During intermittent operation between 1915 and 1984 the Horn Silver mine produced 391 111 tonnes of silver-gold ore, containing 333 kilograms gold and 127 194 kilograms silver.

Camp McKinney

Camp McKinney deposits occur in greenstones, amphibolites, minor ultramafic rocks and schistose metasedimentary rocks of the Carboniferous to Permian Anarchist Group. The veins are generally conformable to the northwest and west-trending regional foliation and are reported to have similarities in structure and texture to the deformed mesothermal veins in the Fairview Camp (Cockfield, 1935). However, a few banded and vuggy veins are present, suggesting that low-temperature epithermal activity may have had an effect on vein development. Gold is by far the dominant precious metal, although modest silver values were reported, together with appreciable quantities of lead, zinc and copper. At the War Eagle property, fractured and brecciated veins contain zones partially replaced by massive sulphides. Alteration is quartz-carbonate rich, with associated sericite and chlorite. The Cariboo-Amelia mine produced 124 452 tonnes of ore containing 2538 kilograms gold and 1009 kilograms silver between 1894 and 1962.

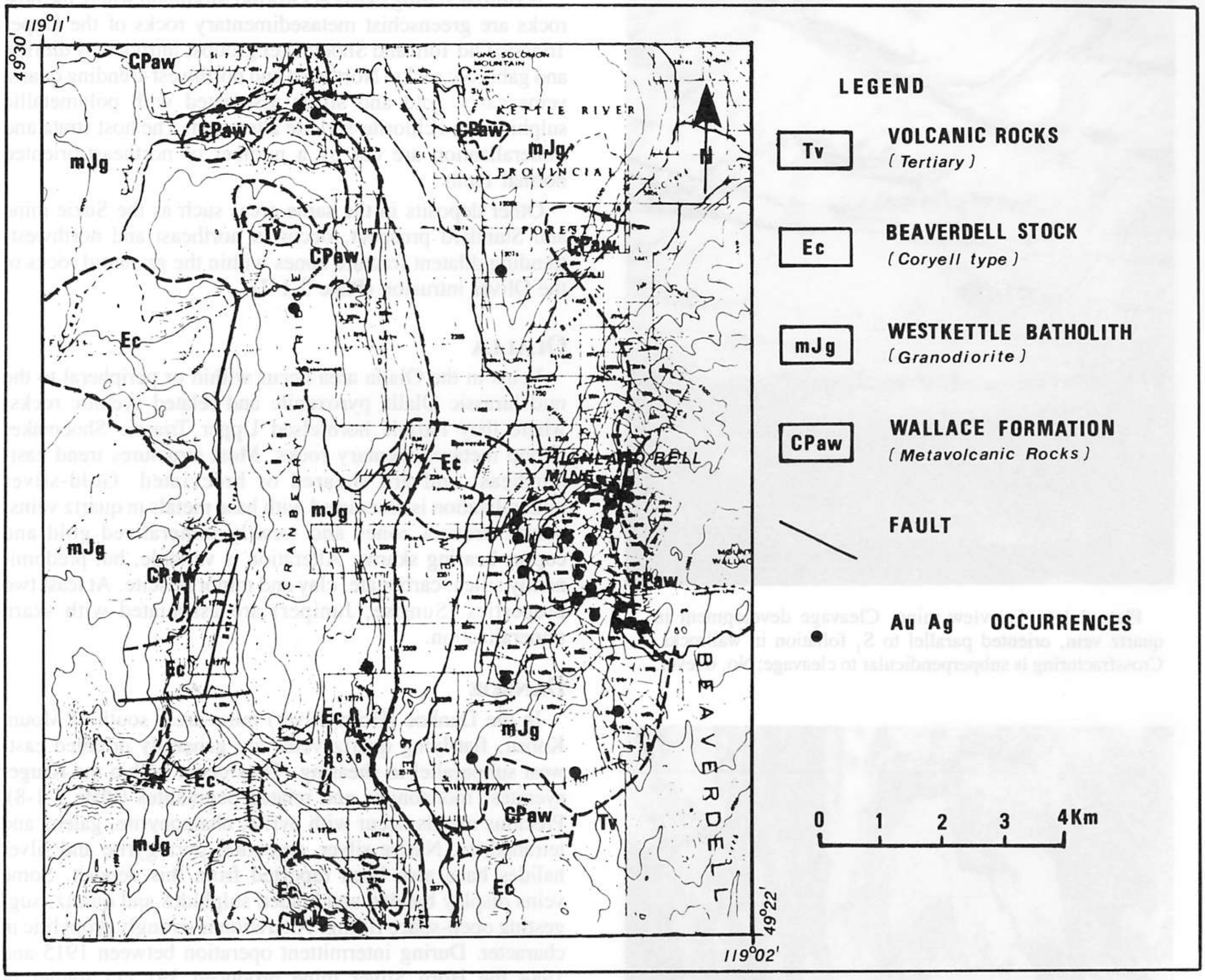


Figure 2-1-2. Distribution of silver and gold occurrences in the Beaverdell-Carmi district. Geology after Watson *et al.* (1982) and Godwin *et al.* (1986).

BEAVERDELL

The Highland-Bell mine, an amalgamation of the former Highland Lass, Bell and Beaver properties, is the oldest continuously operating mine in British Columbia. Between 1900 and 1988 the mine has produced 1278 tonnes of silver and approximately 500 kilograms of gold from 830 743 tonnes of ore.

In the Beaverdell – Carmi district, silver and gold vein mineralization occurs in predominantly northeast and east-trending structures in the Middle Jurassic Westkettle granodiorite. The batholith also contains pendants of the Wallace Formation, a volcanic-sedimentary component of the Anarchist Group (Figure 2-1-2). The granodiorite is intruded by the Beaverdell quartz monzonite, an Eocene Coryell-type intrusion, dated at 58.8 Ma, which has been correlated with the timing of silver-rich mineralization at the Highland Bell mine (Godwin *et al.*, 1986). Watson and Godwin (1983) reported arsenopyrite, tetrahedrite, pyrargyrite, chalcopyrite, polybasite, acanthite and pyrrhotite associated with the silver-lead-zinc mineralization. Alteration in the camp is mainly propylitic with accessory sericite and clay.

In contrast with the Beaverdell area, vein mineralization at Carmi is gold rich, with generally lower sulphide content (Watson *et al.*, 1982). No major production has come from this area.

DISCUSSION

The majority of lode gold-silver occurrences compiled for this study are mesothermal and occur in remnants of late Paleozoic to early Mesozoic eugeosynclinal rocks. The fact that many of them lie within well known established mining

Plate 2-1-8. Dankoe mine. Pegmatite dykes cutting Kruger syenite (mJg) near adit portal.

camps, reflects the historical exploration bias toward pre-Tertiary rocks.

Only five of the properties occur in Tertiary volcanic rocks. Most of these have distinct epithermal characteristics and were discovered during the last twenty years. The more recent discoveries are particularly significant in that they reaffirm the potential for epithermal gold mineralization related to Tertiary volcanism in the Okanagan region.

The deposits fall into three general settings:

(1) **Greenschist-hosted Deposits.** Deposits occurring in sedimentary and volcanic sequences, metamorphosed to greenschist grade, occur as intrafolial veins parallel to bedding or cleavage, breccia fillings, multiple veins and stringers in ductile shears, and in discordant brittle cross-fractures. Host-rocks are deformed, foliated rocks originating as accretionary arc or oceanic assemblages (Wheeler and McFeely, 1987). Precious metals are usually intimately associated with base metals, and the sulphide and alteration mineral assemblages are typical of mesothermal lode deposits (Hodgson, 1985).

Deposits of this type are common in greenschist terranes, particularly in the Archean of central Canada (Colvine *et al.*, 1984, 1988) and Western Australia (Barley *et al.*, 1986). They are believed to have formed from metamorphogenic fluids contemporaneous with ductile deformation and syntectonic plutonism. However, to avoid direct comparisons between Cordilleran and Archean terranes, a better analogy might be drawn with lode deposits in the Juneau gold belt of southeastern Alaska, where Goldfarb *et al.* (1988) have determined a subduction-related metamorphic origin for mesothermal vein mineralization in greenschist to amphibolite-grade rocks of late Paleozoic to Cretaceous age.

(2) **Intrusive-hosted Deposits.** Except for the Beaverdell deposits, intrusive-hosted occurrences in the region are generally less well known. They occur in faults, dilational fractures or fissures, shear zones and breccia zones. The most significant of these are the Beaverdell deposits, which are fault and fissure controlled and silver rich. Although they occur in Jurassic granodiorite of the Westkettle batholith, they are considered to be Tertiary in age (Godwin *et al.*, 1988). The Sunrise/Shepherd veins at Olalla occur within the Olalla pyroxenite and are breccia and skarn-related. The latter association suggests that metasomatic activity related to intrusion may have been important during vein development.

(3) **Epithermal Deposits.** The important epithermal prospects in the region occur at Okanagan Falls and Whiteman Creek. They are hosted by Eocene volcanic and sedimentary sequences that are inferred to be related in time, to "detachment-type" extensional tectonics associated with the Okanagan fault system (Parrish *et al.*, 1988).

Mineralization is best developed in porous tuffs, tectonic fracture zones, and laharic and epiclastic breccias. It is associated with faulting, intense brittle fracturing, widespread silicification and moderate to strong pyritization of adjacent wallrocks. Clay (illite), sericite and to a lesser extent, carbonate are common alteration products. Quartz veins are vuggy, banded, bladed and rebrecciated, all of which are features characteristic of boiling in a hotspring environment (Buchanan, 1981).

Relationships between epithermal mineralization and extensional deformation have been proposed for deposits in the western United States (Spencer and Welty, 1986) and in Spain (Doblas *et al.*, 1988). The fact that normal faulting is widespread throughout Eocene sequences in the Okanagan (Church, 1979, 1980a, b) and is spatially related to Eocene volcanic centres and mineral deposits, is indicative that extensional tectonism likely gave rise to Eocene volcanism. The open-space textures in epithermal quartz veins are further evidence, on a local scale, that dilatent deformation took place. Consequently, one can expect that the evolving models for extensional tectonics and Eocene volcanism in the region will have important and far-reaching genetic implications for epithermal precious metals exploration in the Okanagan.

ACKNOWLEDGMENTS

This study benefited from a number of property visits and on-site discussions with company project geologists. We acknowledge permission to visit several inactive properties and we thank Dirk Tempelman-Kluit for access to his data for

the Penticton map sheet. Field assistance, property research and drafting assistance was enthusiastically provided by Todd Hubner.

REFERENCES

Bardoux, M. (1985): The Kelowna Detachment Zone, South-central British Columbia, *Geological Survey of Canada*, Paper 85-1A, pages 333-339.

Barley, M.E., Groves, D.I. and Phillips, G.N. (1986): Archean and Tertiary Volcanic-hosted Gold Mineralization: Similarities and Contrasts, Symposium 5: Volcanism, Hydrothermal Systems and Related Mineralization, *International Volcanological Congress*, February 1986, Auckland, New Zealand.

Bostock, H.S. (1941): Okanagan Falls, British Columbia, *Geological Survey of Canada*, Map 637A.

Buchanan, L.J. (1981): Precious Metals Associated with Volcanic Environments in the Southwest, *in* Relations of Tectonics to Ore Deposits in the South Cordillera, Dickinson, W.R. and Payne, W.D., Editors, *Arizona Geological Society Digest*, Volume XIV, pages 237-261.

Church, B.N. (1969): Dusty Mac Property, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration and Mining, pages 294-296.

——— (1973): Geology of the White Lake Basin, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 61, 120 pages.

——— (1979): Geology of the Penticton Tertiary Outlier, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 35.

——— (1980a): Geology of the Terrace Mountain Tertiary Outlier, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 37.

——— (1980b): Geology of the Kelowna Tertiary Outlier, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 39.

——— (1982): Notes on the Penticton Group, A Progress Report on a New Stratigraphic Subdivision of the Tertiary, South-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1981, Paper 1982-1.

Cockfield, W.E. (1935): Lode Gold Deposits of Fairview Camp, Camp McKinney, Vidette Lake Area, and the Dividend-Lakeview Property near Osoyoos, B.C., *Geological Survey of Canada*, Memoir 179.

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, J.A., Lavigne, M.J., Macdonald, A.J., Marmont, S., Poulsen, K.H., Springer, J.S. and Troop, D.G. (1984): An Integrated Model for the Origin of Archean Lode Gold Deposits, *Ontario Geological Survey*, Open File Report 5524.

Colvine, A.C., Fyon, J.A., Heather, K.B., Marmont, S., Smith, P.M. and Troup, D.G. (1988): Archean Lode Gold Deposits in Ontario, *Ontario Geological Survey*, Miscellaneous Paper 139, 136 pages.

Dawson, K.M., Friday, S.J., Simpson, M., Simpson, R.H.F., and Watson, P.H. (1984): Mineral Deposits and Principal Mineral Occurrences of the Canadian Cordillera, *Geological Survey of Canada*, Map 1513A.

Doblas, M., Oyarzun, R., Lunar, R., Mayor, N. and Martinez, J. (1988): Detachment Faulting and Late Paleozoic Epithermal Ag-base-metal Mineralization in the Spanish Central System, *Geology*, Volume 16, pages 800-803.

Godwin, C.I., Watson, P.H. and Shen, K. (1986): Genesis of the Lass Vein System, Beaverdell Silver Camp, South-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, pages 1615-1626.

Godwin, C.I., Gabites, J.E. and Andrew, A. (1988): Leadtable: A Galena Lead Isotope Data Base for the Canadian Cordillera, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1988-4.

Goldfarb, R.L., Leach, D.L., Pickthorn, W.J. and Paterson, C.J. (1988): Origin of Lode-gold Deposits of the Juneau Gold Belt, Southeastern Alaska, *Geology*, Volume 16, pages 440-443.

Hodgson, C.J. (1985): Precambrian Lode Gold Deposits, *Geological Association of Canada*, Cordilleran Section, Short Course No. 6, Nov. 29, 1985.

Jones, A.G. (1959): Vernon Map Area, British Columbia, *Geological Survey of Canada*, Memoir 296.

Little, H.W. (1961): Kettle River, West Half, British Columbia, *Geological Survey of Canada*, Map 15-1961.

Mathews, W.H. (1981): Early Cenozoic Resetting of Potassium-argon Dates and Geothermal History of North Okanagan Area, British Columbia, *Canadian Journal of Earth Sciences*, Volume 18, pages 1310-1319.

Medford, G.A. (1975): K-Ar and Fission Track Geochronology of an Eocene Thermal Event in the Kettle River (West-half) Map Area, Southern British Columbia, *Canadian Journal of Earth Sciences*, Volume 14, pages 1690-1695.

Meyers, R.E., Taylor, W.A. and Tempelman-Kluit, D. (1989): Lode Gold-silver Occurrences of the Okanagan Region, South-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1989-5.

Meyers, R.E. (1988a): Brett Property, Vernon Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, pages B15-B22.

——— (1988b): Fairview Mine, Osoyoos Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, pages B7-B15.

Okulitch, A.V. (1969): Polyphase Deformation in the Kobau Group, Mount Kobau, British Columbia, *Geological Survey of Canada*, Proceedings, Volume 20.

——— (1973): Age and Correlation of the Kobau Group, Mount Kobau, British Columbia, *Canadian Journal of Earth Sciences*, Volume 10, page 1508.

——— (1979): Thompson-Shuswap-Okanagan, *Geological Survey of Canada*, Open File Map 637.

Okulitch, A.V., and Woodsworth, G.J. (1977): Kootenay River, *Geological Survey of Canada*, Open File Map 481.

Parkinson, D. (1985): U-Pb Geochronology and Regional Geology of the Southern Okanagan Valley, British Columbia: the Western Boundary of a Metamorphic Core Complex, Unpublished M.Sc. Thesis, *The University of British Columbia*, 149 pages.

Parrish, R.R., Carr, S.D. and Parkinson, D. (1988): Eocene Extensional Tectonics and Geochronology of the Southern Omineca Belt, British Columbia and Washington, *Tectonics*, Volume 7, No. 2, pages 181-212.

Spencer, J.E. and Welty, J.W. (1986): Possible Controls of Base and Precious-metal Mineralization Associated with Tertiary Detachment Faults in the Lower Colorado River Trough, Arizona and California, *Geology*, Volume 14, pages 195-198.

Tempelman-Kluit, D. (1989): Penticton Map Area, British Columbia, *Geological Survey of Canada*, In Press.

Tempelman-Kluit, D. and Parkinson, D. (1986): Extension Across the Eocene Okanagan Crustal Shear in Southern British Columbia, *Geology*, Volume 14, pages 318-321.

Watson, P.H., Godwin, C.I. and Christopher, P.I. (1982): General Geology and Genesis of Silver and Gold Veins in the Beaverdell Area, South-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 19, pages 1264-1274.

Watson, P.H. and Godwin, C.I. (1983): Silver-gold Zonation in the Lass Vein System, Beaverdell Camp, South-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1982, Paper 1983-1.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America, *Geological Survey of Canada*, Open File Map 1565.

NOTES

CHARACTERISTICS OF MINERALIZING FLUIDS IN THE BRALORNE-PIONEER MESOTHERMAL GOLD VEIN DEPOSIT: RESULTS OF A FLUID INCLUSION, STABLE ISOTOPE, AND THERMODYNAMIC STUDY*

(92J/15W)

By C.H.B. Leitch, C.I. Godwin and T.H. Brown
The University of British Columbia
B.E. Taylor and W.C. Cornell
Geological Survey of Canada

KEYWORDS: Economic geology, fluid inclusions, stable isotopes, thermodynamic model, Bralorne Pioneer, gold, mesothermal veins, isotopic zoning, geothermometry, "fault-valve" model.

INTRODUCTION

Results from fluid-inclusion and stable-isotope studies, and thermodynamic modelling, have led to estimates of the pressure-temperature-composition (P-T-X) characteristics of mineralizing fluids in the Bralorne-Pioneer mesothermal gold vein deposits. Observed wallrock alteration mineral assemblages, and pressure-temperature (P-T) conditions estimated from fluid inclusions, were used to constrain a water-rock thermodynamic computer model. Stable-isotope studies confirm that significant interaction of wallrocks with the ore fluid took place. The "fault valve" hypothesis of Sibson *et al.* (1988) offers an explanation for fluid migration, and is consistent with the main features of the ribbon-banded, yet coarsely crystalline quartz veins at Bralorne.

The major gold-bearing veins at Bralorne strike about 110° azimuth and dip north at 70°, with slickensides plunging 45° east indicating that the last movement was reverse. Major ore shoots occupy somewhat less than 20 per cent of the veins and plunge steeply west, roughly perpendicular to the slickensides. The best host for veins seems to have been the competent Bralorne diorite (consisting of albite, hornblende and quartz) and the Cadwallader greenstone. The veins contain thin dark ribbons of fine-grained sulphide in massive milky quartz with minor calcite.

Hydrothermal alteration envelopes around the veins are extensive and grade outwards from intensely foliated quartz/ankeritic carbonate/sericite(+fuchsite) to less sheared calcite/chlorite/albite to unsheared epidote/calcite. Chemical studies of the alteration on a constant volume basis (based on Al_2O_3 and TiO_2, which have remained relatively immobile), show that there has been addition of K_2O, CO_2, S, As and Au, while Na_2O, FeO (total) and MgO have been strongly depleted close to the vein. SiO_2 and CaO are locally depleted and reconcentrated.

Disseminated pyrite, pyrrhotite and much lesser chalcopyrite occur within envelopes for up to several metres from the veins. Arsenopyrite is confined to vein selvages. Minor amounts of sphalerite and especially galena appear to correlate with vein sections that are richer in gold. Traces of tetrahedrite and stibnite have been observed but tellurides have not. Gold is principally found as thin smeared flakes of the native metal in the black sulphidic septae of the strongly ribboned shear veins. Gold is only rarely found by itself in the quartz, usually in the rare extensional veins, where it forms extremely rich pockets.

FLUID INCLUSION STUDIES

Samples for fluid-inclusion studies were collected from quartz veins at surface and over a 2-kilometre depth extent; in general, the sites were the same as those sampled for oxygen isotope measurements (Figure 2-2-1a). Vein quartz forms

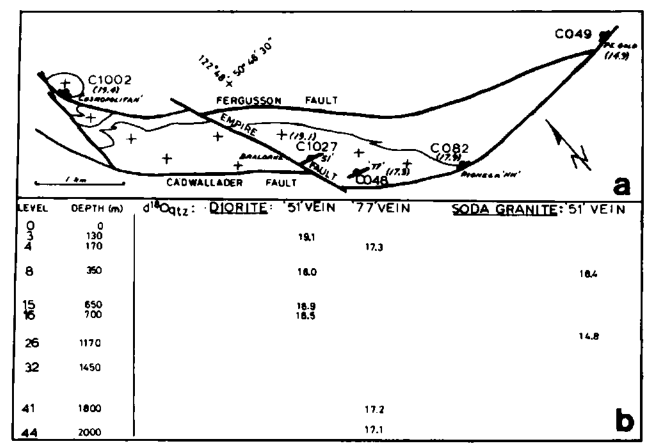


Figure 2-2-1a. Geographic zoning of oxygen isotope ratios of vein quartz from the Bralorne-Pioneer vein system. Plus symbols indicate extent of Bralorne intrusives; sample numbers are C1002, etc.; d[18]O values are in brackets, vein designation is in inverted commas, with vein strike and steep northerly dip indicated.

Figure 2-2-1b. Vertical zoning in oxygen isotope ratios in the Bralorne-Pioneer vein system is shown schematically, by variation in d[18]O quartz with reference to the mine levels.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

euhedral crystals up to 1 centimetre long that are outlined by concentric growth zones of minute (1-2 micron diameter) primary fluid inclusions. None of these inclusions were large enough for microthermometric measurements; instead, larger isolated (assumed primary) and fracture-controlled (pseudosecondary) inclusions in the 3 to 10 (rarely up to 30) micron range were studied. Particles of gold were not seen directly associated with any fluid inclusions, but the primary and pseudosecondary inclusions are assumed to have accompanied the main and subsequent stages of mineralization, respectively. The pseudosecondary inclusions are interpreted as later, based on their mode of occurrence and their lower temperatures of homogenization.

Preliminary fluid-inclusion data for the Bralorne deposit were reported in Leitch and Godwin (1987, 1988). Further fluid-inclusion studies, carried out with a United States Geological Survey gas-flow stage adapted by Fluid Inc., confirm the bulk of the results obtained with the Chaixmeca equipment, particularly the final homogenization temperatures (Th) and salinities from ice-melting temperatures (Tmi). However, the fluid compositions of the fluids in the inclusions can now be characterized in greater detail. This is due to: (1) the increased visibility of the inclusions because of the better optics with the adapted stage, leading to recognition of additional phases, either optically or by observation of phase transitions, and (2) the increased precision of measurements of phase-transition temperatures by the "cycling" technique and the rapid response of the gas-flow system. This high precision is accompanied by a high degree of accuracy, since the thermocouple/readout unit is calibrated to better than 0.4°C from −56.6° to +660.4°C.

Some of the scatter observed, for instance in the $H_2O:CO_2$ ratios and final homogenization temperatures (Figure 2-2-2), is possibly due to necking of the inclusions after they formed. Such inclusions were avoided, but textural evidence for necking may not always be present. Useful information may still be obtained from these inclusions; Roedder (1979), demonstrated that the true homogenization temperature will be intermediate to the homogenization temperatures of the necked parts.

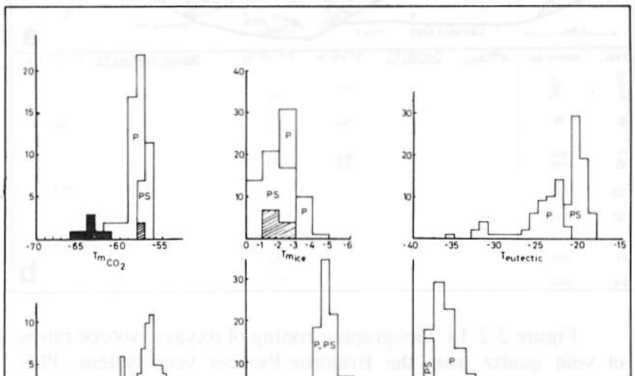


Figure 2-2-2. Summary of data for carbonic fluid inclusions in the Bralorne mesothermal gold-quartz vein deposit. P, PS, S correspond to primary, pseudosecondary, and secondary inclusions respectively; black areas to methane-rich (Type 1b) inclusions. All inclusions are in quartz except for hachured areas which are inclusions in calcite. Other abbreviations are in Table 2-2-1.

Results are summarized in Table 2-2-1 and in Figure 2-2-2. They show that the fluids contain a significant carbonic ($CO_2 + CH_4$) component.

CLASSIFICATION OF FLUID INCLUSIONS

Type 1a isolated primary inclusions in quartz, marked "P" in Figure 2-2-2, usually homogenize to liquid. They contain moderate amounts of carbonic fluid (0.1 to 0.4 mole fraction of the total contents of the inclusions, with a mode of 0.15), and consist of carbon dioxide and minor methane ($X_{CO2} = 0.10$, $X_{CH4} = 0.05$).

TABLE 2-2-1: SUMMARY OF FLUID INCLUSION CHARACTERISTICS FOR THE BRALORNE DEPOSIT (all temperatures in °C).

Type	Description
Type 1a Primary	**Three-phase, CO_2-bearing, CH_4-poor**
	(H_2O 0.8, CO_2 0.1, CH_4 0.05, NaCl 0.03)[1]
	Th: range 235 to 425, average[2] 280
	Th_{CO2}: range 15 to 27, mode[3] 20.5
	Tm_{cl}: range 8.2 to 11.0, mode 9.6
	Tm_i(?): range −2 to −7, average −3.5
	Tm_{CO2}: range −57.3 to −59.8, mode −58.8
	V/V+L: range 10-45 vol.%, mode 20 vol.%
	r carbonic: $0.7 g/cm^3$ r bulk: $0.95 g/cm^3$
	Vbar: 23 $moles/cm^3$
Type 1b	**Three-phase, CO_2-CH_4-rich**
	(H_2O 0.45, CO_2 0.25, CH_4 0.25, NaCl 0.03)
	Td: range 230 to 330, average 270
	Th_{CO2}: range 3.3 to 9.0, mode 7.5
	Tm_{cl}: range 11.1 to 13.0, mode 12.4
	Tm_i(?): not observable
	Tm_{CO2}: range −61.3 to −66.5, mode −63(?)
	V/V+L: range 30-85 vol.%, mode 50 vol.%
	r carbonic: $0.6 g/cm^3$ r bulk: $0.8 g/cm^3$
	Vbar: 31 $moles/cm^3$
Type 2 Pseudosecondary	**Two-phase, H_2O-liquid rich**
	(H_2O 0.95, CO_2 0.05, NaCl <0.01)
	Th: range 160 to 260, average 200
	Th_{CO2}: range 20 to 31, mode 27.5
	Tm_{cl}: range 7.0 to 10.5, mode 9.5
	Tm_i(?): range −0.5 to −2.5, average −1.8
	Tm_{CO2}: range −56.6 to −57.5, mode −56.8
	V/V+L: range 5-15 vol.%, mode 10 vol.%
	r carbonic: $0.7 g/cm^3$ r bulk: $0.97 g/cm^3$
	Vbar: 20 $moles/cm^3$
Type 3 Secondary	**Two-phase, H_2O-liquid rich**
	(H_2O 0.99, NaCl <0.01)
	Th: range 120 to 180, average 150
	Tm_i: range −0.1 to −1.0, average −0.5
	V/V+L: 2-7 vol.%, mode 5 vol.%
	r bulk: $1.00 g/cm^3$
	Vbar: 18 $moles/cm^3$

[1] Approximate mole fractions.
[2] Averaged from histogram modes in Leitch and Godwin (1988). Mean value is 280, standard deviation ± 36, 276 measurements.
[3] Mode from histograms in Figure 2-2-1.
[4] Abbreviations: Th = final homogenization temperature; Td = decrepitation temperature; Th_{CO2} = homogenization temperature of CO_2; Tm_{cl} = final melting point of clathrate; Tm_i = final melting point of ice; Tm_{CO2} = final melting point of CO_2; V/V+L = ratio of vapour bubble to liquid; r = density; Vbar = molar volume.

Type 1b inclusions in quartz, shown in solid black in Figure 2-2-2, usually homogenize to vapour. They are vapour-rich and contain abundant methane and carbon dioxide (0.3 to 0.9 mole fraction carbonic component of the total contents, with a mode of 0.5), consisting of $X_{CH4}=0.25$, $X_{CO2}=0.25$.

Type 2 inclusions in quartz are pseudosecondary (marked "PS" in Figure 2-2-2). They homogenize to the liquid phase, and contain no methane and only minor carbon dioxide (mode of less than 0.1 mole fraction of the total contents), that is not often visible as a separate phase but may be inferred from clathrate melting temperatures. Primary inclusions in calcite (hachured in Figure 2-2-2) have similar characteristics to pseudosecondary inclusions in quartz.

Type 3 inclusions in both quartz and calcite are secondary (S in Figure 2-2-2), and are localized along through-going fractures. They have no detectable carbonic behaviour and homogenize to the liquid phase.

DENSITIES

Data in Table 2-2-1 and Figure 2-2-2 indicate that the carbonic (non-aqueous) portions of Type 1b (methane-rich) inclusions have lower densities (0.60) compared to Type 1a carbon-dioxide-rich inclusions (0.70) and to Type 2 inclusions (0.70). These densities are based on the temperatures of homogenization of the carbonic portion of the inclusion (Th_{CO2}), and data in diagrams from Swanenberg (1979) and Hollister (1981). The homogenization temperatures of the carbonic fluid, difficult to measure reliably for Type 1b inclusions because of the overlap with the clathrate melting temperatures, are well defined for Type 1a and Type 2. Bulk densities, equivalent mole fraction CO_2, and molar volumes (Vbar) for the inclusions were estimated from Brown and Lamb (1986), assuming a density of 1.02 grams per cubic centimetre weight per cent for a 3 weight per cent equivalent NaCl solution (Potter and Brown, 1977) and using Swanenberg's method of computing equivalent CO_2 for inclusions containing both methane and carbon dioxide.

SALINITIES

Salinities of primary and pseudosecondary fluid inclusions at Bralorne are difficult to estimate because of variable amounts of both carbon dioxide and methane (compare Collins, 1979). The withdrawal of water attendant upon the formation of clathrates causes the aqueous solution to become more saline, depressing the melting point of ice. Thus the Tmi data presented in Leitch and Godwin (1988) for Type 1 inclusions (5 weight per cent NaCl equivalent), and for Type 2 inclusions (2 weight per cent NaCl equivalent), overestimates the salinity of the aqueous solutions (using the equation of Potter *et al.*, 1978). If only carbon dioxide is present, the salinity can be correctly estimated from clathrate melting temperatures (Bozzo *et al.*, 1973). A clathrate melting temperature of +9.5°C (mode from P, PS peak in Figure 2-2-2), suggests 1 weight per cent NaCl equivalent for the Type 2 inclusions in quartz and calcite. Ice melting is not seen in the Type 1b methane-rich inclusions and the clathrate melting temperature (12.4°C) is well above 10°C (the presence of methane has an opposite effect on the clathrate melting temperature from that of dissolved salt), so the method of Bozzo *et al.* is not applicable. Using the method of Linnen (1985), the positive correlation between mole fraction CH_4 and Tmi in Type 1a and 1b inclusions suggests roughly equivalent salinities. The salinity of the Type 1 inclusions can therefore only be estimated to be between 1 and 5 weight per cent NaCl equivalent; hence a value of 32 weight per cent is assumed. Type 3 inclusions have ice melting temperatures just below that of pure water (−0.5°C), implying a salinity of about 0.8 weight per cent NaCl equivalent.

COMPOSITIONS

Estimates of the salt composition of ore fluids at Bralorne were hampered by an inability to clearly see eutectic (first melting) temperatures. Vaguely detectable eutectic temperatures in inclusions in quartz (Figure 2-2-2) show modes at −20.5°, −23° and possibly −32°C. When compared to eutectic temperatures for different salt-water systems (for example, Roedder, 1984), these mean temperatures indicate that the fluids in Type 2 inclusions probably contained only NaCl, but that fluids in Type 1 inclusions may have also had minor amounts of KCl. This conclusion is supported by the computer modelling of the ore fluid (see below), which suggests a Na:K ratio of about 8:1. The uncertain eutectic temperature of −32°C might indicate the presence of a divalent cation, such as magnesium (compare Crawford, 1981). Occasionally observed eutectic temperatures in primary inclusions in calcite (Leiteh and Godwin, 1988) of about −26°C may also indicate the presence of magnesium (or possibly calcium).

PRESSURE ESTIMATES

Bulk density estimates of the inclusion fluids, and specifically for the carbonic portion of the various types of inclusion, serve to define isochores on a pressure-temperature (P-T) plot. Assuming pure CO_2 in the carbonic fluid, the isochores may be projected to temperatures of entrapment (estimated from Th), providing estimates of entrapment pressures (Hollister and Burruss, 1976). Similarly, if temperatures of entrapment are estimated independently from sulphur isotope fractionations between coexisting galena-sphalerite pairs as 350°C for primary inclusions and 250°C for pseudosecondary inclusions (Leitch and Godwin, 1988), estimated entrapment pressures are about 150 and 75 megapascals (1.5 and 0.75 kilobars) respectively. Pressure estimates for entrapment at 350° and 250°C based on the simple assumption of pure H_2O fluids, are 100 and 50 megapascals respectively (Leitch and Godwin, 1988).

Type 1b (vapour-rich), and to a lesser extent Type 1a inclusions, decrepitate at temperatures ranging from 230° to 330°C (most decrepitated before homogenizing). Decrepitation over such a small temperature range is consistent with rapid pressure increases in carbonic fluids at temperatures above 250°C (Malinin, 1974). Since internal pressures of up to 120 megapascals (1.2 kilobars) are required to decrepitate 12 to 13 micron size inclusions in quartz, and up to 270 megapascals for smaller inclusions (Leroy, 1979), a minimum trapping pressure of at least 100 megapascals is implied for the 3 to 10 mieron Bralorne inclusions, in agreement with the pressure estimates from projection of isochores.

The pressure-temperature conditions of entrapment of the primary and pseudosecondary fluids at Bralorne can also be evaluated using solubility relationships for H_2O and CO_2 in salt solution (Bowers and Helgeson, 1983a). Fluids in Type 1a inclusions, with mole fractions of $XCO_2=0.1$ and $XCH_4=0.05$, salinities of about 3 weight per cent NaCl equivalent, and Th less than or equal to 300°C, would have been supercritical at pressures above 150 megapascals. If the 0.95 gram per cubic eentimetre isochore is projected to the solvus for these inclusions at the estimated trapping temperature of 350°C, the pressure of entrapment is constrained to 175 megapascals (Bowers and Helgeson, 1983b). For primary Type 1b fluids, with mean carbonic mole fraction of 0.5, estimated mean bulk density of 0.8 gram per cubic centimetre and salinity of 32 weight per cent NaCl equivalent, decrepitation temperatures of 230° to 300°C give minimum estimates of internal (and, therefore trapping) pressures of 150 megapascals.

TABLE 2-2-2
SUMMARY OF PRESSURE ESTIMATES FOR THE BRALORNE DEPOSIT

Fluid Type	Primary		Pseudosecondary
Inclusion Type	(1a)	(1b)	(2)
L&G (1988)	1.0 (100)		0.5 (50)
Leroy (1979)	>1.0 (>100)	>1.0 (>100)	
H&B (1975)	1.5 (150)		0.75 (75)
B&H (1983b)	1.75 (175)	1.5 (150)	1.0 (100)

References: L&G = Leitch and Godwin (1988); H&B = Hollister and Burruss (1975); B&H = Bowers and Helgeson (1983b) Pressures in kb; bracketed figures are in megapascals

The presence of occasional vapour-rich, methane-rich Type 1b inclusions with the far more abundant vapour-poor, methane-poor Type 1a inclusions raises the possibility of trapping at subcritical temperatures. However, Type 1b inclusions are so rare in comparison to Type 1a that most trapping was probably at or above the solvus. Also, continued fault movement at lower temperatures could have produced heterogeneous populations of inclusions when earlier inclusions were broken.

Similarly, Type 2 pseudosecondary fluids, with $XCO_2=0.05$, mean salinity of 1 weight per cent NaCl equivalent, and mean Th of 200°C, would have been supercritical above 75 megapascals (Bowers and Helgeson, 1983a). If the 0.97 gram per cubic centimetre isochore is projected to the solvus for these inclusions at the estimated trapping temperature of 250°C, the pressute of entrapment is constrained to 100 megapascals (Bowers and Helgeson, 1983b).

In summary, pressures of entrapment that consider the combined CO_2-CH_4 compositions of the fluids (Bowers and Helgeson, 1983a,b) imply higher pressures (from 100 to 175 megapascals) than those that consider the inclusions as pure carbon dioxide (Hollister and Burruss, 1975) at 75 to 150 megapascals, or from the pressure corrections necessary to correlate homogenization temperatures of aqueous inclusions with temperatures from sulphur isotopes (50 to 100 megapascals). Estimated pressures of entrapment for pseudosecondary and primary fluids are compared in Table 2-2-2.

EVOLUTION OF MINERALIZING FLUIDS

There appears to be a progression in fluid composition at Bralorne from Type 1 to Type 2 to Type 3. Early, Type 1 primary fluids were high temperature (350°C), carbon dioxide and methane rich ($XCO_2+XCH_4=0.15$), with low salinities (approximately 3 weight per cent NaCl equivalent). Later, Type 2 pseudosecondary fluids were lower temperature (250°C), with less carbon dioxide ($XCO_2=0.05$), no methane, and had lower salinities (less than 1 weight per cent NaCl equivalent). Type 3 (secondary) fluids were coolest (180°C), with carbon dioxide below the detection limit of 0.03 mole fraction, but the same low salinity as the pseudosecondary fluids. The evolution of the fluids can be explained by a simple mixing of hotter, more saline, carbon dioxide and methane-rich fluid with progressively greater amounts of cold, more dilute meteoric water over time, as the hydrothermal system waned.

The estimated pressures of entrapment are lower for Type 2 pseudosecondary inclusions than for Type 1 primary inclusions. Also, the geothermal gradient was probably lower (10°C per kilometre) at the time of entrapment of the pseudosecondary fluids than it was for the primary fluids (30°C per kilometre; Leitch and Godwin, 1988). These two features suggest that the deposit had been partly unroofed and the rock mass had cooled by the time of entrapment of the fluids in the pseudosecondary, and finally secondary, inclusions.

If the higher pressures estimated above for the primary and pseudosecondary inclusions (Table 2-2-2), which are consistent with calculations of Leroy (1979), are correct, then the early (main) mineralizing event took place at depths of 6 to 10 kilometres from fluids of Type 1. Later mineralization took place at depths of 2 to 6 kilometres from fluids of Type 2. These pressures and depths are comparable to those estimated by Smith *et al.* (1984: 130 to 290 megapascals, or 5 to 12 kilometres) for a similar mesothermal gold vein deposit at Timmins, Ontario. These figures have since been questioned by Brown and Lamb (1986), who suggested much higher pressures (350 to 800 megapascals; 15 to 30 kilometres depth), based on extrapolation to elevated temperature and pressure of isochores calculated from molar volumes at room temperature, rather than from molar volumes at the elevated conditions. Such pressures seem unrealistically high for the Bralorne camp, if the geothermal gradient was as high as 30°C per kilometre (Leitch and Godwin, 1988).

OXYGEN ISOTOPE STUDIES

One hundred oxygen isotope analyses (ineluding 11 duplicates) of mineral separates and whole-rock samples from 15 different vein systems in the deposit were obtained, in order to establish lateral and vertical zonations within the deposit; derive estimates of the temperature of alteration and mineralization independent of the fluid inclusion and sulphur-isotope studies; examine fluid-wallrock interactions and water:rock ratios; and estimate the isotopic compositions and origin of the mineralizing fluids. These isotopic data are presented in Tables 2-2-3 and 2-2-4. Vein quartz was sampled at surface over a distance of almost 6 kilometres from the Cosmopolitan vein at the northwest end, to the P.E. Gold

TABLE 2-2-3

OXYGEN ISOTOPE COMPOSITIONS OF MINERALS AND ROCKS IN THE BRALORNE-PIONEER MESOTHERMAL GOLD VEIN SYSTEM.

Vein Quartz: (all milky quartz except clear quartz, marked*)

Sample	Level	Vein Name	Host Rock	d^{18}O	Tt	d^{18}O Fluid
C1002	0	Cosmopolitan	Diorite	19.4		
C1027	3	51 (Surface)	Diorite	19.1	320	12.9
C048	4	77 (Surface)	Diorite	17.3		
Pioneer	4	HW Main	Soda Gr	18.0		
C049	10	PE Gold	Pioneer	14.9	360	9.4
851B(FW)	8	51B, in FW	Diorite	18.0	385	13.6
8-51Bsp	8	51B Split	Diorite	16.6		
8-51Bsp*	8	51B Split	Diorite	17.4	380	12.8
C081-2	8	51B Main	Diorite	18.4	350	13.1
C111-28	8	51B Main	Soda Gr	18.4	375	13.7
C111-28*	8	51B Main	Soda Gr	13.5	450	10.6
15-51(C)	15	51, center	Diorite	18.9	340	13.3
16-51(E)	16	51, in FW	Diorite	18.1	315	11.7
16-51 c	16	composite	Diorite	18.4	315	12.1
16-51(1)	16	1 cm from HW	Diorite	19.4		
(2)	16	3 cm from HW	Diorite	19.0		
(3)	16	6 cm from HW	Diorite	18.3		
(4)	16	10 cm from HW	Diorite	18.9	(315)	12.5
(5)	16	13 cm from HW	Diorite	18.6		
(6)	16	17 cm from HW	Diorite	18.9		
(7)	16	20 cm from HW	Diorite	18.6		
C118-11	26	85 vein	Soda Gr	14.8		
C118-11*	26	85 vein	Soda Gr	15.5	365	10.6
C116-3/16	41	77 vein	Diorite	17.3	400	13.2
C116-14	41	77 vein	Diorite	17.1	400	13.3
C128-20	44	79 vein	Diorite	17.1	410	13.0

Vein sericite and chlorite

Sample	Level	Vein	Mineral	d^{18}O mineral	permil qz-mineral fractionation	T °C
Pioneer	0	HW Main	sericite	13.6	4.4	400
C049	?	PE Gold	chlorite	12.0	2.8	1260
8-51Bsp	8	51B	sericite	13.9	3.5	460
C111-28	8	51	sericite	14.1	4.3	400
C117-7	32	79	sericite	10.7	(no qz)	—
C116-3/16	41	77	sericite	16.0	1.3	845
C128-20	44	79	sericite	12.1	5.0	360

Wall rock minerals: Unaltered rocks

Sample	Rock Type	d^{18}O mineral qz	ab	hb	mica[1]	permil qz-mineral fractionation ab	hb	mica[1]	T °C
C092A	Albitite	10.6	14.0			(R)			
C071	Albitite	9.5			11.7^{c}			(R)	
C4141	Albitite		12.8			(R)			
C093A	Diorite	14.3	13.8	6.2		0.5			730
							8.1		340
C094B	Soda Gr	11.5	12.3		9.9^{c}			1.6^{c}	1040
Wall rock minerals: Altered Rocks									
C033-9	Diorite	16.1	14.5	8.3		1.6			290
							8.3		350
C033-5/6	Diorite	16.2							
C033-1/2	Diorite	17.5			14.7^{f+m}			2.8^{m}	530
C002FW4	Diorite	15.3			7.8^{c}			2.7^{c}	325
C002FW1	Diorite	16.4			13.7^{m}			2.7^{m}	560
C080	Albitite				13.8^{f}				

Whole rocks: Unaltered rocks

Sample	Host Rock	d^{18}O	D(m)[3]	Sample	Host Rock	d^{18}O	D(m)
C083A	Hb Porphyry	10.0	>10	C094B	Soda Granite	12.7	>10
C092A	Albitite	13.5	>10	C095A	Pioneer	6.5	>10
C093A	Diorite	10.6	>10	C4141	Albitite	13.4	>10
Whole rocks: Altered rocks							
C1027HW3	Diorite	11.1	2.3	C116-23	Diorite	11.7	10.0
HW2	Diorite	12.9	0.3	-22	Diorite	13.0	5.0
HW1	Diorite	13.7	0.1	-21	Diorite	13.2	3.0
C002FW4	Diorite	13.9	3.5	-20	Diorite	13.0	2.0
FW3	Diorite	14.2	1.5	-19	Diorite	13.4	1.0
FW2	Diorite	15.2	0.4	-18	Diorite	12.8	0.3
FW1	Diorite	16.1	0.1	C128	Diorite	11.0	6.0
C033- 9	Diorite	11.8	10.0	-5	Diorite	11.9	4.0
-10	Diorite	13.0	10.0	-3	Diorite	11.6	2.0
-8	Diorite	14.1	8.0	-1	Diorite	12.1	0.1
-7	Diorite	13.4	5.0	C111-29	Soda Gr	13.7	0.5
-5/6	Diorite	14.9	3.5	-30	Soda Gr	13.8	1.0
-3/4	Diorite	16.1	1.5	-31	Soda Gr	13.9	3.5
-1/2	Diorite	16.4	0.3				

[1] For micaceous minerals, c = chlorite, m = muscovite, f = fuchsite.
[2] Abbreviations: R = reversal of d^{18}O values; Tt = trapping temperature estimated from fluid inclusions and sulfur isotopes; qz = quartz, ab = albite, hb = hornblende, ch = chlorite; Soda Gr = Soda granite, Pioneer = Pioneer greenstones, Albitite = albitite dyke, Hb Porphyry = hornblende porphyry dyke.
[3] Distance from vein in metres.

vein at the southeast end of the vein system (Figure 2-2-1a: plan view). To investigate isotopic variations with depth, samples were collected as deep as 44 level (2 kilometres deep) in the Bralorne mine (Figure 2-2-1b: section view).

PROCEDURE

Mineral separation for vein minerals (quartz, carbonate and sericite) was achieved by coarse crushing in an agate mortar and hand picking under a binocular microscope. Whole-rock samples of apparently "fresh" and altered wall-rocks were pulverized to approximately 95 per cent -200 mesh in a tungsten carbide or a chrome steel ring mill. Mineral separates from these crushed whole-rock samples were obtained by a combination of techniques including wet shaking table, heavy liquids, Frantz isodynamic separator and hand picking.

Standard procedures were used for oxygen isotope analyses: oxygen was extracted quantitatively with ClF_3 at 575°C (Borthwick and Harmon, 1982), and the isotopic ratios were determined on carbon dioxide produced by reaction with a hot carbon rod at 750°C (Clayton and Mayeda, 1963). The isotopic data are reported in Table 2-2-3 in the usual delta (d) notation relative to Standard Mean Ocean Water (SMOW). The mass spectrometric analyses are normalized to both SMOW and Standard Light Antarctic Precipitation (SLAP). The mean variation of delta determined from duplicate analyses is 0.09 per mil (Table 2-2-4). Our d^{18}O value for sample NBS-28 is 9.6 ± 0.1.

LATERAL AND VERTICAL ISOTOPIC ZONING IN QUARTZ VEINS

Except for one sample from the Pioneer Hangingwall Main vein, there appears to be a variation from lower d^{18}O

TABLE 2-2-4
DUPLICATE OXYGEN ISOTOPE DATA FOR THE BRALORNE-PIONEER DEPOSIT

Sample No.	Mineral[1]	Original $d^{18}O$	Duplicate $d^{18}O$	Average $d^{18}O$	Variation (±)
8-51B(FW)	qz	18.04	17.90	17.97	0.07
C111-28	qz	18.31	18.42	18.36	0.05
15-51(C)	qz	18.86	19.00	18.93	0.07
16-51	qz	18.10(E)	18.44(C)	18.27	0.17
C118-11	qz*	15.70	15.33	15.52	0.18
C049	qz	14.93	14.84	14.90	0.04
C082	qz	17.87	18.03,18.11	18.00	0.12
C1027	qz	19.19	19.08	19.13	0.06
C128-20	qz	17.24	17.03	17.13	0.10
C116-3/16	qz	17.20	17.39	17.29	0.09
C033-1/2	se/fu	14.81(se)	14.58(fu)	14.69	0.11
				Mean variation = 0.09	

[1] Abbreviations: qz = quartz, se/fu = sericite or fuchsite.

for vein quartz (+ 14.9) in the southeast to higher $d^{18}O$ (+ 19.4) in the northwest (Figure 2-2-1a). However, samples from the Pioneer mine and from the 77 vein at the Bralorne mine are almost within analytical error. The $d^{18}O$ of quartz from the P.E. Gold vein is lower than any of the other surface samples. The observed geographic variation in $d^{18}O$ of quartz may reflect spatial variations in $d^{18}O$ of the mineralizing fluids, or variations in temperature from hottest at the southeast to coolest at the northwest. Mineralogical data (biotite is more common towards the southeast: Leitch and Godwin, 1988; Joubin, 1948; Nordine, 1983) and structural data suggesting a deeper level of exposure to the southeast (Joubin, 1948) are consistent with a geographic variation in temperature of vein formation, at the level of exposure sampled.

A similar variation in $d^{18}O$ of quartz, where d-values decrease with depth, is suggested by data in Figure 2-2-1b. Highest values of $d^{18}O$ are found at greater elevations in the system (Cosmopolitan vein at surface); lowest values are in the deepest levels (41 and 44 levels, 1800 to 2000 metres depth).

A detailed traverse across the 51 vein on 16 level (samples 1 to 7 in Table 2-2-3) was made to test for small-scale variations in the vein quartz. However, there was no significant change across the 20-centimetre width sampled, so the vein quartz at Bralorne appears to be relatively homogeneous in terms of its $d^{18}O$.

GEOTHERMOMETRY

Mineral pairs of quartz-sericite and quartz-chlorite were analysed from veins and wallrocks to estimate the temperature of mineralization based on oxygen isotope fractionations. Other mineral pairs (quartz-albite and quartz-hornblende) were analysed to estimate the temperature of emplacement of the host Bralorne intrusions. All these mineral pairs were observed intergrown with each other and are assumed to have formed in equilibrium. Temperatures of mineralization, calculated with the relevant fractionation equation, are presented in Table 2-2-3. In the following discussion, the term "unaltered" is used for rocks that are not visibly hydrothermally altered (C093A and C094A), although their isotopic ratios and lower greenschist mineral assemblages show that they are not truly fresh.

For **quartz-sericite,** the equation of Bottinga and Javoy (1975) was used rather than that of Clayton *et al.* (1972) combined with that of O'Neil and Taylor (1969), because the latter approach gave unreasonably low temperatures. Calculated temperatures vary from 360° to 405°C for milky quartz from the Bralorne 51 vein on 8 level (350 metres depth), 86 vein on 26 level (1200 metres depth), and Pioneer HW Main vein (at surface). A sample of clear quartz (Bralorne 51 vein on 8 level) and associated, but not intergrown, mica yielded a high temperature of 470°C. This quartz is paragenetically distinct, forming clear euhedral crystals that also have anomalously high homogenization fluid-inclusion temperatures (Leitch and Godwin, 1988). The quartz-sericite pair from the 79 vein (41 level) gives an unrealistically high temperature of 845°C. However, contamination of the sericite by fine-grained quartz is likely since the separate was not hand-picked and the sericite $d^{18}O$ value of 16.0 is 2 to 3 per mil higher than all other sericites. For altered wallrocks, estimates of mineralization temperature range from 530° to 560°C for the 51 vein on 15 level (650 metres below surface) to 560°C for the same vein on 8 level (Table 2-2-3).

With the quartz-chlorite equation of Wenner and Taylor (1971) most of the **quartz-chlorite** pairs analysed give either unrealistically high temperatures or are reversed (provide no valid temperatures). Only one sample, C002FW4, from altered wallrock around the 51 vein on 8 level, gave a geologically reasonable temperature of 325°C. Isotopic disequilibrium indicated between the quartz-chlorite vein minerals may stem from crystallization at different times and/or re-equilibration of the chlorite with subsequent fluids at lower temperatures.

Using the **quartz-albite** pair (Matthews *et al.*, 1983), a weakly altered sample, 10 metres from the 51 vein on 15 level (C033-9), gives a temperature of 290°C, which appears to be strongly isotopically reset towards lower temperatures by the hydrothermal alteration. Unaltered "fresh" wallrock (C093A) gives a possibly magmatic quartz-albite temperature of 730°C.

For **quartz-hornblende** (Bottinga and Javoy, 1975), hornblende from unaltered Bralorne diorite (C093A), well removed from the main veins, gives a similar temperature (340°C) to that from quartz-hornblende in C033-9, 10 metres from the 51 vein on 15 level, which gives 350°C. Both these figures are extrapolated slightly outside the listed range of the equation. However, as for the quartz-albite pairs, they imply a high degree of interaction of the wallrock with the altering fluids, (that is: a high water:rock ratio). The interaction is apparently more marked for the hydrous minerals, chlorite and hornblende, than for albite.

IMPLICATIONS FOR WATER:ROCK RATIOS

Samples from five detailed traverses across altered wallrocks at several levels within the mine, were analysed for whole-rock oxygen isotope ratios to test for isotopic zoning. Distances of samples from the vein are in Table 2-2-3; the width and style of the alteration envelopes are described in Leitch and Godwin (1988). Along two of these traverses, oxygen isotope measurements were also made on minerals.

Whole-rock and mineral oxygen isotope ratios increase as the veins are approached (Table 2-2-3). For instance, in the series C033-1 to 10, taken through altered diorite near the 51 vein on 15 level, there is a progression from $d^{18}O = +10.6$ in unaltered rock (estimated by C093A), to +18.9 immediately adjacent to the vein. The minor reversal between 7 and 8 is due to a subsidiary fracture off the main vein. The $d^{18}O$ varies in a similar way among samples from the other two series in diorite host rocks (51 vein on 8 level, C002FW1 to FW4; 51 vein on surface, C1027HW1 to HW3).

Whole-rock $d^{18}O$ values are also changed for at least 3.5 metres from the 51 vein on 8 level where it is hosted by a rock rich in quartz (soda granite). Values remain relatively constant at about 13.7 to 13.9 over this interval, compared to the unaltered rock at 12.7, and a vein $d^{18}O$ of 18.4. There is thus a clear pattern of widespread re-equilibration of the whole-rock $d^{18}O$ values in diorite and soda granite, due to hydrothermal alteration, for up to 10 metres from the veins.

Oxygen-isotope gradients are apparently not as pronounced at deeper elevations (lower mine levels) as for upper levels. On 41 level, 1600 metres below surface, around the 77 vein, the C116-23 to 18 series shows that there is a small increase from a value of 11.7 at 10 metres from the vein, to a plateau value of about 13.0 within 5 metres of the vein. Vein quartz here has a $d^{18}O$ value of 17.1. On 44 level, 1800 metres below surface, the C128 series shows very little or no variation within the limits of measurement: $d^{18}O$ whole-rock values remain at about 11 to 12. Both these traverses are in much more mafic wallrock than the typical diorite. These more mafic variants contain less than 5 per cent quartz, and are principally composed of large amounts of clinopyroxene, hornblende, or their alteration products (chlorite).

Quartz in the altered envelopes on 8 and 15 levels has a high $d^{18}O$ compared to quartz in the unaltered rock. Quartz $d^{18}O$ values increase systematically towards the veins (that is 51 vein on 15 level, C033 series, from 18.9 to 14.3; Table 2-2-3). Similarly, for the C002FW1 series around the 51 vein on 8 level, the variation is 18.0 to 14.3. The other major rock-forming minerals in the diorite, plagioclase and hornblende, show increases in $d^{18}O$ toward the veins (to within 10 metres) as long as they are stable. The variation in $d^{18}O$ of plagioclase is from 13.8 to 14.5, and for hornblende from 6.2 to 8.3.

In summary, the whole-rock $d^{18}O$ patterns in hydrothermally altered wallrock envelopes may be largely due to the amount of quartz added during the alteration of diorites and soda granites, which as shown, is shifted towards higher $d^{18}O$ values closer to the vein. In the more mafic host rocks at deeper levels, the lack of alteration quartz may explain the smaller shifts observed in whole-rock $d^{18}O$ values. The strong shifts in $d^{18}O$ values for both mineral separates and whole-rock samples imply high water:rock ratios during the alteration, a feature common to other carbonate alteration zones around mesothermal gold quartz veins (Kerrich, 1983; Taylor, 1987).

OXYGEN-ISOTOPE COMPOSITION OF THE ORE FLUID

Oxygen isotope compositions of mineralizing fluids were calculated from isotopic analyses of vein quartz, trapping temperatures estimated from fluid-inclusion studies, and the quartz-water fractionation equation of Clayton *et al.* (1972). Calculated values of $d^{18}O$ fluid are given in Table 2-2-3.

The $d^{18}O$ of the ore fluid appears to have been reasonably constant at 131 per mil from bottom to top of the vein system. Two quartz samples, from the P.E. Gold vein and the 51 vein on 26 level have lower $d^{18}O$ fluid values. The vertical spatial variation in $d^{18}O$ of vein quartz (decreasing d-values with depth) is thought due to a gradual increase in temperature with depth rather than variation in $d^{18}O$ fluid.

The small-scale variation above, is similar to the regional lateral variation in observed $d^{18}O$ of quartz described by Nesbitt *et al.* (1987). Deposits are zoned from the high-temperature Bralorne-type gold-quartz veins with $d^{18}O$ quartz $= 17.5 \pm 1.0$, to intermediate temperature antimony-silver-gold veins with $d^{18}O$ quartz $= 21.0 \pm 1.0$, to low-temperature mercury deposits with $d^{18}O$ quartz $= 29.0 \pm 2.0$, by deposition from the same or similar deeply circulating, highly evolved ($d^{18}O$-shifted) fluids of around 11.52 per mil (corrected to the estimated trapping temperature of 350°C), which is within analytical uncertainty of the value obtained for Bralorne in this study. The strong enrichment in $d^{18}O$ values of quartz, combined with D/H studies of fluid inclusions, led Nesbitt *et al.* (1985, 1987) to propose that the ore-forming fluids were composed simply of meteoric water that had circulated deeply during regionally extensive transcurrent faulting. The calculated $d^{18}O$ fluid of +13 per mil at Bralorne is virtually identical to the values for the Coquihalla deposits near Hope, British Columbia and the Mother Lode deposits in California (Taylor, 1987), and is in the middle of the range for metamorphic waters. However, the concept of "metamorphic water" must be clarified, as its original isotopic definition (Taylor, 1974) is not meant to imply water of dehydration (*see* Taylor, 1987). Inasmuch as most water/rock reactions involve either sea water or meteoric water, the evolved meteoric water hypothesis seems reasonable but might be further constrained by data from hydrogen isotope studies (in progress). For example, in similar deposits in the Mother Lode of California, sericite and mariposite associated with alteration and gold mineralization formed from waters with somewhat higher dD than waters in some fluid inclusions in adjacent quartz veins, indicating mixing of waters with different evolutionary histories (*see* Taylor, 1987).

The hypothesis of meteoric water (Nesbitt *et al.*, 1987) as the principal ore fluid does not explain the abundance of carbon dioxide in the ore fluids. Such high carbon dioxide contents are consistent with fluids produced by metamorphic devolatilization at amphibolite to granulite facies, and have been interpreted as metamorphically derived fluids (Kerrich, 1983; Colvine *et al.*, 1984). A more complex, mixed origin for hydrogen-oxygen-carbon-sulphur in the mineralizing fluids must be considered for fluids circulating along principal structural and tectonic boundaries. For example, emplacement of mafic magmas along major tectonic zones provides a source of carbon dioxide isotopically similar to that found in the Mother Lode (Taylor, 1987).

THERMOCHEMICAL MODELLING OF WATER/ROCK REACTION

FLUID CHARACTERISTICS

The chemical characteristics of the ore-forming fluid at Bralorne were modelled using the PATH computer program (Helgeson *et al.*, 1970; Perkins, 1980). Thermodynamic data from Helgeson (1969) were used for the aqueous species and from Helgeson *et al.* (1978) for solid phases. Gold chloride complexes were included but not thiosulphide complexes, although if the latter were included the results would not change except to increase the total gold in solution (Seward, 1973). The program models the ore fluid by progressive titration, or step-wise water/rock reactions, first calculating the fluid that would be in equilibrium with the observed alteration assemblage, then "reacting" the fluid with "fresh" rock of the observed composition. The program writes detailed reactions for each step in the process, considering as many as 25 reactants and as many products.

Any model for mineralization at the Bralorne deposit must account for the strong, widespread carbonate alteration accompanying ore deposition. The typical mineral assemblage in altered wallrock includes quartz, muscovite, dolomite, calcite, albite, chlorite, pyrite and native gold. Thermodynamic data for arsenic compounds are not available, so the implications of the arsenopyrite commonly seen in the vein assemblage cannot be assessed. The ore fluid in equilibrium with the observed alteration assemblage is characterized in Table 2-2-5. Except for the carbon dioxide fugacity, the characteristics are similar to those described by Helgeson and Garrels (1968) for deposition of gold, pyrite and quartz in response to temperature drop. The high carbon dioxide content is dictated by the carbonate alteration in the present study, supporting gold deposition by reaction with the wallrock. The gold content of the ore fluid predicted by our model (roughly 0.1 to 0.2 ppb), is also much lower than previous estimates. Our estimate is much closer to the average from mineralized areas of 0.1 ppb, measured by McHugh (1988). Such low predicted gold contents emphasize the importance of understanding gold depositing mechanisms, rather than transporting mechanisms, in order to adequately explain the formation of large gold deposits like Bralorne.

In order to model chemical reaction between wallrock and ore fluid, the Bralorne diorite was assumed to comprise an original mineral assemblage of 60 per cent albite, 6 per cent tremolite and 34 per cent ferrosilite (thermodynamic data are not available for hornblende, a compositionally complex mineral). The temperature and pressure constraints applied were constant at 300°C and 100 megapascals (selected to be as close as possible to the fluid inclusion information without being out of the range of the experimental data in PATH). The alteration mineralogy predicted by the program fits well with the sequence observed outwards from the veins at Bralorne. Close to the vein, the model predicts dissolution of the starting minerals (albite and tremolite + ferrosilite), and precipitation of major amounts of quartz, dolomite and muscovite, minor amounts of pyrite, and minute amounts of native gold. Gold precipitation is most favoured in the early steps of the process; the bulk of the gold (about two-thirds of the total) is deposited immediately adjacent to the vein as the carbon dioxide bearing fluids react with the wallrock. Gold precipitation is predicted to decrease sharply as soon as graphite (in trace amounts) becomes stable. Further from the vein, chlorite becomes stable (approximated thermodynamically by talc, for which data are available), and further out still, albite becomes stable where muscovite is no longer stable. Concurrent with these changes, as the fugacity of sulphur in the fluid drops, the stable sulphide becomes pyrrhotite rather than pyrite, and the precipitation of gold is no longer favoured. Where magnetite becomes stable (furthest from the vein), gold is dissolved. The model thus predicts a strong correlation of gold with pyrite and an absence of significant gold from pyrrhotite or magnetite-bearing assemblages.

TABLE 2-2-5
CHARACTERISTICS OF THE ORE FLUID AT THE BRALORNE DEPOSIT, PREDICTED BY THE PATH PROGRAM

Temperature = 350°C[1]		Pressure = 1.75 Kb[1]	
pH = 4.5 (slightly acid at 350°C and 1.75 Kb)			
Na/K = 8:1	[Na] = 0.4 m	[K] = 0.05 m	[Cl] = 0.5 m
(Total salinity = 0.5 m, approximately 3 wt. %)			
$f_{CO2} = 10^{2.5}$	$f_{CH4} = 10^{0.5}$	$f_{O2} = 10^{-30}$	$f_{S2} = 10^{-7}$
$[Fe^{++}] = 1 \times 10^{-7}$ m	$[Mg^{++}] = 0.003$ m		$[Ca^{++}] = 0.01$ m
$[S^{--}] = 10^{-10}$ m		$[Au^{+}] = 10^{-10}$ m (0.1 ppb, as $AuCl_2^-$)	

[1] Estimated from fluid inclusion studies

The actual precipitation of the gold in the constructed PATH reaction model involves reduction of the aurous gold, Au^+, in the $AuCl_2^-$ complex, to native gold, Au^o, by donation of an electron. This process seems to be controlled by a concurrent oxidation reaction, of S^- in H_2S, to sulphur in pyrite, FeS_2, which may be thought of as S_{S-}. This is suggested by the strong correlation in the model between Fe^{++} consumption and pyrite production on the one hand, with gold produced on the other. Consideration of charge balance requirements for Equation 2 (Table 2-2-4) shows that in this reaction, the small extra amount of S^{2-} (in H_2S) being oxidized to S in pyrite (thought of as S^-) is the same as the small amount of gold being precipitated. As soon as carbon (graphite) becomes stable ($C^{4+} + 4e^- = C^o$), the competition for available electrons appears to sharply reduce the possibility of precipitating gold.

COMPARISON OF PREDICTED AND OBSERVED MINERAL ASSEMBLAGES

Many of the features predicted above correspond to observed mineral assemblages. In the altered envelopes there is a transition outwards from a quartz-sericite-ankeritie-pyrite zone to a chlorite-albite-calcite zone. Amorphous carbon is seen occasionally in altered wallrocks but is never abundant. Only occasionally, in a late-stage carbonate alteration that is black with fine amorphous carbon, does it form as much as 1 per cent of the rock.

Assay data at the mine show that gold concentrations drop off sharply immediately outside the veins. From hand-specimen and microscope studies, the bulk of the gold is in the thin black ribbons of the quartz veins, not in the milky white quartz itself. In the ribbons, which are black due to finely divided pyrite (carbon has not been identified here), the gold is closely associated with the pyrite, plus arsenopyrite, sericite and minor ankerite. Pyrite and other sulphides are almost never seen in the quartz itself; the bulk of the sulphides are in the adjacent wallrocks and in the dark ribbons. Pyrrhotite is occasionally present in the altered wallrocks, but there is insufficient data to confirm the predicted inverse relationship between gold and pyrrhotite. Magnetite is not found in any rocks at Bralorne except as primary grains in the postmineral Bendor intrusives.

In detail, there is an empirically observed correlation between higher gold values and the presence of galena, and to a lesser extent, sphalerite (Joubin, 1948; Dolmage, 1934; Leitch and Godwin, 1988). Microscopically this is seen as gold, up to several hundred microns across, intergrown with galena in some of the Bralorne-Pioneer specimens, whereas the gold inclusions in pyrite and arsenopyrite tend to be smaller (less than 15 microns). The richest gold ore shoots are in diorite, peripheral to soda granite bodies, (Campbell, 1975; James and Weeks, 1961). This has formerly been explained by suggesting either a genetic relationship of ore to the soda granite (now disproved by isotopic dating: Leitch and Godwin, 1988), or by brittleness of the soda granite causing an inability to sustain large openings. However, the PATH model suggests that the more abundant iron in the diorite, the favoured host at Bralorne, and in the greenstone, the favoured host at Pioneer, could increase the precipitation of pyrite, and hence of gold.

FLUID MIGRATION AND MINERAL DEPOSITION

Any explanation for ore deposition at Bralorne must account for two notable features of the quartz veins: dark ribbons within the veins that contain the bulk of the gold; and syntaxial, coarse milky quartz crystals up to 1 centimetre long outlined by growth zones of minute primary fluid inclusions. Although many random orientations exist, these crystals are occasionally perpendicular to the ribbons or walls of the veins. This observation is supported by the strong induced piezo-electric-response of the quartz, which indicates alignment of the c-axes of many grains (M.M. Gomshei, personal communication, 1988).

The dark ribbons in the quartz imply a cyclic process, with repeated fracturing and precipitation of quartz. The coarse quartz crystals imply open-space growth under conditions of high fluid pressure. This might at first seem to be in conflict with the mesothermal environment of deposition (4 to 8 kilometres depth) where confining pressure is normally lithostatic. However, repeated fracturing and deposition of quartz at high hydrostatic pressures may be explained by the "fault-valve" model of Sibson *et al.* (1988). This model proposes that a geopressured reservoir of fluids derived by metamorphic devolatilization at amphibolite or granulite grade is developed by ponding below the ductile-brittle transition zone. This transition at the base of the seismogenic zone (the zone in which earthquakes are mainly concentrated) roughly corresponds to the transition to greenschist facies. Pore pressures become very high because steeply-dipping (55-75°) faults in a horizontally compressive stress field are in an inappropriate orientation for slip; the pressures are a maximum for structures dipping at about 57 degrees (Sibson *et al.*, 1988). In order to permit slip, and therefore rupture and fluid flow along the steep faults which host the Bralorne veins, the pore pressure must have exceeded the lithostatic pressure by the amount of the cohesive strength of the already-cemented faults. Such extremely high fluid pressures provide the environment for open-space coarse crystal growth at depths of over 4 kilometres. When rupture occurs, fluid flows into the open space of the fault where the sudden drop in pressure may promote deposition of quartz (Walther and Helgeson, 1977) and sulphides (Helgeson and Lichtner, 1987). Fluid flow would tend to die away slowly in such a system over a period of a few months (Sibson, 1981), possibly allowing time for coarse crystal growth.

As mineral deposition occurs and the fracture becomes sealed, pressure can rise again, leading to a repetition of the process. Such a cyclic process may explain the ribboning in the Bralorne veins. Each ribbon of quartz would have associated with it a black layer of intensely altered host rock consisting of pyrite, arsenopyrite, sericite and occasional ankerite, with gold, that formed the vein wall before rupture took place and the process was repeated again. The PATH model predicts that the bulk of the gold would be precipitated in the immediate envelope to the vein, so that incorporating even a sliver of wall rock into the vein would include most of the gold.

ACKNOWLEDGMENTS

Thanks are extended to Corona Corporation for access to underground workings and field support. Research at The University of British Columbia has been supported by grants from the British Columbia Ministry of Energy, Mines and Petroleum Resources and the Canada/British Columbia Mineral Development Agreement. Fluid inclusion studies were completed using equipment at the Ministry of Energy, Mines and Petroleum Resources in Victoria. Carbon dioxide from oxygen isotope extractions performed at the Geological Survey of Canada (Ottawa) was analysed in a mass spectrometer at the Ottawa Centre for Geoscience Studies/Geological Survey of Canada Stable Isotope Laboratory, with the assistance of G. St. Jean.

REFERENCES

Borthwick, J. and Harmon, R.S. (1982): A note Regarding ClF_3 as an Alternative to BrF_5 for Oxygen Isotope Analysis, *Geochimica et Cosmochimica Acta*, Volume 46, pages 1665-1668.

Bottinga, Y. and Javoy, M. (1975): Oxygen Isotope Partitioning Among the Minerals in Igneous and Metamorphic Rocks, *Reviews in Geophysics and Space Physics*, Volume 13, pages 401-418.

Bowers, T.S. and Helgeson, H.C. (1983a): Calculation of the Thermodynamic and Geochemical Consequences of Nonideal Mixing in the System H_2O-CO_2-NaCl on Phase Relations in Geologic Systems: Equation of State for H_2O-CO_2-NaCl Fluids at High Pressures and Temperatures, *Geochimica et Cosmochimica Acta*, Volume 47, pages 1244-1275.

——— (1983b): Calculation of Thermodynamic and Geochemical Consequences of Nonideal Mixing in the System H_2O-CO_2-NaCl on Phase Relations in Geologic Systems: Metamorphic Equilibria at High Pressures and Temperatures, *American Mineralogist*, Volume 68, page 1059-1075.

Bozzo, A.T., Chen, J.R. and Barduhu, A.J. (1973): The Properties of the Hydrates of Chlorine and Carbon Dioxide, *in* 4th *International Symposium on Fresh Water from the Sea*, A. Delyannis and E. Delyannis, Editors, Volume 3, pages 437-451.

Brown, P.E. and Lamb, W.M. (1986): Mixing of H_2O-CO_2 in Fluid Inclusions; Geobarometry and Archean Gold Deposits, *Geochimica et Cosmochimica Acta*, Volume 50, pages 847-852.

Campbell, D.D. (1975): Bridge River Gold Camp, Unpublished Report, *Dolmage Campbell & Associates (1975) Ltd.*, 7 pages.

Clayton, R.N., O'Neil, J.R. and Mayeda, T.K. (1972): Oxygen Isotope Exchange Between Quartz and Water, *Journal of Geophysical Research*, Volume 77, p. 3057-3067.

Clayton, R.N. and Mayeda, T.K. (1963): The Use of Bromine Pentafluoride in the Extraction of Oxygen from Oxides and Silicates for Isotopic Analyses, *Geochimica et Cosmochimica Acta*, Volume 27, pages 43-52.

Collins, P.L.F. (1979): Gas Hydrates in CO_2-bearing Fluid Inclusions and the Use of Freezing Data for Estimation of Salinity, *Economic Geology*, Volume 74, pages 1435-1444.

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, A.J., Lavigne, M.J., Jr., Macdonald, A.J. Marmont, S., Poulsen, K.H., Springer, J.S and Troop, D.G. (1984): An Integrated Model for the Origin of Archean Lode Gold deposits, *Ontario Geological Survey*, Open File Report 5524.

Crawford, M.L. (1981): Phase Equilibria in Aqueous Fluid Inclusions, *in* Short Course in Fluid Inclusions, L.S. Hollister and M.L. Crawford, Editors, *Mineralogical Association of Canada*, Volume 6, pages 75-97.

Dolmage, V. (1934): The Cariboo and Bridge River Goldfields, British Columbia, *Canadian Institute of Mining and Metallurgy*, Transactions, 1934, pages 405-430.

Helgeson, H.C. (1969): Thermodynamics of Hydrothermal Systems at Elevated Temperatures and Pressures, *American Journal of Science*, Volume 167, pages 729-804.

Helgeson, H.C. and Garrels, R.M. (1968): Hydrothermal Transport and Deposition of Gold, *Economic Geology*, Volume 63, pages 622-635.

Helgeson, H.C., Brown, T.H., Nigrini, A. and Jones, T.A. (1970): Calculation of Mass Transfer in Geochemical Processes Involving Aqueous Solutions, *Geochimica et Cosmochimica Acta*, Volume 34, pages 569-592.

Helgeson, H.C., Delany, J.M., Nesbitt, H.W. and Bird, D.K. (1978): Summary and Critique of the Thermodynamic Properties of Rock Forming Minerals, *American Journal of Science*, Volume 278-A, 229 pages.

Helgeson, H.C. and Lichtner, P.C. (1987): Fluid Flow and Mineral Reactions at High Temperatures and Pressures, *Geological Society of London Journal*, Volume 144, pages 313-326.

Hollister, L.S. (1981): Information Intrinsically Available from Fluid Inclusions, *in* Short Course in Fluid Inclusions, L.S. Hollister and M.L. Crawford, Editors, *Mineralogical Association of Canada* Volume 6, pages 1-12.

Hollister, L.S. and Burruss, R.C. (1976): Phase Equilibria in Fluid Inclusions from the Khtada Lake Metamorphic Complex, *Geochimica et Cosmochimica Acta*, Volume 40, pages 163-175.

James, D.H. and Weeks, J.P. (1961): Bridge River Mineral Area, British Columbia, *Canadian Institute of Mining and Metallurgy*, paper presented at Victoria Branch meeting Sept. 29, 1961, 10 pages.

Joubin, F.R. (1948): Structural Geology of the Bralorne and Pioneer Mines, Bridge River District, British Columbia, *Western Miner*, July 1948, pages 39-50.

Kerrich, R. (1983): Geochemistry of Gold Deposits in the Abitibi Greenstone Belt, *Canadian Institute of Mining and Metallurgy*, Special Volume 27, 75 pages.

Leitch, C.H.B. and Godwin, C.I. (1987): The Bralorne Gold Vein Deposit: an Update (92J/15), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 35-38.

——— (1988): Isotopic Ages, Wallrock Chemistry and Fluid Inclusion Data from the Bralorne Gold Vein Deposit (92J/15W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 301-324.

Leroy, J. (1979): Contribution a L'etalinnage de la Pression Interne des Inclusions Fluides lor de leur Decrepitation, *Bulletin Mineralogique*, Volume 102, pages 584-593.

Linnen, R. (1985): Contact Metamorphism, Wallrock Alteration, and Mineralization at the Trout Lake Stockwork Molybdenum Deposit, Southeastern British Columbia, Unpublished M.Sc. Thesis, *McGill University*, 220 pages.

Malinin, S.D. (1974): Thermodynamics of the H_2O-CO_2 System, *Geochemistry International*, Volume 11, pages 1060-1085.

Matthews, A., Goldsmith, J.R. and Clayton, R.M. (1983): Oxygen Isotope Fractionations Involving Pyroxenes: the Calibration of Mineral-pair Geothermometers, *Geochimica et Cosmochimica Acta*, Volume 47, pages 631-644.

McHugh, J.B. (1988): Concentration of Gold in Natural Waters, *Journal of Geochemical Exploration*, Volume 30, pages 85-94.

Nesbitt, B.E., Murowchick, J.B. and Muehlenbachs, K. (1985): Dual Origins of Lode Gold Deposits in the Canadian Cordillera, *Geology*, Volume 14, pages 506-509.

Nesbitt, B.E., Muehlenbachs, K. and Murowchick, J.B. (1987): Genesis of Au, Sb, and Hg Deposits in Accreted Terranes of the Canadian Cordillera, *Geological Asso-*

ciation of Canada, Annual Meeting, Program with Abstracts, Volume 12, page 70.

Nordine, G. (1983): Geological Report on the Pacific Eastern Property, Lillooet Mining Division, Private Report, *Amir Mines Ltd.*, 48 pages.

O'Neil, J.R. and Taylor, H.P., Jr. (1969): Oxygen Isotope Equilibrium Between Muscovite and Water, *Journal of Geophysical Research*, Volume 74, pages 6012-6022.

Perkins, E.H. (1980): A Re-investigation of the Theoretical Basis for the Calculation of Isothermal-isobaric Mass Transfer in Geochemical Systems Involving an Aqueous Phase, Unpublished M.Sc. Thesis, *The University of British Columbia.*

Potter, R.W. and Brown, D.L. (1977): The Volumetric Properties of Aqueous Sodium Chloride Solutions from 0° to 500°C at Pressures up to 2000 Bars Based on a Regression of Available Data in the Literature, *United States Geological Survey*, Bulletin 1421-C, 36 pages.

Potter, R.W., Clynne, M.A. and Brown, D.L. (1978): Freezing Point Depression of Aqueous Sodium Chloride Solutions, *Economic Geology*, Volume 73, pages 284-285.

Roedder, E. (1984): Fluid Inclusions, *Mineralogical Society of America*, Reviews in Mineralogy, Volume 12, 644 pages.

Roedder, E. (1979): Fluid Inclusions as Samples of Ore Fluids, *in* Geochemistry of Hydrothermal Ore Deposits, H.L. Barnes, Editor, *John Wiley and Sons*, New York, Second Edition, pages 684-737.

Seward, T.M. (1973): Thio Complexes of Gold and the Transport of Gold in Hydrothermal Ore Solutions, *Geochimica et Cosmochimica Acta*, Volume 37, pages 379-399.

Sibson, R.H., Robert, F. and Poulsen, K.H. (1988): High-angle Reverse Faults, Fluid-pressure Cycling, and Mesothermal Gold-quartz Deposits, *Geology*, Volume 16, pages 551-555.

Sibson, R.H. (1981): Fluid Flow Accompanying Faulting: Field Evidence and Models, *in* Earthquake Prediction: An International Review, D.W. Simpson, and P.G. Richards, Editors, *American Geophysical Union*, Maurice Ewing Series, Volume 4, pages 593-603.

Smith, T.J., Cloke, P.L. and Kesler, S.E. (1984): Geochemistry of Fluid Inclusions from the McIntyre-Hollinger Gold Deposit, Timmins, Ontario, Canada, *Economic Geology*, Volume 79, pages 1265-1285.

Swanenberg, H.E.C. (1979): Phase Equilibria in Carbonic Systems, and their Application to Freezing Studies of Fluid Inclusions, *Contributions to Mineralogy and Petrology*, Volume 68, pages 303-306.

Taylor, B.E. (1987): Stable Isotope Geochemistry of Ore-forming Fluids, *in* Short Course in Stable Isotope Geochemistry of Low Temperature Fluids, T.K. Kyser, Editor, *Mineralogical Association of Canada*, Short Course Handbook, Volume 13, pages 337-418.

Taylor, H.P., Jr. (1979): Oxygen and Hydrogen Isotope Relationships in Hydrothermal Ore Deposits, *in* Geochemistry of Hydrothermal Ore Deposits, 2nd Edition, H.L. Barnes, Editor, *John Wiley and Sons*, New York, pages 236-277.

——— (1974): The Application of Oxygen and Hydrogen Isotope Studies to Problems of Hydrothermal Alteration and Ore Deposition, *Economic Geology*, Volume 69, pages 843-883.

Walther, J.V. and Helgeson, H.C. (1977): Calculation of the Thermodynamic Properties of Aqueous Silica and the Solubility of Quartz and its Polymorphs at High Pressures and Temperatures, *American Journal of Science*, Volume 277, pages 1315-1351.

Wenner, D.B. and Taylor, H.P., Jr. (1971): Temperatures of Serpentinization of Ultramafic Rocks Based on $^{18}O/^{16}O$ Fractionation Between Coexisting Serpentine and Magnetite, *Contributions to Mineralogy and Petrology*, Volume 32, pages 165-185.

NOTES

SEDIMENTOLOGICAL CONTROLS ON GOLD DISTRIBUTION IN PLEISTOCENE PLACER DEPOSITS OF THE CARIBOO MINING DISTRICT, BRITISH COLUMBIA

By Nicholas Eyles and Stephen P. Kocsis
Glaciated Basin Research Group
University of Toronto, Scarborough Campus

KEYWORDS: Economic geology, Cariboo district, placer gold, Wisconsin glaciation, older gravels, postglacial gravels, lodgement till.

INTRODUCTION

Canada produces just over 100 tonnes of gold annually from lode, base metal and placer deposits. Placer gold production accounts for about 4.5 tonnes per year with the bulk of production shared between British Columbia and Yukon. In western Canada, gold and other precious metals are recovered from a wide range of Quaternary and Tertiary sediments but the stratigraphy and origin of the deposits remains poorly understood; it is the purpose of this report to describe the geology and sedimentology of Quaternary placers on the western flanks of the Cariboo Mountains in north-central British Columbia (Figure 2-3-1). The Cariboo district is a pre-eminent gold mining area with a long history of production and excellent prospects; the total placer gold production to date is close to 3 million ounces (100 000 kilograms). Prolific gold placers occur in relatively young Pleistocene sediments (less than 125 000 years before present) including subglacial deposits that accumulated below the last Cordilleran ice sheet after 30 000 years before present. The economic concentration of gold in lodgement tills and other subglacially deposited facies is of considerable interest given the more usual tendency of ice to disperse mineralized "float" (for example, Shilts, 1976). In this paper we attempt a preliminary discussion of concentrating mechanisms that may act subglacially; an exploration model developed for the Cariboo Mining District may apply to other gold placer areas in British Columbia and Yukon.

There is a substantial, largely anecdotal history of mining in the Cariboo area but geological details are elusive. Eyles and Kocsis (1988b) provide a summary of the evoluton of mining methods up to the present day. Hydraulic mining methods, used in the past to work large low-grade deposits by sluicing, can no longer be employed given stricter environmental controls to protect the tourism and fishing industries. Modern operators must be much more selective and a more detailed appreciation of the geology, origin and likely three-dimensional distribution of the Quaternary deposits is required.

PHYSICAL SETTING AND BEDROCK GEOLOGY

The Cariboo Mining District is centred on the two historic mining communities of Wells and Barkerville. Part of the study area, centred around Likely, lies within the Quesnel Mining District. The principal gold-producing valleys have been Lightning and Williams creeks (Figures 2-3-1 and 2). The area consists of an undulating, deeply dissected plateau with mountains rising to 2100 metres above sea level. Valleys are infilled with many tens of metres of Quaternary sediments but elevations above 1700 metres are generally drift-free.

The study area lies in an area of complex bedrock geology consisting of allochthonous terranes separated by moderately to steeply east-dipping thrust faults that trend northwest. Four terranes have been recognized in the area, each with an overlapping relationship as a result of dextral accretion of crustal blocks along the western margin of North America (Price *et al.*, 1981; Jones *et al.*, 1983; Howell *et al.*, 1987). From west to east, Struik (1985, 1986) identified Quesnel, Slide Mountain, Barkerville and Cariboo terranes separated by the Eureka, Pundata and Pleasant Valley faults. The study area lies almost entirely within the Barkerville terrane Figure 2-3-1) which is composed of about 2 kilometres of Late Proterozoic and Paleozoic limestones, tuffs, turbidites, pelites, siltites, quartzites and conglomerates.

The Barkerville terrane is divided stratigraphically into the lower and upper Snowshoe Group and the Sugar limestone. The Lower Snowshoe group, comprising pelites and minor marbles, tuffs and orthoquartzites, is of Precambrian age and lies unconformably below early Paleozoic upper Snowshoe strata, in part of Mississippian age. Upper Snowshoe strata are overlain by the early Permian Sugar limestone (Struik, 1986). In the context of the present paper, the Downey Creek succession within the upper Snowshoe Group is the most significant rock unit in the Barkerville terrane because it hosts lode gold mineralization and there is a good geographic correlation between the outcrop belt of the Downey Creek succession and placer operations (Figure 2-3-2). The Downey Creek rocks trend northwest through the study area. The lode gold is associated with interbedded marble and tuffs; the rock assemblage suggests sedimentation on a continental carbonate margin subject to episodic rifting and volcanism. Preliminary sedimentological observations suggest a deep-water volcanically influenced slope dominated by turbidite sedimentation.

Lode gold occurs in two principal associations within the Downey Creek succession. In the first, native gold and tellurides occur in hydrothermal quartz veins associated with iron sulphides (Cariboo Gold Quartz mine, Wells). Secondly, at the Mosquito Creek mine, also in Wells, very fine-grained native gold occurs as films on disseminated pyrite and

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

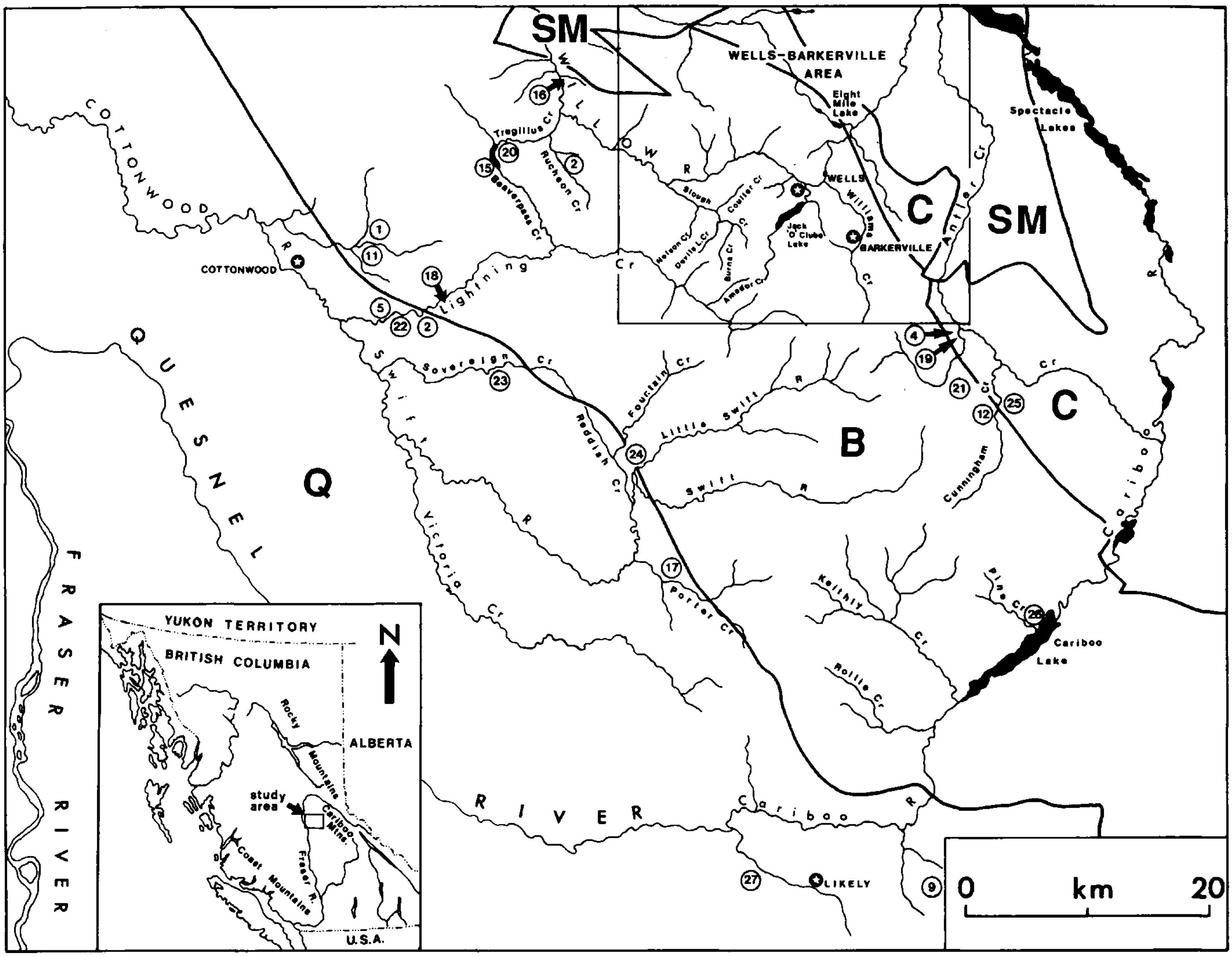


Figure 2-3-1. Location of Cariboo Mining District showing the distribution of Quesnel (Q), Barkerville (B), Slide Mountain (SM) and Cariboo (C) terranes. After Struick (1985). Numbers identify the 33 placer mines studied; mines within the Wells-Barkerville area (inside box) are shown on Figure 2-3-2. The sedimentology of placer mines 1-21 is shown on figures 2-3-4 and 5. (1) Alice Creek, (2) Lightning Creek (east of Moustique Creek), (3) Williams Creek, (4) California Gulch, (5) Lightning Creek (Lookout Point), (6) Grouse Creek (Heron Channel), (7) Eight Mile Lake, (8) Mary Creek (same as 11), (9) Spanish Mountain, (10) Eight Mile Lake, (11) Mary Creek, (12) Cunningham Creek, (13) Mount Nelson, (14) Pinus Creek, (15) Tregillus Lake (Quesnel Ready-Mix), (16) Alces Creek, (17) Porter Creek, (18) Lightning Creek (Wingdam), (19) Wolfe Creek, (20) northeast Tregillus Lake, (21) Nugget Gulch hydraulic pit, (22) Lightning Creek (west of Moustique Creek), (23) Sovereign Creek, (24) Little Swift River, (25) Cunningham Creek, (31) Devils Lake Creek, the hydraulic pits at (26) Pine Creek, (27) Bullion Pit, (28) Coulter Creek, (29) Point and (30) Ketch Benches along Slough Creek, (32) Burns Creek and (33) Fosters Ledge along upper Lightning Creek.

arsenopyrite occurring as replacement or possibly syngenetic sulphides in marble.

The precise origin of gold found in placer deposits world wide is not well constrained (Boyle, 1979; Wilson, 1984) and requires further work. Johnson and Uglow (1926) argued that deep weathering of quartz veins containing arsenopyrite and pyrite released free gold that could accumulate in crystal form as a result of supergene enrichment and this model is supported by the present study. Under conditions of deep Tertiary weathering, manganiferous siderite produced by oxidation would generate manganese dioxide which would promote gold solution transport, and sulphides could be expected to produce sulphuric acid. Placer gold varies in fineness from about 775 to 950; much gold is crystalline in the form of dodecahedrons, cubes and octahedrons, suggesting deposition from solution and limited transport. Mamillary nuggets indicating gradual accretion of gold particles are also found. Gold from each placer creek has distinct characteristics; this together with a common association with pyrite, galena and quartz, and the presence of only slightly worn crystal faces further suggests very local derivation and limited transport.

STRATIGRAPHIC SETTING OF PLACER DEPOSITS

In general, glacial and nonglacial sediments older than the last (Wisconsin) glaciation (less than 125 000 years before present) are not recognized in the Cariboo area. Older deposits and placers may be selectively preserved along buried preglacial drainage systems, an example being possibly the buried valley of the Quesnel River 4 kilometres west of Likely, where the Bullion mine (Figure 2-3-1) has produced over 3.7 million grams of gold during periodic mining over the last 100 years (Sharpe, 1939; Clague, 1987). The majority of the placers are hosted within relatively young Pleistocene sediments (less than 125 000 years before present). A generalized Pleistocene stratigraphy in the Cariboo recognizes thick lowermost gravels deposited during the lengthy cool-temperate nonglacial interval overlain by subglacial deposits from the late Wisconsin glaciation when the area was covered by westward-moving ice flowing from the Cariboo Mountains (Figure 2-3-3). Late Wisconsin glaciation was responsible for depositing extensive plugs of lodgement till and related subglacial facies along most valleys. These in turn, have been reworked or buried by postglacial (Holocene) mass-wasting and fluvial activity which has left valleyside fan deposits and terraced gravel sequences.

Figures 2-3-1 and 2 show the location of 33 placer operations that have been studied to date. What follows is a description of the sedimentology of representive preglacial, glacial and postglacial placers.

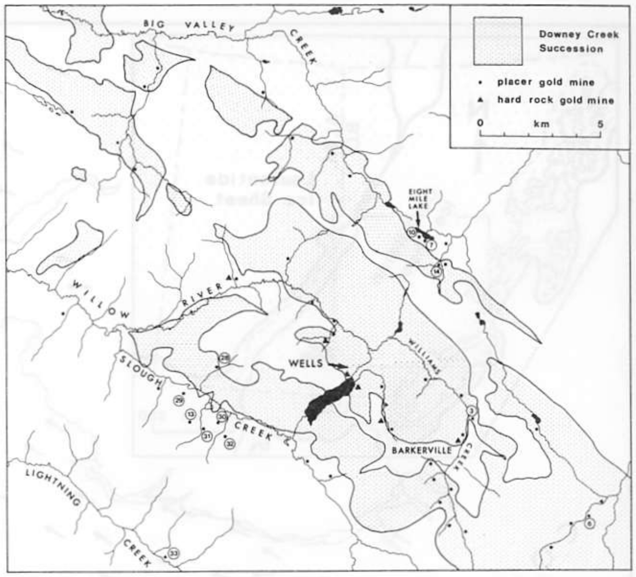


Figure 2-3-2. Distribution of the Downey Creek succession (stippled) together with placer and hardrock gold mines in the Wells-Barkerville area (Figure 2-3-1). Numbers identify location of placer operations noted in the text. Sedimentological logs from pits 1-21 are shown on Figures 2-3-4 and 5.

SEDIMENTOLOGY OF PLACER DEPOSITS

OLDER GRAVELS

Thick and extensive gravel units, truncated by Late Wisconsin glacial deposits, can be recognized throughout the study area (Figure 2-3-4). These gravels are older than 30 000 years and evidence suggests that they accumulated during a lengthy cool-temperate nonglacial interval (Clague, 1980; Clague, *et al.*, 1988; Fulton, 1984) when older glacial deposits and contained placers were extensively reworked by low-sinuosity braided rivers. These gravels, which commonly rest on bedrock as a result of a lengthy period of downcutting and reworking, are volumetrically the most important placers in the Cariboo area. They are often the most difficult to work, however, given the thickness of overburden. These gravels were, and still are, regarded as "Tertiary" by many placer miners because of their stratigraphic position below glacial sediments.

The basal, and in general the most coarse-grained gravels are the richest paying. At Alice Creek (Figure 2-3-5) gold values range from 0.52 grams per cubic metre to as high as 4.38 grams and there is a good correlation between gold values and boulder size. Gravels are weathered to a brown colour and show streaks of manganese dioxide. On the northeast margins of Tregillus Lake the highest gold values are also associated with boulder horizons within tabular beds of massive gravel that show a weak horizontal bedding. Deposition on longitudinal bars is indicated by boulder clusters suggesting frequent flood events (Brayshaw, 1984; Morison and Hein, 1987). At the Ballarat claim on Williams Creek gold grains, up to 1 gram in weight, occur within bouldery gravels recording sedimentation on the tops of longitudinal bars.

Because of the wide exposure of these preglacial gravels in placer mines, tentative paleogeographic reconstruction is possible. Braided rivers along valley floors, flanked by large valleyside fans and talus slopes, appear to have been dominant landscape elements. At California Gulch, about 7 kilometres southeast of Barkerville (Figures 2-3-1 and 2) talus 2 to 5 metres thick and consisting of crudely bedded downslope-dipping sheets of angular clasts, occurs below late Wisconsin lodgement tills. These gravels produce coarse, angular gold particals indicating local derivation, with grades averaging between 0.67 to 8.18 grams per cubic metre. These talus gravels are derived from nearby bedrock phyllites and limestones, and are representative of the "slide rocks" described by early placer miners (Johnson and Uglow, 1926).

On the western slope of Spanish Mountain, a large interstadial alluvial fan, blanketed by lodgement till, is currently exposed by placer mining. The upper surface of the fan gravels has been deformed by glacial overriding. Crudely bedded gravels dip down valley between 5 to 7 degrees and provide a profitable, low-yielding but high-volume operation. The area is well known for its good lode gold prospects and the fan may have received gold stripped from the surrounding plateau areas by cold-climate weathering processess (*see* Discussion). Two placer operations along the lower portion of Lightning Creek are working fan gravels of a similar character and genesis.

The key to the preservation of older fluvial and fan gravels below lodgement till sequences appears to be the protective role of lacustrine horizons. As ice expanded over the area during the early phases of the late Wisconsin glaciation, drainage disruption resulted in the formation of extensive ice-dammed lakes. These left a capping of fine-grained sediments over gravels (for example, Alice, Lightning and Mary creeks; Figure 2-3-5). Glacial erosion of the underlying gravels was limited, possibly because of reduced basal shear stresses at the ice base as it overrode fine-grained, saturated

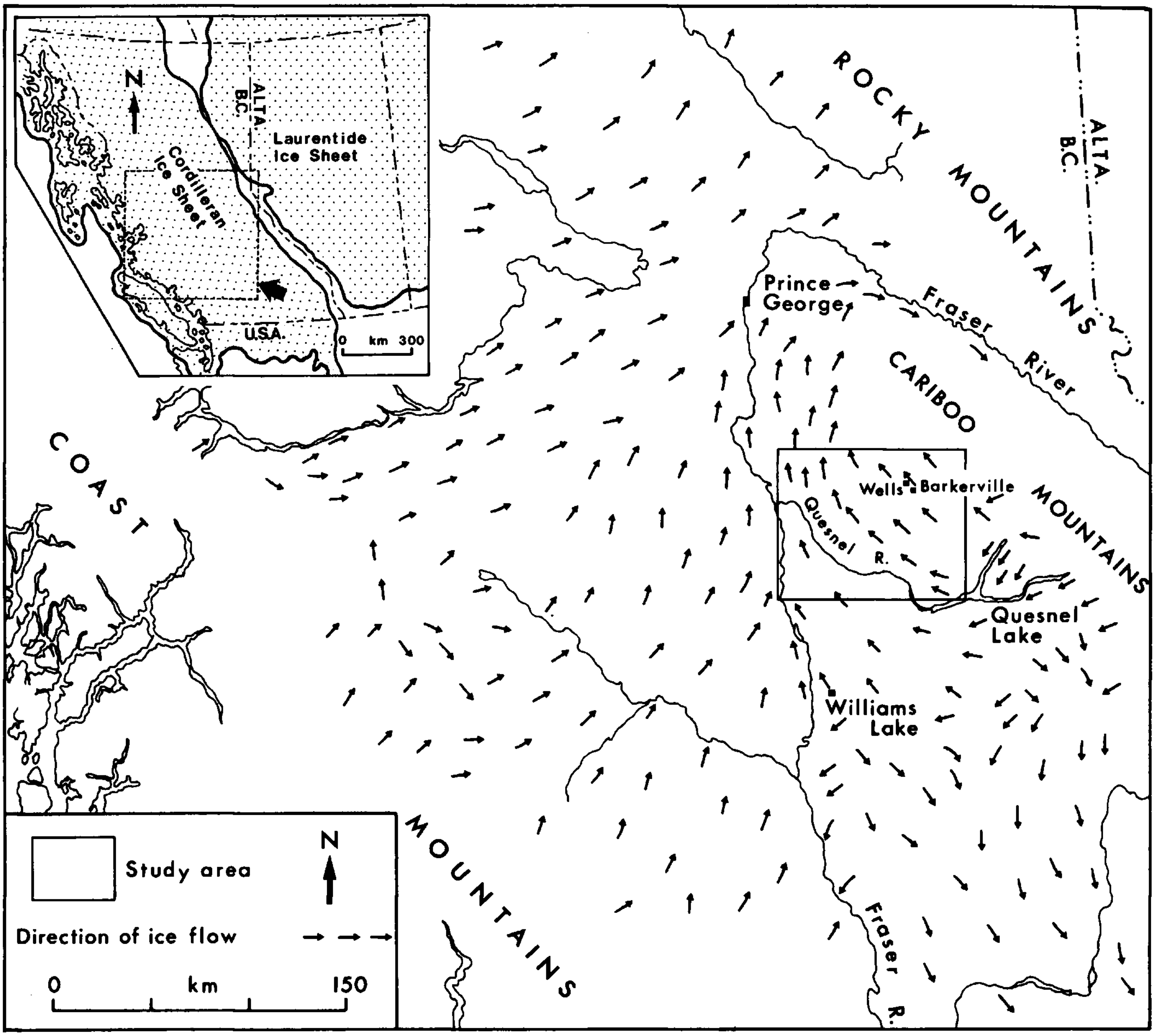


Figure 2-3-3. Ice-flow directions during the late Wisconsin (Fraser) glaciation at about 20 000 Y.B.P. After Tipper (1971).

lacustrine sediments (termed "slum" by early miners). In cases such as these, overlying subglacial lodgement tills contain uneconomic concentrations of gold and represent a major cost problem with regard to overburden excavation. In other locations late Wisconsin glaciers were able to erode into underlying auriferous gravels which contain sufficient reworked gold to be mined profitably.

SUBGLACIAL COMPLEXES

Figures 2-3-4 and 6 show the typical stratigraphic distribution and geometry of placers associated with subglacial deposits in the Cariboo Mining District. The principal subglacial placers are contained within lee-side deposits on the down-ice side of bedrock highs, the basal portions of lodgement tills, intraformational boulder pavements and channel fills, and along narrow gravel-filled notches cut by subglacial meltwaters on bedrock.

Where ice velocities are sufficiently high to allow bridging in the lee of bedrock highs or "points" as they are locally known (Johnson and Uglow, 1926), an open subglacial cavity develops (Hillefors, 1973; Boulton, 1975). Basal debris held within ice accumulates in the cavity as poorly sorted talus and is flushed by subglacial meltwaters. Subglacial fluvial reworking in cavities below the ice sheet has produced talus aprons in the lee of bedrock highs that are lucrative placer deposits. The placers are commonly draped by lodgement till deposited when the cavity was closed. The Quesnel Ready-Mix site at Tregillus Lake (Figure 2-3-5) shows evidence of multiple episodes of cavity filling and closure; overlying lodgement till has incorporated gold from the underlying gravels and can also be worked (Eyles and Kocsis, 1988b).

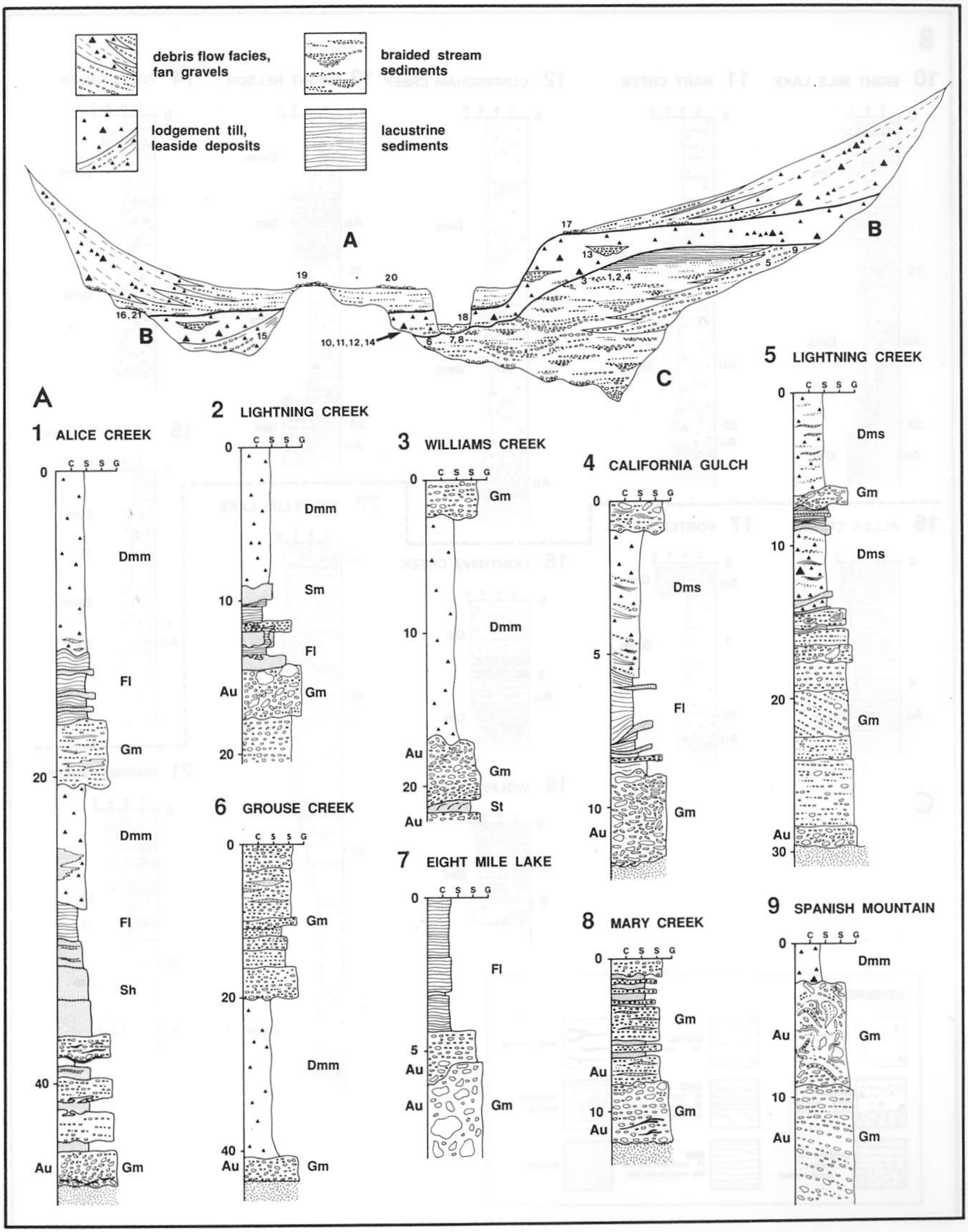


Figure 2-3-4. Stratigraphy of Cariboo gold placers;

(A) Older Gravels (older than 30 000 Y.B.P.)

(B) Subglacial deposits (30 000-10 000 Y.B.P)

(C) Postglacial gravels (<10 000 Y.B.P.)

Sedimentological logs through placer mines in Older Gravels. Number identifies locations on Figures 2-3-1 and 2. Au identifies pay-zone.

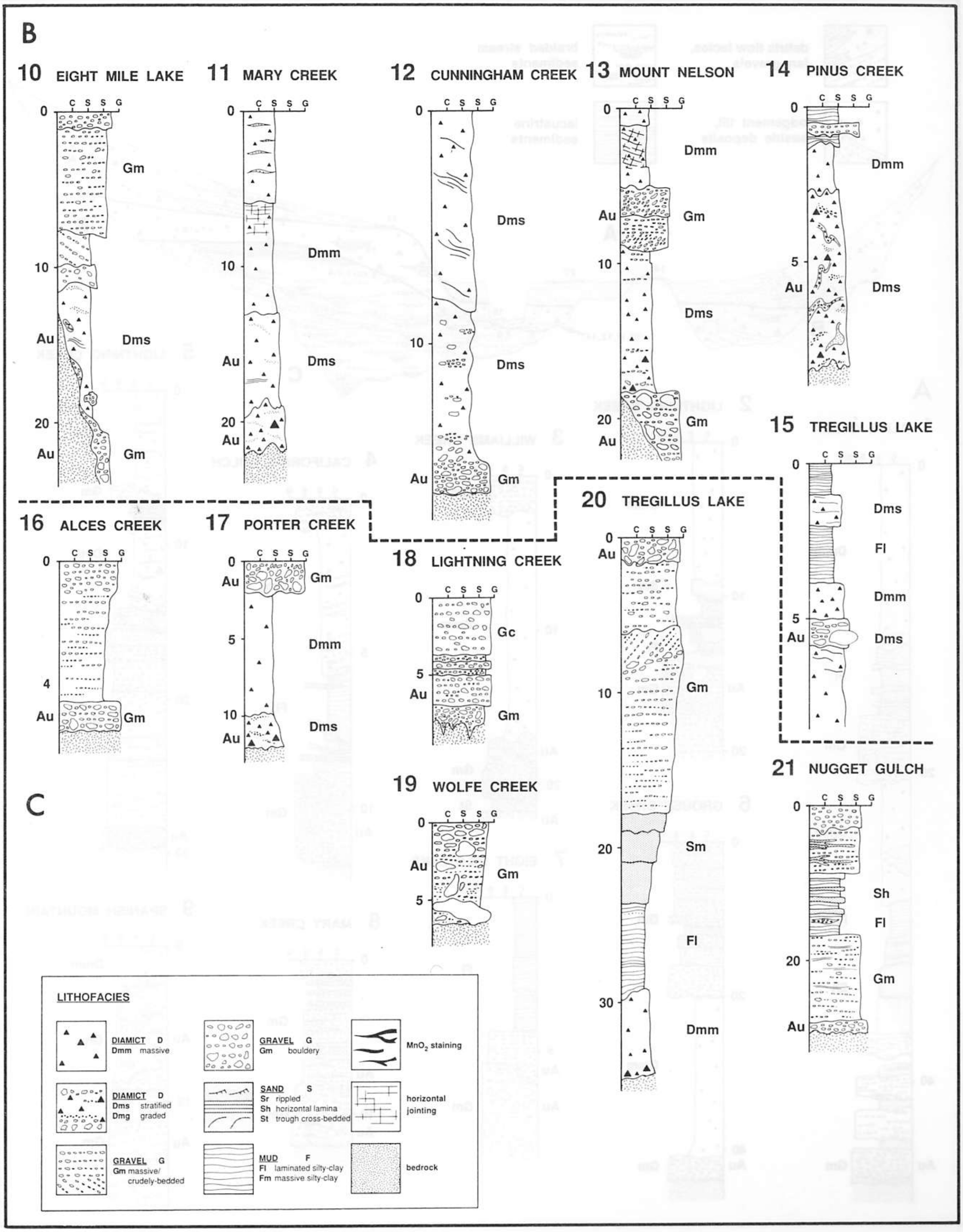


Figure 2-3-5. Sedimentological logs through placer mines working subglacial complexes (B) and postglacial gravels (C). For locations *see* Figures 2-3-1 and 2, for large-scale stratigraphy *see* Figure 2-3-4. Lithofacies code from Eyles *et al.* (1983).

Basal enrichment of lodgement tills as a result of the incorporation of interstadial gravels has been the commonest subglacial placer-forming mechanism in the Cariboo. At Pinus Creek and Eight Mile Lake (Figures 2-3-1 and 2) gold values of 1.4 grams per cubic metre are found within the basal 3 metres of lodgement till. The till shows an orange-brown colour as a result of the weathering of ankeritic limestone clasts and contains rafts of oxidized interstadial gravels. At Mount Burns, adjacent to Devils Lake Creek, gold is being worked from lodgement till resting directly on bedrock; Tyrrell (1919) describes the working of auriferous "boulder clays" at Mosquito Creek. At Mosquito Creek, recent mining operations have reported angular "crystal" gold from the lower 2 to 3 metres of lodgement till where it rests on limestones and tuffs of the Downey Creek succession; at this site these rocks contain gold values of up to 70 grams per tonne. In the Devils Lake Canyon, auriferous lodgement tills similarly rest directly on the Downey Creek succession and were worked extensively until the close of the Second World War. It is apparent that gold is not distributed evenly throughout the basal portions of lodgement tills but is often preferentially associated with intraformational pavements of aligned boulders, with long axes parallel to the ice-flow. These pavements result form the preferential lodgement of large clasts (Boulton 1975, 1982; Eyles *et al.*, 1982) and acted as a "rough bed" in and around which gold could be trapped.

Subglacial waters moving under the ice sheet deposited intraformational gravel-filled channels within lodgement tills. These have a shoestring geometry, aligned parallel to former ice flow, and record erosion and deposition by meltwater flowing on the lodgement till surface; they are genetically related to eskers and may have formed feeders to larger subglacial conduits. A placer mine on the eastern slope of Mount Nelson, 12 kilometres west of Barkerville, is currently working intraformational gravels containing nuggets as coarse as 12.8 grams. Studies of clast imbrication indicate that the channel trends north and there is a possiblity that the same channel was worked at the Point Bench some 800 metres to the north. The Point Bench site produced over 730 kilograms of gold from gravels within lodgement till, between 1906 and the early 1970s. The surrounding lodgement till away from the channel carries only marginal gold values with the exception of gravelly sections resting directly on bedrock.

Several placer operations along Cunningham Creek have mined auriferous lodgement tills. At one site, about 5 kilometres from the creek mouth, a large-volume low-yielding deposit is being worked; gold values average 0.34 grams per cubic metre and are the greatest on lowest bedrock benches as a result of proximity to older gravels along the valley floor. On the higher bedrock benches gold is too dispersed to be worked. On one bedrock bench about 1.5 kilometres further upstream, under a cover of about 20 metres of auriferous lodgement till, almost 20 kilograms of gold was recovered from a narrow bedrock channel less than 1.5 metres deep and 10 metres long. This channel forms part of a larger system cut by subglacial meltwaters under very high hydrostatic pressures. Similar notches are present on Fosters Bench at a hydraulic pit on the upper part of Lightning Creek (Figure 2-3-1).

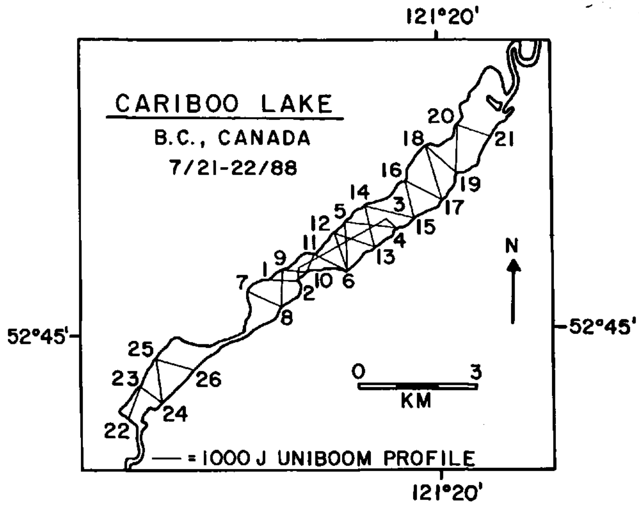


Figure 2-3-6. Cariboo Lake (Figure 2-3-1) showing location of 26 high-resolution seismic traverses.

POSTGLACIAL PLACERS

Postglacial river and fan gravels commonly form a thick valley infill obscuring subglacial and older gravel placers at depth (Figures 2-3-4 and 6). In general gold values are low, but mining costs are reduced substantially in the absence of overburden. Along several valleys, postglacial gravels extend to low elevations and can be assumed to have completely reworked pre-existing placers. In the vicinity of Tregillus Lake, along Lightning Creek, at Nugget Gulch, Porter Creek, Sovereign Creek, Alces Creek, Mary Creek and at Wolfe Creek, coarse-grained proximal outwash gravels are being worked. Gravels are very poorly sorted, contain large boulders and appreciable fine-grained matrix, and are mostly massive; clasts show an upvalley imbrication. These are typical of the deposits of longitudinal bars deposited as planar gravel sheets in shallow water. A wide range of boulder sizes suggests proximity to an active ice margin or valleyside slopes subject to mass wasting. Only minor crossbedded facies are present within multistorey gravel beds. The presence of very large (greater than 2 metres) boulders indicates frequent flood events (Brayshaw 1984; Morison and Hein, 1987). The early postglacial period saw widespread mass-wasting throughout the Cordillera (Church and Ryder, 1972; Eyles *et al.*, 1988, Eyles and Kocsis, 1988a) when large volumes of heterogeneous and often coarse-grained glacial debris derived from nearby valley sides were reworked by braided rivers along valley floors. The distal down-valley portions of these gravels are better sorted, only rarely contain "outsize" clasts and generally are uneconomic. Proximal gravels most likely result from the reworking of subglacial and older placers, and the highest gold values tend to occur toward the base of the gravel sequences. At Mary Creek, postglacial gravels show gold values averaging 0.5 gram per cubic metre where postglacial rivers erode into older gravels containing high gold values.

DISCUSSION

The data presented in this report indicate that the placer deposits of the Cariboo Mining District are restricted to three principal stratigraphic settings within late Pleistocene sediments. The so-called "Tertiary" gravels identified by earlier workers on the basis of their stratigraphic position below tills, were deposited in a long (100 000 years?) cool-temperate and nonglacial episode that terminated about 30 000 years ago. These gravel sequences are the largest by volume of the placer deposits in the Cariboo. These "older gravels" occur along valley floors for the most part buried under younger sediments, and geophysical work is needed to delineate their extent. The rivers of that time had access to older auriferous sediments and the identification of valleyside fan deposits (for example, Spanish Mountian; Figures 2-3-4 and 5) suggests that gold particles were stripped from the surrounding plateau areas by cold-climate mass-wasting processess and concentrated by braided rivers migrating across valley floors.

Paleoclimate data from mid-continent for the period 125 000 to 30 000 years ago indicates the existence of major climatic fluctuations from sub-arctic to cool-temperate. In the absence of a continuous tree-cover during colder intervals when forest tundra developed in the area, solifluction and freeze-thaw activity may have been extremely effective in breaking up bedrock and stripping supergene gold from plateau areas. It is very likely that extensive cold-climate mass-wasting at this time was much more effective in releasing large quantities of gold to the sedimentary environment than later glacial erosion which in general was highly selective. As a result, overlying subglacial placers are more geographically restricted. These deposits record the quarrying of auriferous gravels and bedrock by late Wisconsin glaciers; the basal portions of lodgement tills are good exploration targets. The upper parts of such deposits, containing more far-travelled debris, in general show low gold values and can be disregarded. Thin lodgement till sequences resting on bedrock of moderate to high relief offer the greatest potential because of the likelihood of subglacial cavity formation in the lee of bedrock knobs and the movement of subglacial waters along the lowermost portions of the valleys. Ground-based high-resolution shallow seismic work is clearly required to determine favorable sites and the ultimate extent of intraformational gravel-filled channels that occur within lodgement till (for example, Mount Nelson, Point Bench). Other locations suitable for such investigations are Cunningham Creek, Grouse Creek and Mary Creek (Figures 2-3-4 and 5).

Postglacial gravels, for the most part, do not contain the gold values associated with the older gravels and lodgement tills. Richer runs are usually an indication that the modern rivers have cut down into older placer deposits; many older placer deposits were discovered in this way.

Of critical significance is the need for large-scale, but high-resolution ground and lake-based seismic reflection surveys in order to identify the gross three-dimensional stratigraphies of the valley tills. Good placer prospects can then be identified and selectively worked. High-resolution seismic work was carried out on Cariboo Lake on a trial basis during July, 1988 in conjunction with Professor H. Mullins of Syracuse University.

Continuous seismic-reflection profiling is used to gather data on subsurface geology by emitting an acoustic pulse at regular intervals and then measuring the two-way travel time

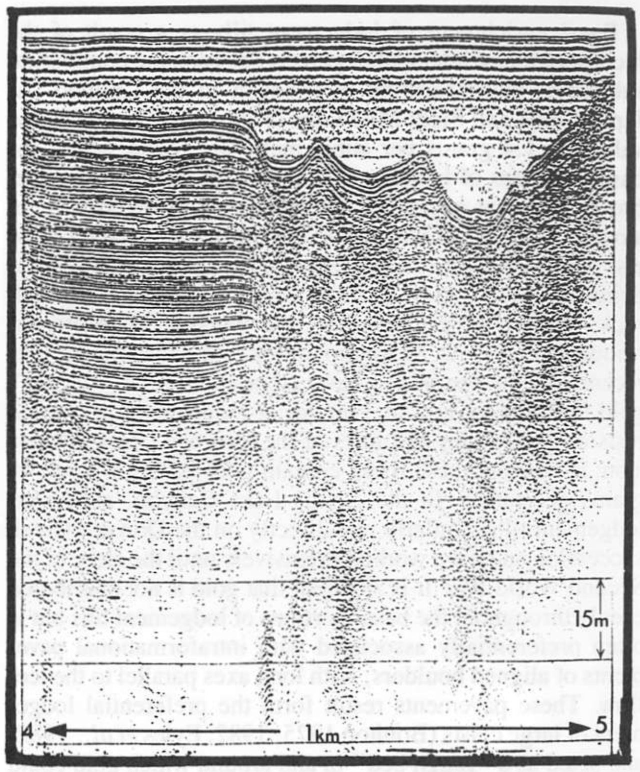


Figure 2-3-7. Seismic traverse across Cariboo Lake; for locations *see* Figure 2-3-6.

as it is reflected from physical (density/velocity) interfaces. The seismic equipment in use is an EG & G Uniboom system that operates on an electro-mechanical basis. Sound is generated approximately every second by forcing two copper plates apart that impact a rubber diaphram against the water surface. The seismic pulse emitted has a frequency spectrum range of 400 to 14 000 hertz with a dominant frequency around 1000 hertz. The uniboom was originally designed for very high-resolution (15 centimetre) work at a power output of 100 to 300 joules. At 1000 joules as much as 200 metres of substrate sediment penetration is possible while maintaining a resolution on the order of 50 centimetres. We can thus achieve sufficient penetration to define bedrock morphology as well as map seismic sequences and facies.

Figure 2-3-7 shows four seismic reflection profiles across Cariboo Lake which is about 1 kilometres wide. The irregular bedrock surface and the thick late Pleistocene infill up to 140 metres thick can clearly be identified. The nature of the infill and its relationship with that seen in placer mines around the lake is currently being investigated.

Detailed sedimentological modelling relating the small-scale distribution of gold within placers to subglacial and fluvial processess is also currently in progress. Given that the same late Pleistocene geologic history has probably obtained over much of British Columbia, the results of stratigraphic and sedimentological work in the Cariboo area should provide a basis for understanding the distribution of gold in other placer gold districts in province (for example, Atlin, Cassiar, Princeton and Fraser River). Figure 2-3-4 may ultimately provide the basis for an exploration model in these areas and should be tested by outcrop and seismic studies.

REFERENCES

Boulton, G.S. (1975): Processess and Patterns of Glacial Erosion, *in* Glacial Geomorphology, Publications in Geomorphology, *State University of New York*, Binghampton, pages 41-87.

——— (1982): Subglacial Processes and the Development of Glacial Bedforms, *in* Research in Glacial, Glaciofluvial and Glacio-lacustrine Systems. R. Davidson-Arnott *et al.* Editors, *Norwich Geo-Books*, pages 1-31.

Boyle, R.W. (1979): The Geochemistry of Gold and its Deposits, *Geological Survey of Canada*, Bulletin 280.

Brayshaw, A.C. (1984): Characteristics and Origin of Cluster Bedforms in Coarse-grained Alluvial Channels, *in* Sedimentology of Gravels and Conglomerates, E.H. Koster and R.J. Steel, Editors, *Canadian Society of Petroleum Geologists*, Memoir 10, pages 77-86.

Church, M. and Ryder, J.M. (1972): Paraglacial Sedimentation: a Consideration of Fluvial Processes Conditioned by Glaciation, *Geological Society of America*, Bulletin 83, pages 3072-3095.

Clague, J.J. (1980): Late Quaternary Geology and Geochronology of British Columbia, Part I: Radiocarbon Dates, *Geological Survey of Canada*, Paper 80-13, pages 1-28.

——— (1987): A Placer Exploration Target in the Cariboo District, British Columbia, *Geological Survey of Canada*, Paper 87-1A, pages 177-180.

Clague, J.J., Easterbrook, D.J., Hughes, O.L., Mathews J.V. (1988): Was There An Ice-sheet in the Cordillera during the Early Wisconsinan? A Re-examination of the Geological Record, *Geological Society of America*, Abstracts with Programs, Volume 20, Number 7, page A4.

Eyles, N. (1983) (Editor): Glacial Geology: An Introduction for Engineers and Earth Scientists, *Pergamon Press*, 431 pages.

Eyles, N., Sladen, J.A. and Gilroy, S. (1982): A Depositional Model for Stratigraphic Complexes and Facies Superimposition in Lodgement Tills, *Boreas*, Volume 11, pages 317-333.

Eyles, N., Eyles, C.H. and Miall, A.D. (1983): Lithofacies Types and Vertical Profile Models; an Alternative Approach to the Description and Environmental Interpretation of Glacial Diamict and Diamictite Sequences, *Sedimentology*, Volume 30, pages 393-410.

Eyles, N., Eyles, C.H. and McCabe, A.M. (1988): Late Pleistocene Subaerial Debris-flow Facies of the Bow Valley, near Banff, Canadian Rocky Mountains, *Sedimentology*, Volume 35, pages 465-480.

Eyles, N. and Kocsis, S.P. (1988a): Sedimentology and Clast Fabric of a Glacially-influenced Alluvial Fan: Fraser River, British Columbia, *Sedimentary Geology*, Volume 59, pages 15-28.

Eyles, N. and Kocsis, S.P. (1988b): Gold Placers in Pleistocene Glacial Deposits; Barkerville, British Columbia, Canada, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 81, 916, pp. 71-79.

Fulton, R.J. (1984): Quaternary Glaciation, Canadian Cordilleran; in Quaternary Stratigraphy of Canada, R.J. Fulton, Editor, *Geological Survey of Canada*, Paper 84-10, pages 39-48.

Hillefors, A. (1973): The Stratigraphy and Genesis of Stoss and Lee-side Moraines. *Geological Institute, Uppsala University*, Bulletin, Volume 5, pages 139-154.

Howell, D.G., Moore, G.W. and Wiley, T.J. (1987): Geology and Resource Potential of the Continental Margin of Western North America and adjacent Ocean Basins – Beaufort Sea to Baja, California, *Circum-Pacific Council for Energy and Mineral Resources*, Earth Sciences Series, Volume 6, pages 1-16.

Johnson, W.A. and Uglow, W.L. (1926): Placer and Vein Gold Deposits of Barkerville, Cariboo District, British Columbia, *Geological Survey of Canada*, Memoir 149.

Jones, D.L., Howel, D.G., Coney, P.J. and Monger, J.W.H. (1983): Recognition, Character and Analyses of Tectonostratigraphic Terranes, Western North America, *in* Accretionary Tectonics in the Circum-Pacific Regions. M. Hasimoto and S. Uyeda, Editors, *Tokyo, Terra*, pages 21-35.

Morison, S.R. and Hein, F.J. (1987): Sedimentology of the White Channel Gravels, Klondike Area, Yukon Territory: Fluvial Deposits of a Confined Valley, *Society of Economic Paleontologists and Mineralogists*, Special Publication 39, pages 205-216.

Price, R.A., Monger, J.W.H. and Muller, J.E. (1981): Cordilleran Cross-section: Calgary to Victoria. *In* Field Guides to Geology and Mineral Deposits, R.I. Thompson and D.G. Cook, Editors, Calgary 1981, *Geological Association of Canada*, pages 261-334.

Sharpe, R.F. (1939): The Bullion Hydraulic Mine, *The Miner*, Volume 12, pages 37-40.

Shilts, W.W. (1976): Glacial Till and Mineral Exploration, *Royal Society of Canada*, Special Publication 12, pages 205-224.

Struick, L.C. (1985): Thrust and Strike-slip Fault Bounding Tectonostratigraphic Terranes, Central British Columbia, Trip 14, Cordilleran Division, *Geological Survey of Canada*.

——— (1986): Imbricated Terranes of the Cariboo Gold Belt with Correlations and Implications for Tectonics in Southeastern British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, pages 1047-1061

Tipper, H.W. (1971): Multiple Glaciation in Central British Columbia, *Canadian Journal of Earth Sciences*, Volume 8; pages 743-752.

Tyrrell, J.B. (1919): Notes on the Placer Mines in the Cariboo, British Columbia, *Economic Geology*, Volume 14, pages 335-345.

Wilson, A.F. (1984): Origin of Quartz-free Nuggets and Supergene Gold found in Laterites and Soils – A Review and Some New Observations, *Australian Journal of Earth Sciences*, Volume 31, pages 303-316.

NOTES

COMPOSITION OF GOLD FROM SOUTHWESTERN BRITISH COLUMBIA: A PROGRESS REPORT

By John Knight and K.C. McTaggart
The University of British Columbia

Keywords: Economic geology, gold, trace elements, lode, placer, Coquihalla, Fraser River, Blackdome, Tranquille River, Cariboo district.

INTRODUCTION

This account gives new data on the composition of gold from various lodes and placers in southwestern British Columbia. This research is a continuation of work reported in a 1986 paper (Knight and McTaggart, 1986). This account repeats some of the introductory material of the earlier paper in order to clarify the present report.

A main objective of this work is to characterize gold by its suite of minor elements; with gold from different sources thus fingerprinted, one can attempt to trace the path of gold from lode to placer. In addition, the composition of lode gold is a parameter which may be used in the genetic classification of gold deposits. The study of placer gold textures is expected to yield information on conditions and distance of travel.

Placer and lode gold are rarely if ever pure, but are alloyed with other elements such as silver, copper and mercury. Early studies on gold composition and its significance were made before the electron microprobe was developed and Boyle (1979) provides an exhaustive account of this research. One of the early studies is that of Warren and Thompson (1944) who spectrographically analysed gold from many areas, mainly British Columbia. Holland (1950) lists gold-silver ratios for many placers in the province. Microprobe studies include those of Desborough (1970) who has studied placer gold from many localities in the United States and Giusti (1983) who reported placer gold compositions from Alberta, Canada.

This paper presents new compositional data on eight lodes and eight placer deposits and the reader may find it useful to compare these results with those of the earlier work (Knight and McTaggart, 1986).

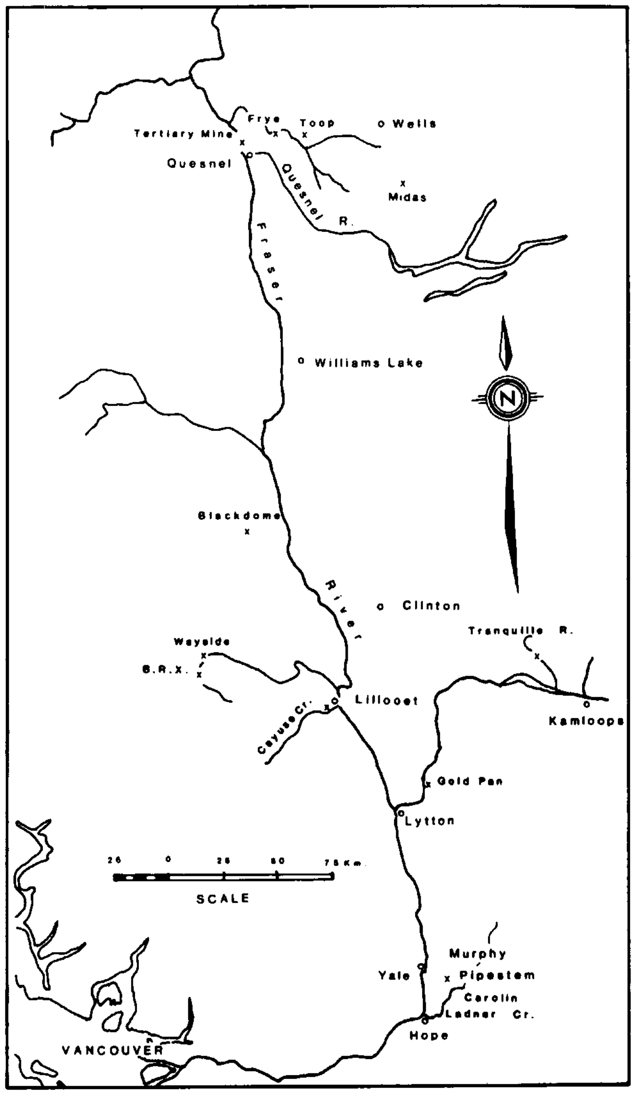


Figure 2-4-1. Location of gold samples.

METHOD

Samples (Figure 2-4-1) were obtained in various ways; some were donated and many were collected by the authors. Vein quartz was crushed and the gold recovered by panning or, in one case, by dissolution in cold hydrofluoric acid. The number of gold particles ranged widely from sample to sample.

Gold particles for analysis must be large enough to be manipulated by needle or tweezers; this means the practical lower size limit is about 0.2 millimetre. All placer particles are photographed so that grains of anomalous composition can be examined for unusual textural features.

Particles are embedded in plastic cylinders, ground and polished. Before being carbon-coated, the gold is examined with an ordinary microsope for contamination, inclusions, heterogeneities and so on. Most gold grains appear to be homogeneous except for rimming (*see* below). Many copper-rich grains show regular two-phase patterns resembling ex-solution textures. Analyses were made using an SX-50 Cameca microprobe which has a practical detection limit for most elements of about 0.05 per cent.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

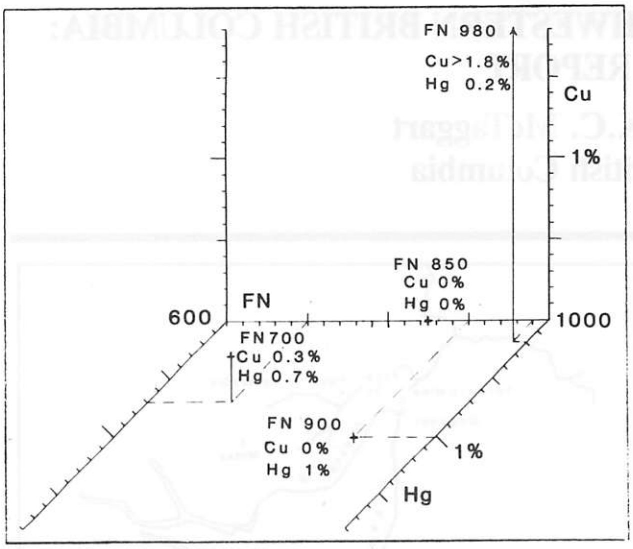


Figure 2-4-2. Explanation of composition diagrams.

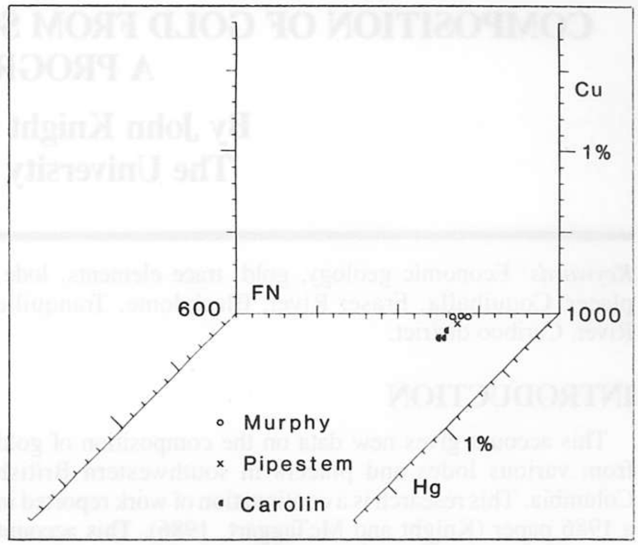


Figure 2-4-3. Lode samples, Coquihalla gold belt.

Preliminary testing indicates that only three elements, silver, copper and mercury, occur at greater than detection limits in gold from southwestern British Columbia. Testing for other elements is being done on a reconnaissance basis, rather than routinely, in order to save time and money. Early, pre-microprobe studies suggested that gold commonly contains a large variety of elements in easily measurable amounts but that work, mainly spectroscopic, was done necessarily on large specimens which held other mineral inclusions. The microprobe, allows an investigator to examine gold under high magnification and thus avoid mineral inclusions.

The analytical results are plotted as in Figure 2-4-2 which shows how they are to be read. Each cross or other symbol represents the composition of a single gold particle.

"NEW" GOLD

Some gold in certain placer deposits may not be detrital in origin but rather formed by precipitation from groundwater or low-temperature hydrothermal solutions at that site. Such gold is said to be of high fineness [fineness, abbreviated FN, $= 1000 \times \%Au/(\%Au + \%Ag)$]. Furthermore, gold particles deposited from solutions within a limited area should show a similarity in composition (compare gold from Blackdome mine, described following). No placer deposit has been sampled in this work in which all of the gold is of consistent high fineness or uniform composition. In addition, most of the gold has the form of clastic grains that have been more or less abraded, flattened or otherwise modified during water transport. For these reasons it is believed that nearly all of the placer gold is detrital in origin.

A few particles, much less than 0.5 per cent of the placer grains, show a thin coating of microcrystalline gold or are agglomerations of particles cemented by coatings of finely crystalline gold. These rare coatings appear to be "new" gold, precipitated on detrital gold.

TEXTURAL FEATURES OF GOLD PARTICLES

Gold grains show much variety in shape. Gold released from lodes is extremely angular, consisting of aggregates of blebs, intersecting flakes, crystals and wires. Much placer gold from the study area consists of subcircular or elliptical discs with regular outlines, and mean dimension up to 40 times thickness but averaging about 15 times thickness. It is assumed that this flattening is the result of fluvial transport. Some of these discs have been wrinkled, folded or torn. Coarse grains greater than 1.5 millimetres are more flattened than small grains of about 0.4 millimetre, which, on average, are less flattened, more elongate, show more re-entrants and have less regular outlines than the larger grains.

A placer sample from Frye Creek shows two quite different textural types which also differ in composition.

GOLD RIMS

Every placer sample includes gold grains with complete or partial rims of gold of high fineness. In an earlier account Knight and McTaggart (1986) reported that rimming was not found in samples from the Bridge River or Cariboo districts. New samples from the Cariboo show rimming and, after careful repolishing of original samples, rimming and partial rimming were found in nearly all placer samples. The nature and origin of rimming are discussed in the earlier paper so only a brief note is given here. Rims are outer zones or coats that enclose the placer grain. They range in thickness from a few microns to 25 per cent or more of the grain diameter. They are invariably of high fineness, 970-999, and are devoid of copper and mercury. No evidence has been found to contradict the conclusion that rims from this region are probably the result of leaching of silver and other metals from the placer grains.

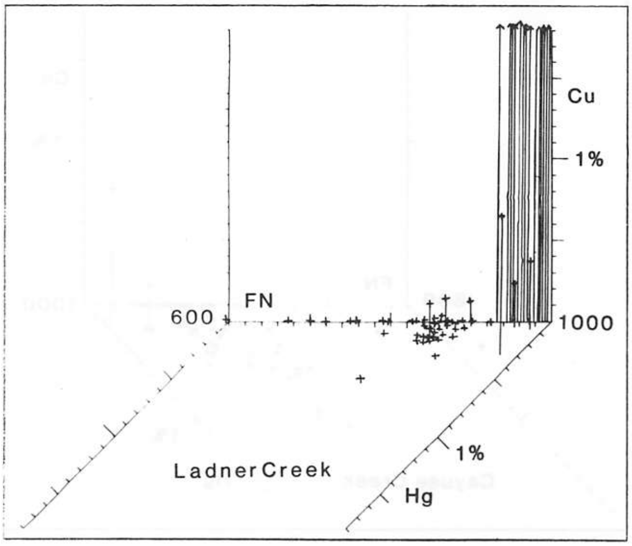


Figure 2-4-4. Placer sample, Ladner Creek.

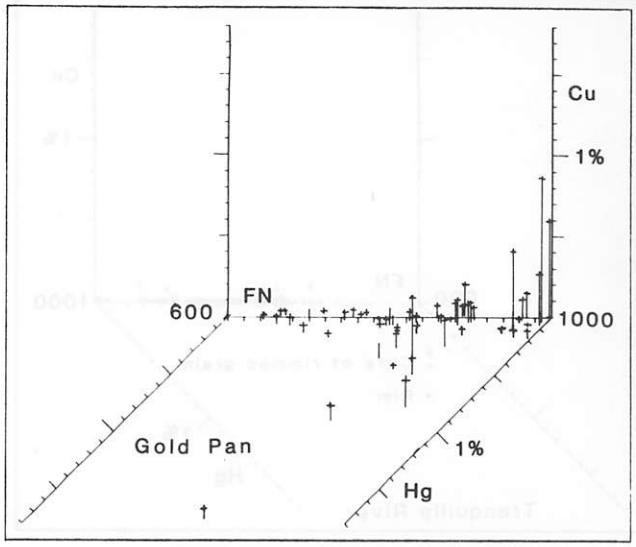


Figure 2-4-5. Placer sample, Gold Pan Park.

MERCURY AND COPPER IN GOLD

Many of the placer gold particles contain mercury and the maximum value found is approximately 10 per cent. It is believed that the mercury in placer gold reported here is primary and is not the result of contamination. The presence of mercury in lode gold that has not been exposed to contamination, for example Wayside (Figure 2-4-8) and Bralorne mine (Knight and McTaggart, 1986) shows that mercury in placer gold derived from these lodes can be primary.

A few grains with thin mercury-rich rims and rare aggregates of gold grains held together by mercury were found in this study. They were easily recognized by their silvery colour and are almost certainly the result of contamination. They were not analysed.

It has been generally observed that high-copper gold has a high fineness and this is borne out in the present study. Mercury is generally low or near the detection limit in such gold. Cupriferous gold is slightly redder than pure gold. Although it is said to be harder than pure gold, copper-rich placer grains do not seem to have distinctive textural features. Cupriferous gold is reported (Knight and McTaggart, 1986) from Relay Creek (north of Bralorne), Bridge River and Fraser River. It also occurs in the Coquihalla River (Figure 2-4-4) and is presumeably derived from the lodes of the Coquihalla gold belt.

RESULTS

COQUIHALLA GOLD BELT AND LADNER CREEK

Deposits of the Coquihalla gold belt, northeast of Hope, have been described by Cairnes (1924, 1930) and by Ray (1984). The present writers have analysed gold from three lodes and from gravels in Ladner Creek, some 4 kilometres downstream from the Carolin mill.

The scanty lode samples (*see* Figure 2-4-3) are from the Carolin and Pipestem mines and the Murphy prospect. The Pipestem and Murphy samples, fineness about 880, lack both copper and mercury. The Carolin sample contains up to 0.2 per cent mercury.

The placer sample (Figure 2-4-4) from Ladner Creek shows a wide range of compositions. Of 81 gold particles, 21 contain abundant copper. The maximum copper value found is near 24 per cent (3 grains) and most of the rest contain well over 2 per cent copper. These copper-rich particles have a fineness greater than 930. Much of the gold with more than 10 per cent copper consists of a copper-rich and a copper-poor phase forming an irregular exsolution intergrowth with alternating layers less than 10 microns wide. Most of these analyses represent bulk compositions. The copper-poor particles of the sample show a strong concentration between 830 and 900 fine, with up to 0.2 per cent mercury, which easily includes the compositions of the lode samples already described.

Clearly a lode source has not been identified for the copper-rich grains which make up a quarter of the placer sample. Such compositions appear to be restricted to gold deposits in ultramafic rocks. A clue to the nature of the source is provided by Cairnes (1930) who describes the Fifteenmile group of claims which lie along the western side of the "Serpentine Belt" in the headwaters of Fifteenmile Creek. Gold occurs on this property in narrow talcose zones, associated with serpentine, diorite, "white rock" (rodingite) and chalcocite. Cairnes states that "the colour of the gold is distinctly reddish as contrasted with other properties where it has a more normal appearance". He suggests "that its colour may be due to the presence of a small proportion of copper as an alloy with the gold". The Fifteenmile showing is situated so that it could not supply material to the Ladner Creek drainage by normal fluvial processes. Unless glaciation rearranged some of the residual or placer deposits, it seems likely that the copper-rich gold in Ladner Creek originated in some other lode, probably of the Fifteenmile type, in the upper Ladner drainage.

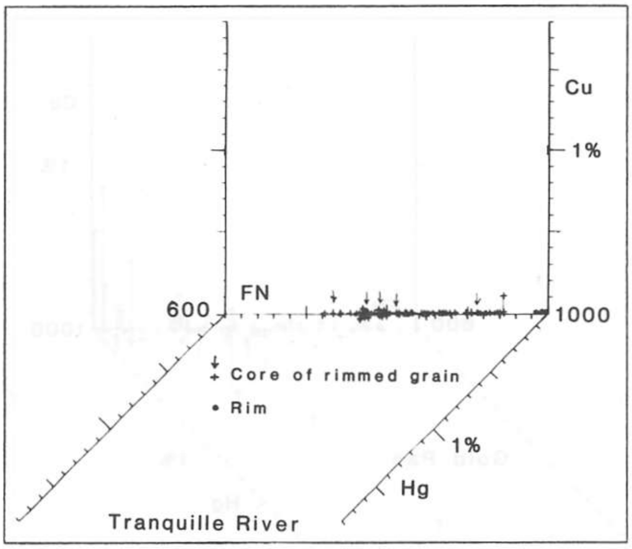


Figure 2-4-6. Placer sample, Tranquille River.

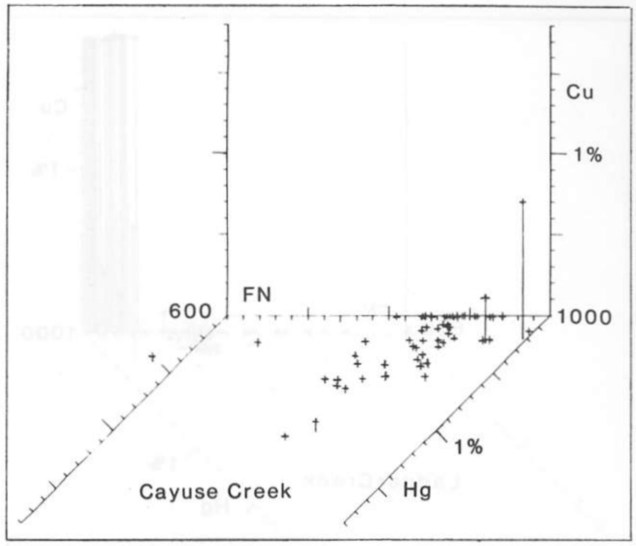


Figure 2-4-7. Placer sample, Cayuse Creek.

THOMPSON RIVER, GOLD PAN PARK

A sample from the Thompson River at Gold Pan Park, about 18 kilometres northeast of Lytton, shows a wide range in fineness and in amounts of mercury and copper (Figure 2-4-5). It resembles a sample taken at Lytton (Knight and McTaggart 1986) and is probably a mixture of contributions from many sources, including glacial drift.

TRANQUILLE RIVER

A sample from Tranquille River is unusual in its wide range of fineness and the almost complete absence of mercury and copper. Five analysed, rimmed grains are indicated in the diagram (Figure 2-4-6). Rims are greater than 980 fine.

CAYUSE CREEK

A placer sample from Cayuse Creek, at a point some 13 kilometres southeast of Lillooet, was taken almost directly below the Golden Cache lode. In general, a placer sample taken close to a productive lode shows a narrow range of compositions reflecting the compositions of the parent lodes; examples are found in diagrams for placers near the Bralorne, Blackdome and Coquihalla gold belt lodes. Unexpectedly, for a placer so close to a lode, the diagram (Figure 2-4-7) for Cayuse Creek shows a relatively wide dispersion in fineness and also in mercury content. The general pattern resembles, in part, that of some Bridge River samples (Knight and McTaggart, 1986).

WAYSIDE PROSPECT

This lode sample is reported to be from the Zero adit, also called the Paxton adit, from a 45-centimetre quartz vein. For this sample, gold was released by dissolution in cold hydrofluoric acid.

The diagram (Figure 2-4-8) is notable for a strong concentration at 770 fine and 1.3 per cent mercury. Three grains in this vicinity show measurable copper. None of this gold is recognizable in samples from Bridge River.

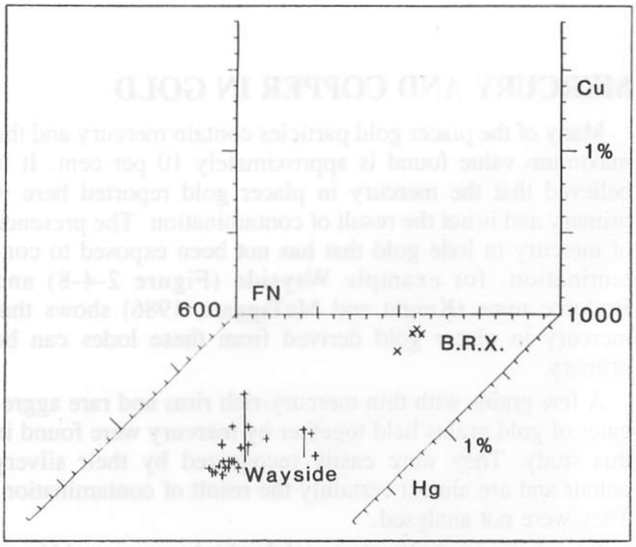


Figure 2-4-8. Lode samples, B.R.X. and Wayside veins.

B.R.X. PROPERTY

This small sample (Figure 2-4-8) from the Whynot vein on the B.R.X. property in the Bridge River area, closely resembles the Bralorne mill sample reported by the authors in an earlier paper.

BLACKDOME MINE

Gold from the Blackdome mine (Faulkner, 1986) has a fineness near 600, which is markedly lower than that of other lode gold so far analysed. Such low average fineness is one characteristic of epithermal deposits.

Gold-quartz samples, collected from exploration trenches, were crushed and panned. Samples 126 and 129 (Figures 2-4-9 and 2-4-10) from No. 1 vein differ slightly in that measurable mercury occurs in the latter.

Samples 127 and 128 (Figures 2-4-9 and 2-4-11) are from No. 2 vein and differ slightly in fineness.

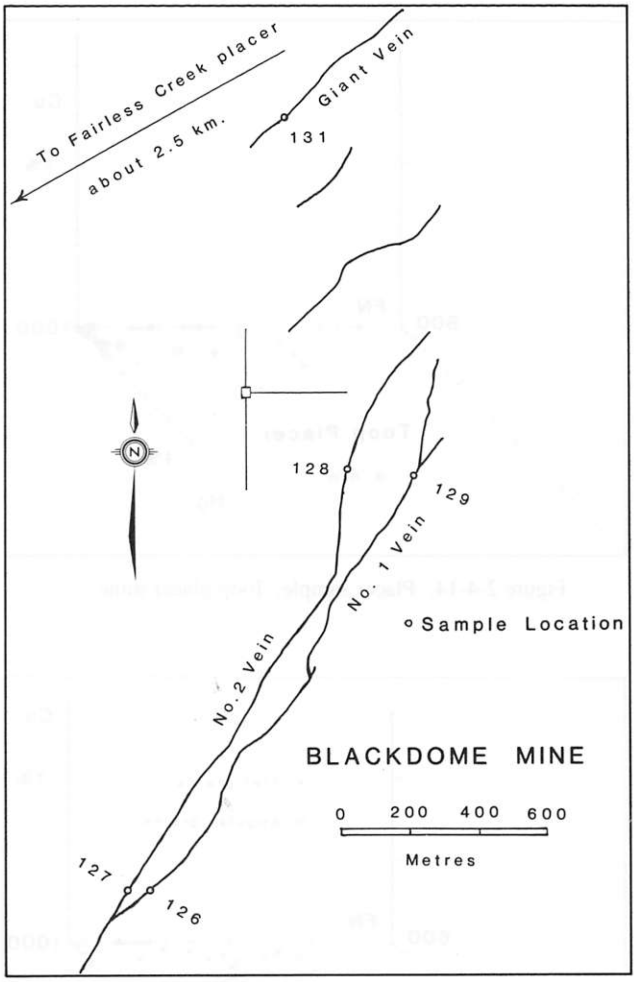


Figure 2-4-9. Blackdome mine, sample locations.

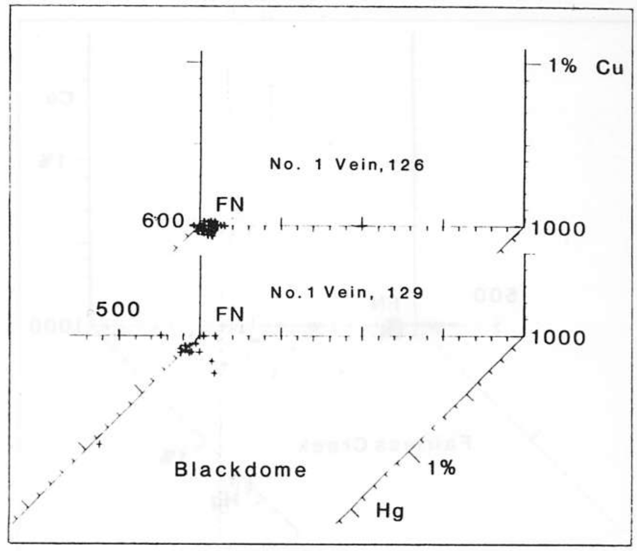


Figure 2-4-10. Lode samples, No. 1 vein, Blackdome mine.

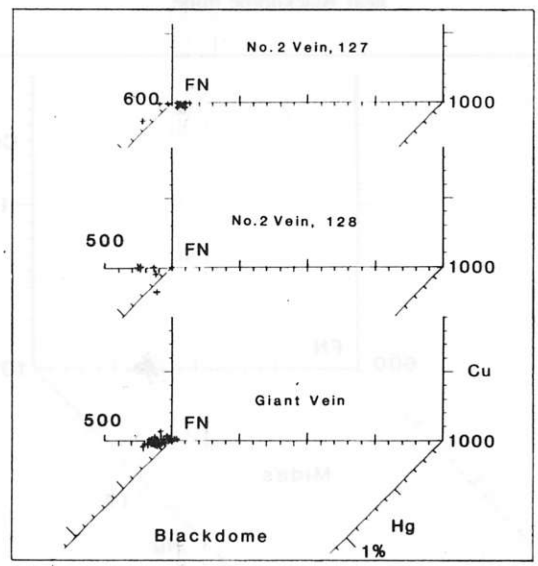


Figure 2-4-11. Lode samples, No. 2 and Giant veins, Blackdome mine.

Sample 131 (Figure 2-4-11) from the Giant vein is interesting in that gold-coloured and silver-coloured grains could be distinguished during picking and mounting. The gold-coloured grains have normal cores (fineness about 600) but marginal parts of high fineness (~990). The analyses shown in Figure 2-4-11 are from the cores.

A sample from underground, a polished section with only four grains of gold, has a fineness of 650 and some grains contain a little mercury. This sample is significant in connection with the Fairless Creek placer, described below.

FAIRLESS CREEK PLACER

The Fairless Creek placer is a small inactive operation, about 2 kilometres downhill and west of the Blackdome veins.

Fifty particles (Figure 2-4-12) were recovered by sluicing and panning. Compositions show a wide range. Samples of 580 to 610 fineness are easily related to the No. 1, No. 2 and Giant veins at Blackdome. The strong concentration at about 630 fineness is close in composition to the sample from underground. Two particles of 980 fine may be marginal parts of the gold-coloured grains from the Giant vein. Grains of fineness 700-900 are of unknown provenance.

CARIBOO DISTRICT

The authors report on five new samples from the Cariboo district: a lode sample from the Midas lode on the Snowshoe property in the Yanks Peak area; a placer sample from the Toop placer near Cottonwood House; a placer sample from Frye Creek, a tributary of Cottonwood River; a sample from the Tertiary mine just north of Quesnel; and a placer sample from the Fraser River at the Tertiary mine.

MIDAS LODE

The sample from the Midas lode (Figure 2-4-13) (Holland, 1953) shows a tight concentration at about 860 fine. In the absence or near absence of copper and mercury the sample is similar to earlier reported lode and placer samples (Knight and McTaggart, 1986) from the Cariboo district. Samples

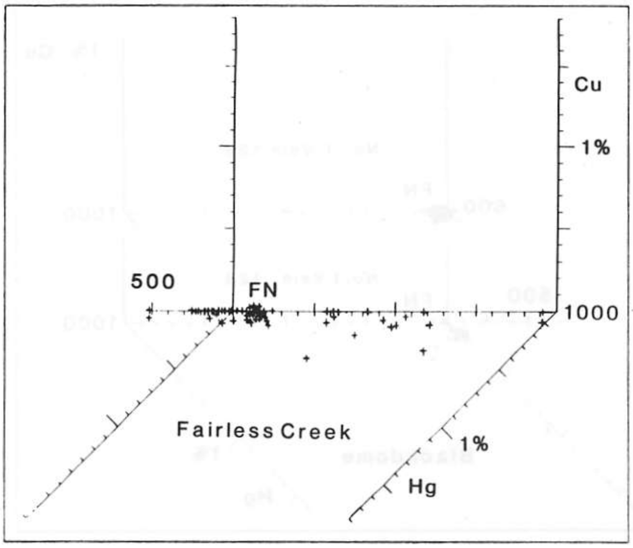


Figure 2-4-12. Placer sample, Fairless Creek, near Blackdome mine.

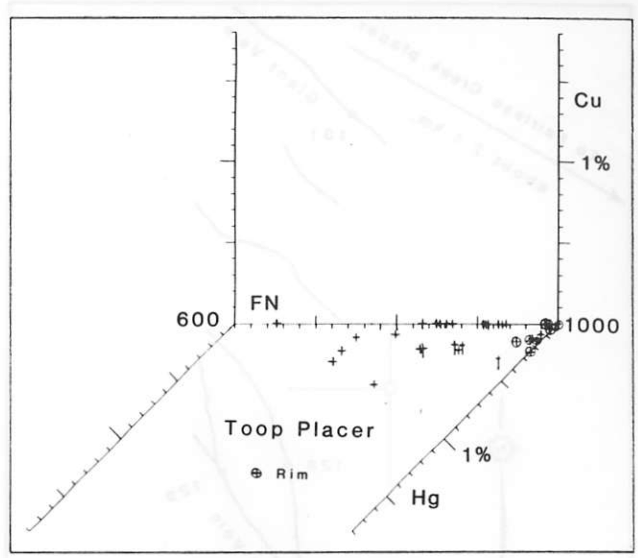


Figure 2-4-14. Placer sample, Toop placer mine.

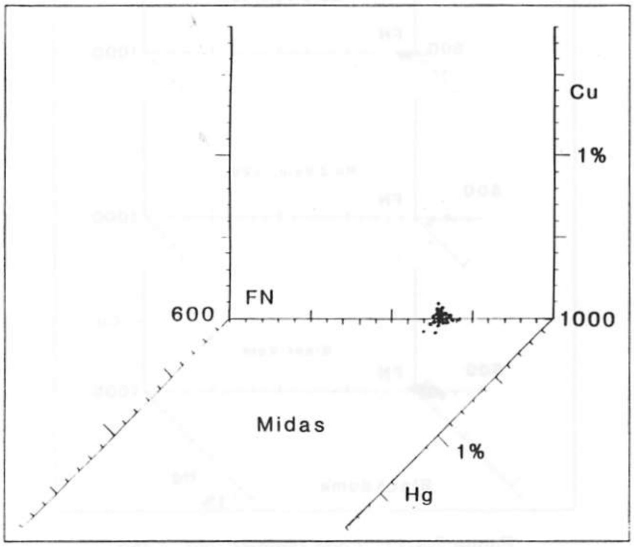


Figure 2-4-13. Lode sample, Midas showing, Cariboo district.

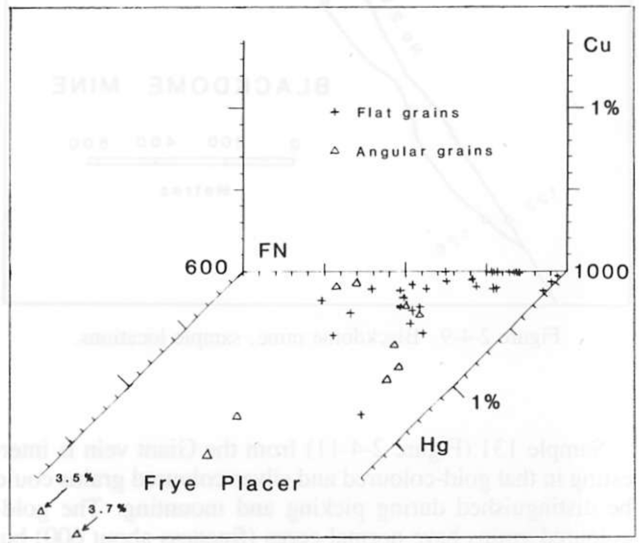


Figure 2-4-15. Placer sample, Frye Creek placer mine.

from the western part of the area, however, (*see* below) show abundant mercury. The concentration at fineness 860 has not been identified in any of the Cariboo placers.

Toop Placer

The Toop placer is some 8 kilometres northeast of Cottonwood House. Particles show well developed rims of nearly pure gold (Figure 2-4-14). The sample shows a higher mercury content than the gold from the four Cariboo placers reported on earlier.

Frye Placer

The Frye placer is near the confluence of Cottonwood River and Frye Creek. The sample has several features of interest (Figures 2-4-15 and 2-4-16). Firstly, the compositions of the thick rims and cores of several grains are shown in Figure 2-4-16; tie lines join rim and core. Rim formation, if the result of leaching, clearly involved removal of mercury as well as silver. Secondly, the sample consists of two very distinct textural types: highly angular grains, many with quartz attached, and strongly flattened grains. These types are distinguished in Figure 2-4-15. The first appear to be little travelled and the second much travelled. These two populations overlap a little in composition but the angular grains show a wide range in mercury content, up to 3.7 per cent, and a slightly lower average fineness. One might speculate that a nearby lode contributed the angular particles.

Much of Fraser River placer gold has appreciable mercury. In the first four samples from the Cariboo district (Knight and Mctaggart, 1986) mercury was very low and the origin of mercury-bearing gold from the upper Fraser River was a

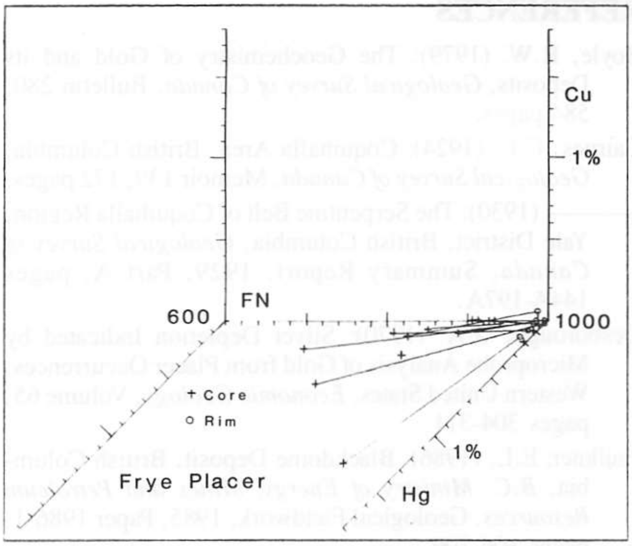


Figure 2-4-16. Placer sample, Frye Creek, showing compositions of cores and rims.

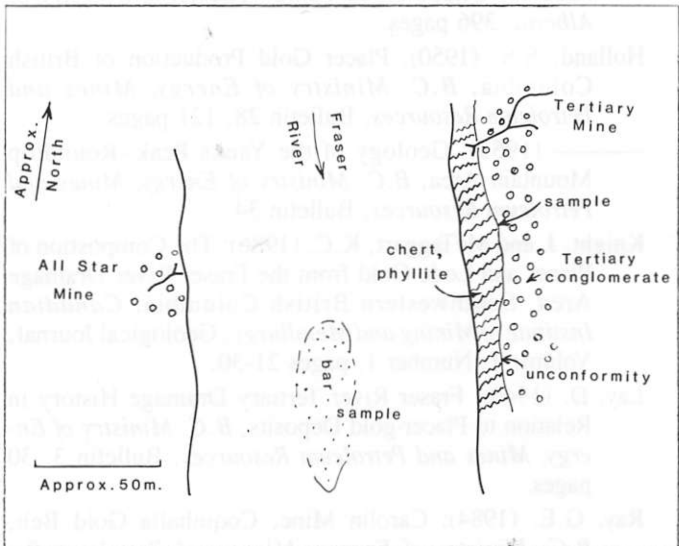


Figure 2-4-17. Sample location sketch map, Tertiary mine.

mystery. It now appears that some Cariboo placers (*see also* the Toop placer sample), carry appreciable mercury and could have contributed mercury-bearing gold to the Fraser River placers.

Tertiary Mine

The Tertiary mine is about 8 kilometres north of Quesnel, on the east side of Fraser River (Figure 2-4-17). It produced about 31 kilograms of gold and closed in 1926 (Lay, 1940). The stopes and portal are partly caved. The stopes were developed in a fossil placer that lies along an unconformity between Cache Creek pelite and chert, and a well-cemented Tertiary conglomerate. The All Star mine was developed in similar rocks on the west side of the river. The sample (Figure 2-4-18) consists of 75 grains panned from material dug from along the unconformity. Many of the grains are rimmed with

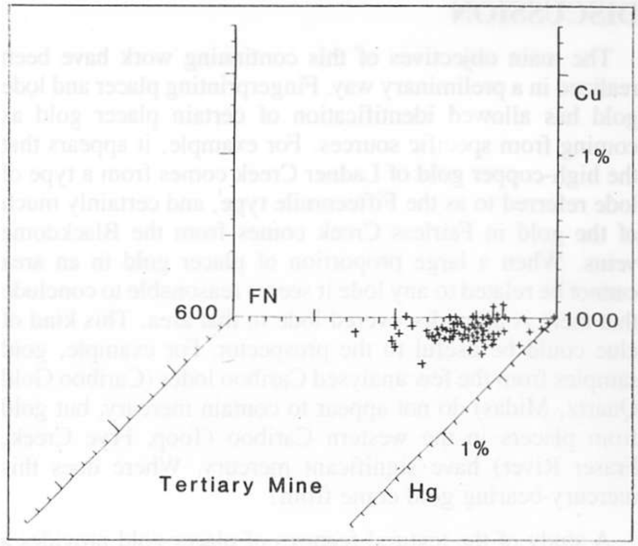


Figure 2-4-18. Lode sample, Tertiary mine.

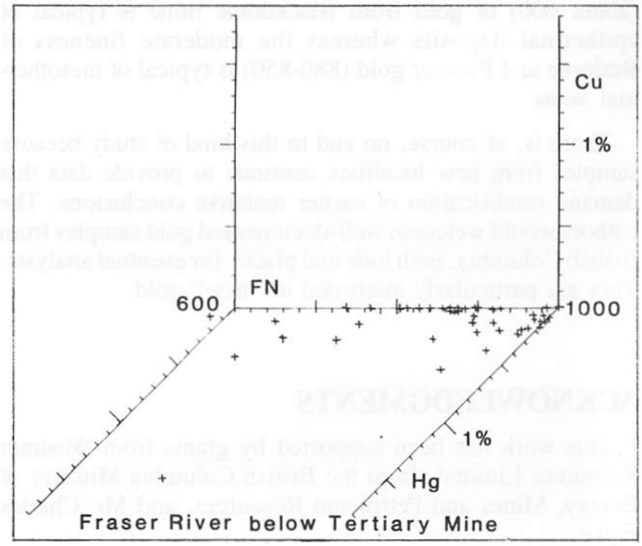


Figure 2-4-19. Placer sample, Fraser River just below Tertiary mine.

almost pure gold and show no exceptional textural features. Mercury is mostly under 0.2 per cent, the gold thus differs markedly from the angular grains of the Frye Creek sample which was taken only a few kilometres away.

Fraser River Placer, at Tertiary Mine

This sample (Figure 2-4-19) is from a river bar less than 500 metres downstream from the adit of the Tertiary mine. It includes compositions that could be from the Tertiary mine deposit, which possibly extended across the Fraser River to the All Star mine, but clearly includes other gold of low fineness. It lacks the high mercury "plume" that is present at Chimney Creek and Fountain on the Fraser River (Knight and McTaggart, 1986). The wide scatter of compositions is seen in other samples from the Fraser River and seems typical of placers some distance from their sources.

DISCUSSION

The main objectives of this continuing work have been realized in a preliminary way. Fingerprinting placer and lode gold has allowed identification of certain placer gold as coming from specific sources. For example, it appears that the high-copper gold of Ladner Creek comes from a type of lode referred to as the Fifteenmile type, and certainly much of the gold in Fairless Creek comes from the Blackdome veins. When a large proportion of placer gold in an area cannot be related to any lode it seems reasonable to conclude that there is an undiscovered lode in that area. This kind of clue could be useful to the prospector. For example, gold samples from the few analysed Cariboo lodes (Cariboo Gold Quartz, Midas) do not appear to contain mercury, but gold from placers in the western Cariboo (Toop, Frye Creek, Fraser River) have significant mercury. Where does this mercury-bearing gold come from?

A study of the textural features of placer gold provides a clue to the distance the gold has travelled. The composition of lode gold helps to distinguish or confirm the genetic type of the deposit. For example, the relatively low fineness (about 600) of gold from Blackdome mine is typical of epithermal deposits whereas the moderate fineness of Bralorne and Pioneer gold (880-850) is typical of mesothermal veins.

There is, of course, no end to this kind of study because samples from new localities continue to provide data that demand modification of earlier tentative conclusions. The authors would welcome well-documented gold samples from British Columbia, both lode and placer, for eventual analysis. They are particularly interested in "new" gold.

ACKNOWLEDGMENTS

This work has been supported by grunts from Westmin Resources Limited, from the British Columbia Ministry of Energy, Mines and Petroleum Resources, and Mr. Charles Fipke.

Gold samples have been provided by the Ministry of Energy, Mines and Petroleum Resources, Dr. Paul Richardson, Dr. W.R. Danner, Mr. Gary Polischuk, Mr. Bradford Cooke, Blackdome Mines Ltd., Mr. James Logan, Mr. E. Toop, Mr. Gordon Lund, and Mr. Leonard Knudson.

REFERENCES

Boyle, R.W. (1979): The Geochemistry of Gold and its Deposits, *Geological Survey of Canada*, Bulletin 280, 584 pages.

Cairnes, C.E. (1924): Coquihalla Area, British Columbia, *Geological Survey of Canada*, Memoir 139, 172 pages.

——— (1930): The Serpentine Belt of Coquihalla Region, Yale District, British Columbia, *Geological Survey of Canada*, Summary Report, 1929, Part A, pages 144A-197A.

Desborough, G.A. (1970): Silver Depletion Indicated by Microprobe Analysis of Gold from Placer Occurrences, Western United States, *Economic Geology*, Volume 65, pages 304-311.

Faulkner, E.L. (1986): Blackdome Deposit, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 106-109.

Giusti, L. (1983): The Distribution, Grades and Mineralogical Composition of Gold-bearing Placers in Alberta, Unpublished M.Sc. Thesis, *University of Alberta*, 396 pages.

Holland, S.S. (1950): Placer Gold Production of British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 28, 121 pages.

——— (1953): Geology of the Yanks Peak–Roundtop Mountain Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 34.

Knight, J. and McTaggart, K.C. (1986): The Compostion of Placer and Lode Gold from the Fraser River Drainage Area, Southwestern British Columbia, *Canadian Institute of Mining and Metallurgy*, Geological Journal, Volume 1, Number 1, pages 21-30.

Lay, D. (1940): Fraser River Tertiary Drainage History in Relation to Placer-gold Deposits, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 3, 30 pages.

Ray, G.E. (1984): Carolin Mine, Coquihalla Gold Belt, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 55-66.

Warren, H.V. and Thompson, R.M. (1944): Minor Elements in Gold, *Economic Geology*, Volume 39, pages 457-471.

STRATIGRAPHIC AND STRUCTURAL SETTING OF THE SHASTA SILVER-GOLD DEPOSIT, NORTH-CENTRAL BRITISH COLUMBIA (94E)

By Henry Marsden
Carleton University
and
John M. Moore
Ottawa-Carleton Geoscience Centre

KEYWORDS: Economic geology, Shasta silver-gold deposit, Toodoggone volcanics, stratigraphy, structure, alteration, mineralization, ore controls.

INTRODUCTION

The Shasta silver-gold stockwork deposit (Figure 2-5-1) is situated in north-central British Columbia, approximately 300 kilometres north of Smithers. The property is accessed by a four-wheel-drive road from the Sturdee airstrip, 9 kilometres west of the property, or from Fort St. John via the Omineca mining road and the newly constructed Cheni mine road, however, road use is currently being restricted by Cheni Gold Mines Inc.

The objective of this study is to define the stratigraphy, structure and geologic environment of the deposit. It should result in an understanding of the relationship between volcanism, brittle deformation and hydrothermal activity in the Toodoggone precious metal camp. The research is part of a 2-year mapping and research project that is the basis of an M.Sc. thesis at Carleton University.

Fieldwork, conducted between June 2 and August 30, 1988, consisted of geologic mapping and the examination of drill core and surface trenches. Mapping was conducted at two scales; 1:10 000 property mapping on an orthophoto base supplied by Esso Minerals Canada, and 1:1000 mapping on a contour map prepared from earlier orthophoto coverage. Samples were collected for age determinations, whole-rock analysis and petrographic study.

HISTORY

The Shasta deposit was discovered in 1972 when W. Meyers and Associates carried out surface exploration on ground staked for Shasta Mines and Oil Ltd. (now International Shasta Inc.) that led to the Main (Rainier) zone discovery. In 1973 the property was optioned by Newmont Exploration of Canada Limited and by the end of 1984 extensive geochemical and geophysical surveys, some surface mapping, hand trenching and 2700 metres of diamond drilling had been completed. This work defined the newly discovered Creek zone, indicated precious metal mineralization in the Jock and Rainier zones and intersected the JM zone. Reserves were estimated at 2.4 million tonnes of 2.7 grams gold-equivalent per tonne (47 g Ag = 1 g Au) or 0.7 million tonnes of 5.0 grams gold-equivalent per tonne.

Esso Minerals Canada optioned the property in 1987 and immediately started an extensive program of geochemical and geophysical exploration, surface mapping, backhoe trenching and diamond drilling.

Follow-up trenching and diamond drilling on geochemical and electromagnetic (VLF) and resistivity anomalies led to the discovery of the JM (Just Missed) zone. This exploration program continued in 1988; over 4000 metres of diamond drilling, and surface exploration work, have defined the JM zone over 800 metres, extended the Rainier vein, tested the newly discovered Cayley vein and two other new discoveries, the O zone and the Baker zone. Mineralization found on surface within a strong resistivity anomaly (East zone) has not been tested by drilling.

REGIONAL SETTING

The project area lies within the Stikine terrane along the eastern margin of the Intermontane Belt of the Canadian

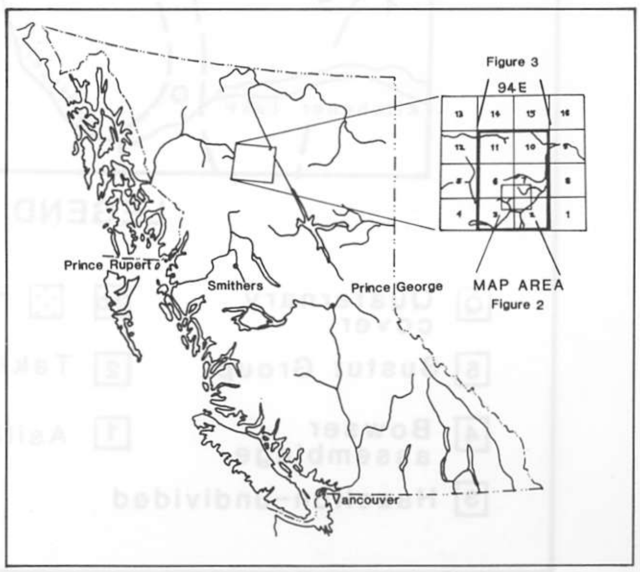


Figure 2-5-1. Location map.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

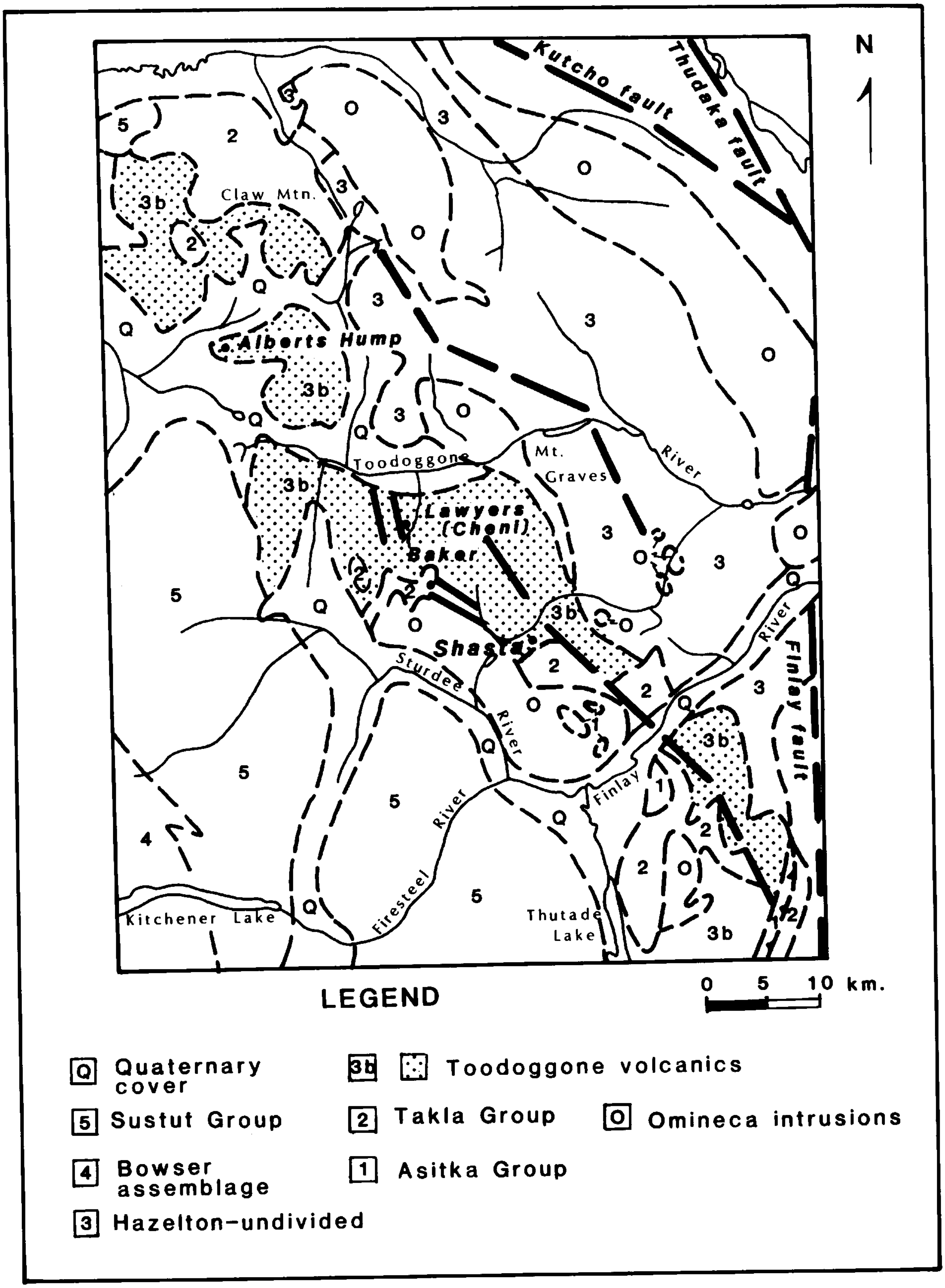


Figure 2-5-2. Regional setting.

Cordillera. Stikinia is an allochthonous terrane composed predominantly of Paleozoic Asitka Group sedimentary rocks, mafic volcanics of the correlative Takla and Stuhini groups, Lower to Middle Jurassic volcanic and sedimentary rocks of the Hazelton Group, the eoeval Omineca intrusions and clastic sediments of the Middle to Upper Jurassic Bowser assemblage and the Cretaceous Sustut Group. Paleontologic and paleomagnetic evidence, combined with reconstructions of correlative terranes, suggest that terranes east of the northern Rocky Mountain Trench may have been displaced northwards relative to the North American craton by as much as 1300 kilometres (Gabrielse, 1985).

The oldest rocks exposed in the area are Permian limestones and minor clastic sediments of the Asitka Group, commonly overthrust on Upper Triassic rocks or occurring as pendants within the Omineca intrusions. The Upper Triassic Takla Group consists predominantly of mafic, alkaline to subalkaline volcanics, associated epiclastic and minor shallow-marine sedimentary rocks. The volcanics are mainly submarine with some subaerial facies, suggesting locally emergent volcanic edifices.

Unconformably overlying the Takla Group are Jurassic Hazelton Group volcanic and associated sedimentary rocks. The unconformity has been noted in several localities; the base of the Hazelton Group consists of either polymictic conglomerate carrying chert and limestone clasts (Monger and Church, 1977; Mihalynuk and Ghent, 1986; Thorkelson, 1988) or conglomerate with abundant, equigranular intrusive clasts (Diakow, 1985). Tipper and Richards (1976) defined the stratigraphy flanking the south and west margins of the Bowser Basin as Hazelton Group, an island arc sequence of volcanics and sediments deposited in the Hazelton trough between Sinemurian and Lower Callovian time. They further divided the Hazelton into three formations and five geographically restricted facies; the most extensive formation being the Sinemurian to Lower Pliensbachian Telkwa Formation. Since that time correlative volcanic rocks have been recognized along the east and northeast margins of the Bowser Basin: the Toodoggone volcanics (Diakow *et al.*, 1985) and the Coldfish volcanics (Thorkelson, 1988) respectively. Diakow is currently completing a Ph.D. thesis study on the Toodoggone volcanics and will propose them as a distinct formation within the Hazelton Group (personal communication, 1988).

The Hazelton volcanics, in the Toodoggone area, have been traditionally divided into the quartz-bearing Toodoggone volcanics and undivided Hazelton volcanics lacking visible quartz, following the lead of Carter (1972) and Gabrielse (1976). More recent work by Diakow (1983, 1985), Diakow *et al.* (1985), Panteleyev (1982, 1984) and Schroeter (1982) defined the Toodoggone volcanics as a predominantly calcalkaline, felsic, subaerial volcanic succession spanning an age range between 204 and 182 Ma. The sequence includes a middle member of intermediate composition that has yielded ages between 197 and 200 Ma. These rocks may be similar to the undivided Hazelton volcanics exposed further east. The youngest part of the Toodoggone pile is the Saunders grey dacite, a distinctive welded tuff, suggested by Clark and Williams-Jones (1987) to represent a single volcanic episode (Phase 2), 182 to 179 Ma old, that is separated from the rest of the Toodoggone activity (Phase 1) by a hiatus that coincided with the end of significant gold mineralizing events.

The Toodoggone volcanics are bounded to the east by coeval, undivided Hazelton Group volcanics and the Omineca intrusions which are in turn bounded by the Finlay and Thudaka faults, major right-lateral strike-slip faults that mark the eastern boundary of the Intermontane Belt (Figure 2-5-2). To the south and southeast the Toodoggone sequence is in fault contact with, and in places unconformably overlies, Upper Triassic rocks of the Takla Group. The Triassic rocks are best exposed where they are uplifted around the margins of the Black Lake stock. To the north and northwest the Toodoggone volcanics are buried beneath mid-Jurassic to Cretaceous sedimentary rocks of the Bowser assemblage and Sustut Group.

LOCAL GEOLOGY

The Shasta deposit is hosted by a succession of predominantly quartz, biotite, hornblende and feldspar-phyric pyroclastic and epiclastic rocks with some intercalated flows. They were mapped by Diakow *et al.* (1985) as the Toodoggone crystal ash tuffs or Attycelley tuffs and a sample from similar rocks near the Lawyers deposit (Figure 2-5-2) gave a hornblende potassium-argon date of 186 ± 6 Ma. Holbek and Thiersch (1987) established a preliminary detailed stratigraphy for the Shasta property. Figure 2-5-4 is a stratigraphic column based on their work and more extensive mapping done during 1988.

Rocks exposed beneath the Saunders grey dacite west of the Saunders fault (Figure 2-5-3) are different from those to the east, suggesting considerable displacement prior to the emplacement of the Saunders dacite.

TAKLA GROUP

1A, B. AUGITE-PLAGIOCLASE PORPHYRY AND ASSOCIATED SEDIMENTS

The oldest rocks in the study area are pyroxene-plagioclase porphyry flows and breccias of the Upper Triassic Takla Group. The porphyritic volcanics form a thick succession of pillow basalts and volcanic breccias with poorly defined amygdaloidal and porphyritic clasts, and local amygdaloidal to scoriaceous flows. Some subvolcanic rocks are "flower porphyries" with glomeroporphyritic plagioclase. The volcanic breccias locally carry accidental limestone clasts that contain pyroxene crystal detritus. The section mapped includes 110 metres of purple and green to varicoloured volcanic conglomerate, composed entirely of Takla clasts, with interbedded green to dark grey volcanic siltstone and sandstone. These rocks are sandwiched between porphyritic Takla flows and are cut by an extremely coarse feldspar-pyroxene porphyry dyke.

1C, D. MONOMICTIC VOLCANIC CONGLOMERATE

A distinctive maroon to green (colour depends on degree of carbonate-chlorite alteration) monomictic volcanic conglomerate, consisting almost entirely of fine-grained, crowded pyroxene (or hornblende) porphyry cobbles, locally

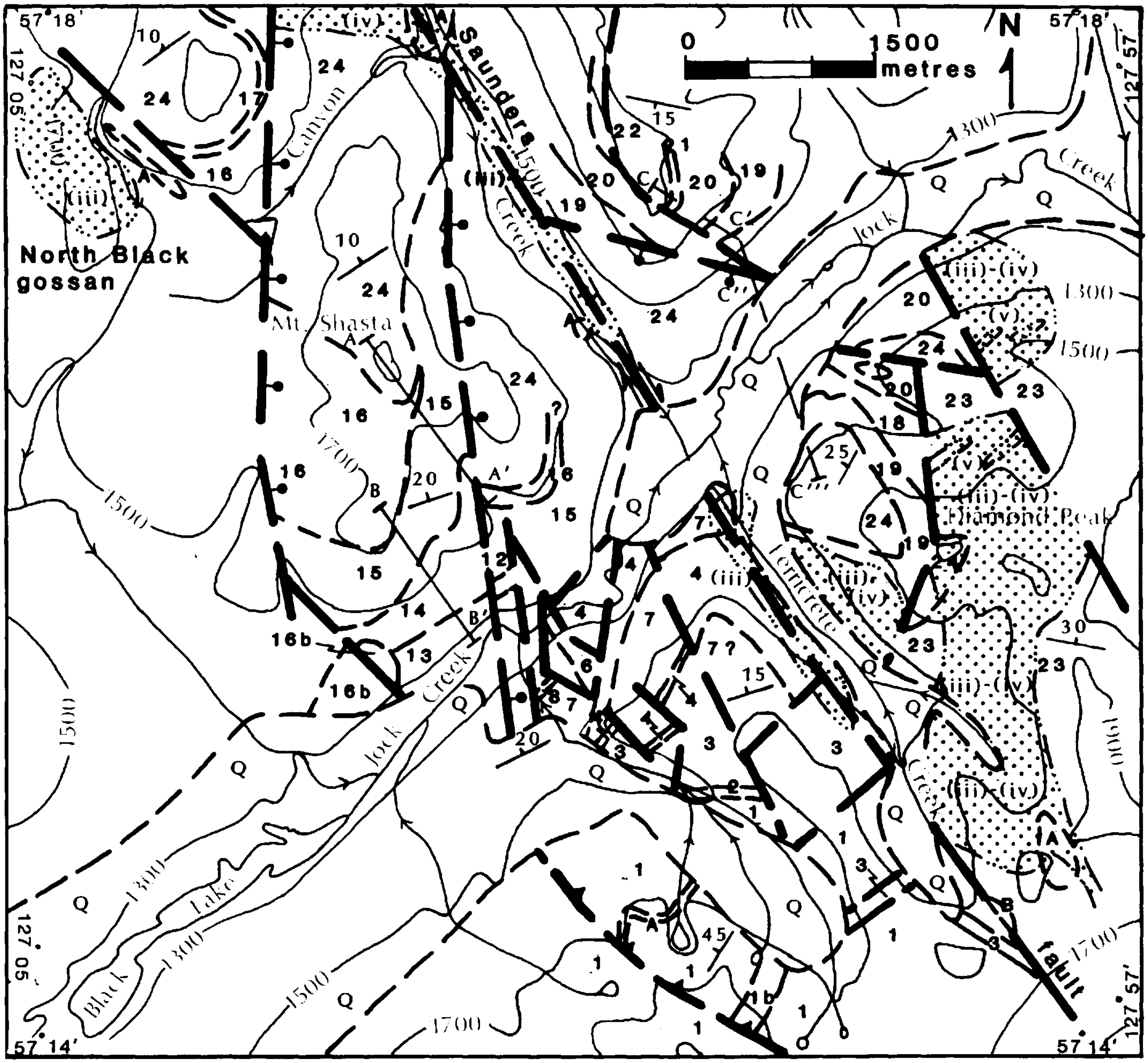


Figure 2-5-3. Local geology.

rests on a finer grained, more heterolithic purple volcanic conglomerate containing red-brown amygdaloidal clasts and rare fossilized wood fragments. These rocks are tentatively assigned to the Takla Group, but have only been observed in fault contact with both Toodoggone and Takla rocks.

The intimate association between subaerial and submarine facies suggests the Takla was extruded in a locally emergent environment.

TOODOGGONE VOLCANICS WEST OF SAUNDERS FAULT

2. Heterolithic Conglomerate With Intrusive Clasts

Between the Toodoggone and Takla volcanics is a transitional unit 30 metres thick that consists of a heterolithic conglomerate containing subrounded Takla clasts and granitic pebbles to cobbles, overlain by a dark purple to green angular volcanic conglomerate that is composed entirely of Takla clasts. Presumably this deposit marks an episode of uplift and erosion related to the onset of Jurassic volcanism.

3a, b. Green and Purple Tuffs, Volcanic Siltstone, Sandstone and Conglomerate

The oldest quartz-bearing unit is a very heterogeneous sequence of thinly bedded volcanic and epiclastic sedimentary rocks, 50 to 100 metres thick, that is well exposed in bluffs on the east side of Paradise Creek (Figures 2-5-3 and 2-5-6). The unit is divided into a green welded chloritic lapilli tuff with interstratified epiclastics, and a purple to purple and

LEGEND FOR FIGURES 2-5-3, 4, 5 AND 6

ALTERATION

(i) Propylitic alteration
(ii) Carbonate-chlorite
(iii) Chlorite-sericite-pyrite
(iv) Quartz-sericite-pyrite with some strong silicification
(v) Advanced argillic alteration
(vi) Potassic alteration

INTRUSIVE ROCKS

A Biotite-hornblende-feldspar porphyry
B Fine-grained equigranular intrusive

STRATIFIED ROCKS

Q Glacial sediments, no drill-hole or trench information

Toodoggone volcanics

24 Saunders grey dacite; welded tuff
23 Feldspathic welded tuff
22 Pyroxene porphyry flows and volcanic mudstone
21 Purple and green thin-bedded epiclastic rocks
20 Purple lapilli tuff
19a,b Heterolithic green lapilli tuff, crystal tuff
18 Monomictic hornblende-feldspar volcanic breccia
17 Brown lapilli tuff
16a,b Hornblende-feldspar porphyry flow, intrusive
15 Hornblende-feldspar-phyric volcanic breccia and spherulitic tuff
14 Laminated crystal tuff
13 Coarse laharic breccia and volcanic sandstone and conglomerate
12 Welded chloritic lapilli tuff
11 Green and purple laharic breccia, sandstone and siltstone
10 Red-rimmed volcanic conglomerate
9 Purple and green volcanic conglomerate
8 Brown volcanic sandstone and conglomerate
7a,b Heterolithic lapilli tuff and volcanic conglomerate, volcanic sediments
6 Quartz-feldspar lapilli tuff
5 Volcanic siltstone and carbonaceous tuff
4,4b Quartz-biotite-feldspar porphyry, associated epiclastic rocks
3a,b Green, purple tuffs and epiclastic rocks
2 Heterolithic conglomerate with intrusive clasts

Takla Group

1c,d Monomictic volcanic conglomerate and purple volcanic conglomerate
1a,b Augite-plagioclase porphyry and associated sedimentary rocks

green welded lapilli tuff with interbedded volcanic siltstone. The green welded tuff has a characteristic foliated appearance with recessive highly flattened chloritic lapilli, fine white to pink feldspar crystals, biotite and quartz. The interbedded epiclastic rocks are similar but the clasts are slightly rounded and the section includes fine-grained crystal-rich sandstones. The purple to purple and green tuff contains flattened clasts within a purple matrix; coarse epiclastics are rare and welded tuffs and volcanic siltstone form most of the section. Both subunits are very thin bedded and rapid lateral facies variations are the rule; they occur in varying proportions and probably represent lateral rather than vertical facies equivalents.

4a, b, c. Quartz-Biotite-Feldspar Porphyry Flow and Epiclastics

Previously described as a crystal tuff, this unit occurs only in the central part of the map area (Figure 2-5-2 and 2-5-3). It is a 70 to 100-metre-thick orange-brown weathering, locally layered, green, subcrowded quartz-biotite-feldspar porphyry. The pink feldspar and chloritized biotite crystals are euhedral to subhedral and the layering is locally highly contorted. Near the Rainier zone (Figure 2-5-6) fragmental rocks, dominated by clasts very similar to the porphyry, are exposed in the same stratigraphic position and are tentatively interpreted as an epiclastic facies equivalent. Lithologies similar to the porphyry, but variably purple and containing hornblende phenocrysts and white feldspars, are exposed on the south side of Ferricrete Creek (Figure 2-5-3) and are interpreted as a facies variant, but may simply be less altered porphyry.

5. Green Volcanic Siltstone and Dark Carbonaceous Tuff

This a very thin unit (1 to 2 metres) that is rarely exposed on surface but occurs in several drill holes and is genetically significant. Lying on top of the felsic porphyry, it consists of highly contorted dark green siltstone that is overlain by and mixed with a dark green to black lapilli tuff containing abundant carbonized wood fragments. This suggests a temporary hiatus after deposition of the porphyry, during which fine sediments accumulated. Vegetation on these sediments was roasted by and incorporated into the base of the ensuing pyroclastic deposit to result in a dark carbonaceous tuff.

6. Quartz-Feldspar Lapilli Tuff

This is a distinctive orange-brown weathering unit 90 metres thick, well exposed in the central part of the property. Recessive weathering, moderately flattened chloritic lapilli with crowded quartz and pink feldspar crystals are supported by a green crystal-rich matrix. Accessory clasts include brown, subrounded quartz-feldspar porphyry clasts and small red lithics. In one drill hole a section at the base of this unit consists mostly of altered orange-brown clasts similar to the porphyry in Unit 4.

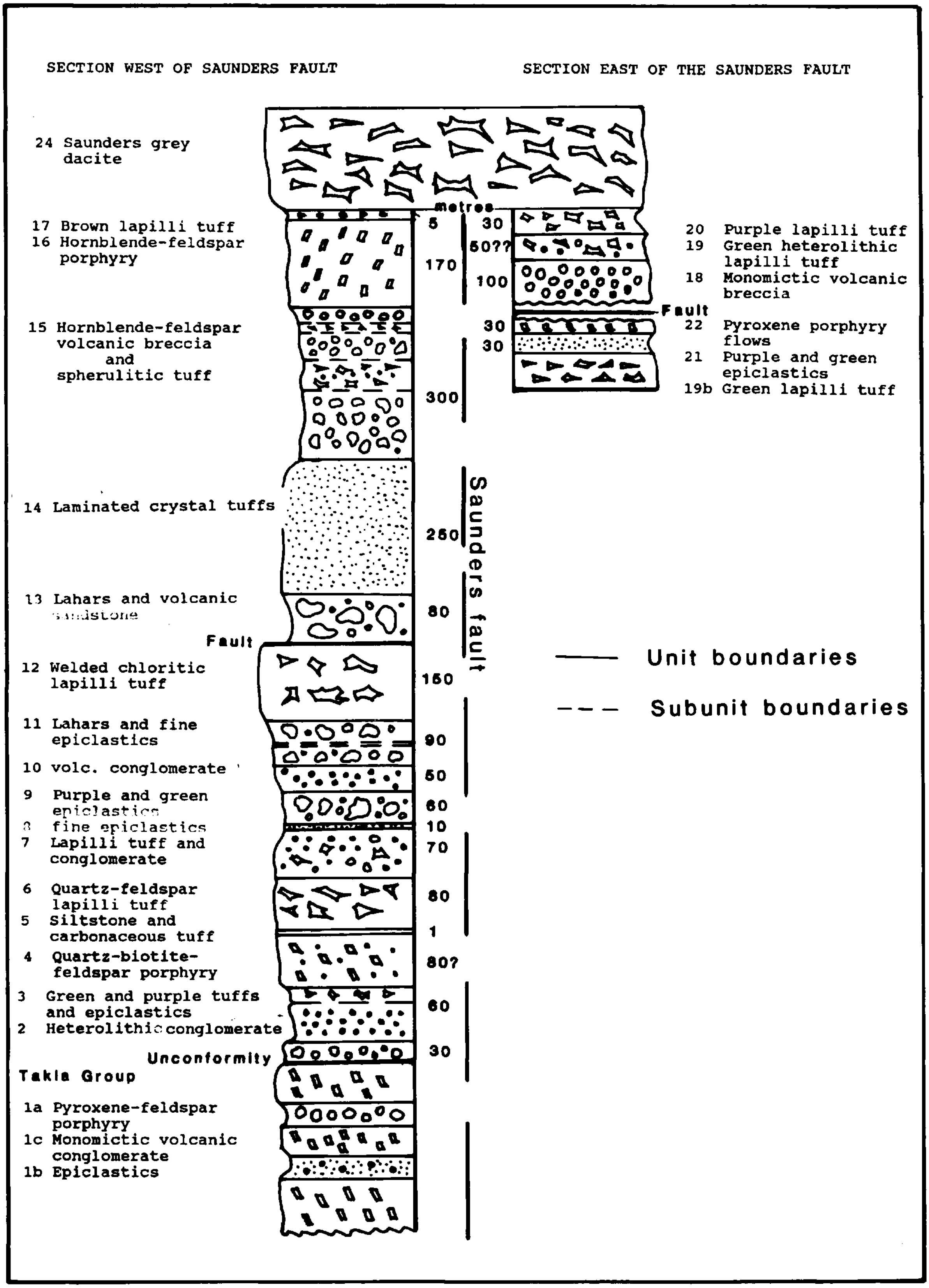


Figure 2-5-4. Stratigraphic column (to scale).

7. Heterolithic Quartz-Feldspar Lapilli Tuff and Volcanic Conglomerate

Immediately overlying Unit 6 is a 50 to 70-metre-thick unit superficially similar to Unit 6. However, flattened clasts lack pointed and cuspate ends and there are more accessory clasts, especially fine-laminated, pyritic, green siltstone clasts and fine red lithic clasts. The section consists predominantly of reworked pyroclastic rocks with at least two thin, welded pyroclastic units.

Overlying the fine heterolithic unit are purely epiclastic biotite and quartz-bearing lithologies that have been divided into several units (8, 9, 10, 11) on the basis of drill-core data.

8. Brown Volcanic Sandstone and Conglomerate

The change to a predominantly sedimentary regime is marked by a 10-metre-thick succession of brown and green, thin-bedded volcanic conglomerate and very thin beds of graded, crystal sandstone and siltstone deposits. There are two fairly distinctive beds within the section: one is a very fine-grained purple siltstone or ash tuff and the other is a dark green fine-grained unit with sparse, tiny chloritic fragments. Quartz, biotite and white to pink feldspar crystals are present throughout the section and some homogeneous beds superficially resemble the porphyry (Unit 4).

9. Purple and Green Volcanic Conglomerate

Comprising fine to coarse volcanic conglomerate, this 60-metre-thick section is characterized by pale green porphyritic fragments in a purple matrix. The rest of the section consists of green to dark maroon, coarse, heterolithic debris flows. Much of this unit is moderately hematized, either pervasively or along fractures. Several thin interbeds of graded purple siltstone to sandstone are present low in the section.

10. Red-Rimmed Volcanic Conglomerate

This distinctive 50-metre-thick unit is a grey-green, poorly sorted volcanic conglomerate with heterolithic subangular to subrounded pebbles, each coated with a hematitic rind. These clasts are resistant and their brick-red surfaces protrude from weathered outcrops. A purple-brown interbed, 2 metres thick, with identical clasts was noted in some sections.

11. Green and Purple Laharic Breccia, Sandstone and Siltstone

Coarse, very poorly sorted laharic deposits containing pebbles and boulders of varied porphyry units, locally with hematitic rinds, are interbedded with graded, crossbedded siltstone to sandstone layers. The 90-metre section is further divided into a green subunit at the base, a very similar middle purple section and an upper green subunit that is identical to the basal part of the section except that it contains numerous boulders of a green foliated welded tuff that looks like pyroclastic interbeds where intersected by drilling. This section consists of numerous small debris-flow deposits locally reworked by small streams.

12. Welded Chloritic Lapilli Tuff

A green-weathering pyroclastic deposit is characterized by strongly flattened recessive quartz and feldspar-phyric lapilli and small chloritic fiammé that impart a foliated appearance to weathered outcrops. Two other clast types are commonly present; angular, brown quartz-feldspar porphyry blocks and flattened, purple, collapsed pumice clasts.

Above the welded tuff the section is truncated by a major northeasterly striking fault and no stratigraphic overlap was observed on either side of the fault. Some stratigraphy is undoubtedly missing from the section but it is not clear how much.

13. Coarse Laharic Breccia and Volcanic Sandstone and Conglomerate

The next unit observed consists of over 80 metres of coarse, very poorly sorted laharic deposits and volcanic sandstone to pebble conglomerate. The laharic deposits are thick bedded and the coarser clasts are all either grey to purple quartz-biotite-hornblende-feldspar porphyry or angular clasts of a green, foliated, welded tuff. The finer sedimentary rocks are dark green sandstone, pebbly sandstone and conglomerate, composed of quartz, biotite and feldspar crystals and heterolithic pebbles, some with hematitic rims.

In two localities a green chloritic tuff with highly contorted purple ash partings was noted at the top of the epiclastics.

14. Laminated Crystal Tuffs

The epiclastic rocks are directly overlain by 250 metres of grey to purple, platy fracturing, thinly laminated quartz, biotite, hornblende and feldspar-bearing crystal tuffs. Near the base this unit is not clearly laminated and resembles a porphyry. The laminations vary from less than a centimetre to 2 centimetres thick and are only obvious on weathered surfaces. Some exposures are cut by narrow, vertical, sandy clastic dykes.

15a, b. Hornblende and Feldspar-Phyric Volcanic Breccia and Spherulitic Lapilli Tuff

The next unit is a thick section that consists of two distinct interbedded rock types. The section is dominated by green to maroon to red-brown hornblende-biotite-feldspar-phyric volcanic breccia. This contains prominent black hornblende needles and is typically fragmental with bomb-sized clasts that lack chilled margins or welded textures. To the north the unit is clearly epiclastic with thin crosslaminated clastic interbeds, whereas to the south it is more massive. The section contains at least two pyroclastic interbeds (15b), consisting of small green chloritic fiammé, collapsed, chloritic, feldspar-phyric lapilli, and rare blocks of hornblende-feldspar porphyry. In three localities the pyroclastic deposits include coarse bombs of porphyry with chilled and cracked margins and spheres 1 to 4 centimetres in diameter, that sometimes impinge on each other along flat faces. These are interpreted as spherulites; they commonly weather in relief giving the outcrop a very distinctive appearance.

16a, b. Hornblende-Feldspar Porphyry Flow

Overlying the volcanic breccias of Unit 15 is a brown to maroon, massive hornblende-biotite-feldspar porphyry flow that is mineralogically and texturally similar to the clasts in the underlying breccia. An intrusive with similar features is exposed near Black Lake.

17a, b. Brown Lapilli Tuff

The flow is overlain by a very thin but laterally continuous, distinctive brown-weathering heterolithic lapilli tuff. On the north face of Black Mountain (Figure 2-5-3) there are 30 metres of thin-bedded green, black and maroon fine-laminated siltstones, sandstones and volcanic pebble conglomerate between the brown tuff and porphyry flow unit.

The brown tuff is overlain by the Saunders grey dacite (*see* below). East of the Saunders fault (Figure 2-5-4) the units exposed beneath the Saunders grey dacite are completely different from those described above. Diakow *et al.*, (1985) mapped these rocks as the Lawyers quartzose andesite and interpreted them to be older than the Toodoggone crystal ash tuffs, although no stratigraphic evidence for this relationship was seen within the study area. The stratigraphic section exposed east of the fault and south of Jock Creek is fairly clear, but to the north the rocks appear to be different with only one unit that may be correlative (Figure 2-5-5). Further work is required to define the stratigraphy and relationships in this area.

TOODOGGONE VOLCANICS EAST OF SAUNDERS FAULT

18. Monomictic Volcanic Breccia

The lowest unit within this part of the stratigraphy is a dark green fragmental rock consisting solely of subcrowded hornblende-feldspar porphyry clasts. Commonly the clasts are indistinct and the rock resembles a porphyry. Over 100 metres of section is exposed on the west side of Ferricrete Creek (Figure 2-5-3).

19a, b. Heterolithic Green Lapilli Tuff

The breccias are overlain by a green heterolithic lapilli tuff. North of Jock Creek it is predominantly a quartz-biotite-hornblende-feldspar-phyric crystal tuff with indistinct lapilli, while to the south it is more heterolithic with subrounded clasts. Some parts of the section have small chloritic fiammé and higher in the stratigraphy there are distinctive red lithic fragments.

20. Purple Lapilli Tuff

The heterolithic tuff is overlain by 20 to 30 metres of welded purple tuff with weakly to moderately flattened, red, collapsed pumice clasts and a weakly foliated appearance. In the southern part of the map area this unit is overlain by the grey dacite while to the north it is overlain by the units described below.

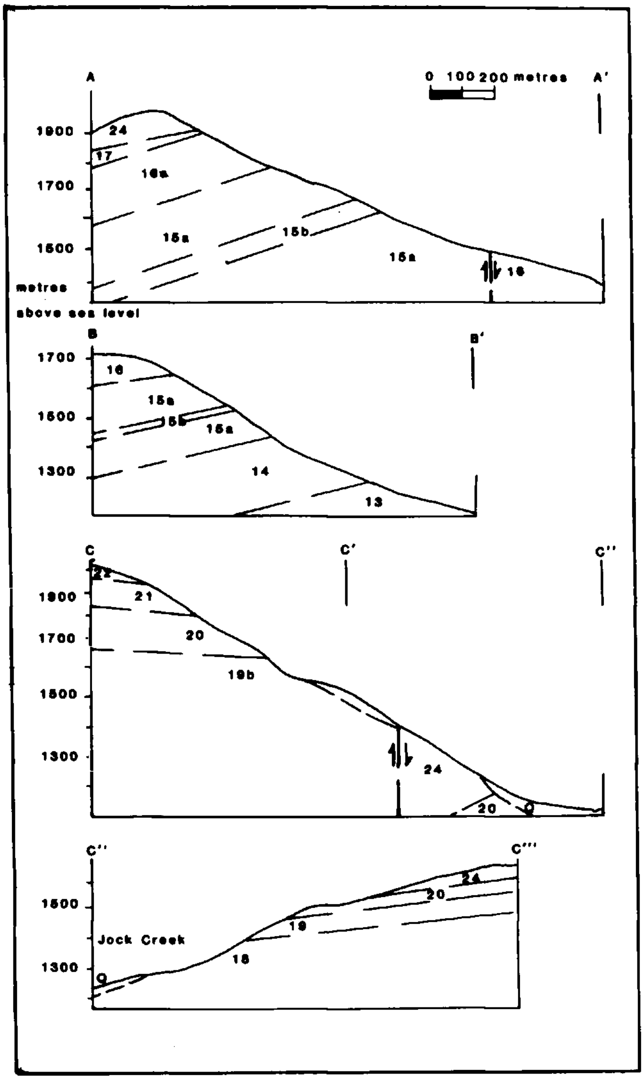


Figure 2-5-5. Sections A-A', B-B' C-C'' and C''-C''' looking east (*see* Figure 2-5-3 for locations).

21. Purple and Green Thin-Bedded Epiclastic Rocks

This 20-metre-thick unit consists of thinly bedded, laminated, graded and crossbedded volcanic siltstone and sandstone with abundant quartz and feldspar crystals.

22. Pyroxene Porphyry Flows and Volcanic Mudstone

Directly overlying the thin-bedded epiclastic rocks is more than 30 metres of medium to coarse-grained pyroxene porphyry flows and pastel-coloured pink and green laminated mudstone.

23. Feldspathic Welded Tuff

A fifth stratigraphic unit is exposed east of the Saunders fault but is always in fault contact with the other units, thus its stratigraphic position is unclear. It is a dark green lapilli tuff with crowded white feldspar crystals, rare to sparse quartz eyes and abundant moderately to highly flattened chloritic clasts. These rocks are exposed in the southeast corner of the map area (Figure 2-5-3) where they are extensively altered.

24. Saunders Grey Dacite

The grey dacite is a distinctive welded lapilli tuff with characteristic uncrowded to subcrowded, green, feldspar porphyry clasts that commonly have a fine-grained equigranular matrix set in a chocolate-brown matrix of ash with abundant quartz, biotite, hornblende and feldspar crystals. The clasts are flattened and aligned. Near the Saunders fault this unit also contains abundant granitic clasts.

The dacite is at least locally unconformable; the porphyry unit that underlies the dacite throughout the rest of the western half of the map area is missing on the east side of Mount Shasta.

INTRUSIVE ROCKS

Intrusive rocks are abundant only within the Saunders fault zone and the feldspathic welded tuff (Unit 23); both host macroscopically similar brown-grey to pink biotite-hornblende-feldspar porphyry dykes, small stocks (Unit A) and fine-grained equigranular granitic rocks (Unit B). Other intrusive rocks in the area are: pyroxene porphyry dykes on the north face of Diamond Peak, a pale-coloured quartz-feldspar porphyry dyke on the south end of Mets Ridge and several dark green aphanitic dykes observed in drill core on the Shasta property.

Takla Group rocks are cut by a pink hornblende-feldspar porphyry and a very shallowly dipping fine-grained equigranular granitic dyke (Units A and B respectively).

STRUCTURE

Most of the stratified rocks within the map area dip gently north or northwest, except for those exposed east of the Saunders fault and north of Jock Creek that dip gently south, and a fault-bounded panel in the centre of the map area that dips moderately northwest.

The stratigraphy is dissected by numerous high-angle faults. In plaees the net slip can be determined but as the stratigraphy is inclined, most displacements could be any combination of dip-slip and strike-slip motion. The faults mapped clearly group into three orientations; high-angle faults striking 170 to 180 degrees, faults at roughly 150 degrees, and short cross-faults at 050 and 110 degrees. The map area is transected by a major northwest-striking fault, the Saunders fault (Figure 2-5-3), that can be traced south of the Finlay River where it cuts a small stock, indicating up to 5 kilometres of left-lateral displacement (L.J. Diakow, personal communication, 1988). Two important faults striking 170 to 180 degrees cut rocks east of the Saunders fault and have downdropped the Saunders dacite on their east side. A smaller fault, striking 170 degrees, cuts the epiclastics north of the Shasta property and has either an eastern downdropped block or a left-lateral movement. Many other southeasterly striking faults of uncertain movement occur within the map area. The east-southeast-striking faults in the Jock zone (Figure 2-5-6) show right-lateral offset of a stratigraphic contact.

Two property-scale faults bound a block of rotated stratigraphy that hosts much of the Shasta deposit. The western bounding fault is the Shasta fault, which consists of a north-striking, moderately west-dipping segment near Jock Creek and a southeasterly trending segment further south. The dip of the southern segment is uncertain and it may be a different fault, but it is also the western boundary of the rotated block. The eastern margin of the block is the Christmas Creek fault, a prominent topographic linear trending 010 to 030 degrees and locally marked by float blocks of coarse calcite. To the north the rotated block is probably bounded by an east-southeast-striking fault. The rotated block has changed both in strike and dip, implying a plunging hinge line. The southeastern bounding fault is cut by mineralized veins and stockworks that maintain a consistent geometry on both sides of the fault, indicating that rotation occurred prior to the mineralizing event. Near Jock Creek, however, the JM and Creek zones are offset by three or four splays of the Shasta fault, indicating some movement also occurred after the mineralization.

A red, white and black mylonite zone, 2 metres thick, occurs within the laharic deposits of Unit 12. Although impressive, this bedding-parallel zone of deformation is restricted in extent and does not clearly offset the stratigraphy. It is localized within a zone of strong quartz-sericite alteration.

ALTERATION AND MINERALIZATION

Six distinct alteration types were noted during mapping:

(1) Regional propylitic alteration. All rock types except the Saunders grey dacite have been weakly to moderately altered. Chlorite, epidote and carbonate replace the groundmass, mafic phenocrysts and locally feldspar phenocrysts. Alteration intensifies near mineralized zones, for instance, around the Shasta deposit, where mafics are totally replaced by secondary minerals and feldspar phenocrysts are pink.

(2) Some units within the Takla Group are altered to a chlorite-carbonate assemblage with a pale green colour and indistinct primary textures. This alteration type affects most units to some degree, but is locally very strong within the monomictic volcanic breccias of Unit 1d.

(3) There are numerous gossanous exposures of quartz(?)-sericite-chlorite-pyrite alteration zones throughout the map area. Alteration intensity varies greatly and can result in total replacement of primary textures by a white, fine-grained mass of quartz, sericite and disseminated pyrite. Rocks may retain some phenocryst outlines and a pale green colour, suggesting the presence of some chlorite, or have a distinct green colour and well-preserved phenocrysts. Some zones, such as the North Black gossan (Figure 2-5-3) are large and exhibit strong alteration, while many others are narrow and probably localized around zones of fracture-enhanced permeability. A large system exposed in the southeast part of the map area contains numerous small, white carbonate-clay-sulphate(?) stringers that locally carry some chalcopyrite and sphalerite.

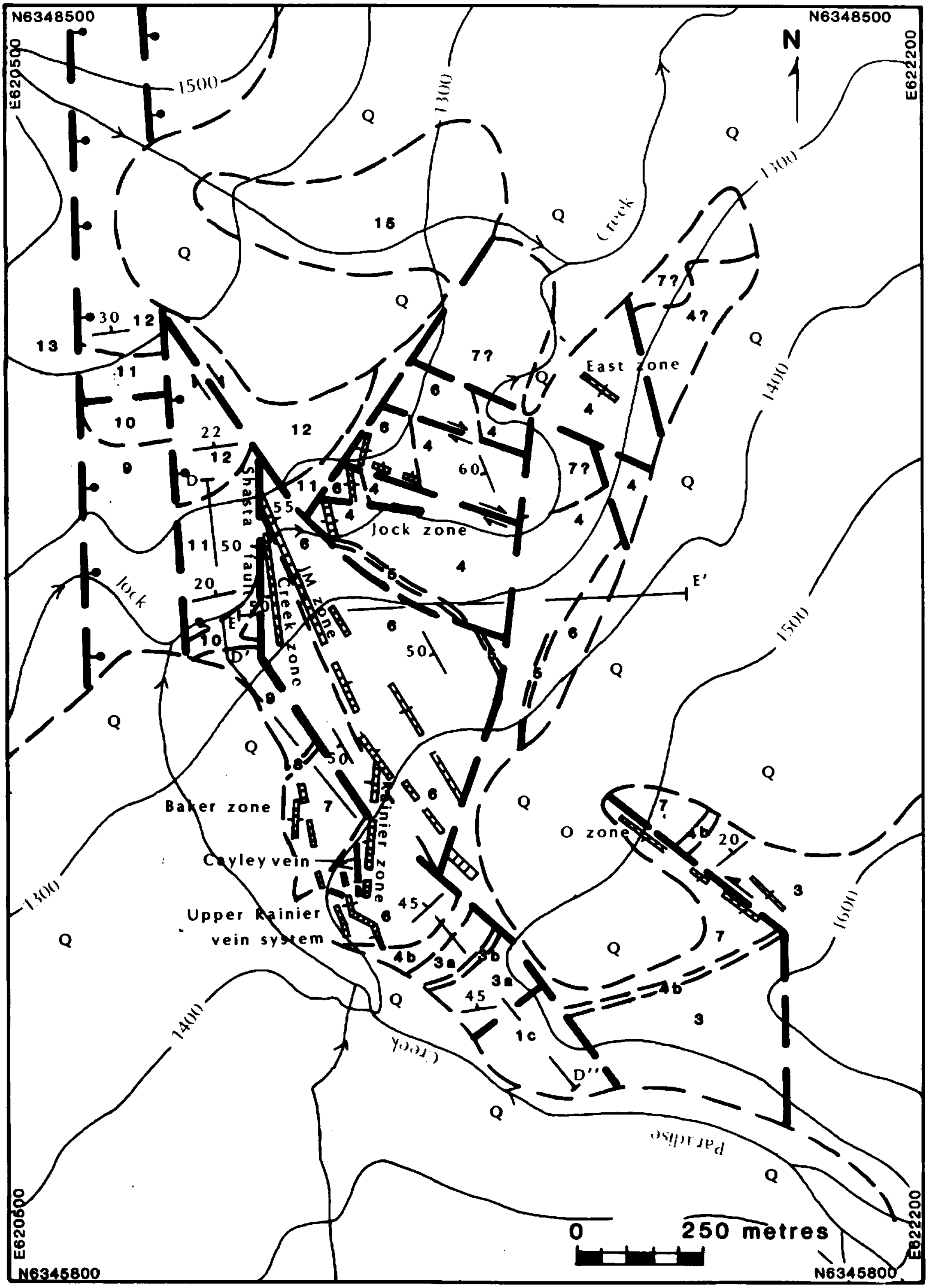


Figure 2-5-6. Shasta property geology.

(4) Several of the strong quartz-sericite-pyrite alteration zones host narrow cores of total silicification, locally with minor clay. These zones weather a characteristic red colour.

(5) Several Type 3 alteration zones in the southeast part of the map area host linear zones of advanced argillic (acid-sulphate) alteration characterized by resistant ribs of intense silicification with disseminated pyrite, minor barite and stringers of foliated (platy) pink alunite within recessive-weathering, rusty, white to grey quartz-sericite-alunite-clay-pyrite alteration. Some of the silicified cores contain sections of a translucent, grey, aphanitic quartz-clay assemblage instead of alunite. Several of the zones trend northeasterly. None of these mineral assemblages has yet been confirmed by X-ray diffraction and are based solely on field observations.

(6) The precious metal bearing stockwork zones at the Shasta property are hosted within zones of potassic alteration and are discussed in detail below.

Alteration is mostly confined to four localities, suggesting four major hydrothermal cells:

(a) Potassic alteration is unique to the area around the Shasta deposit and although all rocks are propylitically altered, fluid flow was largely restricted to relatively narrow, linear fracture zones and their immediate wallrock. These zones host both precious and base metals.

(b) Advanced argillic alteration on the JK property, in the southwest part of the map area, is centred within a very large area of pervasive alteration that is strongest around 060, 110 and 150-degree-striking zones. Where a structural control is obvious, the advanced argillic alteration zones trend northeasterly. No significant precious or base metal values have yet been reported from these interesting zones.

(c) Zones of strong quartz-sericite-pyrite alteration with local cores of intense silicification, minor clay and disseminated pyrite are localized around the north end of the Saunders fault, in the headwaters of Canyon Creek. Sampling by various companies has indicated, at best, anomalous precious metal values from mineralized shears within a small intrusive exposed in Canyon Creek (Figure 2-5-3) and from silicified zones near a pass to the north.

(d) The North Black gossan is a fourth important hydrothermal circulation cell, an elliptical zone of strong alteration. No significant precious metal values have been obtained from this area, even from layered quartz-vein float from the north part of the gossan.

Significant mineralization is not restricted to the alteration zones mentioned above. Coarse galena, sphalerite and chalcopyrite mineralization occurs in coarse carbonate float associated with a fault crossing Rip Ridge north of Jock Creek. Numerous quartz and quartz-carbonate veins with local quartz-sericite-pyrite alteration halos and some pyrite, galena and disseminated grey sulphides occur in the Takla Group at the head of Paradise Creek. Some have yielded significant gold values.

ALTERATION AND MINERALIZATION OF THE SHASTA DEPOSIT

On the Shasta property, mineralization is confined to Units 3 to 7 and the overlying epiclastics are not affected even by the strong propylitic alteration that is pervasive in the felsic porphyry and the lapilli tuff (Figures 2-5-6 and 2-5-7). This suggests they may be pre-mineral but this is not possible since they are involved in post-mineral rotational faulting. Mineralization is best developed in the tuffs and volcanic conglomerate of Units 6 and 7, and to a lesser extent in the underlying porphyry, but appears to feather in the underlying stratigraphy.

Gold and silver are present as the native alloy electrum, as native silver and in argentite with variable amounts of pyrite, sphalerite, galena, argentite and chalcopyrite (Todoruk, 1983) within braided stockwork zones consisting predominantly of quartz, calcite and potassic feldspar with lesser amounts of chlorite, barite, fluorite and sulphides.

Significant precious metal grades are usually associated with visible "grey sulphides" and native metals in quartz and calcite veinlets, but the highest grades yet obtained are from coarse calcite carrying abundant sphalerite, argentite, galena and native silver. The carbonate typically forms the centre of layered quartz-carbonate veins, indicating it was precipitated late in the mineralizing event. The calcite-sulphide-rich zones tend to occur as irregular pods within the stockwork system.

Wallrock alteration around the stockwork systems is characterized by the progressive addition of potassium and silica with a concordant decrease in sodium and aluminum, a reflection of the progressive replacement of the matrix, the clasts, and finally the phenocrysts, by potassium feldspar, minor sericite and quartz with significant amounts of epidote and chlorite remaining up to the margins of the veins. The alteration is marked by a progressive pink coloration of the rock and alteration zones have been defined on the basis of "pinking", first of the matrix, then of included clasts and phenocrysts with only relict textures preserved, and finally total pinking and destruction of all primary textures (Holbek and Thiersch, 1988). The degree and extent of alteration is not related to the grade of the mineralization; electrum has been observed in very narrow stringers cutting weakly altered rocks. Where large pods of carbonate veining are seen, the wallrock is altered to a green chlorite-carbonate assemblage that is locally superimposed on potassic alteration. This is particularly notable in restricted parts of the O and Baker zones.

The stockwork zones consist of numerous anastomosing chalcedonic to coarsely crystalline, locally vuggy quartz and quartz-calcite veinlets. They are referred to as zones because they are highly irregular and rarely form distinct, continuous veins. In places the centre of the system is marked by a grey to pale green fine-grained quartz breccia within broad zones of strong stockworking. These breccias are not particularly rich in precious metals except where crosscut by carbonate and sulphide-bearing veinlets and pods. The central parts of the stockwork zones anastomose and braid, forming an irregular lensoidal pattern within a broader zone of alteration, weak stockwork veining and anomalous gold and silver values. It is difficult to correlate good drill-hole intersections

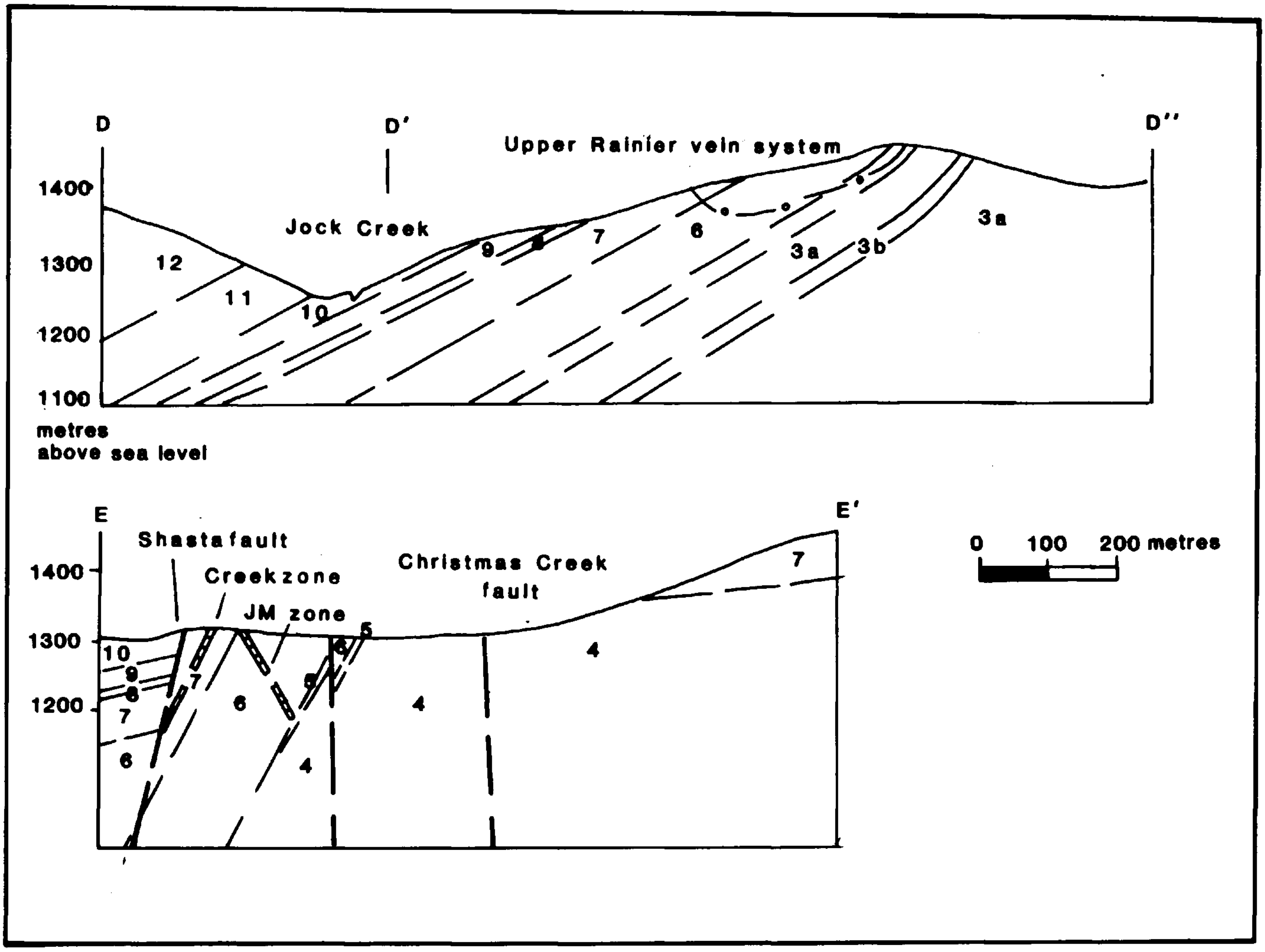


Figure 2-5-7. Section D-D′ and E-E′, looking east and north respectively (*see* Figure 2-5-6 for locations).

only 50 metres apart, yet when viewed on a broader scale, individual zones such as the JM zone can be traced along strike for 800 metres.

Eleven mineralized zones have currently been identified on the property. In the north part of the deposit they form braided stockwork zones while further south in the Rainier and, to a lesser extent, in the Baker and O zones they form narrower and better-defined vein systems. The orientations of the veins and zones are confined to three structural orientations, similar in strike to the trends of the faults (Figures 2-5-6 and 2-5-7). Within the central deposit area the JM zone strikes 150 degrees and dips moderately northeast. The Creek and Rainier zones splay off the JM zone and strike roughly north and dip moderately to the west. These zones carry precious metals and tend to pinch out several hundred metres south of the JM zone. The intersections of the JM zone and these splays commonly yield exceptionally good mineralized intercepts. The third important orientation group are east-southeast-striking veins. Splays off a northern offset of the JM zone, known as the Jock zone, strike 110 degrees and the Upper Rainier vein system can be traced through several segments alternately striking 110 and 150 degrees that in places carry very good precious metal grades but tend to be of limited extent. The Baker zone consists of 150 and 180-degree-striking zones and the East zone consists of mineralization within a southeasterly trending VLF and resistivity anomaly. The JM East zone is an untested zone subparallel to the JM zone.

ACKNOWLEDGMENTS

Esso Minerals Canada provided generous support throughout the field season. A research grant from the British Columbia Ministry of Energy, Mines and Petroleum Resources will allow the project to proceed through the academic year. Although they may not be in accord with all that is presented in this paper, Peter Holbek, Peter Thiersch and Ron Britten, who worked on the property in 1987, and Margaret MacPherson who joined the project in 1988, have done much of the work and contributed heavily to both the data and to the ideas presented in this paper. My supervisor, John Moore, helped me understand the rocks in the field, and has patiently edited this paper.

REFERENCES

Carter, N.C. (1972): Toodoggone River Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration and Mining, 1971, pages 63-70.

Clark, J.R. and Williams-Jones, A.E (1987): Metallogenic Implications of Lithotectonic Assemblages in the Toodoggone Au-Ag District, North-central British Columbia, *Geological Association of Canada*, Program with Abstracts, 1987, Volume 12, page 32.

Diakow, L.J. (1983): A Comparison of the Volcanic Stratigraphy, Structure and Hydrothermal Alteration of the Silver Pond (Cloud Creek) and Wrich-Awesome Claims, Toodoggone River, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1982, Paper 1983-1, pages 134-141.

——— (1985): Potassium-argon Age Determinations from Biotite and Hornblende in the Toodoggone Volcanic Rocks, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 298-300.

Diakow, L.J., Panteleyev, A. and Schroeter, T.G. (1985): Geology of the Toodoggone River Area (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 61.

Gabrielse, H. (1985): Major Dextral Transcurrent Displacements along the Northern Rocky Mountain Trench and Related Lineaments in North-central British Columbia, *Geological Society of America*, Bulletin, Volume 96, pages 1-14.

Gabrielse, H., Dodds, C.J. and Mansy, J.L. (1976): Toodoggone River (94E) Map-area *Geological Survey of Canada*, Open File 306.

Holbek, P. and Thiersch, P. (1988): 1987 Exploration Report on the Shasta Claim Group, Unpublished Company Report, *Esso Minerals Canada*.

Mihalynuk, M.G. and Ghent, E.D. (1986): Stratigraphy, Deformation and Low Grade Metamorphism of the Telkwa Formation near Terrace, British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 86-1B, pages 721-726.

Monger, J.W.H. and Church, B.N. (1977): Revised Stratigrapby of the Takla Group, North-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 14, pages 318-326.

Panteleyev, A. (1982): Toodoggone Volcanics South of the Finlay River, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1981, Paper 1982-1, pages 135-141.

——— (1984): Stratigraphic Position of the Toodoggone Volcanics, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 137-138.

Schroeter, T.G. (1982): Toodoggone River Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1981, Paper 1982-1, pages 122-133.

Thorkelson, D.J. (1988): Jurassic and Triassic Volcanic and Sedimentary Rocks in Spatsizi Map Area, North-central British Columbia, *in* Current Research, Part E, *Geological Survey of Canada*, Paper 88-1E, pages 43-48.

Tipper, H.W. and Richards, T.A. (1976): Jurassic Stratigraphy and History of North-central British Columbia, *Geological Survey of Canada*, Bulletin 270.

Todoruk, S.L. (1983): Opaque Mineralogy of the Shasta Gold-silver Prospect, Unpublished Undergraduate Report, *The University of British Columbia*.

NOTES

NEW K-Ar ISOTOPIC AGES OF EPITHERMAL ALTERATION FROM THE TOODOGGONE RIVER AREA, BRITISH COLUMBIA (94E)

By James R. Clark and A.E. Williams-Jones
McGill University

KEYWORDS: Geochronology, Toodoggone, epithermal, alteration, potassium-argon, gold, silver.

INTRODUCTION

This report presents three new potassium-argon isotopic age determinations of minerals associated with epithermal alteration from the Toodoggone district, north-central British Columbia.

The Toodoggone area has received extensive exploration attention over the past 10 years. In addition to a former gold-silver producer (Baker mine), the district contains a major new gold-silver mine in development (Lawyers), several gold deposits undergoing final feasibility studies (Bonanza, BV and Thesis III), and numerous other precious metal prospects. Most of these deposits exhibit characteristics typical of epithermal mineralization. Schroeter (1982) and Schroeter *et al.* (1986) have demonstrated that alteration associated with some of the occurrences is Early to Middle Jurassic in age. Further, Clark and Williams-Jones (1987, 1988) have suggested that gold-silver deposits in the Toodoggone area are restricted to mid-Toarcian (approximately 190 Ma) and older rocks, and represent a district-wide period of alteration and mineralization.

The objective of the current study is to provide additional estimates of the age of epithermal alteration and mineralization in the Toodoggone district. The new data will contribute to ongoing research on the gold-silver metallogeny of the camp, to specific ore deposit genesis studies, and to the placement of the mineralization within a lithotectonic framework relevant to the exploration community.

GEOLOGICAL SETTING

The "Toodoggone volcanics" (Carter, 1972) comprise the most important lithologie assemblage in the district. These volcanic rocks are dominantly andesitic to dacitic pyroclastics and flows of Early to Middle Jurassic age, and have been described by Schroeter (1981, 1982), Panteleyev (1982, 1983), Diakow (1984), Forster (1984) and Diakow *et al.* (1985). The Toodoggone volcanics are underlain by mafic to intermediate volcanic rocks of the Takla-Stuhini assemblage and are overlain by sediments of the Sustut Group. The better known gold-silver deposits in the district, Baker and Lawyers, have been described by Barr (1978) and Vulimiri *et al.* (1987) respectively.

Previous potassium-argon studies of hornblende and biotite from the Toodoggone area indicate the age of the Toodoggone volcanics ranges from 204 to 182 Ma. These ages appear divisible into two main groups: (I), an older, lower stage of volcanism with ages of 204 ± 7 Ma (Panteleyev, 1983), 202 ± 7, 200 ± 7, 199 ± 7, 197 ± 7 (Diakow, 1985), and 189 ± 6 Ma (Carter, 1972; value recalculated using constants of Steiger and Jäger, 1977); and (II), a younger, upper stage of volcanism with ages of 183 ± 8 and 182 ± 8 Ma (Gabrielse *et al.*, 1980; first value recalculated using constants of Steiger and Jäger, 1977). The older volcanic rocks are dominantly andesitic pyroclastics and flows characterized by widespread propylitic and zeolitic alteration. The upper volcanic rocks, corresponding to the "grey dacite" and equivalent units of Diakow *et al.* (1985), dominantly consist of andesitic ash-flow tuffs which generally lack significant epithermal alteration. All the known epithermal gold-silver deposits and prospects are restricted to the lower Toodoggone volcanics and underlying units. Clark and Williams-Jones (1987, 1988) have proposed that Toodoggone volcanism can therefore be divided into two stages and that mineralization took place during the waning of Stage I volcanism, and/or during a hiatus between Stages I and II.

Gold and gold-silver deposits in the Toodoggone district are associated with adularia-sericite and acid-sulphate alteration. The ages of several of the former class of deposits have been determined by potassium-argon analysis (Schroeter *et al.*, 1986) of adularia vein selvages from the Lawyers AGB deposit (180 ± 6 Ma), the Golden Lion prospect (176 ± 6 Ma), and the Metsantan prospect (168 ± 6 Ma). These age determinations may represent minimum values due to loss of radiogenic argon from the adularia structure. The structural state of the measured adularia samples is not known; deviation from near-ideal high sanidine structures by postdepositional ordering (Cerny and Chapman, 1986) or thermal effects could yield younger, non-absolute ages. The age of gold deposits directly associated with acid-sulphate alteration has not been previously determined. One sample from the Alberts Hump alteration zone yielded an alunite potassium-argon age of 190 ± 7 Ma (Schroeter, 1982). The alunite alteration zone is spatially associated with a number of gold deposits but is not known to directly host mineralization.

POTASSIUM-ARGON ANALYSES

Potassium-argon isotopic age determinations were conducted on three samples. The samples were selected from deposits and alteration zones exhibiting characteristics of, or spatial relationships to, the aeid-sulphate style of alteration: the Bonanza deposit, the BV deposit and the Jan alunite zone.

TABLE 2-6-1
K-Ar AGE DETERMINATIONS, TOODOGGONE DISTRICT

Sample No.	Location UTM Coordinates		Mineral Analysed[1]	K (wt %)	$^{40}Ar^2$ ($\times10^{-10}$ mol/g)	$\%^{40}Ar^2$	Calculated Age (Ma, ±1σ)
A84-4-19.5 (Bonanza)	598200E	6371700N	sericite	4.26	13.246	96.4	171±6
A84-19-72.5 (BV)	596800E	6369900N	sericite	1.93	5.336	78.4	152±5
JN-12 (Jan alunite)	629400E	6347800N	alunite	3.28	11.582	95.1	193±7

[1] Mineral concentrates; density fractions include quartz and kandite-group clay minerals.
[2] Radiogenic argon.

The Bonanza deposit is located 3 kilometres east-northeast of Alberts Hump, and contains a minimum 248 000 tonnes grading 9.5 grams per tonne gold (G. Sivertz, personal communication, 1988). The deposit comprises at least three main mineralized structures hosted by an andesitic-dacitic ash-flow tuff, and is locally intruded by a porphyritic rhyodacite dyke. Mineralization in the high-grade Verrenass zone consists of barite-hosted native gold and electrum deposited in the acid-leached core of an intensely altered north-northwest-trending structure (Clark and Williams-Jones, 1986). Quartz-dickite alteration is dominant adjacent to the mineralization and is enclosed by a quartz-illite-hematite assemblage. The marginal illite-bearing alteration is the only assemblage suitable for geochronological study.

The BV deposit is located 2.5 kilometres southeast of Alberts Hump, and contains 53 000 tonnes grading 10.4 grams per tonne gold (G. Sivertz, personal communication, 1988). The deposit is also barite hosted, but differs from those in the Bonanza area in that high-grade mineralization occurs in discrete barite-quartz-pyrite veins in a silicified andesite flow. The veins are commonly brecciated and sheared at depth, and are associated with strong sericitic alteration. The alteration zone lacks the abundant advanced-argillic and acid-leached features of other acid-sulphate associated deposits in the area, but may provide genetic linkage between these and the adularia-sericite alteration. Sericite appears to be the only mineral in the deposit which is suitable for geochronological study.

The Jan alunite zone is located 2.0 kilometres southeast of the confluence of Jock and Red creeks. The zone is not known to contain mineralization but represents the second largest (after Alberts Hump) alunite-bearing zone in the Toodoggone district. The zone is characterized by a central area of intense quartz-alunite alteration which grades outwards into increasingly dickite and hematite-rich assemblages. An andesitic ash-flow tuff hosts the alteration but the zone appears to be fault-bounded and outcrops adjacent to andesitic flows of the Hazelton Group.

SAMPLE DESCRIPTIONS

Polished thin sections were prepared from each of the samples and were examined for potassium-bearing phases and paragenetic relationships. X-ray diffraction was conducted on randomly oriented powder mounts of each sample, using a Siemens D500 diffractometer, in order to evaluate the mineralogy of the fine-grained alteration.

Sample A84-4-19.5 is from 19.5 metres downhole in diamond-drill hole A84-4 on the Verrenass zone of the Bonanza deposit. Illite occurs as very fine-grained (0.01-0.1 millimetre) aggregates which completely replace the original feldspars in the ignimbrite host rock. Dickite is locally intergrown with the illite. Other major phases in the sample are quartz and hematite, and the trace phase is rutile.

Sample A84-19-72.5 is from 72.5 metres downhole in diamond-drill hole A84-19 on the BV deposit. Sericite (probably illite) occurs as very fine-grained (0.01-0.1 millimetre) aggregates which completely replace plagioclase phenocrysts and groundmass feldspar in the andesite host rock. Minor kandite-group clay minerals are locally intergrown with the sericite. The other major phase in the sample is quartz and the minor phase is pyrite.

Sample JN-12 was collected from the central outcrop area of the Jan alunite zone. Alunite occurs as fine-grained (0.05-0.2 millimetre) clusters which completely replace the feldspars in the ignimbrite. Minor alunite also occurs with dickite as veinlets and fracture fillings. The other major phase in the sample is quartz, and minor and trace phases are hematite and rutile.

ANALYTICAL METHODS

Mineral concentrates, and potassium and argon measurements were conducted by the Geochronometry Laboratory at The University of British Columbia, under the direction of R.L. Armstrong and J.E. Harakal. Potassium analyses were done in duplicate by atomic absorption using a Techtron AA4 spectrophotometer. Argon was extracted by fusion of the sample, followed by purification of the argon and addition of a ^{38}Ar spike. Isotopic compositions were determined by isotope dilution using an AEI MS-10 mass spectrometer. Age calculations were done using the constants: $^{40}K = 0.581 \times 10^{-10}a^{-1}$, $^{40}K_{\beta} = 4.96 \times 10^{-10}a^{-1}$, and $^{40}K/K = 0.01167$ atom per cent (Steiger and Jäger, 1977). Errors are given for one standard deviation.

RESULTS AND DISCUSSION

Age determination results are given in Table 2-6-1. The calculated ages are 152±5 and 171±6 Ma for the sericite-bearing (illite) BV and Bonanza alteration, and 193±7 Ma for the Jan alunite zone. The Jan alunite zone age is concordant with the age of alunite from Alberts Hump. The 152 ± 5 Ma age from the BV deposit is younger than any age previously determined for material from the Toodoggone district. The age of illitic alteration at the Verrenass zone of the Bonanza deposit is in agreement with minimum ages determined for adularia from other deposits in the district. Sericite from the BV and Bonanza deposits is dominantly very fine grained and may have been subject to processes causing partial loss of radiogenic argon. Both deposits show structural evidence of postmineralization tectonism, and the Bonanza deposit may also have been thermally affected by synmineralization to postmineralization dykes. The sericite ages of the BV and Verrenass zones should therefore be considered as the minimum ages of alteration and mineralization of these deposits.

CONCLUSIONS

The new potassium-argon age determinations for alteration minerals associated with the Bonanza and BV deposits and the Jan alunite zone confirm that hydrothermal activity and mineralization in the Toodoggone district is of Jurassic age. The alunite age of 193 ± 7 Ma is in agreement with a two-stage model of volcanism, with alteration and mineralization confined to Stage I and older rocks. However, sericite ages support the conclusion of Schroeter *et al.* (1986) that gold-silver mineralization may postdate the youngest volcanism. Because there are no known volcanic or intrusive events younger than 182 Ma capable of providing heat sources for the widespread alteration in the district, we conclude that the sericite and adularia ages of 180 to 152 Ma represent ages of minerals which have undergone radiogenic argon loss. More accurate geochronological methods, such as $^{40}Ar/^{39}Ar$, may be required to obtain the absolute ages of Toodoggone gold-silver deposits.

ACKNOWLEDGMENTS

This study was conducted with funding from the British Columbia Geoscience Research Grant Program. Support from Natural Sciences and Engineering Research Council of Canada and Energy, Mines and Resources Canada operating grants, and the Ixion Research Group (Montreal) are also gratefully acknowledged. The study would not have been possible without the cooperation of G. Sivertz and L. Eccles (Energex Minerals Ltd.), and P. Weishaupt (Canasil Resources Inc.).

REFERENCES

Barr, D.A. (1978): Chappelle Gold-silver Deposit, British Columbia, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 72, Number 790, pages 66-79.

Carter, N.C. (1972): Toodoggone River Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology, Exploration and Mining in British Columbia, 1971, pages 63-71.

Cerny, P. and Chapman, R. (1986): Adularia from Hydrothermal Vein Deposits: Extremes in Structural State, *Canadian Mineralogist*, Volume 24, pages 717-728.

Clark, J.R. and Williams-Jones, A.E. (1986): Geology and Genesis of Epithermal Gold-barite Mineralization, Verrenass Deposit, Toodoggone District, British Columbia, *Geological Association of Canada*, Program with Abstracts, Volume 11, page 57.

——— (1987): Metallogenic Implications of Lithotectonic Assemblages in the Toodoggone Au-Ag District, North-central British Columbia, *Geological Association of Canada*, Program with Abstracts, Volume 12, page 32.

——— (1988): A Preliminary Appraisal of the Au-Ag Metallogeny of the Toodoggone District, North-central British Columbia: Geology and Metallogeny of Northwestern British Columbia, Workshop, *Smithers Exploration Group - Geological Association of Canada*, Program with Abstracts, pages A33-A37.

Diakow, L.J. (1984): Geology between Toodoggone and Chukachida Rivers (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 139-145.

——— (1985): Potassium-argon Age Determinations from Biotite and Hornblende in Toodoggone Volcanic Rocks (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 298-301.

Diakow, L.I., Panteleyev, A. and Schroeter, T.G. (1985): Geology of the Toodoggone River Area (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 61.

Forster, D.B. (1984): Geology, Petrology and Precious Metal Mineralization, Toodoggone River Area, North-central British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*, 223 pages.

Gabrielse, H., Wanless, R.K., Armstrong, R.L. and Erdman, L.R. (1980): Isotopic Dating of Early Jurassic Volcanism and Plutonism in North-central British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 80-1A, pages 27-32.

Panteleyev, A. (1982): Toodoggone Volcanics Sonth of Finlay River (94E/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1981, Paper 1982-1, pages 135-141.

——— (1983): Geology between Toodoggone and Sturdee Rivers, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1982, Paper 1983-1, pages 143-148.

Schroeter, T.G. (1981): Toodoggone River Area (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1980, Paper 1981-1, pages 124-131.

——— (1982): Toodoggone River Area (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1981, Paper 1982-1, pages 122-133.

Schroeter, T.G., Diakow, L.J. and Panteleyev, A. (1986): Toodoggone River Area (94E), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 167-174.

Steiger, R.H. and Jäger, E. (1977): Subcommission on Geochronology: Convention on the use of Decay Constants in Geo- and Cosmochronology, *Earth Planetary Science Letters*, Volume 36, pages 359-362.

Vulimiri, M.R., Tegart, P. and Stammers, M.A. (1987): Lawyers Gold-silver deposits, British Columbia, *in* Mineral Deposits of the Northern Cordillera, A. Morin, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 37, pages 191-201.

GALENA LEAD ISOTOPES OF THE TOODOGGONE EPITHERMAL GOLD CAMP, NORTH-CENTRAL BRITISH COLUMBIA* (94E)

By Colin I. Godwin, Janet E. Gabites, The University of British Columbia, and T.G. Schroeter

KEYWORDS: Economic geology, Toodoggone, Takla Group, epithermal gold deposits, galena lead isotopes.

INTRODUCTION

The Toodoggone gold camp in central British Columbia hosts epithermal mineralization in Late Triassic rocks of the Takla Group, and in Early to Middle Jurassic rocks of the Toodoggone volcanics. The object of this lead isotope study was to: (1) determine if the deposits are coeval with the Toodoggone volcanic host rocks, as generally supposed; (2) compare the isotope signature to deposits of approximately equivalent age that are hosted in the Hazelton Group; (3) define the lead isotope fingerprint for Jurassic lead in Stikinia; and (4) determine if there are differences between the Takla-hosted and Toodoggone-hosted deposits.

DATA

Data for 26 analyses of 20 samples from 13 deposits in the Toodoggone epithermal gold camp are listed in Table 2-7-1 and plotted in Figure 2-7-1. Two of the analyses (30406-AVG and 30815-001) are probably unsatisfactory, as explained in the footnote in Table 2-7-1, and are omitted in this interpretation. Analytical details are available in Godwin *et al.*, (1988).

All galena lead isotope data from the Toodoggone epithermal gold camp plot tightly in Figure 2-7-1 about a mean of $^{206}Pb/^{204}Pb = 18.79$, $^{207}Pb/^{204}Pb = 15.59$, and $^{208}Pb/^{204}Pb = 38.32$ (Tables 2-7-1 and 2-7-2). The cluster defining the Toodoggone camp as a whole plots with, and slightly below, the lowest values in the Early to Middle Jurassic Hazelton Group cluster defined by Alldrick *et al.* (1987: their Cluster 1 with additional unpublished data).

TABLE 2-7-1
GALENA LEAD ISOTOPE DATA[1] FROM DEPOSITS IN THE TOODOGGONE AREA, CENTRAL BRITISH COLUMBIA (094E)

Sample Number[2]	Source[3]	Deposit Name	Figure Number	Lat. North (decimal deg.)	Long. West (decimal deg.)	Lead Isotope Ratios $^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Host Rock: Toodoggone Volcanics								
[30406-AVG[4]	1	Silver Creek (n = 2)	1	57.31	127.22	18.866	15.632	38.497]
30475-001	2	JD (Schmidt)	2	57.45	127.17	18.803	15.591	38.325
30476-001	4	AL (Bonanza)	3	57.45	127.38	18.789	15.585	38.305
30603-001	3	Norod Lake	4	57.13	126.73	18.789	15.600	38.311
30604-AVG	3,4	Metsantan (n = 3)	5	57.42	127.31	18.811	15.592	38.341
[30815-001[4]	4	Marmot Lake	6	57.38	127.18	18.837	15.607	38.425]
30877-AVG[4]	4	Shas (n = 2)	7	57.44	127.08	18.797	15.595	38.332
30878-AVG	4	JD (n = 2)	8	57.44	127.17	18.812	15.592	38.343
30880-AVG	4	Golden Lion (n = 2)	9	57.57	127.29	18.775	15.588	38.300
30881-001	4	Moose	10	57.47	127.21	18.794	15.589	38.316
AVERAGES AND STANDARD DEVIATIONS FOR TOODOGGONE VOLCANICS (n = 8)[5]						18.796±0.012	15.592±0.005	38.322±0.016
Host rock: Takla Volcanics								
30601-AVG	3,4	Baker (n = 2)	A	57.29	127.11	18.763	15.594	38.310
30602-001	3	Claw Mountain	B	57.27	127.58	18.778	15.589	38.311
30879-001	4	Shas (South)	C	57.20	126.95	18.768	15.589	38.287
AVERAGES AND STANDARD DEVIATIONS FOR TAKLA VOLCANICS (n = 3)						18.770±0.008	15.591±0.003	38.303±0.014
AVERAGES OF ALL DEPOSITS ANALYSED IN THE TOODOGGONE CAMP (n = 11)						18.789	15.591	38.316

[1] All analyses are by J. Gabites, Geochronology Laboratory, The University of British Columbia.
[2] Sample numbers with the suffix -AVG are average values; all others are single analyses. (*See* also listings in Godwin *et al.*, 1988, tables 5.5N and 5.6N.)
[3] 1 = sample from G. Gibson; 2 = sample from C. Scott; 3 = sample from L. Diakow and A. Panteleyev; 4 = sample from T. Schroeter.
[4] Analysis is not of galena; it is either of sphalerite or pyrite.
[5] Analyses in square brackets are excluded from the calculations because analyses of sulphides other than galena are commonly (but not necessarily) erratic.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

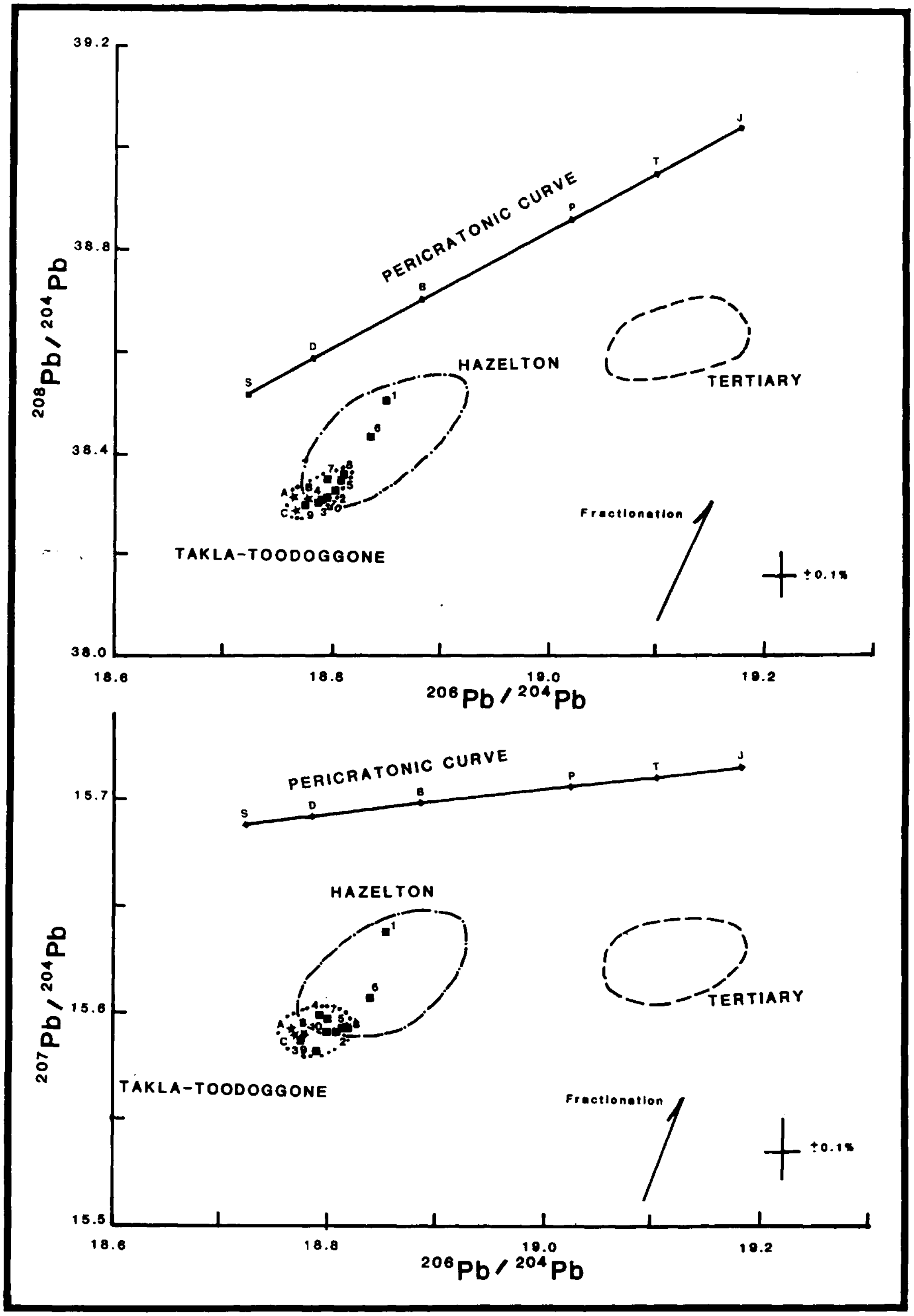


Figure 2-7-1. Lead-lead plots of galena lead isotopes from epithermal gold deposits hosted in Takla Group and Hazelton volcanics, Toodoggone Camp, central British Columbia. Data and codes identifying deposits plotted are in Table 2-7-1. Shown for comparison are part of the pericratonic curve (Goutier, 1986; Godwin *et al.*, 1988; *cf.* Godwin and Sinclair, 1982), and the clusters from the Stewart area (Alldrick, 1987: plus additional data) for Hazelton volcanics and Tertiary intrusive associated veins. The Takla — Toodoggone cluster is well defined at the lower border of the Hazelton cluster. S = Silurian, D = Devonian, B = Carboniferous, P = Permian, T = Triassic and J = Jurassic.

TABLE 2-7-2
AVERAGE LEAD ISOTOPE DATA CLUSTERS FOR DEPOSITS OF DIFFERENT AGES AND TYPES IN THE STIKINE TERRANE, BRITISH COLUMBIA

Age	Description	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Tertiary-Cretaceous	Intrusive-related veins, Stewart area[1]	19.15	15.62	38.63
Jurassic	Volcanogenic deposits, Hazelton Group, Stewart area[1]	18.82	15.61	38.44
Jurassic	Average of all gold deposits, Toodoggone area[2]	18.79	15.59	38.32
Jurassic	Toodoggone volcanic hosted gold deposits, Toodoggone area[2]	18.80	15.59	38.32
Triassic-Jurassic	Takla Group hosted gold deposits, Toodoggone area[2]	18.77	15.59	38.30
Triassic	Kutcho volcanogenic deposits, Kutcho area[3]	18.45	15.53	37.92

[1] Average is from data in Aldrick *et al.*, 1987.
[2] Averages are from Table 2-7-1.
[3] Average is from data in Godwin *et al.*, 1988.

The three lead isotope analyses from deposits hosted in the Takla Group plot at the left side of the overall cluster for the Toodoggone camp (Figure 2-7-1). Lead isotopes for the Takla-hosted deposits compared to those in the Toodoggone volcanics are statistically indistinct for $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$, but are probably significantly less for $^{206}Pb/^{204}Pb$. Students t-tests show the means for $^{206}Pb/^{204}Pb$ to be significantly different at the 0.05 level, but not at the 0.01 level.

CONCLUSIONS

Clearly the Toodoggone epithermal gold deposits in Late Triassic to Middle Jurassic rocks are all closely related genetically. Lead isotope ratios from deposits in the Toodoggone camp are similar to those from deposits that are most likely cogenetic with the Early to Middle Jurassic Hazelton Group in the Stewart area of northwestern British Columbia (Table 2-7-2 and Figure 2-7-1; Alldrick *et al.*, 1987). These values, on the other hand, are markedly different from deposits of other ages in Sitikinia. Specifically, Table 2-7-2 shows that they are not at all similar to Triassic lead from the Kutcho Creek deposit, or to lead from intrusive-related Tertiary deposits in the Hazelton Group of the Stewart area. The similarity in lead isotopes between the Hazelton and Toodoggone volcanics emphasizes their common tectonogenesis within the Stikine terrane. Furthermore, Jurassic lead isotope ratios in Stikinia are now defined within a narrow range.

The similar, but slightly lower, lead isotope ratios for deposits in the Toodoggone camp (Tables 2-7-1 and 2-7-2; Figure 2-7-1), compared to those hosted by the Hazelton Group in the Stewart camp suggest:

(1) Toodoggone volcanics (and possibly Takla Group) and Hazelton Group had a similar geochemical evolution;

(2) the age of most deposits in the Toodoggone camp is possibly slightly older, at Early Jurassic (slightly different geochemical evolutions of Hazelton Group and Toodoggone volcanics also could account for the minor differences in the lead isotopes);

(3) most deposits are cogenetic with their Toodoggone volcanic host.

Lead isotopes from epithermal deposits hosted in Takla Group rocks are marginally distinct statistically from those hosted in the Toodoggone volcanics. The difference may be due to a slightly older, Late Triassic age for the mineralization in the Takla Group. This would imply a very similar geochemical evolution for the Takla and Hazelton rocks. Alternatively, and favoured by the writers, the slightly lower $^{206}Pb/^{204}Pb$, if truly distinct statistically, could be due to mixing of lead from the Toodoggone volcanics with lead from the Takla host rocks. In this case all the deposits would be the same age as the Toodoggone volcanics. This conclusion agrees with the interpretation of Clark and Williams-Jones (1988) that all gold mineralization in the Toodoggone camp was emplaced during one restricted Jurassic episode. More lead isotope analyses of deposits in the Takla Group are desirable.

ACKNOWLEDGMENTS

Cost of analyses was borne by the British Columbia Science Council, the British Columbia Ministry of Energy, Mines and Petroleum Resources, and the Canada/British Columbia Mineral Development Agreement. Several samples were contributed by A. Panteleyev and L.J. Diakow, British Columbia Ministry of Energy Mines and Petroleum Resources. Samples were also donated by G. Gibson and C. Scott.

REFERENCES

Alldrick, D.J., Gabites, J.E. and Godwin, C.I. (1987): Lead Isotope Data From the Stewart Mining Camp (104B/1), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 93-102.

Clark, James R. and Williams-Jones, A.E. (1988): A Preliminary Appraisal of the Au-Ag Metallogeny of the Toodoggone District, North-central British Columbia. Abstract, *Smithers Exploration Group - Geological Association of Canada*, Cordilleran Section Workshop, Smithers, Program and Abstracts, pages A33-34.

Godwin, Colin I., Gabites, Janet E., and Andrew, Anne (1988): LEADTABLE: A Galena Lead Isotope Data Base for the Canadian Cordillera, With a Guide to its Use by Explorationists, *B.C. Ministry of Energy Mines and Petroleum Resources*, Paper 1988-4, 188 pages.

Godwin, C.I. and Sinclair, A.J. (1982): Average Lead Isotope Growth Curve for Shale-hosted Lead-zinc Deposits, Canadian Cordillera, *Economic Geology*, Volume 77, pages 675-690.

Goutier, F.M. (1986): Galena Lead Isotope Study of Mineral Deposits in the Eagle Bay Formation, Southeastern British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 153 pages.

NOTES

THE KECHIKA YTTRIUM AND RARE-EARTH PROSPECT* (94L/11, 12 and 13)

By Jennifer Pell, Richard Culbert, Consulting Geologist and Michael Fox, Canamerica Precious Metals Ltd.

KEYWORDS: Economic geology, Kechika Ranges, rare-earth elements, yttrium, alkaline igneous rocks, diatremes, syenitic tuff.

INTRODUCTION

A suite of alkaline igneous rocks consisting of syenites, melanocratic augite syenite dykes, an alkaline diatreme and related dykes and tuff breccias, and numerous strongly sheared and altered rocks, crops out in the Kechika Ranges of the Cassiar Mountains (RAR and REE claims). These rocks are currently being explored by Formosa Resources Corporation for their yttrium and rare-earth-element potential.

The alkaline rocks are intermittently exposed in a northwest-trending zone in excess of 20 kilometers long, the centre of which is approximately 58°42′ north and 127°30′ west (Figure 2-8-1). Elevations in the area range from 1180 to 2370 metres and there is excellent exposure above treeline. Access is by helicopter from Dease Lake, approximately 160 kilometres to the west, or from Watson Lake, Yukon, which is approximately 150 kilometres north of the property.

The area is underlain by unmetamorphosed to weakly metamorphosed Cambrian to Middle Paleozoic strata (Gabrielse, 1962). To the northeast of the area (Figure 2-8-1), thick-bedded quartzites of probable lower Cambrian age are folded in a broad open antiform with a northwest-trending axis. Along the southwestern limb of the antiform, the quartzites are in contact with a thick, southwest-dipping section of phyllites, thin-bedded marbles and massive, blocky-weathering dolostones of probable Middle and Late Cambrian and Ordovician age (Gabrielse, 1962). Chlorite, sericite, sericite-graphite and calcareous phyllites are all present within this succession. To the southwest, the phyllites are bounded by a shallow southwest-dipping fault, which juxtaposes green tuffs and cherty tuffs overlain by fossiliferous grey limestones and black quartzites with the phyllites. The limestones, which contain beds rich in rugosan corals, favosites-type corals, bryozoans and brachiopod fragments, are probably of Middle Paleozoic age (Silurian). The cherts, tuffs and limestones in the fault panel outline an overturned antiform and to the southwest are in fault contact with graphite-sericite and chlorite-sericite phyllites similar to those to the northeast. The northeastern bounding fault apparently has had normal movement along it as younger strata are present in the hangingwall; however geometry and the presence of the hangingwall anticline imply that at one time there may have been thrust motion along it. The southwestern fault is a moderate to steeply southwest-dipping thrust which places older rocks over younger. The alkaline rocks are present in the tuff-chert-limestone fault panel, between the two phyllitic units.

ALKALINE ROCKS

SYENITES

Syenites and melanocratic titanaugite syenites (malignites) are present at the south end of the property. The melanocratic syenites, which are present as large dykes or elongate stocks, are fine to medium grained, dark green to bluish grey rocks with small pyroxene and feldspar phenocrysts. They contain 40 to 60 per cent microcline, 5 to 20 per cent albite and 10 to 20 per cent titanaugite. Garnet (melanite), biotite, sodalite, cancrinite, allanite, magnetite/ilmenite, pyrite, fluorite and apatite/monazite are all present as accessory phases. Veins or segregations containing coarse calcite and dark purple fluorite ± biotite ± epidote are locally present within the malignites. In the northern part of the property, melanocratic syenites are highly sheared and chlorite-rich.

Leucocratic syenites crop out in the southern part of the property, generally as irregular zones within the melanocratic syenites. They are light grey, medium-grained, massive rocks containing 35 to 40 per cent microcline and 10 to 20 per cent albite, with fluorite, sodalite, cancrinite, sphene, biotite, pyrite and pyrochlore present in variable amounts. Crosscutting calcite-pyrite-fluorite veinlets are common. The syenites vary from massive and relatively unaltered to sheared. Sheared syenites contain potassium feldspar porphyroclasts and unrecrystallized layers in a fine-grained recrystallized and altered matrix containing abundant clay minerals, quartz, plagioclase, dolomite and muscovite.

MOTTLED PHYLLITES

Fine-grained, extremely fissile and micaceous phyllites to massive, white to buff-weathering rocks are commonly associated with other alkaline rocks in the central and northern portions of the property (Figures 2-8-1, 2-8-2). They generally occur in shallow to moderately dipping layers in excess of 25 metres thick. They have mylonitic textures and contain varying amounts of quartz, carbonate (generally dolomite, although calcite and iron-rich magnesite have also been noted), sericite, potassium feldspar, phosphates and pyrite.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

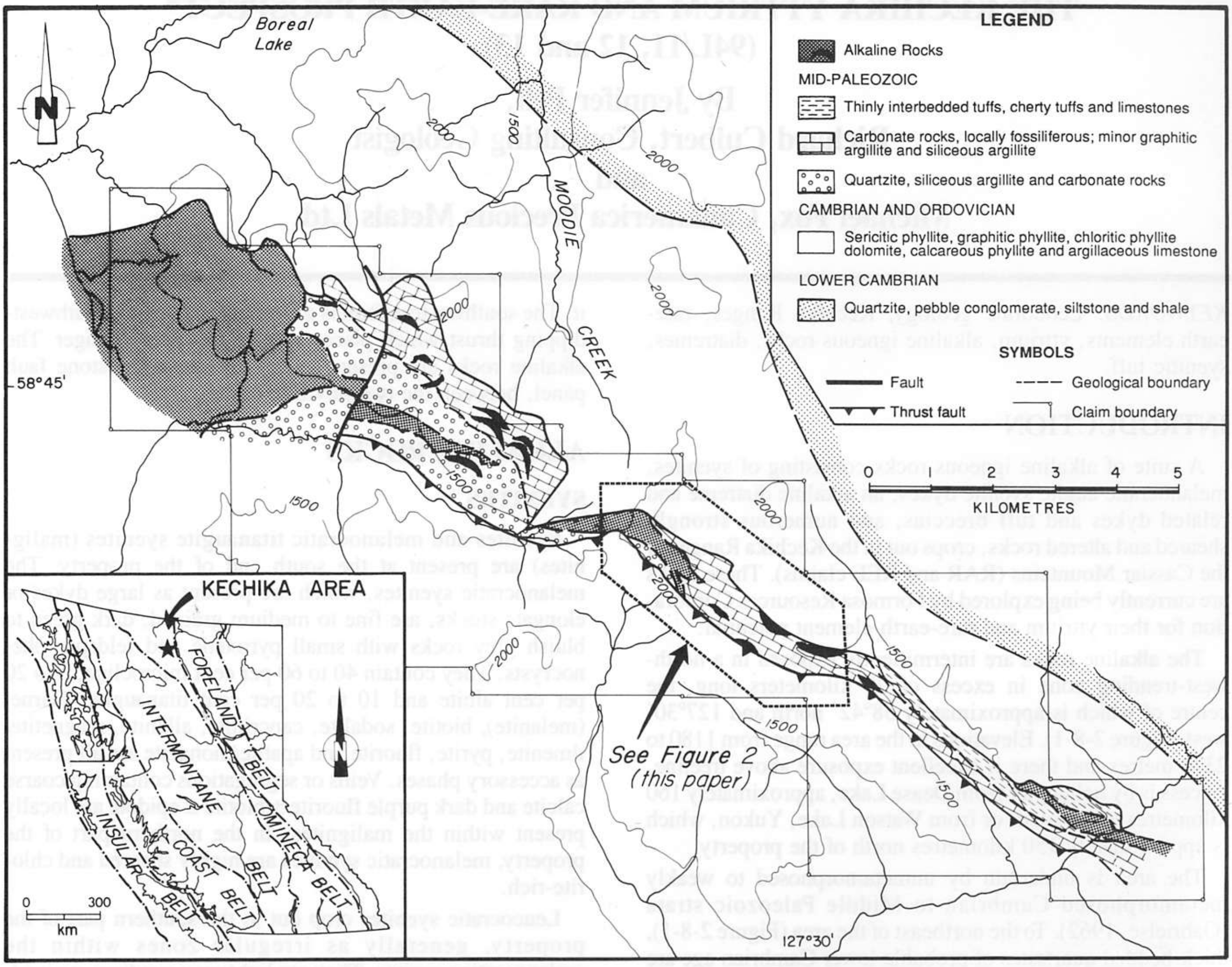


Figure 2-8-1. Geology of the Kechika Yttrium and Rare-earth prospect.

Massive varieties commonly have irregular dolomitic patches in a siliceous matrix. Some increased radioactivity is associated with certain horizons within these rocks.

Locally phosphate minerals comprise in excess of 25 per cent of the rock. In such rocks, a number of phosphate minerals may be intergrown, with apatite the most common species. Monazite (containing cerium, neodymium, lanthanum, calcium, thorium), xenotime (yttrium phosphate, with minor dysprosium, gadolinium and calcium) and an yttrium-thorium-calcium-dysprosium-gadolinium-bearing phosphate have been identified by scanning electron microscopy. Minor amounts of an iron-thorium-yttrium-calcium silicate mineral have also been noted.

In some samples, potassium feldspar porphyroclasts are preserved in a fine-grained quartz-carbonate-sericite matrix, which suggests that the mylonite had a syenitic protolith. In other cases the rocks are very fine grained and completely recrystallized; no textural evidence of the protolith remains. Field evidence indicates that these rocks are conformable to bedding in the hosting limestones and were possibly flows or tuff layers. The high degree of deformation within them compared with the other rock types may be a result of original incompetence, in which case a tuffaceous protolith is favoured. Phosphate-rich rocks are distributed in discontinuous lenses up to a few metres thick and several tens of metres long, parallel to overall layering.

DIATREME BRECCIAS, TUFF BRECCIAS AND RELATED DYKES

A complex diatreme containing a number of breccia phases, related pyroclastic tuffs and breccia dykes, crops out in the central part of the property (Figures 2-8-1, 2-8-2). These rocks weather greenish silver to rusty orange and are weakly to extremely well foliated.

The main diatreme comprises very inhomogeneous, heterolithic tuffisitic breccias with rounded to angular xenoliths up to 7 centimetres across. Quartzite and carbonate rock fragments dominate the xenolith population; some autoliths, rare syenite fragments and some black argillite clasts were also noted. Quartz xenocrysts, rare chrome spinels, juvenile and vesiculated glass lapilli, and altered crystal fragments (predominantly potassium feldspars) are also present. The breccia matrix consists of carbonate minerals and minor muscovite, and locally, chrome micas. In places near its outer contacts, the diatreme breccia is intensely deformed

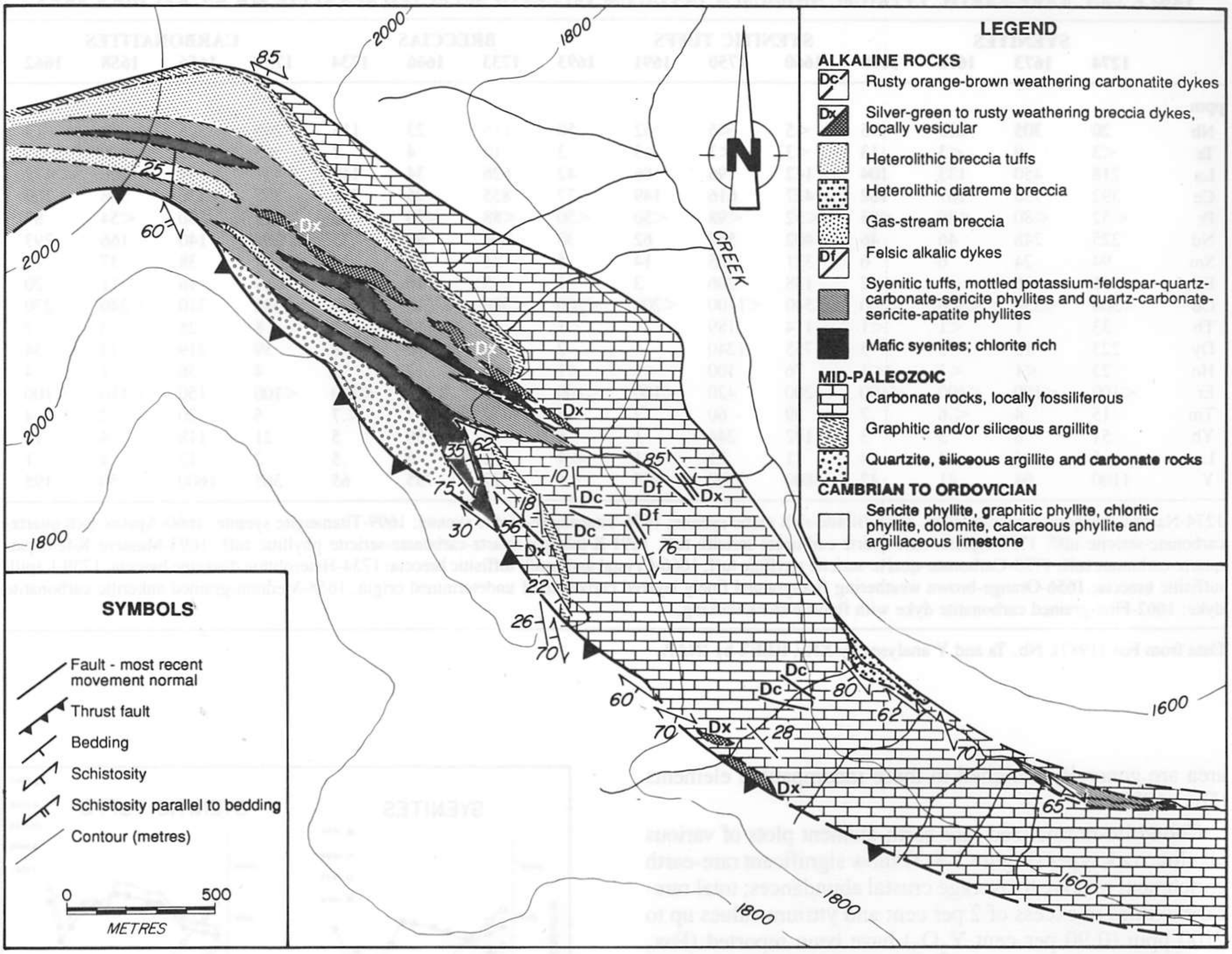


Figure 2-8-2. Detailed geology, central portion of the Kechika prospect.

and has the appearance of a stretched-pebble conglomerate. The northern and central part of the diatreme has been cut by fluorite-calcite and fluorite-calcite-pyrite stockwork veins. Similar breccias are present in the Bull River–White River area of the southern Rocky Mountains (Pell, 1987a, 1987b).

Peripheral to the main diatreme and on the ridges to the north of it (Figure 2-8-2), breccia dykes are quite common. They crosscut both the carbonate host rocks and the mottled phyllites. The dykes, in general, are extremely well foliated and average 1 to 2 metres in thickness. They are similar in composition and appearance to the matrix of the main diatreme and locally contain chrome spinels, small lithic fragments and carbonate-filled vesicles.

Lithic tuffs outcrop on ridges near the centre of the property, immediately north of the main diatreme, and at the north end of the property, south of Boreal Lake (Figures 2-8-1, 2-8-2). These pyroclastic rocks are rusty orange to silver-green weathering and very similar in appearance to the breccia dykes. They are conformable with the host carbonate succession and are interbedded with the mottled phyllites. Well-developed graded layers are present locally, with lithic fragments 1 to 3 centimetres in size at the base and fine-grained, carbonate-rich material at the top of the bed. These rocks are the presumed extrusive equivalent of the diatreme and breccia dykes.

CARBONATITES

Fine-grained igneous carbonate rocks, with a distinctive orange-brown weathering colour, are also present in the Kechika area. They occur as dykes which are generally less than 1 metre wide and crosscut both other alkaline rocks and the carbonate host rocks. Volumetrically, the carbonatites are an insignificant part of the alkaline suite.

The carbonatites are dolomite or ankerite rich (greater than 80 per cent) and contain quartz. Accessory phases include microcline, muscovite, barite, iron oxides, pyrite, fluorapatite, gorceixite, xenotime and an unidentified thorium-calcium-yttrium-iron phosphate mineral.

GEOCHEMISTRY

Only limited geochemical information is currently available for the alkaline rocks in the Kechika area. Samples have been analysed for niobium, tantalum, yttrium and rare earths (Table 2-8-1); no major element analyses have been completed. As with other alkaline suites, rocks in the Kechika

TABLE 2-8-1. RARE-EARTH, YTTRIUM, NIOBIUM & TANTALUM VALUES OF SELECTED ALKALINE ROCKS, KECHIKA AREA

	SYENITES				SYENITIC TUFFS				BRECCIAS			CARBONATITES			
	1274	1673	1676	1699	1660	1750	1691	1693	1733	1666	1734	1739	1656	1658	1662
ppm															
Nb	20	305	200	195	<5	<5	62	50	115	23	115	205	<5	11	13
Ta	<3	9	<3	13	<3	<3	<3	3	10	4	7	<3	<3	6	<3
La	218	450	133	104	142	196	86	42	626	34	140	431	39	406	472
Ce	392	738	167	162	427	616	149	77	835	96	231	557	130	508	709
Pr	<52	<80	<89	<83	<52	<98	<50	<50	<88	<50	<56	<75	<50	<54	87
Nd	225	248	46	46	402	557	62	30	204	90	75	201	140	166	293
Sm	94	24	6	6	331	505	14	5	21	39	14	57	38	37	71
Eu	45	6	1	2	138	206	3	1	5	16	4	19	16	11	20
Gd	<300	<330	<300	<300	<540	<1100	<200	<200	<380	<210	<230	<380	310	<240	<270
Tb	33	1	<1	<1	114	189	1	<1	2	14	2	8	25	3	7
Dy	223	15	3	5	755	1240	4	2	6	110	8	59	219	13	34
Ho	23	<1	<1	<1	76	100	<1	<1	<1	17	1	4	36	<1	4
Er	<100	<100	<100	<100	200	420	<100	<100	<100	<100	<100	<100	150	<110	<100
Tm	15	4	<.6	.7	39	60	.7	<.5	<.7	7	<.7	5	20	2	4
Yb	51	8	3	3	142	244	1	.8	4	50	5	21	118	4	12
Lu	5	.4	.4	.4	11	21	<.1	<.1	.2	6	.5	2	12	.4	1
Y	1100	94	41	42	3800	7100	<5	<5	27	755	65	365	1600	50	195

1274-Narrow leucocratic syenite dyke; 1673-Biotite-rich mafic syenite; 1676-Titanaugite-biotite syenite; 1699-Titanaugite syenite; 1660-Apatite-rich quartz-carbonate-sericite tuff; 1750-Apatite-rich quartz-carbonate-sericite tuff; 1691-K-feldspar-quartz-carbonate-sericite phyllitic tuff; 1693-Massive K-feldspar-quartz-carbonate tuff; 1733-Carbonate-quartz-sericite phyllitic tuff; 1666-Crystal and lapilli tuffisitic breccia; 1734-Heterolithic diatreme breccia; 1739-Lapilli tuffisitic breccia; 1656-Orange-brown weathering fine-grained finely layered carbonate of undetermined origin; 1658-Medium-grained ankeritic carbonatite dyke; 1662-Fine-grained carbonatite dyke with fluorite stockworking.

Data from Fox (1987). Nb, Ta and Y analyses by XRF, REE's by INAA.

area are generally enriched in these incompatible elements (Fox, 1987).

Chondrite-normalized rare-earth-element plots of various alkaline rock types (Figure 2-8-3) show significant rare-earth enrichment relative to average crustal abundances; total rare-earth oxides in excess of 2 per cent and yttrium values up to 7100 ppm (0.90 per cent Y_2O_3) have been reported (Fox, 1987). Malignites are generally enriched in light rare-earths and have flat to erratic heavy rare-earth patterns. The leucosyenite sample analysed has a relatively flat pattern through the light rare-earths to holmium, that is, relative abundances similar to average crust but extremely enriched, and an erratic heavy rare-earth pattern. Syenitic tuffs (mottled phyllites) have rare-earth concentrations which result in steep negatively sloping chondrite-normalized patterns that are typical of carbonatite/alkaline rock complexes. Apatite-rich syenitic tuffs produce elevated, convex upward-curving chondrite-normalized patterns indicative of significant enrichment in rare earths from samarium to thulium, patterns which are not typical of carbonatite/alkaline rock suites. These rocks are also significantly enriched in yttrium. Carbonatites and diatreme breccias give both shallow positive and shallow negative sloping chondrite-normalized patterns, indicating both slight relative light rare-earth and slight relative heavy rare-earth enrichment occurs in these rocks.

MINERALIZATION AND ECONOMIC CONSIDERATIONS

Rare-earth elements are concentrated in all alkaline rocks. Yttrium, although not a rare-earth element, is commonly grouped with them as its chemical properties are similar to

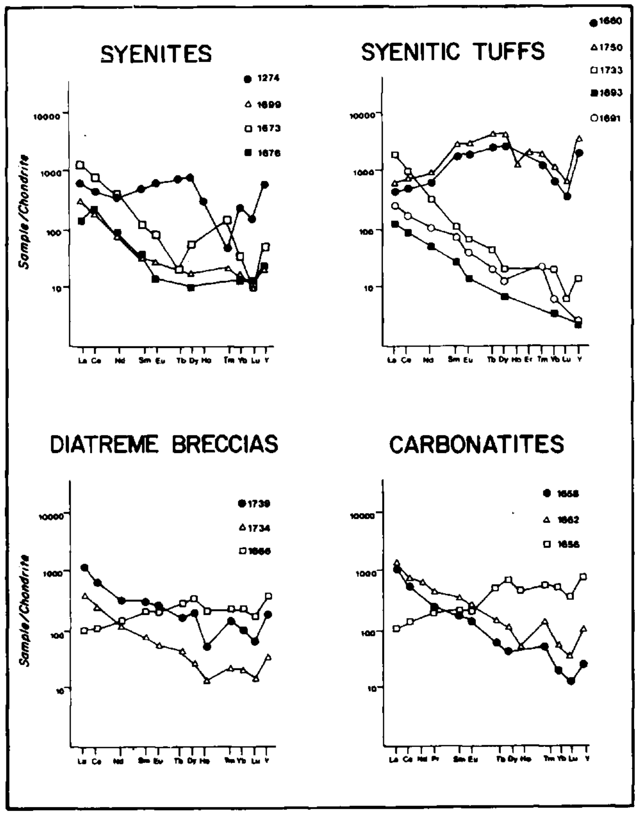


Figure 2-8-3. Chondrite normalized rare-earth element plots for selected samples, Kechika area.

the heavy rare earths. These elements are used principally in petroleum cracking catalysts, steel and metal alloying agents, glass polishing compounds and glass additives, permanent magnets and phosphors for television and lighting tubes. The rare-earths, particularly yttrium, also have important potential in the manufacture of superconductors and applications in advanced ceramics and laser technology.

The demand for light rare-earths is currently supplied by major producers such as Molycorp's Mountain Pass mine in California. In recent years, the demand for mixed rare-earth compounds has declined; however, the demand for high-purity separated rare-earths is rising (Roskill Information Services, 1986). There is a significant current demand for neodymium and praseodymium for use in specialty magnets and for less abundant rare-earth elements such as samarium, gadolinium and europium (Hedrick, 1985). Yttrium is also in demand (Roskill Information Services, 1986). Prices for rare-earth oxides as quoted by Molycorp in January, 1987 vary from a low of US$4.50 per pound for cerium oxide to US$725 per pound for europium oxide and US$1000 per pound for thulium oxide. Prices for yttrium, gadolinium and samarium oxides are all in the range of US$50 to US$55 per pound. These prices, to a certain extent, reflect costs of producing a rare-earth concentrate and processing the pure compounds and must be considered as approximate only. More current information on rare-earth oxide prices is not readily available. Current prices of rare-earth-bearing mineral concentrates, as quoted in Industrial Minerals, September 1988 are US$1.05 per pound of bastnaesite concentrates containing 70 per cent rare-earth oxides, A$700-780 per tonne of monazite concentrate with a minimum of 55 per cent rare-earth oxides, f.o.b.Australia, and US$32-33 per kilogram for yttrium mineral concentrate (xenotime) with 60 per cent yttrium oxide, f.o.b. Malaysia.

In the Kechika area, a number of alkaline rock types have been found to contain anomalously high yttrium and heavy rare-earth values (Table 2-8-1 and Fox, 1987). Of particular note are the apatite-rich zones, which contain up to 25 per cent apatite, within the mottled phyllites of possible syenitic tuff origin. These zones appear to be distributed as lenticular bodies a few metres thick by a few tens of metres in length, separated by apatite-poor zones. Yttrium and the rare earths, particularly dysprosium and gadolinium, are present in phosphate minerals such as xenotime, associated with the apatite. The origin of these zones is uncertain; apatite enrichment may be a result of primary igneous layering processes, or possibly, later metasomatism.

GEOCHRONOLOGY

No radiometric dating has been completed on the Kechika River alkaline rocks. The presence of mylonites and their distribution suggests that they were emplaced prior to orogenesis. Field relationships, in particular the presence of bedded tuff-breccias and possible syenitic tuffs, suggest that the alkaline suite is coeval with the host carbonates, that is mid-Paleozoic. This is similar to ages of 350 to 400 Ma (Pell, 1987b) for carbonatites and alkaline diatremes elsewhere in the Canadian Cordillera and suggests that the Kechika rocks were emplaced in response to major tectonic instabilities in middle Paleozoic time which also resulted in the intrusion of alkaline complexes such as Aley and Ice River.

Clear crosscutting relationships between the many alkaline phases are largely obscured by deformation and, for the most part, the sequence of emplacement cannot be established. Carbonatite dykes, which crosscut syenitic tuffs and some tuff breccias appear to be the youngest igneous rocks in the sequence.

CONCLUSIONS

In the Kechika area, a suite of rocks consisting of leucocratic and melanocratic syenites, possible syenitic tuffs, carbonatites and a diatreme breccia and related dykes and tuff breccias are intermittently exposed in a zone over 20 kilometres in length. These alkaline rocks are hosted by middle Paleozoic carbonate strata and are, at least in part, coeval with their host rocks.

Preliminary studies indicate that the igneous rocks, in particular apatite-rich syenitie tuff layers, are extremely enriched in yttrium, containing up to 0.90 per cent Y_2O_3, and heavy rare earths. More detailed mapping and mineralogical and geochemical studies are necessary to fully assess the economic potential of this suite.

ACKNOWLEDGMENTS

We would like to thank Formosa Resources Corporation for providing helicopter and other logistical support which made preliminary mapping of this property possible, the Canada/British Columbia Mineral Development Agreement for support of the project, and Andy Harmon for sharing his knowledge of the property.

REFERENCES

Fox, M. (1987): Geological and Geochemical Report, RAR 1-9, REE 1-8, and REO 1 and 2 Mineral Claims, *Golden Rule Resources Ltd.* Unpublished Company Report.

Gabrielse, H. (1962): Kechika, B.C., *Geological Survey of Canada*, Map 42-1962.

Hedrick, J.B. (1985): Rare-earth Elements and Yttrium, Mineral Facts and Problems, *United States Department of the Interior, Bureau of Mines*, Bulletin 675, pages 647-664.

Pell, J. (1987a): Alkaline Ultrabasic Diatremes in British Columbia: Petrology, Geochronology and Tectonic Significance (82G, J, N; 83C; 94B), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 259-272.

——— (1987b): Alkaline Ultrabasic Rocks in British Columbia: Carbonatites, Nepheline Syenites, Kimberlites, Ultramafic Lamprophyres and Related Rocks, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-17, 109 pages.

Roskill Information Services Ltd. (1986): The Economics of Rare-earths and Yttrium 1986, 270 pages.

NOTES

CINOLA GOLD DEPOSIT, QUEEN CHARLOTTE ISLANDS (103F/9E)

By Anthony B. Christie
Visiting Scientist with the Geological Survey of Canada and The University of British Columbia

KEYWORDS: Economic geology, Cinola, gold, silver, epithermal hot springs, quartz veins, hydrothermal breccias, silicification, argillization, Miocene, Haida Formation, Skonun Formation, Masset Formation.

INTRODUCTION

The Cinola epithermal gold deposit (also known as the Babe or Specogna deposit; MINFILE 103F-G034) is located on Graham Island of the Queen Charlotte Islands (Figure 2-9-1). Access is via forestry roads from the towns of Port Clements or Queen Charlotte City.

The deposit was discovered in 1970 by two prospectors, Efrem Specogna and Johnny Trico (Champigny *et al.*, 1980; Hollister, 1985). Subsequently a succession of companies carried out exploration work on the deposit and, by early 1987, 323 drill holes, totalling 39 594 metres, had been drilled and 586 metres of underground workings excavated. The current owner of the property, City Resources (Canada) Limited, has estimated mineable reserves of 23.8 million tonnes at 2.45 grams gold per tonne with a cut-off grade of 1.1 grams gold per tonne (City Resources, 1988a). In June 1988 City Resources applied for government approval to open-pit mine the deposit (submission of Stage II report) and in October 1988 it completed a 49-hole diamond-drilling program for geotechnical investigations and the exploration of peripheral areas.

The British Columbia Ministry of Energy, Mines and Petroleum Resources supported previous research on the Cinola gold deposit by Champigny (Champigny, 1981; Champigny and Sinclair, 1980, 1982). Since then, additional exploration on the prospect has provided new information that is relevant to the genesis of the deposit. A reinvestigation of the deposit was considered timely, particularly with regard to the recently recognized epithermal hot-spring nature of the mineralization (Tolbert *et al.*, 1987) and the current exploration interest in epithermal gold deposits in British Columbia. This project was initiated in 1988 with the award of a British Columbia Ministry of Energy, Mines and Petroleum Resources Geoscience Research Grant, and aims to investigate the deposit genesis from the standpoint of geological, fluid inclusion and stable isotope studies. Some preliminary field observations of the veins and breccias made during the 1988 field season are presented here, together with a summary of existing data. Petrographic and analytical work on samples collected during the season is now in progress.

GEOLOGY

The Cinola deposit is located on the Specogna fault, a splay of the regionally important Sandspit fault (Figure 2-9-1). South of Masset Inlet, the Sandspit fault forms a major physiographic and geological boundary on Graham Island, striking northwesterly and separating the western hilly and mountainous Mesozoic and Tertiary rocks of the Skidegate Plateau from the predominantly flat terrain of the Late Tertiary rocks in the Charlotte Lowlands (Sutherland Brown, 1968). At Cinola the Specogna fault juxtaposes Late Cretaceous shale of the Haida Formation against Late Tertiary coarse clastic sediments of the Skonun Formation. These formations are intruded along the fault by a porphyritic rhyolite dyke tentatively correlated with the Miocene rhyolitic rocks of the Massett Formation west of the deposit (Figure 2-9-1).

Work by Champigny (Champigny, 1981; Champigny and Sinclair, 1982) and City Resources (1988b; unpublished drill-hole logs and sections) provided a detailed account of the lithologies present at the deposit and these are summarized here, together with some observations made during this study.

HAIDA FORMATION SHALE

At Cinola the Haida Formation consists of indurated dark grey to black shale with minor sandstone and siltstone beds. It occurs on the western side of the Specogna fault and extends below the Tertiary volcanics west of the deposit.

SKONUN FORMATION SEDIMENTS

Coarse clastic sediments of the Skonun Formation crop out east of the Specogna fault. City Resources recognized several units within the sequence at the deposit (Figure 2-9-1):

Boulder conglomerate represents the deepest unit encountered. It is a medium grey to pale brown coarse conglomerate with clasts of volcanic rocks up to 0.5 metre in diameter in a consolidated mud and sand matrix.

Pebble conglomerate with intercalated sandstone, siltstone and mudstone beds occurs between: (1) the boulder conglomerate and the lower mud-flow breccia (*see* below), (2) between the lower and upper mud-flow breccias, and (3) above the upper mud-flow breccia. The sediments are pale to dark grey or brown, depending on the type of hydrothermal alteration. The dominant lithology is a clast-supported pebble conglomerate in which clasts average 3 centimetres in diameter. Also present are beds of matrix-supported pebble

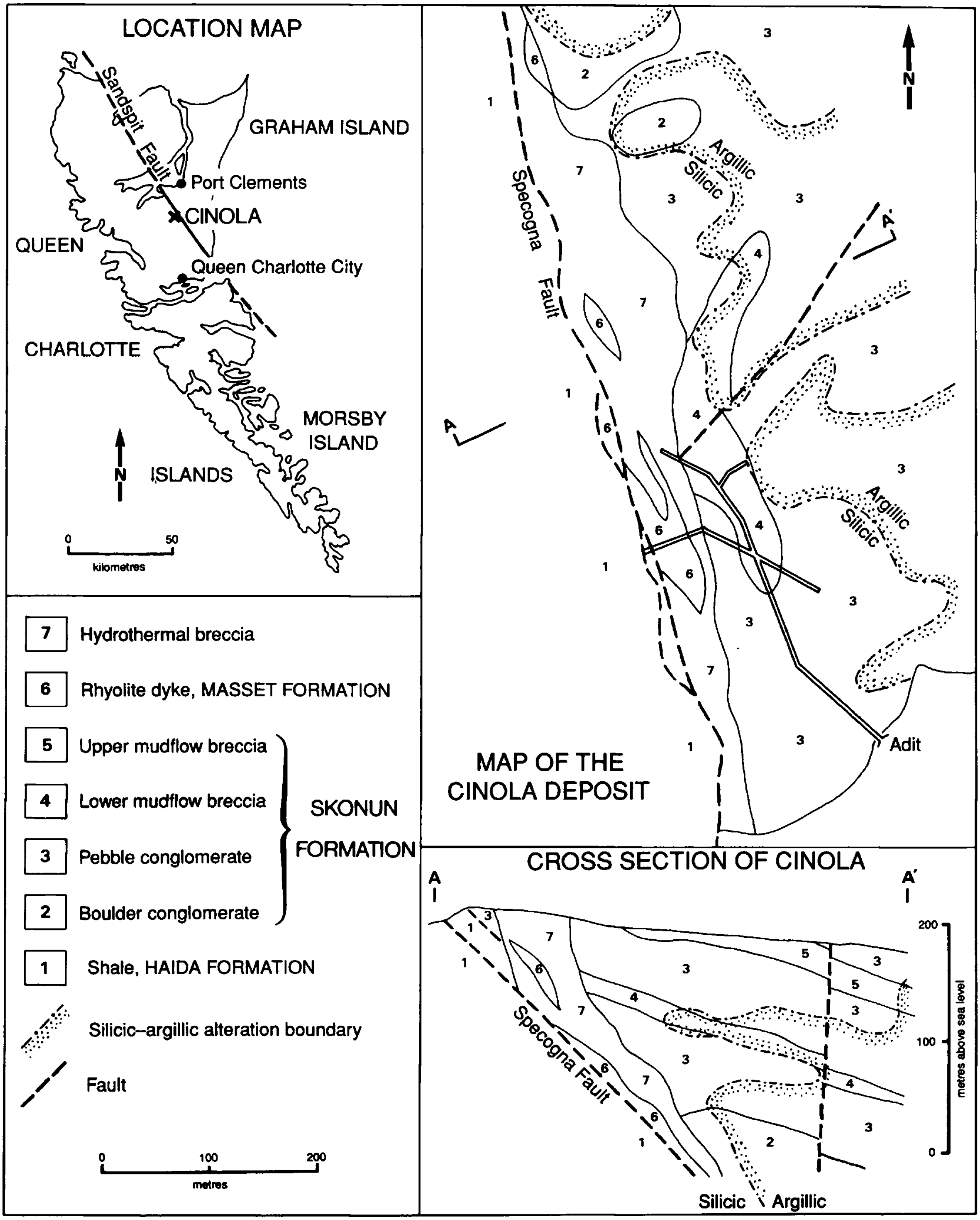


Figure 2-9-1. Location map, and geologic map and cross-section of the Cinola deposit (modified from City Resources (Canada) Ltd., 1988b).

conglomerate, sandstone, siltstone and mudstone. The strata dip 15 to 25 degrees east.

The pebble conglomerates are polymictic. Clasts are predominantly felsic volcanic and plutonic rocks, although clasts of sedimentary (including argillite and shale) and metamorphic rocks are also present.

The sandstone and siltstone units have primary sedimentary structures which include plane and ripple laminations, graded bedding and crossbedding. Penecontemporaneous deformation structures, including convolute bedding and flame structures, are also present. Wood fragments are common (particularly in the finer grained units) and are generally aligned parallel to the stratification. These fragments are generally only a few millimetres long but rare logs range up to a metre or so in length.

The lower mud-flow unit is a sedimentary breccia with rhyolite and sedimentary rock (mainly pebble conglomerate) clasts in a mud matrix. The unit is both distinctive and consistent in appearence. It contains approximately 30 per cent pale-coloured clasts in a brown to reddish brown matrix. The clasts are predominantly 1 to 5 centimetres in size but sedimentary rock clasts up to 2 metres in diameter occur sporadically. Rhyolite clasts often have wispy angular outlines. Some wood fragments are present, including logs. The unit has a restricted distribution and is lobate in plan view (Figure 2-9-1).

The upper mud-flow unit is a grey to brown, sandy, matrix-supported sedimentary breccia containing angular to subangular clasts. The clasts are typically 1 to 5 centimetres in diameter but parts of the unit exposed in the Northwest pit contain coarse clasts ranging up to a metre in diameter. They are predominantly volcanic and sedimentary rocks but some quartz-vein clasts were also noted. The upper part of the unit contains beds of sandstone with abundant shells of bivalve molluscs *[Spisula* (*Mactromeris*) sp., *Chione* (*Securella*) sp. and *Macoma* sp; Champigny *et al.*, 1981].

The upper mud-flow unit differs from the lower mud-flow unit in that it has matrix-rich sections with few clasts, beds of apparently conformable stratified fine sediment, concentrations of bivalve mollusc shells, and a much wider distribution.

Champigny and Sinclair (1982) concluded that the Skonun sediments were deposited in a braided river system discharging into a marine basin, whereas City Resources (1988b) preferred an alluvial fan environment adjacent to the Specogna fault scarp. The latter was considered a better explanation of the fining-upward trend of the sediments and the incursion of the mud-flow breccias.

RHYOLITE

A dyke of porphyritic rhyolite intrudes the Haida shale and Skonun sediments along the Specogna fault. The rhyolite is pale grey to bluish grey and has quartz and feldspar phenocrysts up to 5 millimetres in size. Some parts are flow banded. It is tentatively correlated with rhyolitic rocks of the Masset Formation by Champigny and Sinclair (1982).

SPECOGNA FAULT

The Specogna fault strikes between 150 and 180 degrees and dips east at about 50 degrees. The fault zone is up to 70 metres wide and encloses blocks of Haida mudstone and porphyritic rhyolite. The fault is defined in drill core by zones of clay fault gouge and adjacent sheared mudstone and brecciated rhyolite.

HYDROTHERMAL ALTERATION

A zone of moderate to intense hydrothermal alteration has been defined over an area of about 2 square kilometres by geophysical surveys, outcrop mapping and drilling. Peripheral, less intense alteration occurs over a larger area but its distribution is not well known because of sparse outcrop and extensions of the alteration under covering rocks. Silicic and argillic (kaolinite, quartz and pyrite) types of alteration predominate over lesser, restricted occurrences of chloritic and remnant "phyllic" alteration (illite in the argillic zone; Champigny and Sinclair, 1982). Generally, rocks within the ore zone are extensively silicified and flanked to the east by a peripheral zone of argillic alteration (Figure 2-9-1). Silicification of the Haida Formation rocks quickly dissipates in a westerly direction beyond the Specogna fault. Recent drilling along the eastern border of the deposit (about 600 metres east of the Specogna fault) intersected patches of weak chloritic alteration, a transitional zone of decreasing alteration, and the first appearance in an eastward direction of unconsolidated sediments.

In detail, the distribution of alteration types is complex. The eastern argillic zone interfingers with the silicified zone and pockets of argillic alteration occur within the silicified zone and vice versa. The cross-section (Figure 2-9-1) shows an apparent mushrooming of silicification toward the surface, which is partly blocked beneath the lower mud-flow breccia. The mud-flow breccia may have been an aquiclude during initial silicification but an aquifer during later argillic alteration, as alteration changed the permeability contrast with the underlying sediments.

Some overprinting of earlier stages of alteration has occurred, for example, between silicic and argillic alteration of the conglomerates, as exhibited by the occurrence of silicified clasts in a clayey matrix and vice versa. The presence of cellular, cavernous and spongy rock textures in parts of the silicified zone records an earlier stage of acid leaching. Champigny and Sinclair (1982) noted that illite in the argillic alteration may be a remnant of earlier phyllic alteration (quartz, illite and pyrite?).

The intensity of alteration is influenced by primary and secondary (structural) permeability. The effects of primary permeability are most marked near the periphery of the main alteration zone, where the conglomerates are hydrothermally altered but adjacent interbedded siltstones and mudstones exhibit little alteration. Within the central part of the deposit, the large number of fractures and veins has allowed the hydrothermal fluids to penetrate and intensely alter all lithologies.

Pyrite and marcasite are ubiquitous constituents of the altered rocks. They occur disseminated or concentrated in clots, bands, cores of clasts, and in veins. Their distribution is variable in the conglomerates. In low and intermediate intensity alteration, the sulphides occur scattered in the matrix and as rims around clasts. With increasing intensity, sulphide concentrations occur in zones and cores within the clasts. Adjacent clasts may have sulphides concentrated in the core of one clast and as zones in the other. The concentration is probably related to the permeability of the original clast lithology. Much of the silicified conglomerate is strongly pyritized, and pyrite and marcasite are pervasive in the matrix and clasts.

The hydrothermal alteration was dated by Champigny and Sinclair (1982) at 14 Ma, based on two potassium-argon ages for altered rhyolite.

MINERALIZATION

Gold and silver occur disseminated in silicified wallrocks and in quartz veins and hydrothermal breccias. The ore zone is about 800 metres long and parallels the Specogna fault. It is wedge-shaped in cross-section, being approximately 200 metres wide at surface but thinning to a width of about 50 metres at 200 metres below surface (Figure 2-9-1). Ore grading more that 1 gram of gold per tonne is hosted as follows: 55 per cent in Skonun sediments, 30 per cent in hydrothermal breccia, 13 per cent in rhyolite and 2 per cent in Haida mudstone (City Resources, 1988b).

DISSEMINATED MINERALIZATION

Most of the silicified rocks within the deposit contain gold and silver, however, without associated quartz veining or brecciation precious metals are generally present in low concentrations.

VEINS

The veins and their crosscutting relationships are best exposed in the underground workings. The descriptions given here are based mainly on observations made underground. A wide variety of vein types and stages are present but most can be assigned to one of the five groups listed below. A notable feature of the larger veins is the repetitive invasion of pre-existing veins by later veins.

Dark grey chalcedonic silica veins and stockworks are a characteristic feature of the deposit. They are common in the rhyolite and hydrothermal breccia units described below but decrease in intensity west and east of these units. The stockworks are usually spatially associated with the large dark grey silica veins and have mutual and crosscutting relationships, indicating that both are the result of multiple injections. The density of stockworking varies between subparallel vertical veins and crackle breccias (*see* separate section below). The veins vary from 1 or 2 millimetres to a metre wide, stockwork veins being generally less than 1 centimetre thick.

Multibanded (crustified) veins range in thickness from 15 centimetres to 2 metres but are typically 30 to 50 centimetres wide. In the adit, they are widest and most numerous in the Skonun sediments near the contact between the sediments and the hydrothermal breccia unit. The veins decrease in number and width eastward from about 75 metres east of the contact. They are steeply dipping and generally strike at 030 degrees. Other attitudes occur causing some vein crosscutting. Some of the veins also bifurcate and later rejoin, enclosing horses of country rock. The veins contain multiple bands of brown and white chalcedonic silica 3 to 15 millimetres thick, thicker bands of silica-cemented bladed quartz (quartz pseudomorphs after calcite), and less commonly bands of vein breccia cemented with chalcedonic silica. The banded veins are invaded by coarse pinkish brown and white quartz veins which generally parallel the banding of the primary veins but exhibit crosscutting relationships with them in some places. The primary bands themselves are asymmetrically banded, indicating that the veins were not filled in a simple manner from the margins inwards. Addition of new bands, singularly, in pairs, or in sets, appears to have occurred in various parts of the vein. Although the veins observed have a similar overall appearance, the sequence of bands within the veins differs from vein to vein.

Coarse pinkish brown and white quartz veins, typically 20 centimetres wide, occur as isolated veins or veins crosscutting and invading the previous vein types. The veins are usually symmetrically banded with individual bands being 15 to 40 millimetres thick. A typical sequence from wallrock to the centre of the vein is: white quartz, pinkish brown quartz, white quartz, and clear dog-tooth quartz with occasional drusy vugs. Variations of this sequence include the addition of one or more white quartz bands, one or two thin, dark grey to black (sulphide-bearing?) bands, brown or dark grey silica margins and/or a late central stage of white flinty chalcedonic silica. These veins have a wide distribution, but are most numerous in the northern part of the main drift where they commonly contain vein breccias.

White to translucent banded and massive quartz veins, typically 3 to 5 centimetres wide, generally occur as isolated veins. Some crosscut the previously described veins.

Calcite veins are typically 10 centimetres wide and contain banded white calcite, which is generally fine grained near the margins and coarsely crystalline near the centre. They are uncommon, but occur in most rock types and are late in the vein sequence.

The central cavities of some banded veins are lined with late, finely banded white and/or grey chalcedony which develops a vertical fluted texture on cavity surfaces. Most cavities are partly filled with a brownish grey clay.

Many of the veins have a late brecciation stage which may disturb individual bands or all of the vein. The breccias are usually cemented by white to translucent quartz, but breccias consisting of dark grey chalcedonic silica cementing white quartz fragments also occur. These breccias are correlated with the coarse pinkish brown and white quartz vein and the white banded to massive quartz vein stages.

Generally, in any individual vein, chalcedonic silica precedes translucent to clear crystalline quartz, and the grey and brown phases of chalcedonic silica are earlier than the white phases. The brown colour was previously attributed to the presence of hematite (Champigny and Sinclair, 1982), however recent examination of similar material at the McLaughlin mine in California indicates it may result from the inclusion of hydrocarbons (N. Lehrman, geologist, McLaughlin mine, personal communication, 1988). Some of the grey chalcedonic veins are granular, resulting in silty to fine pebbly textures, indicating the presence of entrained particles and a breccia style of origin.

HYDROTHERMAL BRECCIAS

Hydrothermal breccias are important features with respect to the genesis and economics of the Cinola deposit. Their occurrence was noted by Cruson *et al.* (1983) and later, City Resources mapped and logged the breccias as distinct lithological units. They recognized three groups of breccias; brecciated Haida shale, brecciated rhyolite and a heteromictic breccia.

Brecciated Haida shale occurs near the Specogna fault zone. The shale has been silicified and subsequently brecciated and cemented by white quartz.

Brecciated rhyolite occurs on the margins of the rhyolite intrusion and as large blocks within the hydrothermal breccia unit described below. The degree of brecciation ranges from crackle and mosaic breccias, to matrix-supported rubble breccias with floating rhyolite clasts a few centimetres to about 0.5 metre in size. The breccias are cemented by dark grey silica and, in some places, further brecciated and cemented by white quartz.

Heteromictic breccia was mapped by City Resources as a tabular body 800 metres long, oriented parallel to the Specogna fault and dipping steeply westward. Near surface it is up to 100 metres wide but narrows to a width of 10 metres at a depth of about 200 metres. The breccia unit contains gold grades consistently greater than 1.7 grams per tonne.

Observations made during this study indicate that the breccia body, as mapped by City Resources, includes several different generations of breccia intermixed with large sections of undisturbed rhyolite and sediments. Two types of early breccia are recognized:

(1) Fine-grained breccia with pale grey to white fragments in a pale grey to pale blue flow-textured silica matrix. The fragments are mostly angular to subrounded rhyolite, typically 2 to 15 millimetres in diameter and matrix supported. The flow texture is similar in appearance to that seen in flow-banded rhyolite.

(2) Coarse to finely comminuted heteromictic hydrothermal breccia, cemented by white, brownish or dark grey chalcedonic silica. Fragments of chalcedonic silica (white, grey and black), rhyolite and sediment are present. The fragments are angular to subrounded, mostly between 2 and 30 millimetres in diameter, and predominantly matrix supported. The matrix commonly has a flow-like texture. Parts of the unit exhibit a transition from a silica-flooded matrix-supported conglomerate to a fluidized conglomerate, whereas most of the unit has more angular clasts, many being fragments of rhyolite and chalcedonic silica and quartz veins.

Parts of these early breccias are rebrecciated (one or more times), transported and mixed with wallrock and vein clasts, and then cemented by grey or white chalcedonic silica. The breccias are later invaded by veins and stockworks of grey and/or white chalcedonic silica and white quartz (*see* vein section above). This results in parts of the breccia body having very complex textures. Fragments of breccia within breccia (representing two generations of brecciation) occur frequently but fragments of breccia within fragments of breccia (representing three generations) are rare.

PARAGENESIS OF THE VEINS AND BRECCIAS

Crosscutting relationships suggest the following sequence of veins and breccias:

(1) Flow-textured hydrothermal breccia in rhyolite.
(2) Crackle and mosaic brecciation of rhyolite and heteromictic hydrothermal breccia (several phases).
(3) Grey silica veins and stockworks (several phases continuing intermittently during events listed below).
(4) Multibanded veins (several phases).
(5) Pinkish brown and white (clear) quartz veins and vein breccias.
(6) White (clear) quartz veins and vein breccias.
(7) Calcite veins.

ORE MINERALOGY

Pyrite and marcasite are the dominant metallic minerals. Rutile, magnetite, hematite and pyrrhotite are less common (Champigny and Sinclair, 1982). Gold occurs as native gold and electrum which are rarely visible. Silver is alloyed with gold. No silver minerals other than gold-silver alloys have been identified in the deposit. Champigny and Sinclair (1982) noted "rare" and "very rare" sphalerite, chalcopyrite, galena, cinnabar and tiemannite in quartz veins. City Resources identified needles of stibnite in cavities at a depth of 57 metres in diamond-drill hole 80-104.

DISCUSSION

The hydrothermal alteration, veins and breccias are believed to postdate the intrusion of the rhyolite stock. A possible exception is the flow-banded breccia with abundant rhyolite clasts, which may represent a marginal phase of the rhyolite dyke. The localization of the deposit along the Specogna/Sandspit fault system indicates that these structures were fundamental loci for the ascent of deep hydrothermal fluid. The initial high primary permeability of the Skonun sediments allowed the fluid to flow laterally near the surface. This lateral flow caused widespread silicification and prepared the ground for later brittle-fracture episodes. Subsequent events (characteristic of epithermal hot-spring deposits (Berger and Eimon, 1983) consisted of several phases of brecciation and vein formation associated with cycles of pressure build-up, then failure and pressure release, superimposed on the pattern of local faulting. Evidence for multiple events includes: multiple stages of veining; banding within the veins; breccias within the veins; several episodes of hydrothermal breccias; and crosscutting relationships between the veins and hydrothermal breccias. The generally fine-grained nature of the heteromictic breccias suggests efficient comminution and vertical movement of the fragments.

By analogy with modern geothermal systems, silicification was the dominant form of alteration caused by the deep hydrothermal fluid, whereas argillic alteration formed in a peripheral zone of mixing between groundwater and recirculating steam-heated, near-surface waters. Acid leaching textures within the silicified zone and overprinting relationships between argillic, phyllic (Champigny and Sinclair, 1982) and silicic alteration, indicate that the boundary between the different hydrothermal fluid types was complex and moved in response to changing hydrologic conditions. Local changes in primary (rock) permeability and secondary permeability (fracture and fault fissures), as well as widespread changes in fluid type (gas content and pH) would have occurred during the evolution of the hydrothermal system.

Hydrothermal activity was partly contemporaneous with sedimentation. This is indicated by the presence of fragments of quartz-vein material and hydrothermally altered conglomerates in the silicified upper mud-flow breccia. The type of quartz in the vein fragments correlates with the later stages of veining exposed in the adit. The silicification, brecciation and veining in the upper mud-flow unit and overlying conglomerate may correlate with the late white (clear) quartz veins in the adit.

ACKNOWLEDGMENTS

This research was carried out while on sabbatical from the New Zealand Geological Survey, hosted by the Geological Survey of Canada and in affiliation with the Department of Geological Sciences, The University of British Columbia. These organizations are thanked for their support. Dr. K.M. Dawson of the Geological Survey of Canada suggested the topic and together with Dr. A. Panteleyev of the British Columbia Ministry of Energy, Mines and Petroleum Resources, assisted with grant applications. Fieldwork was funded by a British Columbia Ministry of Energy, Mines and Petroleum Resources Geoscience Research Grant and support from City Resources (Canada) Limited.

Confidential proprietary data, generated by many geologists, particularly R.S. Tolbert, N.V. Froc, C. Baldys and T.A. Watkins, was supplied by City Resources (Canada) Limited. Many City Resources staff and contractors provided assistance during the study, and special thanks are due to Mr. N.V. Froc and Mr. P.H. Cowdery (Project Manager).

REFERENCES

Berger, B.R. and Eimon, P. (1983): Conceptual Models of Epithermal Precious-metal Deposits, *in* Cameron Volume on Unconventional Mineral Deposits, W.C. Shanks, Editor, *Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.*, New York, pages 191-205.

Champigny, N. (1981): A Geological Evaluation of the Cinola (Specogna) Gold Deposit, Queen Charlotte Islands, British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 199 pages.

Champigny, N., Henderson, C. and Rouse, G.E. (1981): New Evidence for the Age of the Skonun Formation, Queen Charlotte Islands, British Columbia, *Canadian Journal of Earth Sciences*, Volume 18, Number 12, pages 1900-1903.

Champigny, N. and Sinclair, A.J. (1980): Progress Report on the Geology of the Specogna (Babe) Gold Deposit, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1979, Paper 1980-1, pages 158-170.

——— (1982): The Cinola Gold Deposit, Queen Charlotte Islands, British Columbia, *in* Geology of Canadian Gold Deposits, Proceedings of the CIM Gold Symposium, September 1980, R.W. Hodder and W. Petruk, Editors, *Canadian Institute of Mining and Metallurgy*, Special Volume 24, pages 243-254.

Champigny, N., Sinclair, A.J. and Sanders, K.G. (1980): Specogna Gold Deposit of Consolidated Cinola Mines, an Example of Structured Property Evaluation, *Western Miner*, Volume 3, pages 35-44.

City Resources (1988a): News Release to Vancouver Stock Exchange, September 6, 1988, *City Resources (Canada) Limited.*

——— (1988b): Project Geology, *in* Volume 2 Project and Facilities Description, Cinola Gold Project Stage 2 Report, *City Resources (Canada) Limited*, pages 2-1 to 2-13.

Cruson, M.G., Limbach, F.W., Brooks, R.A., Sanders, K.G., Bain, D. and Lacy, S. (1983): Geology of the Cinola Deposit, Queen Charlotte Islands, British Columbia, *Nevada Bureau of Mines*, Geology Report, Number 36, pages 27-35.

Hollister, V.F. (1985): Discovery of the Queen Charlotte Gold Deposit, *in* Case Histories of Mineral Discoveries, Volume 1, Discoveries of Epithermal Precious Metal Deposits, V.F. Hollister, Editor, *Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.*, New York, pages 137-138.

Sutherland Brown, A. (1968): Geology of Queen Charlotte Islands, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 54.

Tolbert, R.S., Baldys, C., Froc, N.V. and Watkins, T.A. (1987): The Graham Island (Cinola) Deposit Revisited — Evidence for a Hot-spring type Gold Deposit, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 80, Number 904, page 30 (Abstract).

ALASKAN-TYPE MAFIC-ULTRAMAFIC ROCKS IN BRITISH COLUMBIA: THE GNAT LAKES, HICKMAN, AND MENARD CREEK COMPLEXES*

By Graham T. Nixon and Christopher H. Ash;
James N. Connelly
Memorial University of Newfoundland;
and Glenn Case
Consulting Geologist

KEYWORDS: Economic geology, Alaskan-type ultramafic complex, Hickman, Menard Creek, Gnat Lakes, platinum group elements, geochemistry.

INTRODUCTION

A project designed to investigate the economic potential of mafic and ultramafic rocks in British Columbia was begun in 1987. The initial phase of the project attempts to provide a geological database for Alaskan-type ultramafic complexes in British Columbia as well as preliminary geochemical and mineralogical data with which to evaluate their potential for precious metals, especially platinum-group elements, and other commodities. The 1987 field season focused on the Tulameen complex, an Alaskan-type mafic-ultramafic intrusion in southern British Columbia (Nixon and Rublee, 1988; Nixon, 1988; Findlay, 1963, 1969). The field program continued in July and August 1988 with an investigation of Alaskan-type ultramafic rocks in central and northern British Columbia.

The lithologies that comprise Alaskan-type complexes may include dunite and minor chromitite, olivine clinopyroxenite, magnetite clinopyroxenite, hornblende clinopyroxenite, hornblendite, and various gabbroic rocks. Not all of these lithologies are exposed, or perhaps even present, in each intrusion. Some complexes exhibit a crude zonation of rock types from an inner dunite core through clinopyroxenites to an outer hornblendite and/or gabbroic margin. However, this is not a universal trait and their designation as "Alaskan-type" complexes is preferable to "zoned" complexes (Irvine, 1974a; Taylor, 1967). At the type locality of Duke Island in southeastern Alaska, layering and sedimentary features in cumulate sequences are exceptionally well developed (Irvine, 1974a). However, primary layering in many Alaskan-type complexes is only locally developed, or may be absent altogether, or obscured and modified by post-cumulus processes. The cumulate mineralogy usually includes forsteritic olivine, diopsidic clinopyroxene, and spinel (chromite-magnetite), and may also include phlogopitic mica and hornblende, in addition to plagioclase in the more differentiated rocks. Orthopyroxene is characteristically lacking, which is indicative of an alkalic magmatic affinity. The Tulameen complex serves as a well-documented example with which to compare other Alaskan-type intrusions in British Columbia. The term "ultramafic complex" (or simply "ultramafite") as used below, carries no connotation as to the relative abundance of associated gabbroic rocks; their proportions in outcrop may vary from practically nil (for example, the Turnagain complex) to substantial (for example, the Tulameen complex).

This report describes the geology and geochemistry of three mafic-ultramafic intrusions that have been categorized as Alaskan-type (Evenchick *et al.*, 1986): the Hickman (Telegraph Creek map sheet, 104G), Gnat Lakes (Cry Lake map sheet, 104I), and Menard Creek (McConnell Creek map sheet, 94D) complexes. In addition the Turnagain River complex (Cry Lake map sheet, 104I), an unusually sulphide-rich Alaskan-type body, and the Polaris complex (Mesilinka River map sheet, 94C), one of the largest in British Columbia, are the subjects of Open File releases by the Ministry of Energy, Mines, and Petroleum Resources.

The Regional Geochemical Survey for 104G, released in 1988, revealed anomalous nickel and cobalt over ultramafic complexes but no samples were analyzed for platinum-group

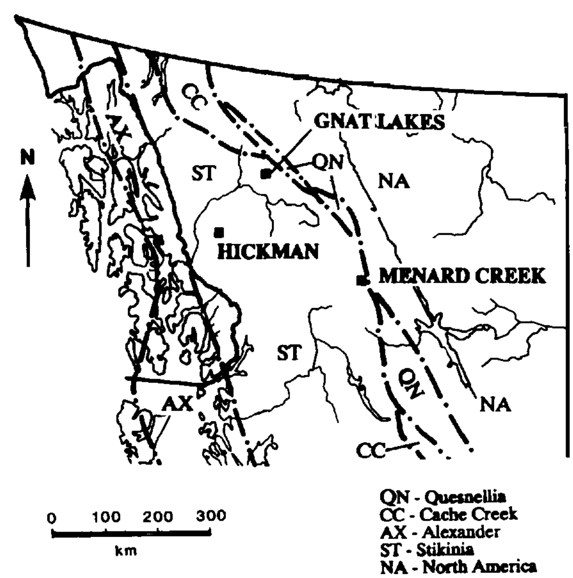


Figure 2-10-1. Location map of the Gnat Lakes, Hickman, and Menard Creek mafic-ultramafic complexes in relation to major tectonostratigraphic terranes in northern British Columbia.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

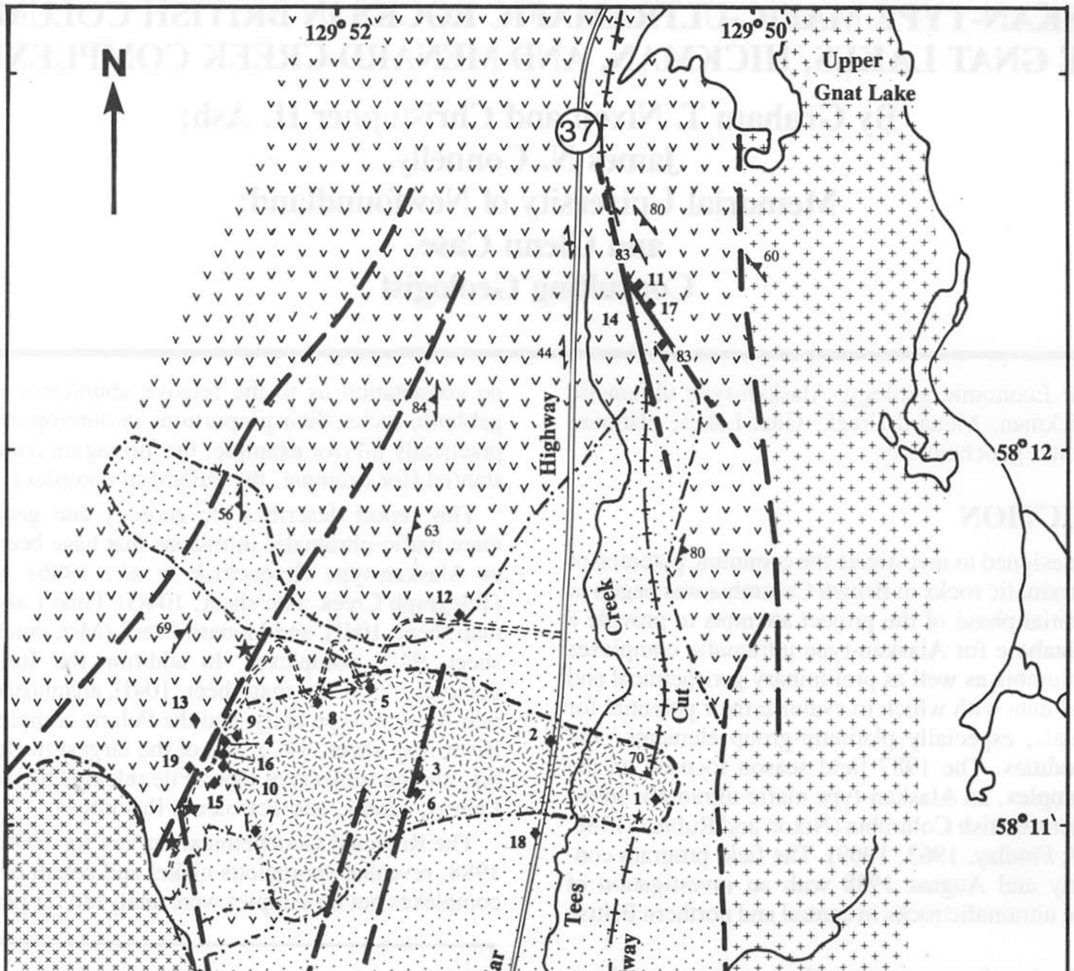


Figure 2-10-2. Geologic map of the Gnat Lakes mafic-ultramafic complex showing distribution of geochemical sample sites and sulphide showings.

elements (PGEs). Analytical data for platinum, palladium, rhodium, and gold in mafic, ultramafic and associated rocks are reported in this paper.

The locations of the Gnat Lakes, Hickman, and Menard Creek complexes and their tectonic setting are shown in Figure 2-10-1. All lie within Stikinia, a tectonostratigraphic terrane comprising Middle Paleozoic to Mesozoic sedimentary, volcanic and plutonie rocks.

THE GNAT LAKES MAFIC-ULTRAMAFIC COMPLEX

LOCATION AND ACCESS

The Gnat Lakes complex (50°11.5′ north, 129°51′ west) is located some 30 kilometres south of Dease Lake on Highway 37, the Stewart-Cassiar Highway (Figure 2-10-2). The complex is named for Lower and Upper Gnat Lakes, and lies approximately 3 kilometres south of Upper Gnat Lake. A four-wheel-drive access road climbs west from the highway to treeline near the western margin of the complex. On the whole, the complex is poorly exposed and probably has a maximum extent of about 2 square kilometres.

GENERAL GEOLOGY AND GEOCHRONOMETRY

The Gnat Lakes complex has traditionally been included as part of the composite Hotailuh batholith (Hanson and McNaughton, 1936) which has been studied in detail by Anderson (1983). The batholith is composed of at least four distinct granitoid plutons, two of which, the Three Sisters and Cake Hill plutons, occur within the map area (Figure 2-10-2). The main outcrops of ultramafic rocks are completely enclosed by metavolcanic and metasedimentary rocks of the Stuhini Group which lie within an embayment at the northwestern margin of the batholith. In addition, small isolated exposures of ultramafic rocks form pendants within the Three Sisters pluton about 2.5 kilometres to the south, and occur in the Cake Hill pluton 14 kilometres south-southeast and 18 kilometres east-northeast of the Gnat Lakes ultramafite (Anderson, 1983). The ultramafic complex bears no unique signature on the regional aeromagnetic map (Geological Survey of Canada, 1978) due to the overwhelming aeromagnetic response associated with a northwest-trending apophysis of the Three Sisters pluton (Anderson, 1983).

Potassium-argon dating of hornblende in hornblendite and hornblende clinopyroxenite of the Gnat Lakes complex yields isotopic ages of $230 \pm 10(2\sigma)$ and 227 ± 14 Ma respectively, or earliest Late Triassic (Carnian) (Anderson, 1983; Stevens *et al.*, 1982). These dates are identical (within analytical error) to potassium-argon isotopic ages for hornblende in the Cake Hill pluton (220 ± 11, 218 ± 11 and 227 ± 14 Ma; Stevens *et al.*, 1982) which according to Anderson (1983) is intruded by the Gnat Lakes ultramafite. A quartz monzonite of the potassic marginal phase of the Three Sisters pluton has been dated by potassium-argon and uranium-lead geochronometry at a locality approximately 3 kilometres west of the Gnat Lakes ultramafite. Zircon fractions lying essentially on concordia yield a preferred uranium-lead isotopic age of 170 ± 1 Ma (Anderson *et al.*, 1982) which is concordant with a potassium-argon date of 169 ± 11 Ma for hornblende in the same sample (Stevens *et al.*, 1982). The age of the Stuhini Group is established as Late Triassic on the basis of ammonite faunas recovered from epiclastic sequences at the northern margin of the Hotailuh batholith (Anderson, 1980).

COUNTRY ROCKS

STUHINI GROUP

The Stuhini Group is composed of volcanic flows and breccias, subvolcanic intrusive rocks, and tuffaceous sandstones, siltstones and shales that appear variably metamorphosed to upper greenschist mineral assemblages. The volcanic rocks are relatively well exposed above treeline immediately west of the ultramafic body. The predominant rock-type is a dark greenish grey porphyry characterized by euhedral phenocrysts (less than 1 centimetre) of augite ± plagioclase ± amphibole set in a finer grained matrix. These augite porphyries form flows and massive shallow intrusions and are incorporated as angular fragments in volcanic breccias and thinly bedded tuffs and epiclastic rocks. Similar lithologies appear in stratigraphic sections measured by Anderson (1980) about 3 kilometres farther west and along the northern margin of the Hotailuh batholith. In thin section, clinopyroxene and hornblende phenocrysts are commonly rimmed and replaced along fractures by actinolitic amphibole, and plagioclase is extensively saussuritized. Locally, secondary amphibole and biotite form rounded radiating crystal aggregates. Rare glomeroporphyritic clots contain intergrowths of augite, hornblende, plagioclase, iron-titanium oxides and apatite, with or without sphene.

In road and railway cuts north of the ultramafic complex augite porphyries are strongly schistose and mylonitic. Under the microscope, relict augite phenocrysts exhibit flaser textures with pressure shadows and are altered extensively to tremolite-actinolite. The fine-grained matrix is recrystallized to actinolite, biotite, chlorite and sericite, which define the foliation, and carbonate, iron-titanium oxides and minor sulphides.

Metasedimentary rocks within the Stuhini Group include grey-green to rusty brown or buff-weathering tuffaceous sandstones, siltstones and black argillites, variably silicified and locally epidotized and pyritic. Near the southwestern margin of the Gnat Lakes complex these rocks have been recrystallized to fine-grained chlorite-biotite-actinolite-feldspar schists.

INTRUSIVE ROCKS

CAKE HILL PLUTON

Outcrops of the Cake Hill pluton were examined south of Upper Gnat Lake in the eastern part of the map area. The rock is a pink to buff-weathering, medium-grained equigranular hornblende syenite to monzonite and monzodiorite with accessory magnetite and sphene. The predominant lithology in the central part of the pluton is hypidiomorphic granodiorite (Anderson, 1983). A penetrative foliation is defined locally by alignment of partially chloritized mafic minerals.

Three Sisters Pluton

The potassic marginal phase of the Three Sisters pluton crops out along the highway and in railway cuts to the south of the Gnat Lakes complex. It is composed of pale pink to white-weathering, medium-grained hornblende monzonite to hornblende-biotite syenite or quartz syenite cut by aplite and diabase dykes. The rocks are generally massive and well jointed. In thin section, plagioclase is seen to be partially altered to sericite and epidote, and hornblende (25 volume per cent) is chloritized. Accessory phases include biotite (less than 1 per cent), iron-titanium oxides (less than 3 per cent) and sphene.

Mafic-ultramafic Rocks

The Gnat Lakes ultramafic complex comprises medium-grained grey-green hornblende clinopyroxenite, black hornblendite, and dark to medium grey feldspathic hornblendite, hornblende gabbro, and rare pyroxene gabbro. The predominant lithologies appear to be feldspathic hornblendite and hornblende gabbro. These rocks are locally pegmatitic with prismatic amphibole crystals reaching 3 centimetres in length.

Ultramafic rocks are well exposed in a railway cut at the eastern edge of the complex (Figure 2-10-2). Here, a continuous gradation is observed from variably carbonatized hornblende clinopyroxenite in the north to saussuritized hornblende gabbro in the south. However, the crude zonation from pyroxenitic core to hornblendite/hornblende gabbro margin, as inferred by Anderson (1983), could not be confirmed. Crude igneous layering involving hornblende clinopyroxenite and feldspathic hornblendite grading into hornblende gabbro was observed in glacially polished outcrops along the access road. The rocks exhibit no tectonic foliation yet in places the layering is contorted and appears to have been remobilized prior to complete solidification. Layered horizons are commonly transected by irregular, locally derived leucocratic veins that appear to have been generated by coalescence of residual gabbroic liquids. Veins of similar style and origin have been documented in the Tulameen complex (Nixon and Rublee, 1988).

Petrography and Mineral Chemistry

As seen in thin section, hornblende clinopyroxenite contains cumulus clinopyroxene with intercumulus hornblende (20 volume per cent), iron-titanium oxides (5 to 10 per cent) and minor sphene (1 per cent). Cumulus clinopyroxene is also present in pyroxene gabbro but is replaced by cumulus amphibole in hornblendite, feldspathic hornblendite and hornblende gabbro. Plagioclase is a cumulus and intercumulus phase in the gabbroic rocks which also contain interstitial iron-titanium oxides (2 to 5 volume per cent), apatite (less than 1 per cent), and sphene (less than 1 per cent). Secondary minerals include epidote, carbonate, chlorite, sericite, and sulphides, largely pyrite.

Anderson (1983) provided electron microprobe data for clinopyroxene and amphibole phenocrysts in Gnat Lakes ultramafic rocks, augite-plagioclase porphyry dykes, and augite ± hornblende ± plagioclase porphyries of the Stuhini Group. Overall, phenocryst compositions are similar. Clinopyroxenes (diopsidic augite to magnesium-rich salite) exhibit little zoning and have low titania (less than 1 weight per cent) and moderate alumina (generally 2.5 to 5 weight per cent) and consequently relatively low octahedral alumina, indicative of crystallization within the erust. However, clinopyroxene compositions alone provide tentative evidence for their magmatic subalkaline affinity and tectonic environment (*see* Anderson, 1983).

Primary amphibole compositions are predominantly ferroan pargasite (Leake, 1978) with low TiO_2 and uniformly high K_2O (1 to 1.6 weight per cent). Amphiboles in Gnat Lakes hornblendite are zoned outwards towards actinolitic hornblende. Their levels of potash enrichment and potassium:sodium ratios are similar to those detected in amphiboles from hornblende clinopyroxenites and gabbroic rocks of the Tulameen complex (G.T. Nixon, unpublished data). Evidently, the liquids with which these crystals last equilibrated were relatively potassic. In general, these data support Anderson's contention that Gnat Lakes mafic and ultramafic rocks are likely comagmatic with Stuhini Group volcanism.

INTRUSIVE RELATIONSHIPS

Despite poor outcrop, intrusive relationships in the map area are well known. A sharp intrusive contact between metasedimentary schists of the Stuhini Group and Gnat Lakes ultramafite is exposed at the southwestern margin of the complex. Hornblende gabbro and hornblendite exhibit a decrease in grain size as the contact is approached, indicating the presence of a marginal chill zone. These observations, together with the Carnian isotopic age (227 ± 14 Ma) for the ultramafic rocks, suggest that the Gnat Lakes complex represents a high-level intrusion coeval with Stuhini Group volcanism. The augite-plagioclase porphyry dykes, presumably the hypabyssal equivalents of Stuhini lavas, must be of various ages since they cut all of the Upper Triassic lithologies including Gnat Lakes ultramafite.

Relationships between ultramafic and granitic rocks are well exposed in railway cuts at the eastern extremity of the complex. Irregular dykes of pink aplite and fine to medium-grained syenite have invaded hornblende clinopyroxenite and hornblende gabbro to produce localized agmatites. Irregular bodies of medium-grained hornblende-biotite syenite to monzonite also intrude the western part of the Gnat Lakes complex. Anderson (1983) considered these intrusions to be apophyses of the potassic marginal phase of the Three Sisters pluton, and therefore Middle Jurassic in age. Other minor intrusions into the Gnat Lakes ultramafite include dykes of pale buff dacite containing phenocrysts of hornblende, plagioclase and quartz, and diabase dykes with abundant plagioclase microphenocrysts and iron-titanium oxides (4 volume per cent).

STRUCTURE

The structure of the map area is poorly understood due to the lack of marker horizons. Major northerly to northeasterly trending lineaments observed on aerial photographs are interpreted as faults. Outcrops located near such lineaments may display a subparallel foliation or localized mylonitic fabric. The western margin of the Cake Hill pluton appears to be a fault.

A steeply dipping regional foliation, defined by amphiboles and micas, has been detected in all lithologies but is poorly developed or absent in the more massive augite porphyries and intrusive rocks. In the northeastern part of the map area, this foliation trends northwesterly, consistent with fabrics further east that characterize the northwestern part of the Hotailuh batholith (Anderson, 1979). Further west, foliations swing north to northeasterly, possibly influenced by faulting. In general, the mineral foliation reflects inhomogeneous regional deformation accompanied by variably developed metamorphic assemblages attaining upper greenschist grade. The timing of this deformation is currently uncertain; it may be synchronous with Late Triassic plutonism or associated with southwesterly verging folds and associated thrust faults of Middle Jurassic (post-Toarcian) to Cretaceous age (Monger *et al.*, 1978; R. G. Anderson, personal communication, 1988).

MINERALIZATION

Minor amounts of disseminated sulphides are distributed throughout the map area but mineralization is preferentially developed near faults.

Sulphides in the mafic and ultramafic rocks generally form no more than 5 volume per cent of the rock and comprise finely disseminated pyrite and rare chalcopyrite. Most of the mineralized outcrops occur near the western margin of the complex. No net-sulphide textures were observed.

Granitoid rocks commonly contain disseminated sulphides (less than 3 volume per cent) and thin (0.5 millimetre) discontinuons stringers of sulphide and chlorite along joint planes. Disseminated pyrite is also found in diabase dykes cutting the granitic rocks.

Control of mineralization by faults is seen at several localities. A fault contact between black argillites and schistose augite porphyry is well exposed in a railway cut in the northern part of the map area. Here, the abundance of disseminated sulphide in the argillite, intensity of carbonate veining, and degree of silicification increase towards the fault.

The most important mineralization occurs along a major north-northeasterly trending fault in the Stuhini Group near the western limit of the ultramafite (Figure 2-10-2). In the mid-1960s, a program of geologic mapping, prospecting and trenching, and an induced polarization survey, were carried out on a number of known mineral showings distributed along the fault (Roed, 1966a, b; Malinsky, 1966; Reynolds, 1967). Mineralized zones comprise massive pyrite, chalcopyrite, and minor pyrrhotite and arsenopyrite in a gangue of siderite, limonite, hematite and smoky quartz.

The age of the mineralization is not well constrained. On the whole, the association of mineralization with brittle phenomena such as faults and joints suggests that the mineralizing event(s) occurred late in the history of regional deformation (presumably post-Toarcian).

GEOCHEMISTRY

Whole-rock analyses of Gnat Lakes ultramafic rocks taken from Anderson (1983), and preliminary assay results for platinum, palladium, rhodium, and gold, are given in Tables 2-10-1 and 2-10-2 respectively. The occurrence of cumulate textures in the ultramafic rocks, and thus accumulative origin, precludes the use of whole-rock compositions as a means of classification (for example, Irvine and Baragar, 1971). The hornblende clinopyroxenites and hornblendites have high total iron and titania, reflecting in part the abundance of intercumulus iron-titanium oxides, and high alkalies and iron:magnesium ratios. These compositions compare rather closely with those of similar rocks in the Tulameen complex (Table 2-10-1). Their relatively high potassium:sodium ratio is a trait shared by the majority of Stuhini Group volcanic rocks and porphyry dykes (Anderson, 1983). However, the latter rocks are altered (2 to 4 weight per cent H_2O and up to 5 weight per cent CO_2) and have clearly suffered some degree of alkali mobility

TABLE 2-10-1
MAJOR AND TRACE ELEMENT COMPOSITION OF GNAT LAKES ULTRAMAFIC ROCKS

	Gnat Lakes				Tulameen	
Rock Type	1 Hb	2 Hb	3 Hb Cpx	4 Hb Cpx	5 Hb Cpx	(Range)
Weight %						
SiO_2	45.00	41.60	39.80	39.60	40.74	(3.84)
TiO_2	1.24	1.58	1.97	2.06	1.48	(1.23)
Al_2O_3	5.80	6.70	11.10	6.50	5.06	(3.29)
Fe_2O_3	6.40	9.60	6.00	13.30	11.59	(6.92)
FeO	8.60	9.90	10.00	9.90	8.84	(2.67)
MnO	0.26	0.20	0.23	0.20	0.22	(0.04)
MgO	11.70	11.07	8.70	10.54	12.58	(2.13)
CaO	17.80	15.48	13.57	15.74	16.86	(1.92)
Na_2O	0.68	0.81	1.60	0.74	0.61	(0.84)
K_2O	0.48	0.55	0.72	0.42	0.53	(1.31)
P_2O_5	0.33	0.35	1.53	0.10	0.05	(0.10)
H_2O_T	1.80	1.30	2.20	0.70	1.03	(0.48)
CO_2	BD	0.70	0.50	0.10	0.16	(0.38)
S	BD	0.21	0.80	BD	0.03	(0.04)
Cl	0.05	0.11	0.10	0.06	NA	
F	0.04	0.05	0.14	0.04	NA	
Total	100.18	100.16	98.76	100.00	99.77	
ppm						
Rb	0	70	100	30		
Sr	270	240	400	140		
Ba	200	650	200	150		
U	0.4	NA	NA	NA		
Zr	21	58	53	39		
Y	BD	44	41	50		
Cr	110	120	27	160		
Co	64	57	53	76		
Ni	63	91	33	150		
V	450	560	530	750		
Cu	13	210	250	17		
Zn	50	80	130	140		

Hb = Hornblendite; Hb Cpx = Hornblende clinopyroxenite; H_2O_T = total water; NA = not analyzed; BD = below detection limit.

Columns 1-4 are analyses from Anderson (1983, Table 2-4-2).

Column 5 is the arithmetic mean (and range) for 4 hornblende clinopyroxenites from the Tulameen complex (Findlay, 1969, Table 4).

TABLE 2-10-2
NOBLE METAL ABUNDANCES OF THE GNAT LAKES
MAFIC-ULTRAMAFIC COMPLEX AND ASSOCIATED ROCKS

Sample Location*	Sample No.	Rock Type	Sulphide (volume %)	ppb[1] Pt	Pd	Au
GNAT LAKES MAFIC-ULTRAMAFIC COMPLEX						
1	GN-88-0005	Hb clinopyroxenite	—	1	20	1
1	GN-88-0006	Hb clinopyroxenite	—	1	17	6
2	GN-88-0001	Hornblendite	—	2	35	3
3	CA-88-0006	Hornblendite	<5	4	2	1
4	GN-88-1029	Hornblendite	Tr	1	11	2
5	GN-88-0009	Feldspathic hornblendite	Tr	2	19	6
6	CA-88-0005	Feldspathic hornblendite	Tr	6	2	1
7	GN-88-4018C	Feldspathic hornblendite	<5	11	17	2
1	GN-88-0007	Hb gabbro	<5	1	2	2
8	GN-88-1022	Hb gabbro	—	2	19	8
9	GN-88-1030	Hb gabbro	5–10	1	2	1
10	GN-88-4006	Hb gabbro	<5	1	2	1
STUHINI GROUP — Metavolcanic Rocks						
11	GN-88-0003	Cpx porphyry schist	—	2	25	1
12	GN-88-0008	Cpx-Plag porphyry schist	—	3	22	1
13	GN-88-1025A	Cpx porphyry (silicified)	Tr	2	29	25
14	GN-88-2025B	Cpx porphyry schist	<5	5	22	1
15	GN-88-4004	Cpx porphyry schist	Tr	3	26	1
16	GN-88-4007	Cpx-Plag porphyry	—	1	13	4
STUHINI GROUP — Metasedimentary Rocks and Veins						
17	GN-88-0004	Argillite	5	1	5	3
18	CA-88-0003	Metasediment (silicified)	<5	26	20	1
14	GN-88-2025A	Quartz vein in argillite	15–20	7	18	1
14	[2]GN-88-2025A			7	15	1
19	GN-88-1026	Pyrite-chalcopyrite	ore	1	4	824

Detection limits: Pt and Au, 1 ppb; Pd and Rh, 2 ppb.
* *See* Figure 2-10-2.
[1] Rh is at or below detection limit in all samples.
[2] Duplicate analysis.
Plag = plagioclase; Hb = hornblende; Cpx = clinopyroxene; Tr = trace sulphides; – sulphides not detected.
Samples designated schist contain abundant tremolite-actinolite, biotite, chlorite, and sericite ± carbonate.

(Na_2O:K_2O greater than 12 in extreme cases), which renders rigorous geochemical comparisons uncertain.

The noble metals were preconcentrated by fire assay from 30 gram splits of 200 grams of rock powder (– 200 mesh) and analyzed by inductively-coupled plasma mass spectroscopy by Acme Analytical Laboratories, Vancouver. Accuracy was checked by in-house standard FA-5X (supplied by Acme) which contains 100, 100, 20, and 100 ppb platinum, palladium, rhodium and gold respectively, and during analysis gave 98, 101, 20 and 100 ppb of each element respectively. Analytical precision (and any nugget effect) was monitored by hidden duplicates and internal standards.

The tenor of noble metals in Gnat Lakes ultramafite, Stuhini Group volcanic and metasedimentary rocks, and sulphide-bearing quartz veins is relatively low (Table 2-10-2). Typical economic PGE deposits have an average platinum grade of 5 to 10 grams per tonne (Macdonald, 1986). One anomalously high gold value (824 ppb) occurs in a sulphide sample collected from a showing located on the fault near the western edge of the ultramafic complex. However, there is no evidence to suggest remobilization of platinum-group elements within the fault zone. It is interesting to note that Stuhini Group augite porphyries are as enriched in palladium as rocks of the Gnat Lakes complex. In general, there is no correlation between the amount of pyritic sulphides in a rock and the abundance of noble metals.

In the Gnat Lakes suite, the abundance of platinum-group elements is slightly lower, on average, in gabbros than in ultramafic rocks, which in turn are distinctly impoverished relative to their counterparts in the Tulameen complex (Table 2-10-3). From a mineral exploration viewpoint, the best prospects in the vicinity of the Gnat Lakes complex would appear to be structurally-controlled gold-bearing sulphide deposits.

THE HICKMAN MAFIC-ULTRAMAFIC COMPLEX

LOCATION AND ACCESS

The Hickman mafic-ultramafic complex (57°16′ north, 131°05′ west) is located approximately 150 kilometres south-southwest of Dease Lake and 55 kilometres south of Tele-

TABLE 2-10-3
MEAN CONCENTRATIONS OF PLATINUM-GROUP ELEMENTS IN ALASKAN-TYPE COMPLEXES

	ppb			
	Pt	Pd	Rh	Au
Alaskan overall	43	32	19	
(range of values)	10–105	8–45	0.7–29	
Tulameen Complex[1]				
Ol clinopyroxenite and clinopyroxenite	30 (10)	—	0.8 (0.3)	0.4 (0.2)
Hb clinopyroxenite and hornblendite	50 (20)	140 (80)	0.2 (0.1)	3.4 (2.9)
Syenogabbro and syenodiorite	20 (10)	25 (15)	0.2 (0.1)	40 (40)
Sulphide-rich[2]	50 (20)	120 (60)	0.2 (0.1)	30 (30)
Magnetite-rich[2]	40 (10)	40 (20)	0.5 (0.2)	0.5 (0.3)
Tulameen overall[3]	80 (20)	100 (50)	1.2 (0.2)	7.8 (6.2)
Tulameen (weighted)[4]	12 (3)	30 (10)	0.4 (0.1)	1.5 (1.2)

Data from Crocket (1981) and St. Louis *et al.* (1986).
— below detection limit.
[1] Mean values and standard error of the mean (in brackets).
[2] Opaque minerals >10 volume per cent.
[3] Arithmetic mean includes PGE-rich chromitites.
[4] Weighted on the volume percentages of all rock types.

graph Creek (Figure 2-10-3). The project area is covered by 1:50 000 topographic maps 104G/6 and 104G/3. Access to the region is by air from Dease Lake to an airstrip at the confluence of the Scud and Stikine rivers. The airstrip provided a staging area to a helicopter-supported base camp established by members of the Stikine and Telegraph projects (Brown and Gunning, Logan and Koyanagi, 1989, this volume) located 25 kilometres to the east on the Scud River floodplain. The base camp lay 16 kilometres west of Mount Hickman for which the ultramafic complex is named. The region has excellent, though rugged, rock exposures that skirt receding monntain glaciers at altitudes between 1200 and 2800 metres.

GENERAL GEOLOGY AND GEOCHRONOMETRY

The Hickman ultramafic complex lies near the eastern edge of the Coast Mountains in the Intermontane Belt. The project area is underlain by Late Triassic granitoid rocks of the Hickman batholith and volcanic sequences that appear to belong to the Late Triassic Stuhini Group. Brief descriptions of the regional geology are given below based on work by Souther (1972), Holbeck (1988), and Brown and Gunning (1989, this volume).

The Hickman batholith (1200 square kilometres) is a composite body incorporating the Late Triassic (Carnian-Norian) Nightout and Hickman plutons and Middle Jurassic (Bajocian-Bathonian) Yehiniko pluton which intrudes the other two (Holbeck, 1988). Potassium-argon and rubidium-strontium geochronometry on mineral separates and whole rocks yields essentially concordant dates of 228 ± 16 (2σ; potassium-argon on hornblende), 221 ± 16 (potassium-argon on hornblende), and 178 ± 22 Ma (rubidium-strontium whole rock) for the Nightout, Hickman, and Yehiniko plutons respectively (Holbeck, 1988). The Hickman pluton underlies some 300 square kilometres at the southern limit of the Hickman batholith. Two phases are recognized within the map area: a main granodioritic to monzonitic phase and a mafic, more gabbroic phase.

The ultramafic rocks were originally considered to form an integral part of the Hickman pluton (Souther, 1972). However, more recent mapping by Holbeck (1988) and Brown and Gunning (1989, this volume), and our work, indicates that Mount Hickman itself is underlain by an assemblage of volcanic and volcaniclastic rocks that extends northeastward along the western margin of the ultramafic complex. We have therefore decided to treat the Hickman ultramafic complex as a separate entity rather than assume genetic links with the Hickman pluton for which there is currently no strong evidence.

The Stuhini Group east of Mount Hickman generally forms elongate outcrops that are bounded by north-trending normal faults or intruded by batholithic rocks. Regionally, the Stuhini Group is characterized by mafic to intermediate augite-phyric flows, sills and volcaniclastic rocks with sub-greenschist metamorphic assemblages. The upper part of the succession contains hornblende-plagioclase-phyric andesitic flows, heterolithic volcanic breccias and conglomerates, and rare felsic tuffs capped by fossiliferous limestones of Norian to Carnian age. These rocks appear to be correlative with similar lithologies that occur 100 kilometres to the northeast around the margin of the Hotailuh batholith (Anderson, 1983, 1988).

The structural and metamorphic history of the region is complex (summarized by Brown and Gunning, this volume). At least two phases of pre-Permian folding are recognized, and deformation also occurred in post-Early Jurassic time with southwesterly directed folding and thrusting. The latter phase of compression involved the margins of the Hickman pluton and the Stuhini Group. Faulting in the region appears to have continued into the Late Tertiary.

COUNTRY ROCKS

STUHINI GROUP

Volcanic assemblages of uncertain age (Holbeck, 1988) almost completely surround the ultramafic complex. In the north, the contact with ultramafic rocks is faulted, but to the east a sharp intrusive contact has been recognized between weakly hornfelsed volcanic rocks and marginal gabbros of the Hickman complex (M. Gunning, personal communication, 1988). The exact position and nature of the wesrern contact just east of Mount Hickman is not known.

The volcanic stratigraphy comprises predominantly mafic aphyric flows with subordinate porphyritic andesites and minor intercalated volcaniclastic material. The rocks are generally dark greenish to medium grey or maroon, and are locally bleached pale green to buff. Andesitic flows contain phenocrysts of plagioclase (20 per cent by volume) up to 3 millimetres in length, and pyroxene and/or amphibole (less than 5 per cent). These lithologies are tentatively included within the Stuhini Group, although doubt remains as to their exact stratigraphic position.

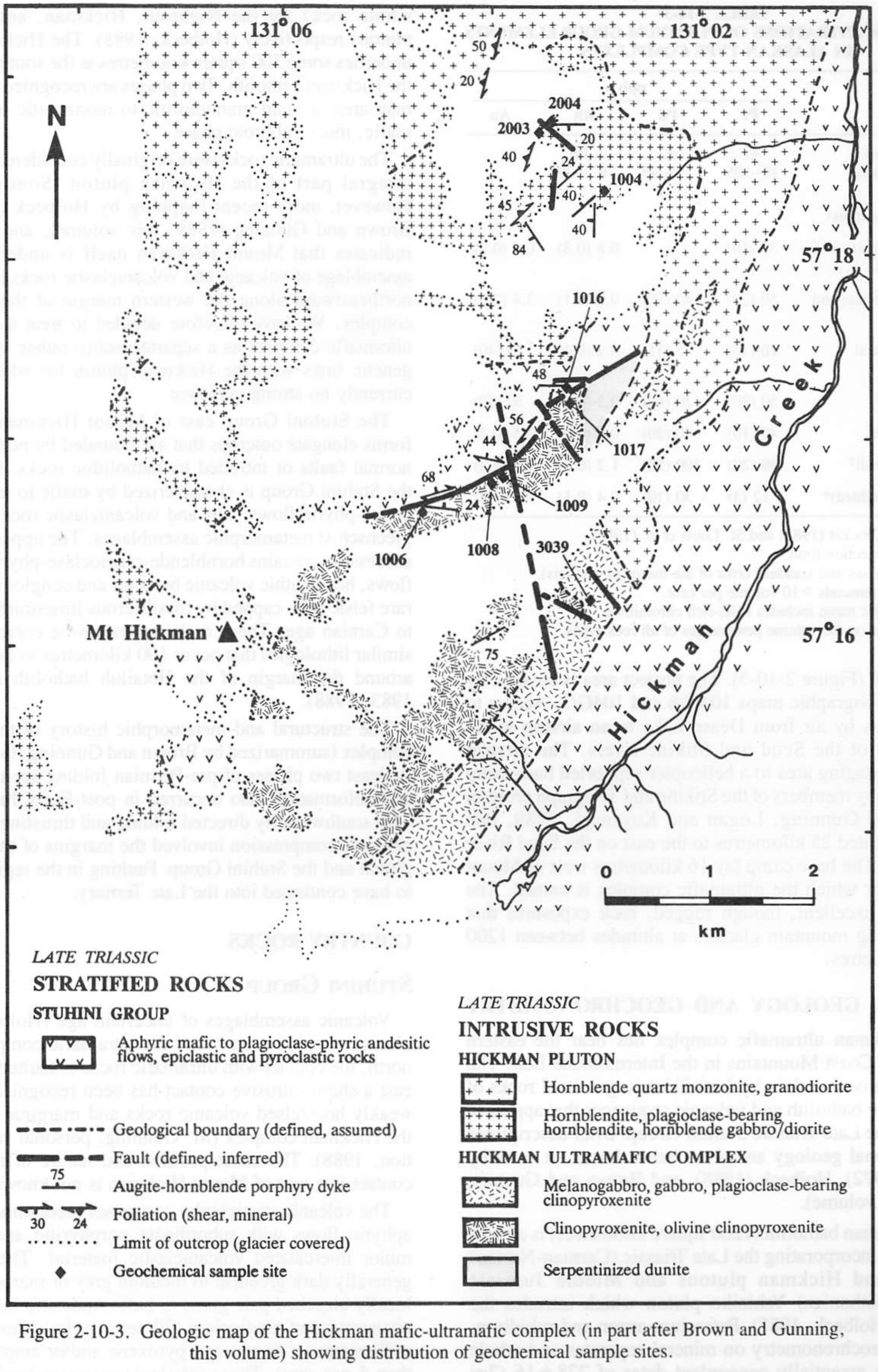


Figure 2-10-3. Geologic map of the Hickman mafic-ultramafic complex (in part after Brown and Gunning, this volume) showing distribution of geochemical sample sites.

INTRUSIVE ROCKS

HICKMAN PLUTON

Main Phase

The main phase of the Hickman pluton delineates the northeastern margin of the ultramafic complex. It comprises a pale grey to pinkish grey-weathering, medium-grained hornblende-biotite monzonite to granodiorite which grades into a more melanocratic phase towards the core of the pluton. The granitoid rocks become finer grained and enriched in biotite towards their contacts and irregular apophyses of fine-grained biotite monzonite locally cut the volcanic assemblages.

Mafic Phase

The mafic phase of the pluton is largely composed of medium to coarse-grained black hornblendite, plagioclase-bearing hornblendite, and dark to light grey hornblende gabbro to diorite with minor biotite. Prismatic hornblende crystals (less than 4 centimetres in length) in the more melanocratic rocks locally define an igneous lamination, probably a flow foliation, that wraps around inclusions. The xenolith suite comprises angular to rounded blocks of hornblendite, hornblende gabbro and grey-green pyritic diorite that appear to be cogenetic, and large rafts of hornfelsed sedimentary(?) rocks.

MAFIC-ULTRAMAFIC ROCKS

The main outcrops of mafic and ultramafic rocks that comprise the Hickman ultramafic complex are found immediately east of Mount Hickman, which itself is underlain by volcanic rocks of uncertain age (Holbeck, 1988), possibly correlative with the Stuhini Group. The ultramafic complex covers 11 square kilometres and forms an elongate body trending northeast with maximum dimensions of about 6 by 3 kilometres. The ultramafic rocks are spatially associated with the Hickman pluton.

Dunite

A small wedge of altered dunite occurs at the northern end of the complex in fault contact with volcanic rocks and intruded by the main phase of the Hickman pluton. The rock is dark to pale grey-weathering, moderately magnetic, and cut by numerous white calcite veins (less than 6 centimetres in width) especially near contacts. Two samples collected within 10 metres of the contact are thoroughly serpentinized. In thin section, olivine is seen to be completely replaced by serpentine and grain boundaries are coated with secondary magnetite dust. Tiny euhedral chromite crystals (1 per cent by volume) are dispersed throughout the rock.

Olivine Clinopyroxenite and Clinopyroxenite

The central part of the Hickman ultramafic complex is predominantly composed of dark grey-green to brownish weathering, coarse to medium-grained clinopyroxenite containing minor olivine (up to 20 per cent by volume) and interstitial magnetite (5 to 10 volume per cent), accessory biotite (less than 1 per cent), and rare hornblende. The rock is generally massive and uniform except in proximity to faults where anastomizing veins of carbonate, serpentine, talc and clay minerals are found. Some fault zones are commonly silicified and contain disseminated sulphides. In northern outcrops, the modal proportion of olivine appears to decrease to the east away from the dunite. Locally, the clinopyroxenite is enriched in biotite which forms crystals up to 1 centimetre across. Clinopyroxenites gradually become feldspathic towards the contact with marginal gabbros. Generally, olivine and clinopyroxene occur as cumulus minerals that locally exhibit adcumulus growth. Iron-titanium oxides and biotite with or without hornblende form an intercumulus framework.

Gabbroic Rocks

Gabbroic rocks crop out in a narrow belt 500 metres wide along the eastern margin of the complex. These marginal gabbros are dark to medium grey, equigranular rocks containing subequal proportions of plagioclase and clinopyroxene, and minor hornblende (5 volume per cent), biotite (usually less than 5 per cent) and magnetite. The gabbros are cut locally by leucocratic plagioclase-rich dykes several centimetres in width.

DYKES

Dykes of variable mineralogy and texture intrude the ultramafic and granitoid rocks. The dominant orientation is east-west with moderate dips to the north. Dark grey mafic dykes (less than 1 metre in width) are weakly vesicular and either aphyric or contain sparse plagioclase microphenocrysts (less than 1 millimetre). Medium to pale grey porphyritic dykes (2 to 4 metres in width), with large (less than 3 centimetres) phenocrysts of hornblende and augite (10 to 20 per cent by volume) and sparse plagioclase, commonly exhibit chilled margins and multiple injection. These dykes mineralogically resemble typical Stuhini Group volcanic rocks although they postdate emplacement of the Hickman pluton and presumed Stuhini Group equivalents that form the immediate country rock of the ultramafic complex.

INTRUSIVE RELATIONSHIPS

The age of emplacement of the Hickman ultramafic complex is tightly constrained by intrusive relationships, stratigraphic correlations and isotopic dating. The complex is truncated on the north by the main phase of the Hickman pluton dated at approximately 221 ± 16 Ma or Late Triassic (Holbeck, 1988), and intrudes volcanic rocks that are Upper Triassic equivalents of the Stuhini Group or older. Thus, the age of the Hickman ultramafic complex is probably Late Triassic.

Internally, the ultramafic complex comprises several distinct lithologies that include dunite, olivine clinopyroxenite to clinopyroxenite, and gabbroic rocks. The contact between dunite and olivine clinopyroxenite appears to be sharply transitional, and that between clinopyroxenite and the gabbroic rocks is sharp to gradational over several metres. The latter transition is marked by a gradual increase in the modal

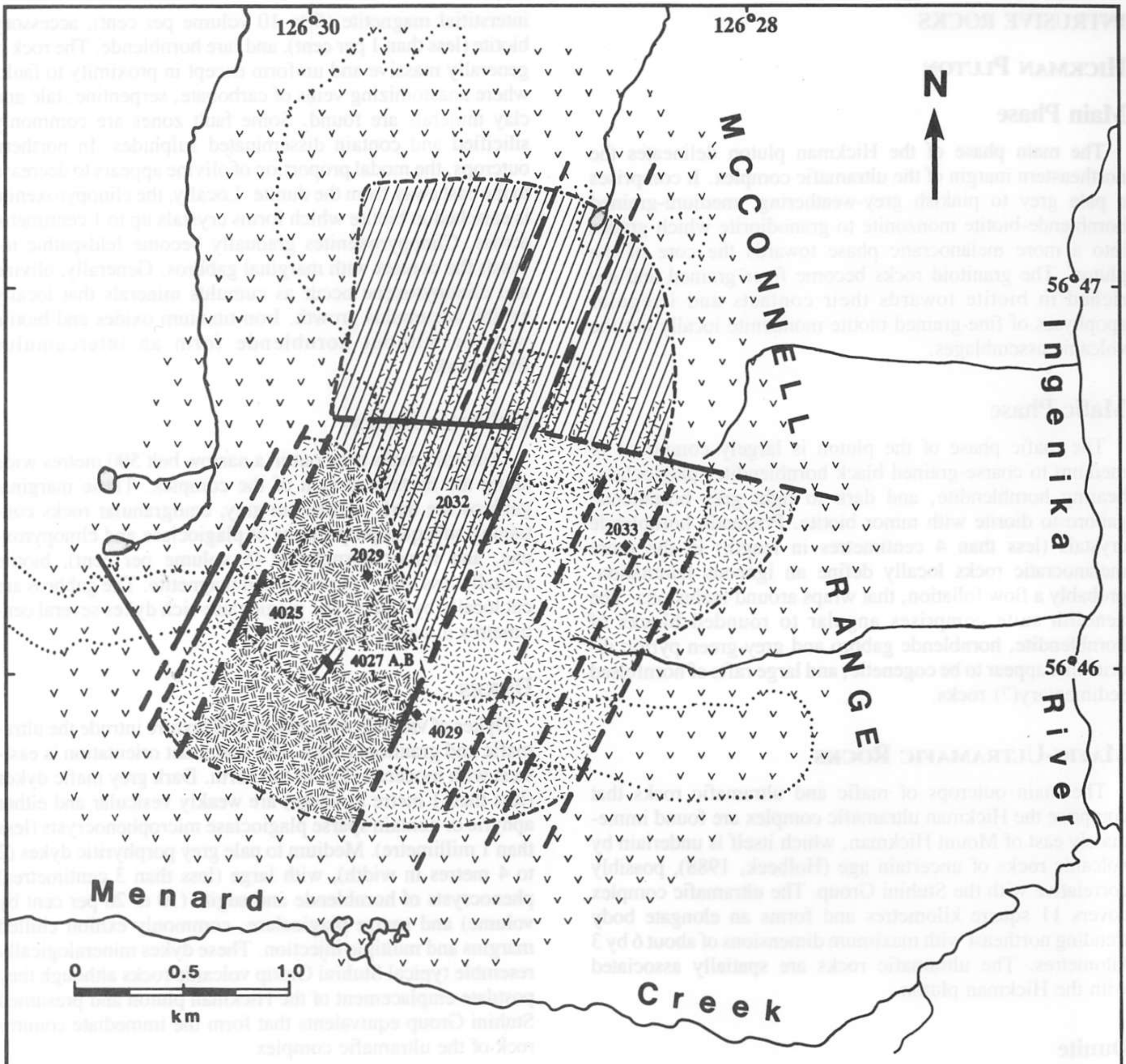


Figure 2-10-4. Geologic map of the Menard Creek mafic-ultramafic complex (in part after Irvine, 1976) showing distribution of geochemical sample sites.

proportion of plagioclase (less than 15 per cent). The youngest intrusives in the map area are mafic to intermediate dykes of Late Triassic age or younger.

STRUCTURE

Faults trending west-southwest and north to northwest are the prominant structural features in the map area. A moderately dipping (60°), west-southwest-trending fault separates the northern margin of the Hickman ultramafic complex from the volcanic rocks. The fault zone is about 30 metres wide, strongly foliated, and mineralized. This fault may belong to a regional set of west-striking normal faults with north-side-down displacement (Brown and Gunning, 1989, this volume). North-trending faults have much narrower foliated zones and may be related to east-west brittle extension in the Tertiary. One such structure offsets the west-southwest-trending fault with an east-side-down sense of displacement.

MINERALIZATION

The Hickman ultramafic complex lies within a metallogenic belt that encompasses the eastern margin of the Coast Mountains and hosts precious metal and base metal deposits, notably copper-molybdenum and copper-gold porphyries, and structurally controlled epigenetic gold deposits. The regional metallogeny is reviewed by Brown and Gunning (1989, this volume).

Mineralization within the map area appears to be dominantly controlled by faulting. The west-southwest-trending fault zone is silicified and locally carbonatized, and weathers a deep orange-brown at its western end due to the presence of disseminated sulphides, mostly pyrite (less than 5 volume per cent). Northerly trending faults appear to be unmineralized though fault zones are locally silicified. The age of the mineralization may be Early to Middle Jurassic (Brown and Gunning, 1989, this volume).

GEOCHEMISTRY

Analytical results for noble metals in the Hickman mafic-ultramafic complex, porphyritic dykes, and mafic phase of the Hickman pluton are given in Table 2-10-4. The abundance of platinum-group elements in the mafic-ultramafic complex is relatively low compared to Alaskan-type intrusions in general, and olivine clinopyroxenites and clinopyroxenites of the Tulameen complex in particular (Table 2-10-3). Platinum abundances are highest in olivine clinopyroxenite whereas gold has an affinity for sulphide-bearing and carbonatized rocks. Proximity to faults may account for the anomalously high gold (87 ppb) content of sample GN-88-1009.

TABLE 2-10-4
NOBLE METAL ABUNDANCES OF THE HICKMAN MAFIC-ULTRAMAFIC COMPLEX AND ASSOCIATED ROCKS

Sample No.	Rock Type	Sulphides (volume %)	ppb[1] Pt	Pd	Au
HICKMAN MAFIC-ULTRAMAFIC COMPLEX					
GN-88-1008	Ol clinopyroxenite	—	18	2	3
GN-88-1009	Ol clinopyroxenite	<5	9	2	87
GN-88-1017	Ol clinopyroxenite	—	2	2	1
GN-88-1006	Clinopyroxenite	—	2	2	3
GN-88-3039	Gabbro (carbonatized)	—	5	28	13
HICKMAN PLUTON — Mafic Phase					
GN-88-2003	Hb gabbro	—	1	2	1
GN-88-1004	Diorite	<5	1	17	8
DYKES					
GN-88-1016	Cpx-Hb porphyry	—	1	2	2
GN-88-2004	Cpx-Hb porphyry	—	1	2	1

[1] Rh is at or below detection limit (2 ppb) in all samples.
Ol = olivine; other abbreviations as in Table 2-10-2.

THE MENARD CREEK MAFIC-ULTRAMAFIC COMPLEX

LOCATION AND ACCESS

The Menard Creek mafic-ultramafic complex (56°45.5′ north, 126°29′ west) is located in the Intermontane Belt of north-central British Columbia. It underlies part of the McConnell Range of the Omineca Mountains (94D/16), and lies just north of Menard Creek for which the complex is named (Figure 2-10-4). Access to the area is by four-wheel-drive vehicle along a seemingly endless gravel road that leads north from Fort St. James to the Toodoggone River. A narrow spur road branches north towards the Menard complex just before Kilometre 423 on the main Cheni mine road. Alternatively, the area may be reached by helicopter from the Sturdee airstrip in the Toodoggone River area. The best exposures of the complex occur along serrated, locally precipitous ridges at altitudes between 1900 and 2200 metres. Lichen cover on the crest of these ridges is fairly extensive.

GENERAL GEOLOGY

Ultramafic rocks of the Menard Creek complex were initially included by Lord (1948) with the Early Cretaceous Omineca intrusions, a granitoid mass of batholithic proportions composed of mainly granodiorite to quartz diorite. Meyer and Overstall (1973) first identified the ultramafic nature of the complex during an exploration program to investigate an intense magnetic high over the body. Later, Irvine (1974b, 1976) identified the clinopyroxenites of the complex as an Alaskan-type association, produced the first detailed geologic map, and formally named the body the Menard Creek complex.

The Menard Creek complex (Figure 2-10-4) is a clinopyroxenite-gabbro body of probable Late Triassic age. It is surrounded by Late Triassic mafic volcanic rocks of the Takla Group. A possibly coeval high-level intrusive phase is represented by an augite and plagioclase-porphyritic dyke swarm which intrudes the northern margin of the complex. Similar rock types occur within the Savage Mountain Formation which is part of the "western assemblage" of Takla Group rocks that crop out to the immediate west of the complex (Richards, 1975).

The structure of the Takla Group is dominated by northerly to northwesterly trending folds and faults and at least two phases of deformation have been recognized (Bellefontaine and Minehan, 1988). The metamorphic grade of the Takla Group is greenschist to subgreenschist (Monger, 1977).

COUNTRY ROCKS

Takla Group

The Takla Group was initially described by Lord (1948) as an essentially Late Triassic to Jurassic conformable assemblage of more than 10 000 metres of mafic volcanic and sedimentary rocks. Subsequent work by Richards (1976), Monger, (1976, 1977), and Monger and Church (1977) refined this definition to include only rocks of Late Triassic age (Late Carnian to Middle Norian). The group was subdivided into two distinct facies, representing eastern and western assemblages, separated by a north-trending lineament, the Ingenika fault, which runs along the Ingenika River (Figure 2-10-4). In the vicinity of the Menard Creek complex, Takla Group rocks have been included as part of the eastern assemblage (Richards 1975), which includes mafic to intermediate lava flows, volcanic and epiclastic breccias, tuffaceous rocks and green phyllite, phyllitic schists and minor metasedimentary rocks.

INTRUSIVE ROCKS

Ultramafic-mafic Rocks

The Menard Creek mafic-ultramafic complex (less than 4 square kilometres) is a roughly circular body with its outcrop pattern modified by faulting. The complex contains a mass of clinopyroxenite in its southwestern corner and a high proportion of gabbro. Igneous layering appears to be absent.

Clinopyroxenites

At the present level of exposure, clinopyroxenites, olivine-bearing clinopyroxenites, and olivine clinopyroxenites form 25 to 30 per cent of the complex. They comprise grey to green-weathering, medium to coarse-grained (5 to 10 millimetres) or locally pegmatitic (less than 2 centimetres) rocks that are generally massive and isotropic. Varieties that contain olivine carry about 5 to 15 volume per cent and contacts between olivine-bearing and olivine-free clinopyroxenites appear gradational. Olivine grains are usually highly altered and weather rusty brown.

In thin section, olivine and clinopyroxene exhibit cumulate textures and clinopyroxene has locally undergone adcumulate growth. Olivine is completely altered to a fine-grained assemblage of magnetite, serpentine and carbonate. Thin (0.5 to 1 millimetre) carbonate veinlets (2 to 3 volume per cent of the rock) are also common.

Gabbro

Pyroxene gabbro variably enriched in magnetite is the dominant lithology in the complex. The principal outcrops occur along east-trending ridges in the eastern part of the body. The gabbro is a dark to pale grey, massive, medium-grained rock that is texturally rather uniform and strongly magnetic. It contains subequal proportions of clinopyroxene and plagioclase, and locally grades into more leucocratic or melanocratic variants.

A fault-bounded sliver of extensively epidotized and sericitized gabbro occurs on the western margin of the clinopyroxenite unit. Melanocratic xenoliths of fine-grained mafic rocks are found within sheared and saussuritized gabbro, and may represent stoped blocks of Takla Group wallrocks. Locally these xenoliths are very abundant.

In thin section, clinopyroxenes are fresh whereas cumulus plagioclase is weakly to highly altered to sericite (10 to 90 volume per cent). Magnetite (5 to 15 modal per cent) forms anhedral intercumulate grains, and subhedral crystals of serpentinized olivine (1 to 2 millimetres) occur in trace amounts together with intercumulus biotite (less than 1 volume per cent).

Mafic Dykes

At the northern margin of the complex, medium-grained equigranular gabbros, and a variety of gabbro with augite phenocrysts set in a fine-grained feldspathic matrix, are intruded by augite-phyric dykes that comprise up to 50 per cent of the outcrop. Further north, gabbro screens disappear and the dykes are sheeted.

Two texturally distinct varieties of dyke rock can be identified. One contains conspicuously bladed subhedral crystals of plagioclase with subtrachytic texture that reach over a centimetre in length; the other carries subhedral to euhedral, roughly equidimensional phenocrysts of augite. However, both types of dyke contain phenocrysts of plagioclase (less than 30 volume per cent), clinopyroxene (3 to 10 per cent) and olivine (1 per cent). In thin section, oscillatory-zoned plagioclase phenocrysts are partially resorbed, augite is partly altered to chlorite and olivine is replaced by serpentine and chlorite. The groundmass is composed of finely crystalline clinopyroxene, feldspar, and iron-titanium oxides (less than 20 per cent).

CONTACT RELATIONSHIPS

Intrusive contacts between the Menard Creek complex and the Takla Group have not been identified, although it is likely that such relationships originally existed. Most contacts are represented by faults. However, the contact between clinopyroxenite and gabbro is well exposed and identified as transitional.

The mafic dykes clearly intrude the gabbros. The contact between the units is represented by an intrusive zone with up to 50 per cent gabbro screens. Chilled margins provide good evidence for the chronology of dyke intrusion. In all cases, augite porphyry dykes are chilled against dykes with bladed plagioclase textures, indicating that the latter dykes are earlier. The timing of dyke intrusion is uncertain, but they may represent feeders for Takla Group volcanism.

STRUCTURE

A system of northeasterly trending faults appears as well-defined lineaments on aerial photographs. The faults are recognized in the field by localized zones of highly fractured rock and clayey gouge. In the vicinity of faults, alteration of the surrounding rock is locally severe, but no mineralization has been identified. Epidote and carbonate veining also becomes more intense within these fault zones.

GEOCHEMISTRY

Noble metal abundances for mafic and ultramafic rocks of the Menard Creek complex and mafic dykes are presented in

Table 2-10-5. Platinum-group element abundances are generally low with weak enrichment of platinum in clinopyroxenites relative to gabbros. Anomalously high palladium (41 ppb) in gabbro sample GN-88-4029 does not appear to coincide with the presence of sulphides and may be related to magnetite enrichment.

SUMMARY AND DISCUSSION

Some remarkable similarities exist among the Gnat Lakes, Hickman and Menard Creek mafic-ultramafic complexes. All occur within the Stikine tectonostratigraphic terrane and are closely associated with Upper Triassic volcanic and epiclastic assemblages of the Stikine and Takla Groups. Isotopic dating and geological relationships indicate that the Gnat Lakes and Hickman bodies are also Late Triassic in age, and this is likely true for the Menard Creek complex although the evidence is not as conclusive. Both the Hickman and Gnat Lakes complexes are spatially associated with large granitoid intrusions (Hickman and Hotailuh batholiths respectively). However, the Alaskan-type bodies are demonstrably separate entities on the geologic maps. Their emplacement within the volcanic pile preceded granitic intrusion, and they appear to have closer genetic ties with their immediate volcanic hosts than with the batholithic rocks.

Some differences among the ultramafic complexes are also apparent. In the Gnat Lakes complex only the more differentiated phases of the Alaskan-type association are present, namely hornblende clinopyroxenite, hornblendite and gabbro. Fortunately, this body has been well studied, and whole-rock and mineral chemistry support an Alaskan-type affiliation. Although gabbroic rocks are a volumetrically dominant phase of the Menard Creek complex, olivine clinopyroxenites and clinopyroxenites are also present. In view of the lack of detailed study, perhaps its most distinctive Alaskan-type trait is the absence of cumulus orthopyroxene, abundance of magnetite, and occurrence of biotite in the gabbroic rocks. The Hickman complex, on the other hand, comprises a more complete suite of Alaskan-type lithologies, including dunite, olivine-bearing clinopyroxenites, and gabbros. A distinctive feature is the presence of phlogopitic mica in olivine clinopyroxenites. In the Tulameen Complex, for example, this mineral first appears in early cumulates (Nixon and Rublee, 1988).

Intrusive relationships with their host rocks have been documented in the case of the Hickman and Gnat Lakes complexes. However, such relationships are rarely observed and external contacts are commonly affected by ductile and brittle faults. In all three cases, internal contacts between the various lithologies are gradational.

Sulphide mineralization in the vicinity of these mafic-ultramafic complexes is predominantly associated with fault zones. Preliminary assay results for the precious metals suggest that these epithermal sulphides carry interesting gold values (up to 0.85 gram per tonne). However, there is no evidence within the mineralized zones for remobilization of platinum-group elements whose concentrations in the mafic and ultramafic rocks appear to be low in comparison to their abundances in the Tulameen complex.

TABLE 2-10-5
NOBLE METAL ABUNDANCES OF THE MENARD CREEK MAFIC-ULTRAMAFIC COMPLEX AND ASSOCIATED ROCKS

Sample No.	Rock Type	Sulphides (volume %)	ppb[1] Pt	Pd	Au
MENARD CREEK MAFIC-ULTRAMAFIC COMPLEX					
GN-88-4025	Ol clinopyroxenite	—	7	2	1
GN-88-2029	Clinopyroxenite	—	6	4	1
GN-88-2033	Gabbro	Tr	1	6	1
[2]GN-88-2033	Gabbro	Tr	1	6	1
GN-88-4029	Gabbro	—	1	41	2
MAFIC DYKES					
GN-88-4027A	Cpx porphyry	—	1	2	1
GN-88-4027B	Cpx porphyry	—	1	2	2
GN-88-2032	Cpx porphyry	—	1	8	1

[1] Rh is at or below detection limit (2 ppb) in all samples.
[2] Duplicate analysis.
All abbreviations as in Tables 2-10-2 and 2-10-4.

REFERENCES

Anderson, R.G. (1979): Distribution and Emplacement History of Plutons within the Hotailuh Batholith in the Cry Lake and Spatsizi Map Areas, North-central British Columbia, *Geological Survey of Canada*, Paper 79-1A, pages 393-395.

——— (1980): Satellitic Stocks, Volcanic and Sedimentary Stratigraphy, and Structure around the Northern and Western Margins of the Hotailuh Batholith, North-central British Columbia, *Geological Survey of Canada*, Paper 80-1A, pages 37-40.

——— (1983): The Geology of the Hotailuh Batholith and Surrounding Volcanic and Sedimentary Rocks, North-central British Columbia. Unpublished Ph.D. Thesis, *Carleton University*, Ottawa, 669 pages.

——— (1988): A Paleozoic and Mesozoic Stratigraphic and Plutonic Framework for the Iskut Map Area (104B), Northwestern B.C., *in* Geology and Metallogeny of Northwestern British Columbia, *Geological Association of Canada, Cordilleran Section Meeting*, Smithers, B.C., pages A1-A3.

Anderson, R.G., Loveridge, W.D., and Sullivan, R.W. (1982): U-Pb Isotopic Ages of Zircon from the Jurassic Plutonic Suite, Hotailuh Batholith, North-central British Columbia, *Geological Survey of Canada*, Paper 82-1C, pages 133-137.

Bellefontaine, K.A., and Minehan, K. (1988): Summary of Fieldwork in the Ingenika Range, North-central British Columbia (94D/9; 94C/12), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, Paper 1988-1, pages 195-198.

Brown, D.A., and Gunning, M.H. (1989): Geology of the Scud River Area, Northwestern British Columbia (104G/5 and 6), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, (this volume).

Crocket, J.H. (1981): Geochemistry of the Platinum Group Elements, *Canadian Institute of Mining and Metallurgy*, Special Volume 23, pages 47-64.

Evenchick, C.A., Monger, J.W.H., and Friday, S.J. (1986): Potential Hosts to Platinum Group Element Concentrations in the Canadian Cordillera, *Geological Survey of Canada*, Open File 1433.

Findlay, D.C. (1963): Petrology of the Tulameen Ultramafic Complex, Yale District, British Columbia, Unpublished Ph.D. Thesis, *Queen's University*, 415 pages.

——— (1969): Origin of the Tulameen Ultramafic-Gabbro Complex, Southern British Columbia, *Canadian Journal of Earth Sciences*, Volume 6, pages 399-425.

Hanson, G., and McNaughton, D.A. (1936): Eagle-McDame area, Cassiar District, British Columbia, *Geological Survey of Canada*, Memoir 194, 16 pages.

Holbeck, P.M. (1988): Geology and Mineralization of the Stikine Assemblage, Mess Creek Area, Northwestern British Columbia, Unpublished M.Sc. Thesis, *The University of British Columbia*, 184 pages.

Irvine, T.N. (1974a): Petrology of the Duke Island Ultramafic Complex, Southeastern Alaska, *Geological Society of America*, Memoir 138, 240 pages.

——— (1974b): Ultramafic and Gabbroic rocks in the Aiken Lake and McConnell Creek Map-areas, British Columbia, *Geological Survey of Canada*, Paper 74-1A, pages 149-152.

——— (1976): Alaskan-type Ultramafic-gabbroic Bodies in the Aiken Lake, McConnell Creek and Toodoggone Map-areas, *Geological Survey of Canada*, Paper 76-1A, pages 76-81.

Irvine, T.N., and Baragar, W.R.A. (1971): A Guide to the Chemical Classification of the Common Volcanic Rocks, *Canadian Journal of Earth Sciences*, Volume 8, pages 523-545.

Leake, B.E. (1978): Nomenclature of Amphiboles, *American Mineralogist*, Volume 63, pages 1023-1053.

Logan, J.M. and Koyanagi, V.A. (1989): Geology and Mineral Deposits of the Galore Creek Area (104G/3 and 4), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork (this volume).

Lord, C.S. (1948): McConnell Creek Map-area, British Columbia, *Geological Survey of Canada*, Memoir 26, 72 pages.

Macdonald, A.J. (1986): The Platinum Group Element Deposits: Classification and Genesis, *Geoscience Canada*, Volume 14, pages 155-166.

Meyer, W, and Overstall, R. (1973): Geological, Geochemical and Geophysical Survey on the ARD Claims, McConnell Creek Area, Omineca Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 4707, 13 pages.

Malinsky, D. (1966): Copper Pass Mines Ltd., Induced Polarization Survey, Dalvenie, Mac, and New Deal Claims, Stikine Plateau Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 899, 11 pages.

Monger, J.W.H. (1976): Lower Mesozoic Rocks in McConnell Creek Map Area (94D), British Columbia, *Geological Survey of Canada*, Paper 76-1A, pages 51-55.

——— (1977): The Triassic Takla Group in McConnell Creek Map-area, North-central British Columbia, *Geological Survey of Canada*, Paper 76-29, 45 pages.

Monger, J.W.H., and Church, B.N. (1977): Revised Stratigraphy of the Takla Group, North-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 14, pages 318-326.

Monger, J.W.H., Richards, T.A., and Paterson, I.A. (1978): The Hinterland Belt of the Canadian Cordillera: New Data from Northern and Central British Columbia, *Canadian Journal of Earth Sciences*, Volume 15, pages 823-830.

Nixon, G.T. (1988): Geology of the Tulameen Ultramafic Complex, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-25.

Nixon, G.T., and Rublee, V.J. (1988): Alaskan-type Ultramafic Rocks in British Columbia: New Concepts of the Structure of the Tulameen Complex, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, Paper 1988-1, pages 281-294.

Reynolds, N.W. (1967): Copper Pass Mines Ltd., Geochemical Report 1, Stikine Plateau Property, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report No. 896, 14 pages.

Richards, T.A. (1975) McConnell Creek Map Area (94D/E), Geology, *Geological Survey of Canada*, Open File 342.

——— (1976): Takla Group (Reports 10-16): McConnell Creek Map Area (94D, East Half), British Columbia, *Geological Survey of Canada* Paper 76-1A, pages 43-50.

Roed, M.A. (1966a): Copper Pass Mines Ltd., Geologic Report No. 1, Dalvenie, Mac, and New Deal Claims, Stikine Plateau Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 898, pages 1-24.

——— (1966b): Copper Pass Mines Ltd., Geologic Report No. 2, Stikine Plateau and Pine Point Properties, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 897, 32 pages.

Souther, J.G. (1972): Telegraph Creek Map-area, British Columbia (104G), *Geological Survey of Canada*, Paper 71-44, 38 pages.

St. Louis, R.M., Nesbitt, B.E., and Morton, R.D. (1986): Geochemistry of Platinum Group Elements in the Tulameen Ultramafic Complex, Southern British Columbia, *Economic Geology*, Volume 81, pages 961-973.

Stevens, R.D., Delabio, R.N., and Lachance, G.R. (1982): Age Determinations and Geological Studies, *Geological Survey of Canada*, Paper 82-2, 56 pages.

Taylor, H.P. Jr. (1967): The Zoned Ultramafic Complexes of Southeastern Alaska, *in* Ultramafic and Related Rocks, P.J. Wyllie, Editor, *John Wiley and Sons Inc.*, New York, pages 97-121.

GEOLOGY AND MINERALIZATION, BEARSKIN (MUDDY) AND TATSAMENIE LAKE DISTRICT (SOUTH HALF), NORTHWESTERN BRITISH COLUMBIA (104K)

By James L. Oliver and C. Jay Hodgson
Queen's University

KEYWORDS: Economic geology, Stikine terrane, Golden Bear, gold, ore controls, structural geology, stratigraphy

INTRODUCTION

The Muddy Lake–Golden Bear project was initiated in 1988 to examine in detail the structural and stratigraphic setting of a sequence of gold occurrences and deposits between Tatsamenie Lake and Muddy Lake, 137 kilometres west of Dease Lake. Upper Paleozoic rocks in this area host several gold occurrences and one developing mine, the Golden Bear property.

The project area, outlined in Figure 2-11-1, covers approximately 150 square kilometres, in an area where relief varies from 940 to 2200 metres. Excellent outcrop exposures are present in much of this region, but permanent snow, ice and felsenmeer limit on the higher plateaus. Detailed field mapping, at a scale of 1:5000, was completed over approximately one half of the project area, extending from Muddy Lake to Sam Creek. Additional data on the style and controls on mineralization have been obtained from underground mapping and sampling in the Golden Bear mine. Work during the 1988 field season has refined the regional stratigraphic column and clarified the structure on both regional and mine scales.

This report emphasizes selected results of surface and underground mapping, but does not include analytical data from samples collected. Results of mapping over the north half of the project area will be presented in a subsequent report, following the 1989 field season.

PREVIOUS WORK

Earliest reports on the regional geology of the map area are recorded by Kerr (1930), covering the Taku district northwest

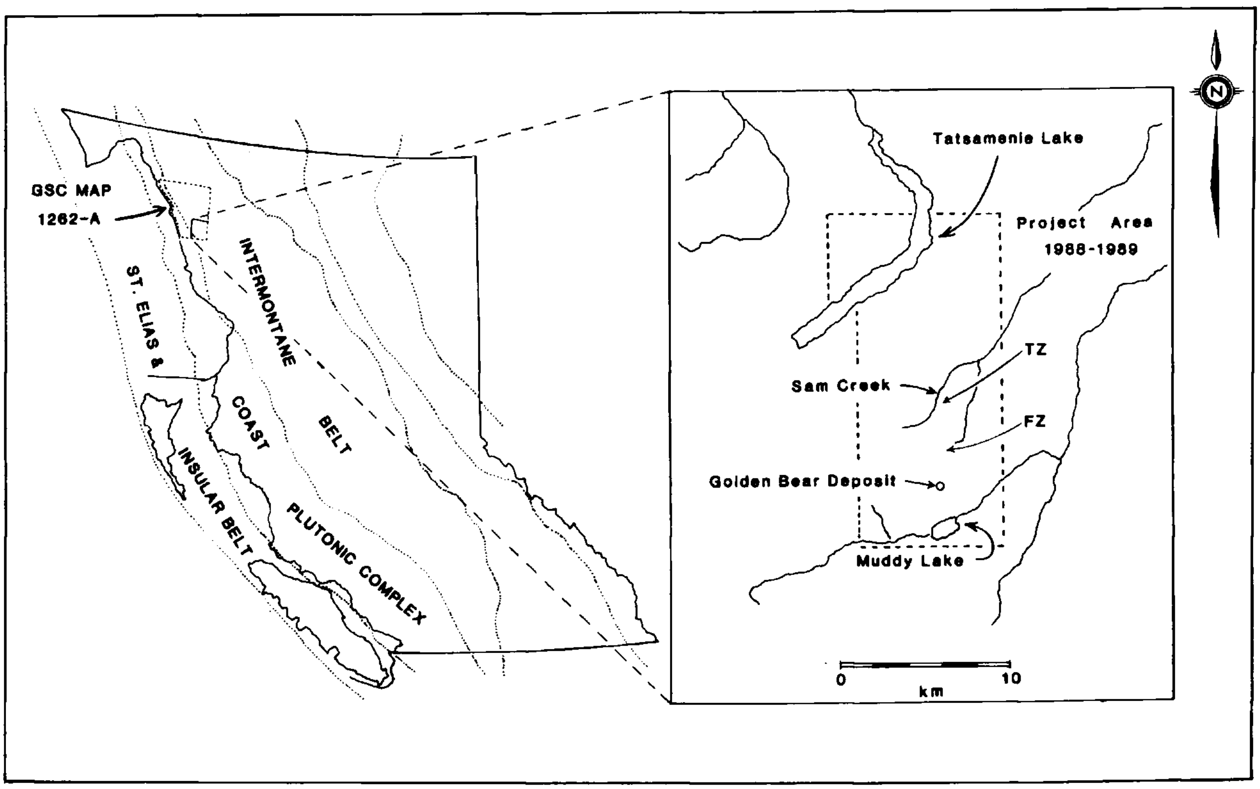


Figure 2-11-1. Location of the Tatsamenie–Muddy Lake project within the tectonic framework of the northwestern Canadian Cordillera. Location of Fleece (FZ) and Totem (TZ) mineralized zones.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

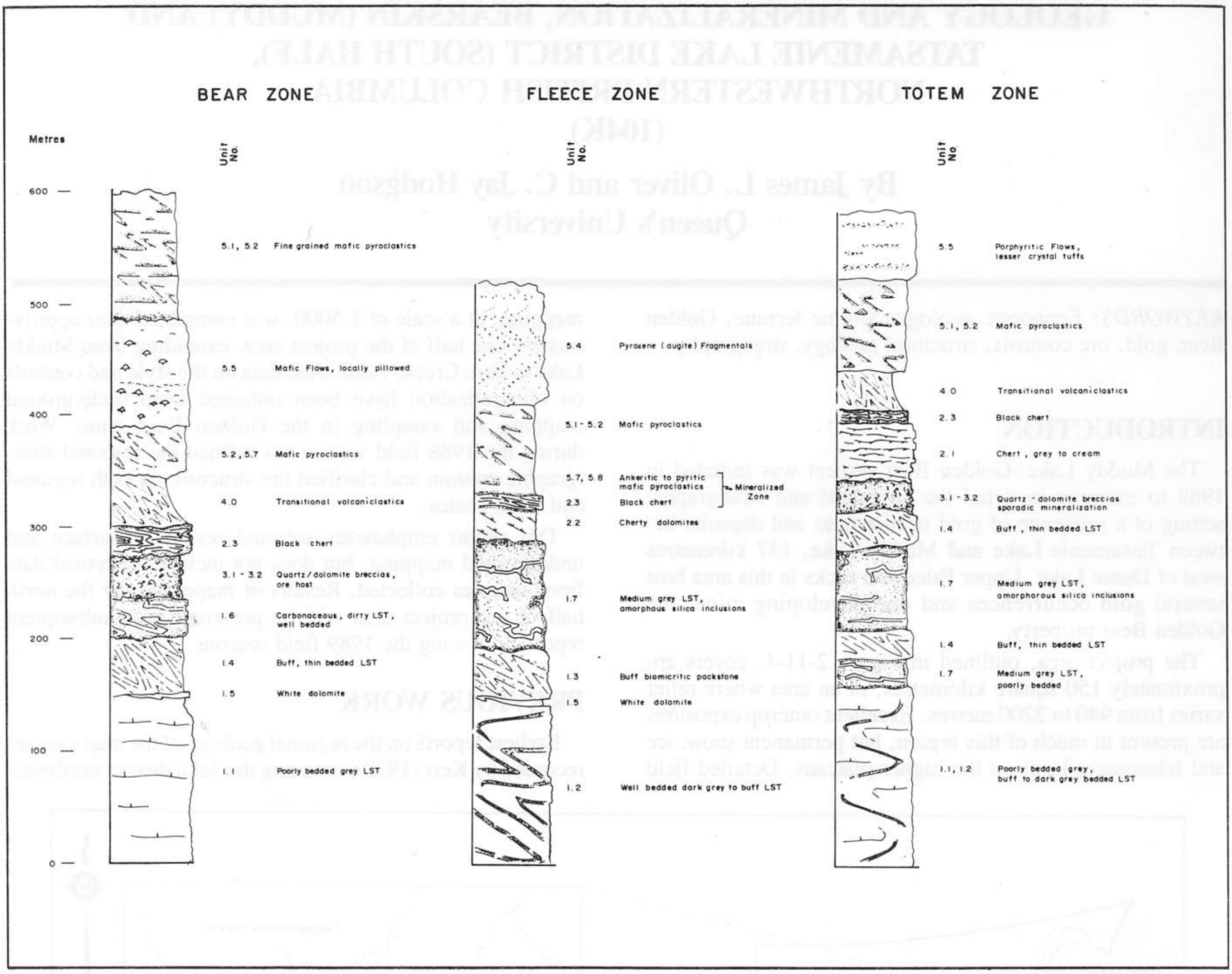


Figure 2-11-2. Stratigraphic sections through Bear, Fleece and Totem mineralized zones, Golden Bear property. Refer to Table 2-11-1 for identification of numbered lithologic units.

of the project area and Cockfield (1926) in the area to the northeast. The geological map and accompanying report produced by Souther (1971) is the principal source of regional data. Stratigraphy within the Tatsamenie Lake area has been briefly examined by Monger (1970). This area, and the Golden Bear deposit, were examined and sampled by Schroeter (1985, 1986, 1987) over a 3-year period during the earlier exploration phases. His reports contain the only published data on isotopic dating of alteration, timing of igneous emplacement, and whole-rock chemical analyses within the study area.

Much of the technical database for the region between Tatsamenie and Muddy Lake, and for the Golden Bear deposit, has been developed by geologists of Chevron Canada Resources Ltd. and its joint venture partner at that time, North American Metals Corporation. The results of surface geological mapping and drill-core data for this region are thoroughly documented in a summary report by Wober and Shannon (1985).

REGIONAL GEOLOGY

The area is underlain by an assemblage of Upper Paleozoic limestones and cherts conformably overlain by pre-Upper Triassic volcaniclastic sediments formed in a back-arc environment. This assemblage forms part of the larger Stikine terrane now located on the northern limit of the Stikine Arc. In the Stikine Arc, strongly deformed supracrustal rocks, and belts of younger intrusions, trend northeast across the north-northwesterly grain of the Cordillera. Stratigraphy within the project area correlates closely with the type-section proposed by Monger (1977) for the Stikine assemblage, but the base of this stratigraphic column, comprising Mississippian and older strata, is not exposed in the project area.

Structures formed during three main deformational periods: the Middle Triassic and earlier, the Late Jurassic, and the Early Tertiary (Souther, 1971). Early folds are typically tight, upright antiforms and synforms with north-trending axial surfaces, and locally sheared to rootless intraforma-

Table of Formations

Pleistocene and Recent		
11.0	Glacial and Fluvial Deposits	
	INTRUSIVE LITHOLOGIES	
Jurassic (?) and Younger		
10.0	Diabase Dykes	
9.0	Felsic Intrusives	
	9.1	Porphyritic Felsic Dykes
8.0	Gabbro	
	8.1	Foliated Gabbro
	8.2	Unfoliated Gabbro
7.0	Granodiorite	
	7.1	Foliated Granodiorite - dioritic marginal phases
	7.2	Pegmatitic Granodiorite
	SUPRACRUSTAL LITHOLOGIES	
Pre Upper Triassic		
6.0	Clastics	
	6.1	Argillites and Interbedded Siltstones
	6.2	Argillites and Interbedded Volcaniclastics
5.0	Mafic Volcanics	
	5.1	Mafic Ash Falls - lesser interbedded epiclastics
	5.2	Mafic Lapilli Pyroclastics - lesser crystal tuffs
	5.3	Mafic Agglomerates
	5.4	Pyroxene Fragmentals
	5.5	Mafic Flows - locally pillowed
	5.6	Feldspar Porphyritic Flows
	5.7	Ankeritic Pyroclastics - fuchsite, quartz and carbonate alteration
	5.8	Pyritic Tuffs - disseminated pyrite greater than 3%
	5.9	Amphibolitic Gneiss - mafic volcanic protolith
	5.10	Chlorite Schist
4.0	Transitional Volcaniclastics and Clastics	
	4.1	Ankeritic Phyllites - lesser silica rich interbeds
	4.2	Sericitic Volcaniclastics - weakly calcareous, chlorite subordinate to sericite
3.0	Fault Breccias - Age of Brecciation Indeterminate	
	3.1	QDx - quartz dolomite breccias, silica rich protolith
	3.2	DQx - dolomite quartz breccias, carbonate protolith
	3.3	QSDx - heterolithic breccias, sericitic fragments
	3.4	QRb - ribbon banded quartz veins
Permian and Older		
2.0	Silicate Facies	
	2.1	Chert - ribbon banded, light to medium grey
	2.2	Cherty Dolomites - pink dolomite, grey chert interbeds
	2.3	Black Chert - lesser fine-grained black clastics
	2.4	Siliceous Intrabiomicritic Limestones
1.0	Carbonate Facies	
	1.1	LST - grey to cream, thick bedded
	1.2	LST - interbedded buff to dark grey carbonate beds
	1.3	LST - buff biomicritic packstones, poorly bedded
	1.4	LST - buff, thin bedded, micritic
	1.5	LST - clean white to pearl-grey dolostone
	1.6	LST - carbonaceous, dark grey, well bedded, lesser black chert interbeds
	1.7	LST - dark to medium grey, amorphous black chert inclusions

Table 2-11-1. Table of Formations.

tional isoclines. The development of broader, northwest-trending open folds is the result of continued east-west shortening during the Jurassic. The onset of extensional deformation during the mid-Tertiary is recorded in a series of normal fault structures which penetrate the youngest Tertiary rocks (Souther, 1971). The principal focus of this study is the documentation of the deformational history of the area.

PROPERTY GEOLOGY: SUPRACRUSTRAL LITHOLOGIES

Details of stratigraphy in the Muddy Lake area, and across the mineralized zones, are outlined on three stratigraphic columns (Figure 2-11-2 and Table 2-11-1). The rocks in these columns correspond only to Units 3 and 4 of Souther's regional map and are all pre-Upper Triassic or older. Stratigraphic ages are based on the paleontologic data of Monger and Ross (1971). Limited isotopic age data for some of the intrusive rocks and alteration minerals are reported by Schroeter (1987).

PERMIAN AND OLDER

1.0 Carbonate Facies

A thick, poorly bedded grey to cream limestone (1.1), prominent in the southern half of the map area, occurs at the base of the carbonate succession. This unit is not exposed to the north where its stratigraphic position appears to be occupied by a well-bedded, buff to dark grey limestone exceeding 100 metres in true thickness (1.2). None of the limestones appear to be extensively dolomitized, quartz-injected or otherwise altered, except near major fault zones. Faulting and folding have resulted in considerable thickening, perhaps by a factor of two or more, of the limestone stratigraphic section (Figures 2-11-3 and 2-11-6).

Buff-weathering, ankeritic limestones (1.3 and 1.4) form prominent stratigraphic markers on the property. Both of these units contain significant crinoidal debris but only one is well bedded (1.4). The contact between buff-weathering limestones and overlying carbonaceous limestones is often marked by a thin, pearl-grey to cream-coloured, clean limestone less than 10 metres thick (1.5).

A dark grey carbonaceous limestone, containing black chert interbeds (1.7), forms the uppermost unit of the carbonate sequence. A lateral facies equivalent of this unit contains distinctive, irregular, black chert inclusions (1.6) and forms the protolith of one of the breccia types in the mineralized zone (3.2). The lack of well-defined bedding within this unit makes it difficult to estimate its true thickness but it appears to range from 50 metres to greater than 100 metres thick.

2.0 Silicate Facies

Quartz-rich chemical sedimentary rocks are abundant in the northern half of the map area. Unit 2.1 is pale grey, cream to buff-weathering, moderately recrystallized, typically well-bedded, clean chert. Ribbon layering, 2 to 5 centimetres thick, is weakly developed and no sulphides were noted. In several localities a black, dirty chert (2.3) occurs at the

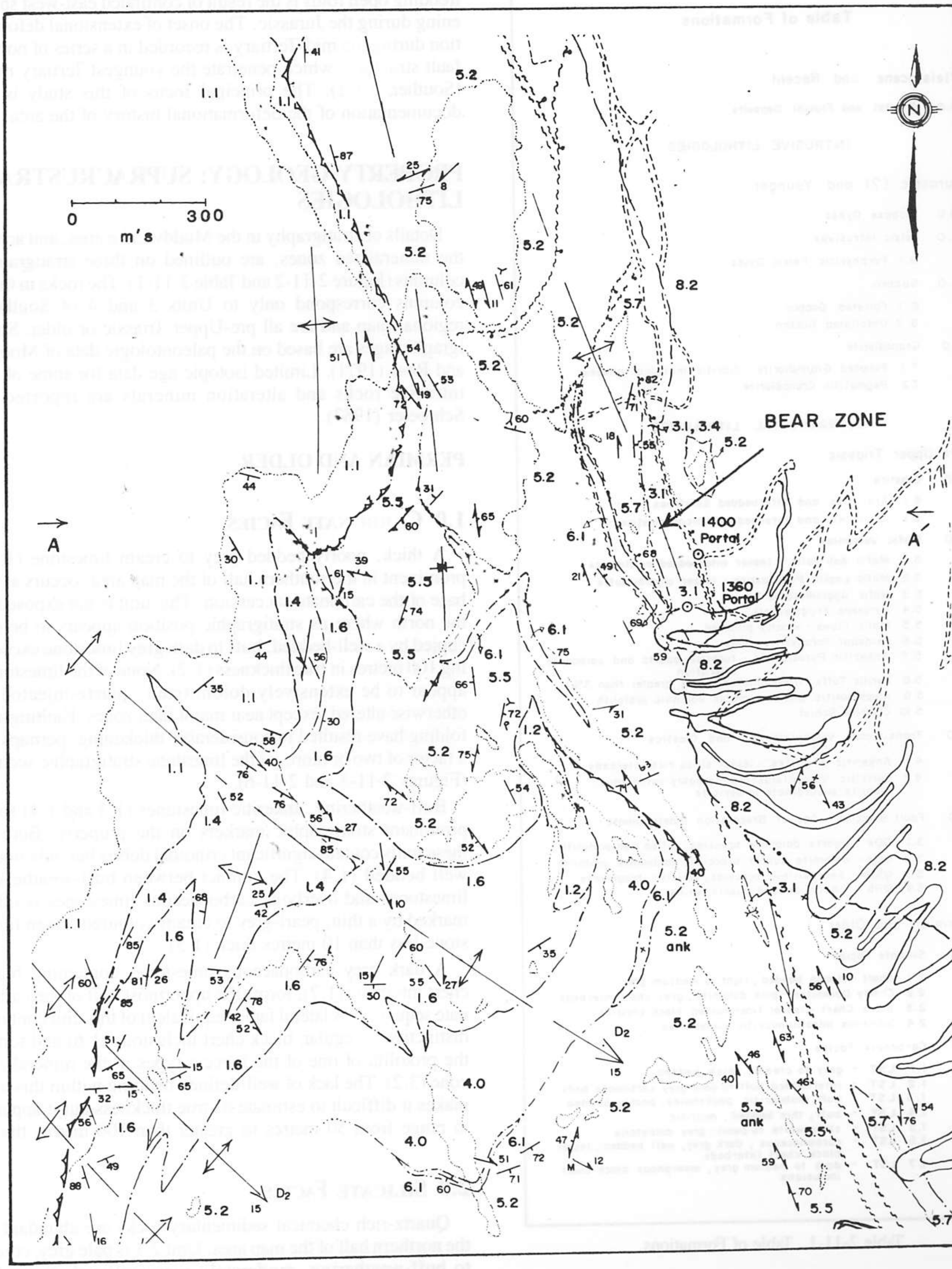


Figure 2-11-3. General surface geological relationships within the immediate vicinity of the Golden Bear deposit. Gold mineralization is developed within steep east-dipping faults which, on this section, are truncated by the large landslide slips forming a fault contact with Unit 8.2. Refer to Table 2-11-1 for identification of numbered lithologic units.

conformable contact between the carbonate and overlying volcanic-dominated successions. The unit is thin, less than 25 metres true thickness, and locally contains a significant proportion of fine-grained black clastic material. Within the Fleece zone this lithology may host ore. Pink cherty dolomites (2.2) and siliceous intrabiomicritic limestones (2.4) occur locally within this cherty sequence.

PRE-UPPER TRIASSIC

3.0 Fault Breccia

Spectacular breccias, dominantly within a limestone/dolomite or chert host, are localized near the Bear fault. The breccia zones range up to 40 metres wide and are a significant ore host. The host limestone is extensively dolomitized and silicified but pyrite is sparse, less than 3 per cent. Protoliths for these breccias may be recognized from the breccia fragments (3.1 and 3.2). Heterolithic breccias (3.3) are predominant immediately adjacent to contacts between limestone and volcanic rocks and contain volcanic fragments completely replaced by sericite. Schroeter (1987) has dated this alteration at 204 Ma. Weakly ribbon-banded quartz veins (3.4) occur locally in the breccias but are not widespread.

4.0 Transitional Volcaniclastic and Clastic Rocks

Two submembers of this unit are recognized: ankeritic phyllites (4.1) and sericitic volcaniclastics (4.2). These lithologies are best exposed in the northern part of the map area in the canyon of Sam Creek. Their strike continuity is interrupted by large-scale faults and fold structures. Unit 4.1 becomes progressively more siliceous near its exposed base and may locally be transitional to the underlying silicate facies of chemical sedimentary rocks. The strong sericite development within the sericitic volcaniclastics, Unit 4.2, is unlikely to be hydrothermal in origin. The unit lacks any significant sulphide development, green micas are conspicuously absent and the presence of secondary quartz is not documented.

5.0 Mafic Volcanic Rocks

Ten subunits were mapped in the mafic volcanic sequence on the property. Units 5.1 to 5.3 are a mafic pyroclastic assemblage ranging from ash tuffs (5.1), through lapilli tuffs (5.2) to agglomerates (5.3). These rocks are typically monolithologic and, except near major fault zones, unaltered. Interbeds within Unit 5.2 are characteristic of well-preserved feldspar crystal tuffs. Feldspars may be weakly sericitized and chlorite may pseudomorph amphiboles.

The base of Unit 5.4 is defined by an abrupt increase in the pyroxene content, principally augite. Small pyroxene phenocrysts, both within angular fragments and in the matrix, may exceed 30 per cent of the rock volume. Amphiboles coexist with pyroxene and olivine is absent in Unit 5.4, indicating this rock is not an ultramafite.

Mafic flow sequences (5.5) are common in the map area; however, pillowed flows were only identified in a small area approximately 200 metres southwest of the Bear zone 1360 portal. Plagioclase-porphyritic flows, containing 20 to 40 per cent phenocrysts, were mapped as a separate unit (5.6). Phenocrysts locally exceeded 1.5 centimetres in length.

Ankeritic mafic tuffs (5.7) and pyritic tuffs (5.8) are altered facies of the volcanic sequence associated with mineralization and faults. Quartz-ankerite veins and veinlets are locally developed in envelopes 20 to 40 metres wide around fault zones. Carbonate exceeds quartz within veins and also in pervasively altered rock, which typically contains no more than 5 to 10 per cent quartz. Similar alteration is common in ankeritic mafic volcanic rocks near their contacts with limestones and dolomites, but is unrelated to mineralization.

The most pyritic mafic volcanic rocks in the area are exposed underground in the Bear zone. In these exposures, pyrite, generally less than 5 per cent, occurs as uniform disseminations, slightly coarser aggregates and along hairline fractures. Pyritic tuffs are the principal hostrock for mineralization in the Golden Bear deposit.

Amphibolitic gneiss (5.9) is developed where mafic rocks have been altered in the aureole, 75 to 100 metres wide, around large granodiorite intrusions. The gneiss is characterized by alternating layers rich in feldspar and amphibole, 5 to 15 centimetres thick. The layering is locally cut by small, sometimes pegmatitic, felsic intrusions. Chlorite schists (5.10) may also be related to intrusive contacts but are more clearly related to fault zones. In most cases the protolith of the chlorite schist appears to be pyroxene fragmental rocks of Unit 5.4.

6.0 Clastic Rocks

Two units are identified within this division: well-bedded argillites and siltstones (6.1), and a thin overlying sequence of fine-grained interbedded mafic pyroclastics and lesser black clastic rocks (6.2). The combined thickness of these units is less than 100 metres. They are intruded by a large gabbro sill. In the Holocene, bedding-parallel slips in the

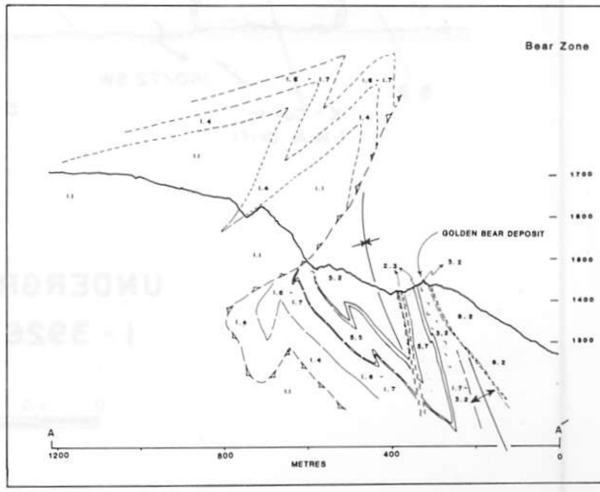


Figure 2-11-4. Geological cross-section, looking north, through the Golden Bear deposit above the 1400-metre portal. Contacts are down-plunge projections of surface data defined in Figure 2-11-3. Numbered lithologic units are identified in Table 2-11-1.

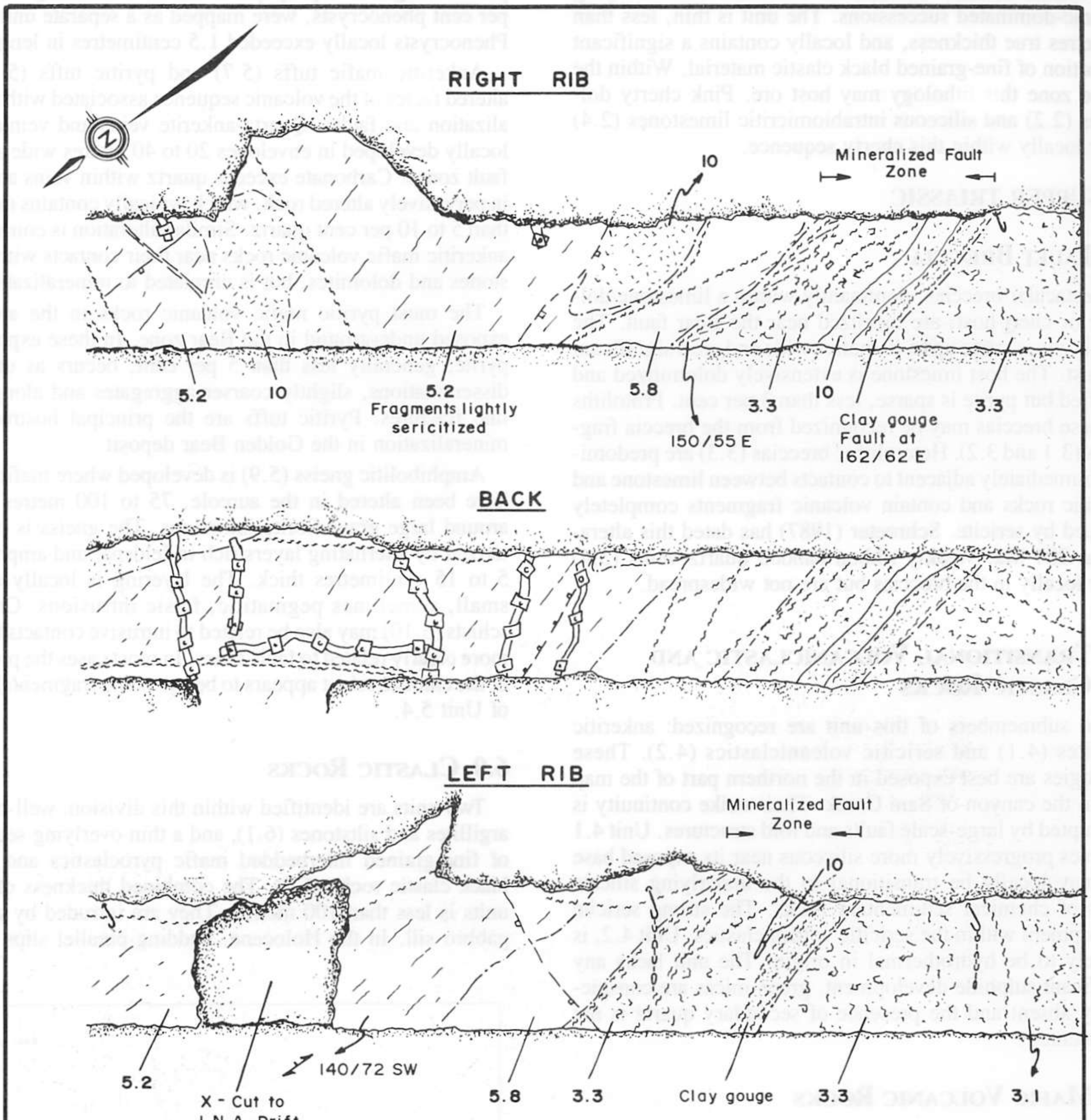


Figure 2-11-5. Underground geological plan, through the I-3926 crosscut, Golden Bear deposit. Strongest mineralization is developed between the fault contacts of a pyritic tuff (Unit 5.8) and extensive quartz dolomite and heterolithic breccia (Units 3.3 and 3.1). Numbered lithologic units are identified in Table 2-11-1.

clastic sediments resulted in a large mass of gabbro sliding downslope as a major rock avalanche which now covers the hangingwall of the deposit.

PROPERTY GEOLOGY: INTRUSIVE LITHOLOGIES

JURASSIC AND YOUNGER

7.0 Granodiorite

Unit 7.0 is a medium-grained granodiorite characterized by the presence of potassic feldspars, free quartz and a light colour index, less than 25. It forms a large intrusive body exposed in the northeast half of the project area. Locally this granodiorite is foliated (7.1) and the fabric is similar to that recognized in the surrounding rocks. Marginal phases of this body are often dioritic and in places are cut by coarse-grained felsic pegmatites (7.2).

8.0 Gabbro

Unfoliated gabbroic intrusions (8.1) are typically coarse grained, amphibole rich and may show poorly developed igneous layering. Gabbros are foliated (8.2) adjacent to major faults.

9.0 Felsic Intrusives

Porphyritic felsic dykes (9.1) were noted infrequently during surface mapping. Small sodic feldspar laths are randomly orientated within a reddish buff fine-grained matrix. Felsic dykes carry ore-grade mineralization in the Fleece zone (Wober and Shannon, 1985) but are not a significant ore host. Quartz phenocrysts are reported from the felsic dykes in this zone.

10.0 Diabase Dykes

Dark green, fine-grained diabase dykes (10.0) cut all other lithologies and are discordant to faults within the main ore zone. Postmineralization dykes are most common within extensional fractures in the main deposit and are rarely noted on surface outside of this zone.

STRUCTURE OF MINERALIZED ZONES

BEAR ZONE

The geological setting of the Bear deposit is illustrated in Figures 2-11-3 and 2-11-4. The hostrocks are deformed into large chevron folds with steeply orientated southwest-dipping axial surfaces and moderate (20 to 25 degree) southerly plunges. The chevron folds are parasitic on a regional south-plunging antiform and are refolded about northeast-dipping axial planes. The second generation of folds is characterized by rounded hinge regions. The interference patterns produced by the interaction of the two fold systems are transitional between Type I and II patterns. Doubly plunging hinge lines are common within some of the finer marker beds in the limestone succession, but southerly plunges dominate.

The contact between limestone and volcanic rocks is conformable in the central part of the map area (Figure 2-11-3) but is discordant elsewhere as a result of a bedding-transgressive thrust which places the oldest limestone units directly against younger volcanics. This thrust is best defined on the cross-section (Figure 2-11-4) drawn through the Bear main zone. All contacts on this section are interpreted from down-plunge projections from surface.

The ductile style of deformation in rocks immediately adjacent to the deposit is in marked contrast to brittle deformation which characterizes the Bear fault zone. A temporal discontinuity in deformational episodes is clearly suggested. The fault zone is controlled by steep easr-dipping, north-striking, late normal faults. The extensive brecciation associated with these faults obliterates all previous rock fabrics and interpretation of fault movements is difficult. Within 500 to 800 metres of the Bear fault system, planar rock fabrics have been rotated from north-northeast strikes into a northerly alignment with the fault. This structural pattern, and the isotopic age data from alteration, suggest that the Bear fault is an old, repeatedly activated fault system in which the last deformational event has been brittle and extensional. The last major failure on this plane is recent, less than 2000 years ago. It resulted in a subsequent landslide slip of a large gabbroic intrusive mass in the immediate hangingwull of the ore zone in some parts of the mine. Apparent offsets across this plane are significant as stratigraphy and structure are not easily correlated across this fault.

The Golden Bear deposit is under active mining development and is estimated to contain 625 390 tonnes diluted geological reserves grading 18.63 grams gold per tonne (L.E. Titely, personal communication, 1988). The orebody is metallurgically complex and contauhs submicron-sized gold particles within a sulphide and silicate matrix (Wober and Shannon, 1985). A significant proportion of the mineralization is contained in a gouge zone, 2 to 6 metres wide, within a fault splay of the main Bear fault. Mineralization gradually weakens away from this structure, in the quartz-dolomite breccias in the footwall, and in the pyritic tuffs on the hangingwall contact. Ore-grade mineralization may exceed 9 metres in width. Postmineralization diabasic dykes were emplaced within, subparallel and locally discordant, to the fault system. The mineralized zone is not characterized by well-defined vein structures or free quartz and there is little vein material present. Macroscopic indicators of alteration are assemblages of ankerite, fuchsite, pyrite and quartz in the hangingwall mafic fragmental rocks and pervasive dolomitization and brecciation of limestone protoliths in the footwall. Alteration diminishes rapidly away from fault structures and is typically weak within 25 metres of mineralization. Contact relationships and general structural features of one of the mineralized areas in the mine are illustrated in Figure 2-11-5.

FLEECE ZONE

The Fleece Bowl mineralized zone contains drill-indicated reserves of 415 000 tonnes of 8.15 grams gold per tonne (Wober and Shannon, 1985) and remains open down the plunge of the regional structure. Mineralization is localized at the intersection of a major fault, identified locally as the

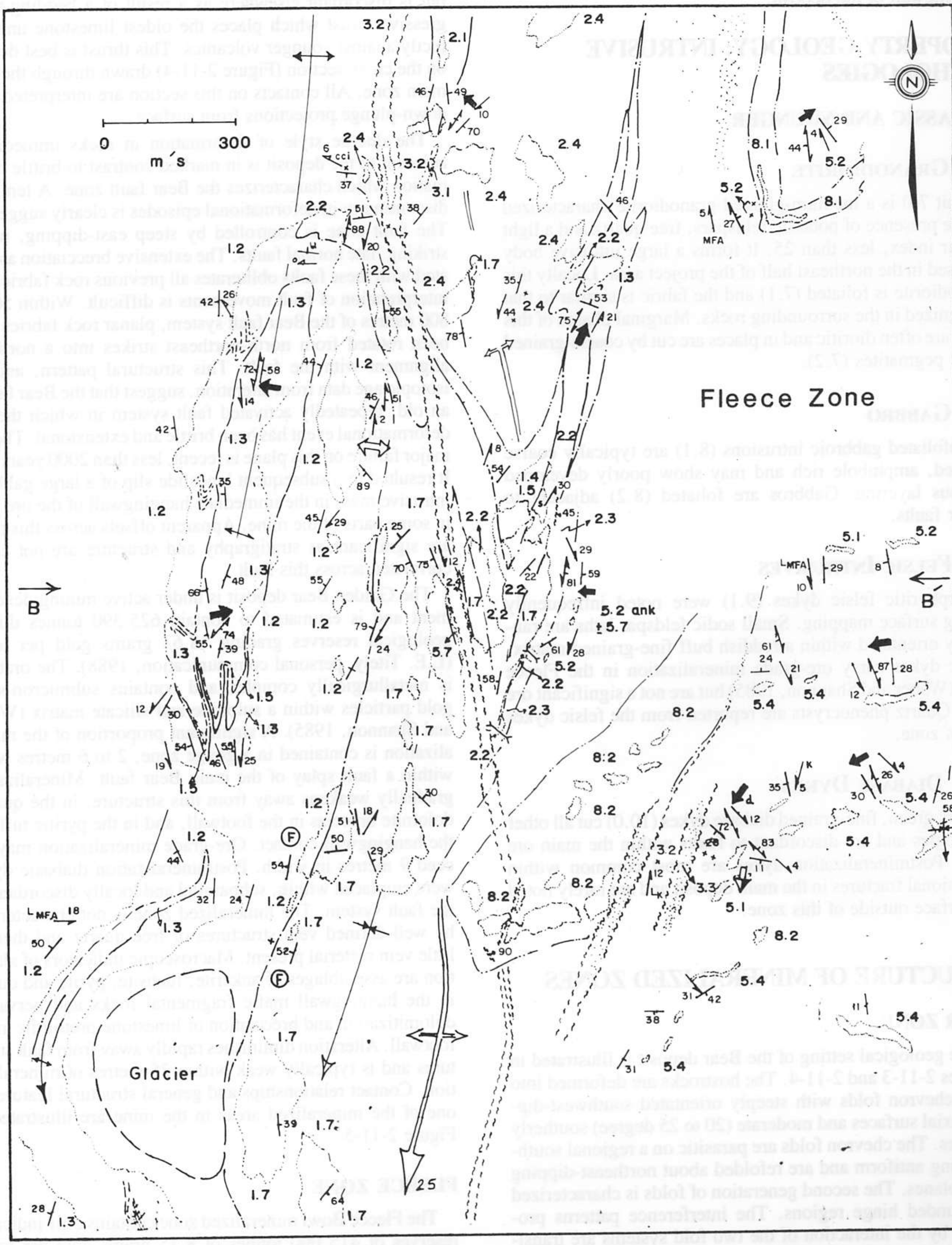


Figure 2-11-6. Surface geology, Fleece zone. Mineralization is confined to the faulted west limb of a south-plunging antiform, one of a series tight, upright chevron folds. Refer to Table 2-11-1 for identification of numbered lithologic units and to Figure 2-11-1 for the approximate location of this zone.

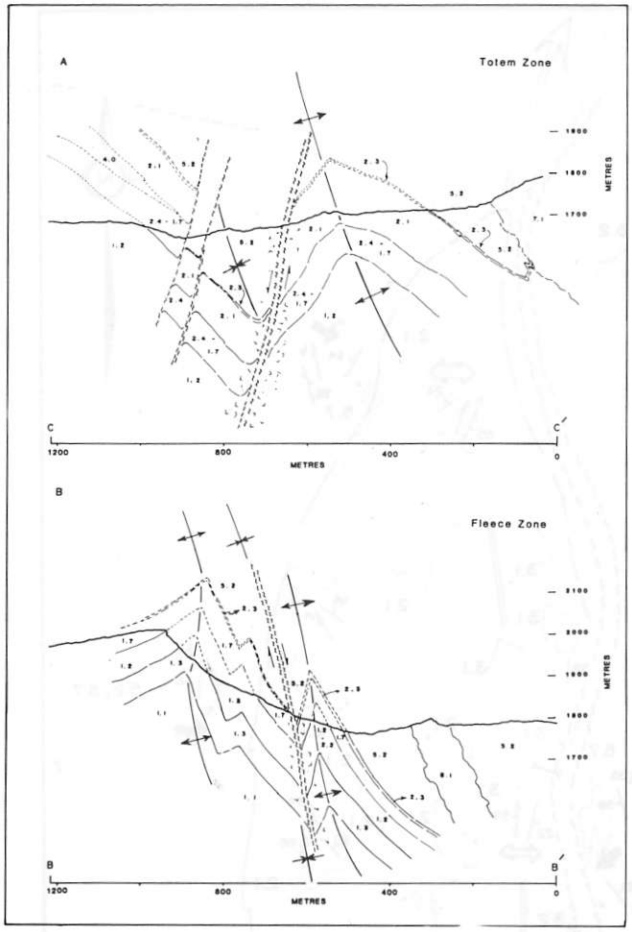


Figure 2-11-7. Geological cross-sections through the Totem zone (7a) and the Fleece zone (7b), looking north. The two sections are separated by 1500 metres of strike, with only limited divergence of hinge lines between these two points. Refer to Table 2-11-1 for identification of numbered lithologic units.

West Wall fault, with the contact of the black chert and argillaceous siltstone unit with the volcanic rocks (Figures 2-11-6 and 2-11-7b). The fault is part of the main Bear fault system and is localized on the western limb of an extremely tight anticline. A sequence of tight fold structures is clearly exposed in the cliffs overlooking the Fleece zone. These structurally repeat the carbonate stratigraphy in the footwall to mineralization. Hinge lines of these folds are traceable for up to 4 kilometres along strike, through all three mineralized zones. Individual hinge lines are well defined by changes in cleavage vergence, structural facing and abrupt changes in bedding attitude.

The Black fault (Wober and Shannon, 1985; Schroeter, 1986) appears most likely to follow the black chert horizon forming the eastern limb of the main antiform which is localized over the Fleece zone. Although this limb may be slightly faulted, unlike the western limb, it is only weakly mineralized. Plunge directions within the Fleece zone are south at 20 to 25 degrees. It is yet to be determined if mineralization also rakes in this direction. This zone differs slightly from the main Bear zone primarily in the weak development or absence of well-defined quartz-dolomite breccias (Figure 2-11-2). Mafic pyroclastic rocks in the stratigraphic footwall of the zone carry a similar alteration assemblage to that noted underground in the Bear zone, with widespread ankerite development, lesser fuchsite, moderate quartz-carbonate veinlets and weak pyritization (5 per cent).

TOTEM SILICA ZONE

The Totem silica zone occurs at the northern limit of mapping. The main feature of the area is an extensive zone of quartz-rich rocks with a strike length of 1800 metres and a maximum width of 300 metres. The zone was initially interpreted as a silica cap to an epithermal system; more recent observations suggest the quartz within this zone is a primary or a very early diagenetic chert: (1) the rock locally displays well-defined bedding features and may be weakly ribbon-banded; (2) it appears to follow a specific stratigraphic horizon; (3) it has been affected by early folds and has well-developed penetrative planar and linear fabrics, unlike the younger breccias of the Bear zone; and (4) structural facings and bedding dips change from west to east across the zone, suggesting an antiformal structure. The fold may be doubly plunging; at its southern limit the antiform plunges toward the Fleece zone, but in the northern part of the Totem zone some lineation measurements indicate steep northerly plunges.

Folds in the area of the Totem zone are slightly more open than those in the Fleece zone and their western limbs are truncated and offset by the main fault system. Surface data suggest the main mineralized structure has been rotated from a steep easterly dip in the area of the Bear deposit, to a steep westerly dip in the area of the Totem zone (Figures 2-11-7a and 2-11-8).

Anomalous gold values are often present along the intersection of the main fault system with the contact of chert and mafic volcanic rocks and are associated with angular, coarse-grained dolomite and chert breccias which are irregularly developed along it. This structural zone and its unique deformational style crosses the Sam Creek drainage and continues north towards Tatsamenie Lake.

DISCUSSION: IMPLICATIONS FOR EXPLORATION

Other gold deposits are likely to be found by exploration in areas within the northwestern Cordillera having a tectonic and stratigraphic framework similar to the Muddy Lake district. The field data summarized in this report suggest the following points should be considered in exploration:

(1) Fault systems, such as the Bear fault and related zones, are likely to be persistent deep-rooted structures. The apparent rotation of rock fabrics into parallelism with these faults suggests late brittle movement may have been localized in pre-existing deformational zones.

(2) Surface expression of the fault systems is often poorly defined. However, as they are located within broader deformational zones, often with anomalous strikes relative to the regional structural grain, they can be identified by careful surface mapping.

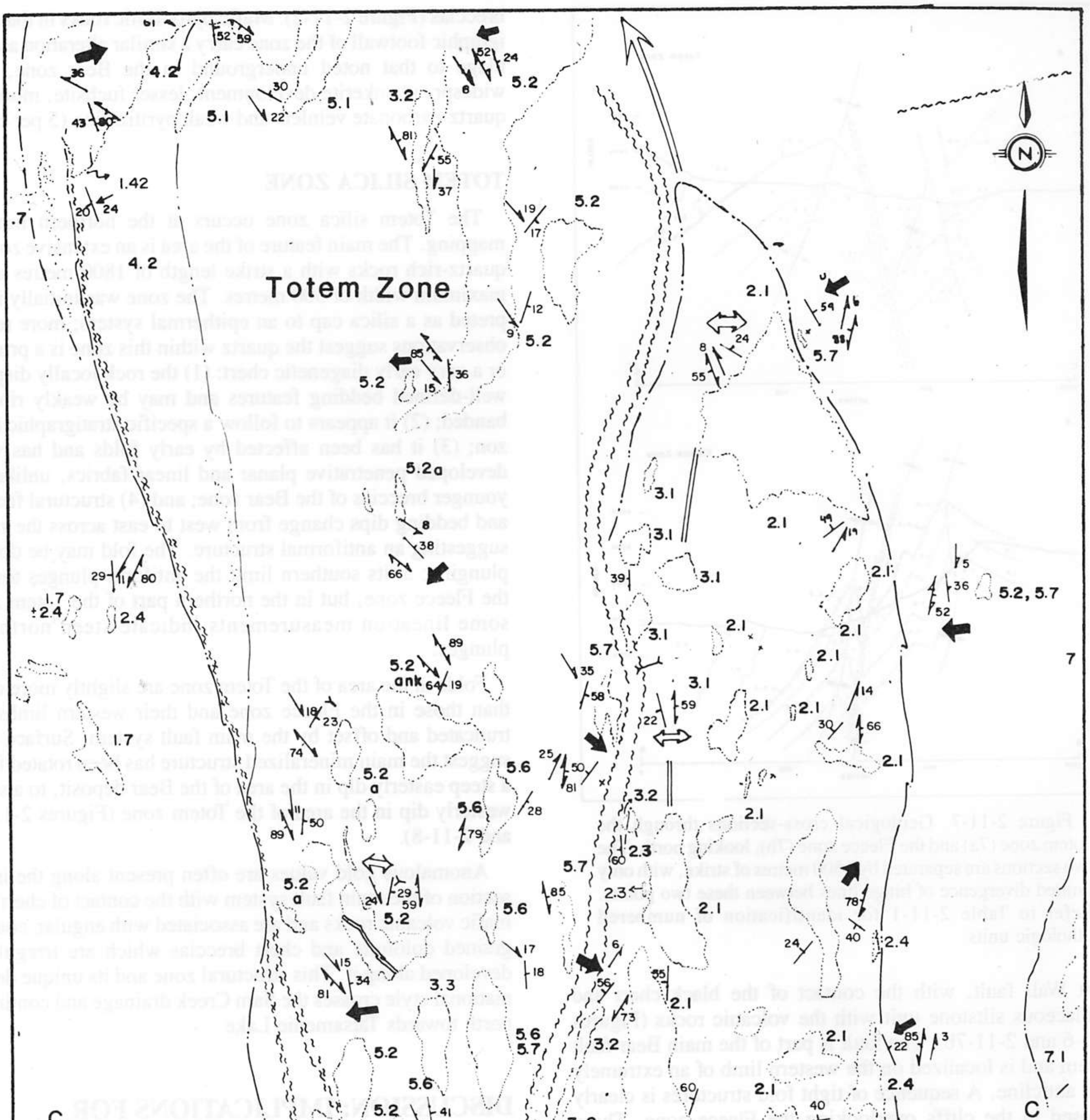


Figure 2-11-8. Surface geology, Totem zone. The zone contains anomalous gold values along the strike of the main fault system, near the volcanic-chert contact which localizes this structure. Numbered lithologic units are identified in Table 2-11-1 and the approximate location of the Totem zone is shown in Figure 2-11-1.

(3) The characteristic alteration assemblages, ankeritic carbonates, silica, fuchsite and lesser sulphides, are common to many gold-producing systems and are a prominent feature of these deposits. Ankeritization, with weak silicification of mafic volcanics along their conformable contacts with limestone, is common throughout this area and is typically not auriferous. Recognition of the differing alteration styles and their structnral settings is important.

(4) Gold mineralization within the study area is discordant to stratigraphy but clearly occurs preferentially along zones of contrasting competency, specifically chert-dolomite-volcanic contacts. These contacts may be extensively deformed and the style of deformation should be recognized in order to efficiently direct subsurface exploration.

(5) No strong relationship between high-level intrusions and gold mineralization has been noted in this area.

ACKNOWLEDGMENTS

The authors thank the British Columbia Ministry of Energy, Mines and Petroleum Resources for the grant supporting this project. Thanks are extended to Ron Smyth for prompt approval of funding, and for his role in the inception of this project. Support of a Reinhart Fellowship to J. Oliver, while at Queen's University, was both timely and appreciated. Discussions with Eric Titely (Golden Bear Operating Co.), Helmut Wober (Chevron Canada Resources Ltd.) and Gordon Nelson (Homestake Mining Ltd.) significantly broadened the authors' understanding of the study area. Approval, data access, and logistical support for this project by the corporations involved (Chevron Canada Resources Ltd. and Homestake Mining Ltd.) is gratefully acknowledged. The implicit contribution and quality of the previous geological mapping in area, principally the efforts of Sandy McAllistor (Chevron Canada), is recognized. The skilled drafting abilities of Brenda McLeod are thoroughly appreciated.

REFERENCES

Cockfield, W.E. (1926): Explorations between Atlin and Telegraph Creek, *Geological Survey of Canada*, Summary Report, 1925, Part A, pages 25-35.

Kerr, F.A. (1930): Explorations between Stikine and Taku Rivers, British Columbia, *Geological Survey of Canada*, Summary Report, 1930, Part A, pages 41-55.

Monger, J.W.H. (1970): Upper Paleozoic Rocks of the Stikine Arch, British Columbia, *Geological Survey of Canada*, Paper 70-1, Part A, pages 41-43.

——— (1977): Upper Paleozoic Rocks of the Western Canadian Cordillera and their Bearing on Cordilleran Evolution, *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

Monger, J.W.H. and Ross, C.A. (1971): Distribution of Fusulinaceans in the Western Canadian Cordillera, *Canadian Journal of Earth Sciences* Volume 8, pages 259-278.

Schroeter, T.G. (1985): Muddy Lake Prospect (104K/1W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 352-358.

——— (1986): Muddy Lake Project (104K/1W), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 175-183.

——— (1987): Golden Bear Project (104K/1), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 103-109.

Souther, J.G. (1971): Geology and Mineral Deposits of Tulsequah Map-area, British Columbia, *Geological Survey of Canada*, Memoir 362 and Map 1262A.

Wober, H.H. and Shannon, K.R. (1985): Bear-Totem Status Report, *Chevron Canada Resources Ltd.*, Private Corporate Report.

NOTES

THE WINDY CRAGGY COPPER-COBALT-GOLD MASSIVE SULPHIDE DEPOSIT, NORTHWESTERN BRITISH COLUMBIA (114P)

By J.M. Peter
University of Toronto

KEYWORDS: Economic geology, Windy Craggy, volcano-sedimentary host rocks, massive sulphide, stockwork and stringer mineralization, hydrothermal alteration, copper, cobalt, gold.

INTRODUCTION

The Windy Craggy copper-cobalt-gold massive sulphide deposit is located at 59°44′ north latitude and 137°44′ west longitude in the Alsek-Tatshenshini River area of the the St. Elias Mountains in extreme northwestern British Columbia (Figure 2-12-1). The deposit is in extremely rugged and glaciated terrain and crops out on Windy Peak (Plates 2-12-1 and 2-12-2). Access is by charter fixed-wing aircraft or helicopter. The airstrip at Windy Craggy is located 192 kilometres from Whitehorse, 135 kilometres from Haines, or 62 kilometres from the Haines highway. A 13-kilometre road built on Tats Glacier leads from the airstrip and camp to the portal and underground workings (Plate 2-12-2).

The deposit was discovered during a regional reconnaissance program in 1958 by Frobisher Ltd., now Falconbridge Limited, under the direction of J.J. McDougall. Exploration work was conducted by Falconbridge and its predecessor companies until 1981 when it entered into an agreement with Geddes Resources Ltd. In late 1983 Falconbridge conveyed title to the property to Geddes Resources. In early 1987 Geddes Resources commenced development of a 1852-metre adit extending close to a gold-enriched part of the deposit. This, and drifting alongside and paralel to the strike of the deposit on its western margin, was completed in the spring of 1988. Exploration work since then (current to September 1988) has consisted of underground drilling with the intention of defining the extent of gold mineralization and outlining reserves of copper and cobalt.

As of September 1988, 11 277 metres of underground drilling have been completed and a crosscut was being driven into massive sulphide mineralization to obtain bulk samples for metallurgical testing (Report to Shareholders, September 7, 1988). Grades and tonnages have not yet been calculated as assays and geological continuity between sections are still being developed, and only 420 metres of strike length has been systematically drilled. Previous estimates of grade and tonnage have ranged from 90 million tonnes grading 2.8 per cent copper to 320 million tonnes grading 1.52 per cent copper and 0.08 per cent cobalt (for example, Northern Miner, January 13, 1983; Canadian Mining Journal, 1986).

This report describes the Windy Craggy deposit and presents new information on the geological setting obtained from detailed underground drilling, mapping and sampling. Additionally, it gives a preliminary description of the styles of mineralization and alteration and their spatial distribution within the deposit. The author spent a period of four months at Windy Craggy this past field season and during this time logged approximately 4270 metres of drill core and examined much more in less detail. Approximately two weeks were spent mapping underground. During the 1987 field season about two months were spent mapping and sampling on the Tats claims, which are located in the immediate vicinity of Windy Craggy; one week was also spent surface mapping at Windy Craggy. This project is part of a Ph.D. thesis in progress at the University of Toronto.

GEOLOGICAL SETTING

The Windy Craggy area is situated within the allocthonous Alexander terrane of the Insular tectonic belt (Figure 2-12-2). Geological mapping by Campbell and Dodds (1979, 1983), MacIntyre (1983, 1984) and Prince (1983) indicates the area is within a broad belt of complexly deformed Paleozoic clastic and carbonate rocks of relatively low metamorphic grade. The area is underlain by intermediate to mafic submarine volcanic units with variable amounts of interbedded calcareous argillaceous sedimentary rocks. MacIntyre (1984) has presented a preliminary stratigraphic section for the Windy Craggy area. The age of the volcanic rocks has been established as early Norian (Upper Triassic) on the basis of conodonts collected from sedimentary interbeds (Orchard, 1986).

The deposit is within a sequence of interbedded graphitic and calcareous argillites and intermediate to mafic volcanic

Plate 2-12-1. View of north face of Windy Peak looking south-southwest. Sulphide mineralization crops out in the dark area immediately below the peak and also in the area of snow slides just below this dark area and above the break in slope near the centre of the photo.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

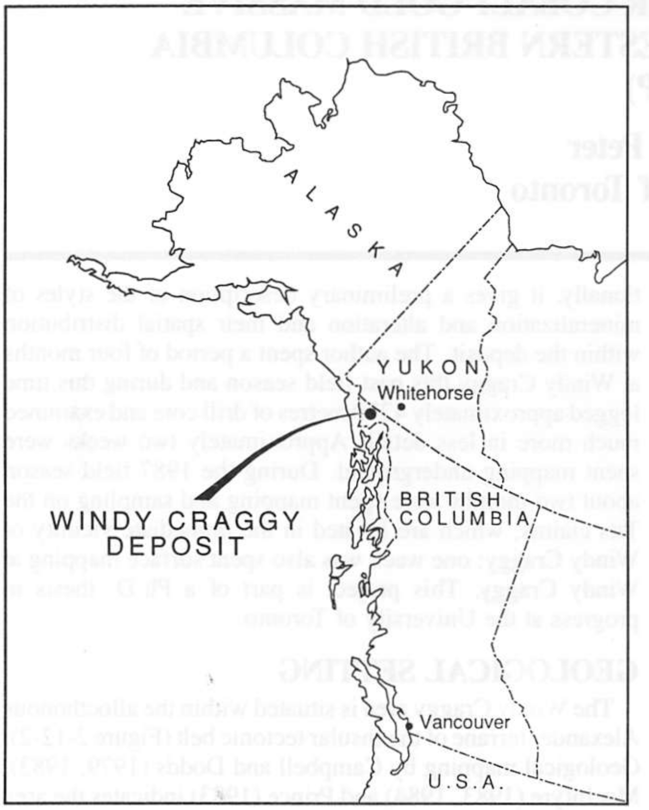


Figure 2-12-1: Location of the Windy Craggy deposit.

flows. These rocks have been intruded by subvolcanic dykes and sills. Up to the end of 1983, the deposit was thought to consist of two distinct sulphide bodies that have been isoclinally folded, crossfolded, faulted, and separated by a thick, altered pillow volcanic flow (Gammon and Chandler, 1986). Systematic underground drilling, which began in early 1988, generally supports these interpretations. Figure 2-12-3 is an isometric perspective view showing the position of the underground development (adit, North and South drifts), surface topography, location of underground drill holes, and positions of massive sulphide mineralization intersected in drill core on each drill section.

LITHOLOGY

The host rocks to the Windy Craggy deposit are a volcano-sedimentary succession consisting of mixed graphitic argillites and intermediate to mafic pillowed and massive flows (Gammon and Chandler, 1986). A summary of rock types and mineralization in the immediate vicinity of the deposit, as identified in drill core and from underground and surface mapping is given below.

FLOWS

Volcanic flows are fine grained and range in colour from medium grey to dark green. They are commonly amygdaloidal with spherical to amoeboid amygdules 1 to 5 millimetres in diameter composed of white, fine-grained calcite and, rarely, fine-grained pyrrhotite. In places amygdules comprise up to 4 volume per cent of the rock. Less commonly, the flows are porphyritic, with euhedral phenocrysts of plagioclase 3 to 8 millimetres in diameter and/or a euhedral mafic mineral (probably hornblende) 0.5 to 3.0 millimetres in diameter and pseudomorphed by chlorite. Flows are pervasively chloritized and carbonatized in many places. Much of this alteration probably relates to a regional greenschist facies metamorphic event. Flows are generally only slightly foliated, and chlorite schist is a very rare occurrence.

Pillows are exposed on surface, however, convincing exposures of pillow structures are present in only a few places underground. Pillows vary from 10 to 70 centimetres in cross-sectional diameter and generally contain finer grained chloritized rims. Where present underground, pillows are invariably slightly sheared and pristine, undeformed examples are rare. Drill-core examination indicates individual flows are up to 100 metres thick and average 10 to 15 metres in thickness.

Field classifications (for example, andesite or basalt) have been made wherever possible, but these necessarily rely heavily on colour index, and regional and local alteration complicates determinations. However, on the basis of field mapping and previous studies of petrochemistry (MacIntyre, 1986), both andesites and basalts are present in the Windy Craggy area.

TUFFS

Tuffs are common in the immediate vicinity of the deposit. They are predominantly dark green-black in colour, fine to very fine grained, and laminated to indistinctly bedded or massive. Individual units range from less than 1 metre to 35

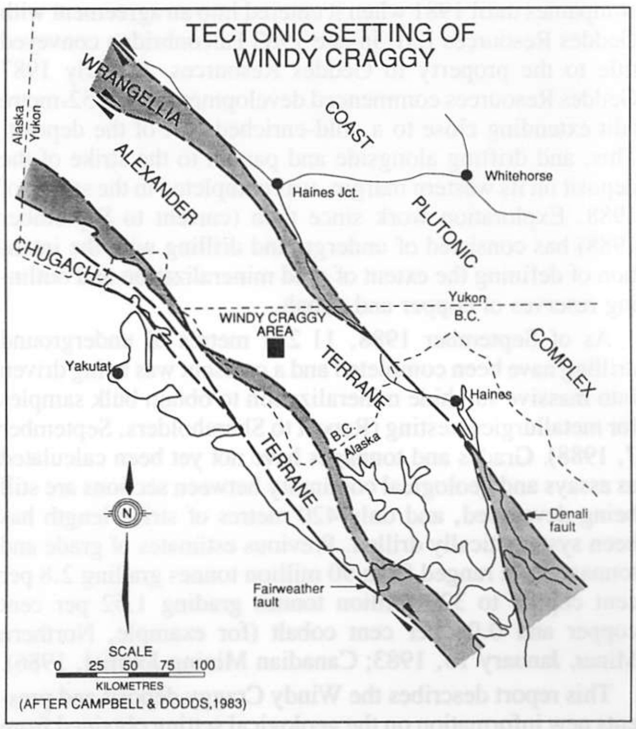


Figure 2-12-2: Tectonic setting of the Windy Craggy area (after Campbell and Dodds, 1983 and modified from Gammon and Chandler, 1986).

Plate 2-12-2. View of south face of Windy Peak and access road looking northeasterly up Tats Glacier. The portal is just above the snow where the road meets Windy Peak. Elevation of Windy Peak is 2000 metres. Access road built on Tats Glacier.

metres thick and average 10 to 15 metres thick. They are chloritic and often contain chlorite-rich interbeds. The tuffs commonly contain an appreciable component of interbedded argillite and in some places appear to grade laterally into argillite. Sedimentary structures such as graded and convoluted bedding (soft-sediment deformation), and sulphide-bearing nodules or concretions are common in drill core.

In places tuffs and argillites are mineralized and may contain up to 65 per cent pyrrhotite and 8 per cent chalcopyrite as fine disseminated grains, foliated bands and wisps, or beds ranging from less than a millimetre to 3 centimetres in thickness (Plate 2-12-3). In places, these sulphides have been deposited by chemical and/or clastic sedimentation. However, some of the sulphides may be diagenetic in origin, and epigenetic stockwork/stringer mineralization is also present within tuff.

ARGILLITE

Argillites are dark grey-black to light grey-buff coloured and range from noncalcareous to calcareous. They are indistinctly to well laminated (less than 1 millimetre to 20 centimetres) and are dominantly fine to very fine grained, but minor thin, sandy lenses or beds containing lighter grey calcareous grains are also present. In places the argillites contain a significant tuffaceous component consisting of chlorite-rich beds and laminae. Individual argillite units vary in thickness from less than a metre to 40 metres but on average are 10 to 15 metres thick. Boudins and sedimentary structures [normal graded bedding and lamination (Plate 2-12-4), soft-sediment deformation and slump structures (Plate 2-12-5), scours, pebble dents and concretions] occur within argillite.

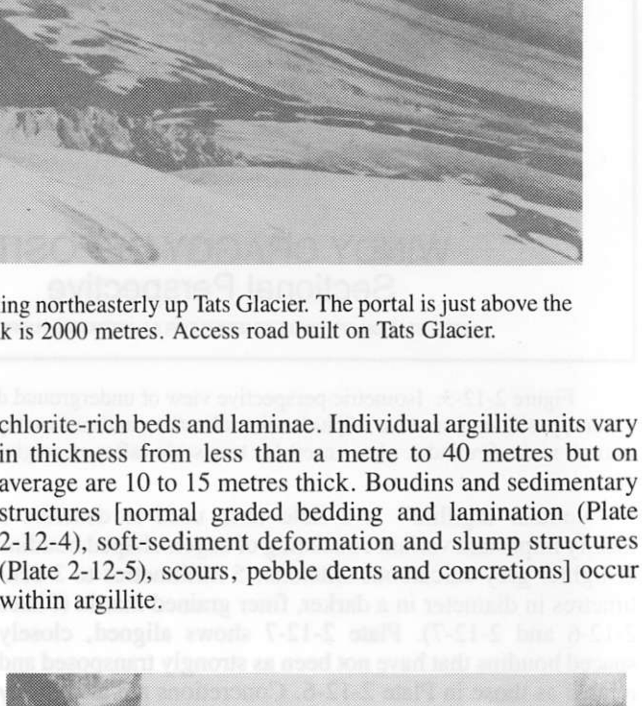


Plate 2-12-3. Mafic tuff with laminae of fine-grained pyrrhotite (sample 88-44; 35.0 m). White scale card is 9 cm long.

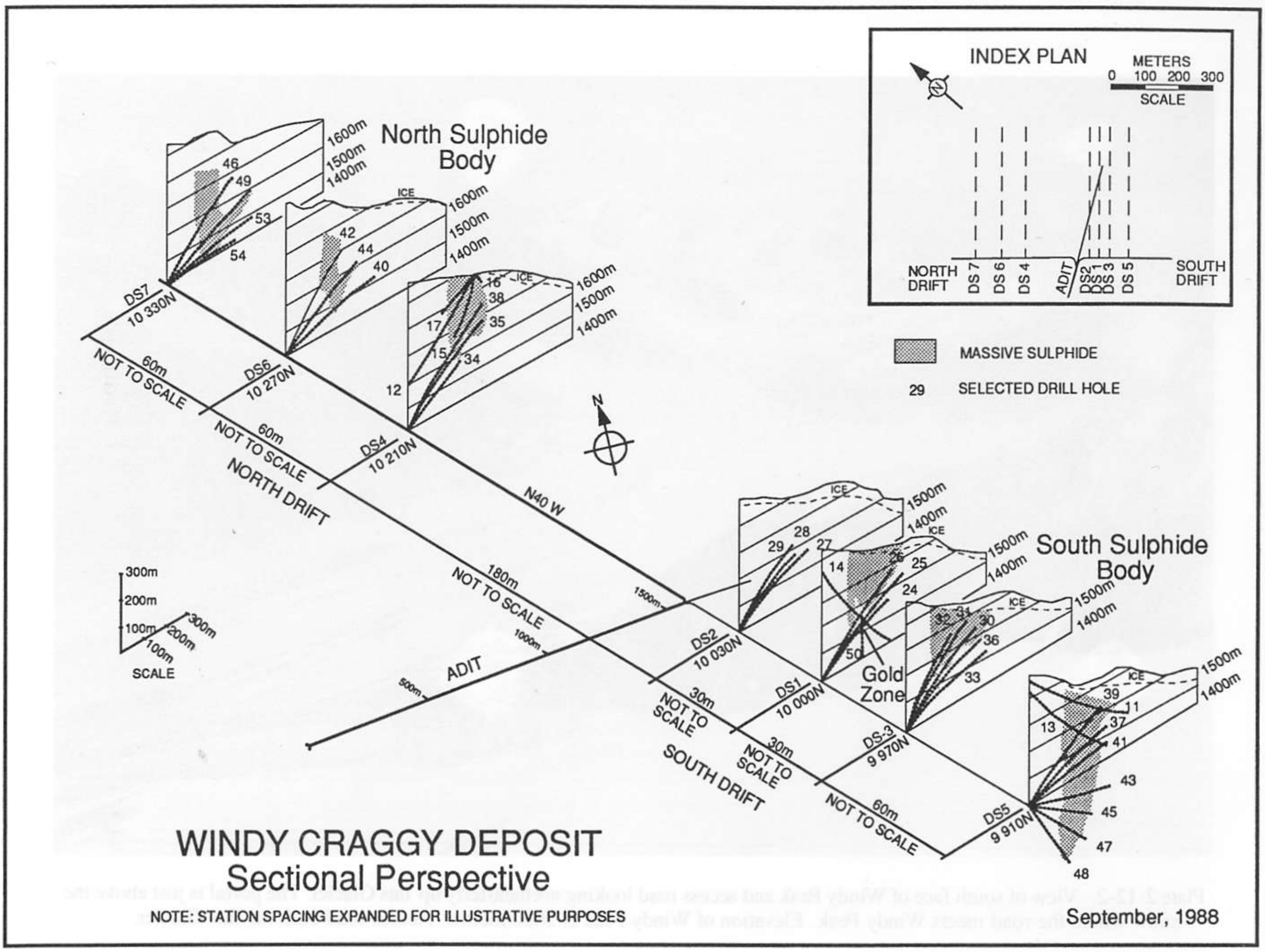


Figure 2-12-3: Isometric perspective view of underground development (adit, North and South drifts), location of underground drill holes, position of massive sulphide mineralization, and surface topography for each drill section. Spacing between sections is expanded and not to scale. *See* index plan (inset) for true scale (after an original diagram by Geddes Resources Ltd.).

"Nodular argillite" is a field term used to describe a locally important variant consisting of augen-shaped boudins of lighter grey calcareous siltstone, 5 millimetres to 3 centimetres in diameter in a darker, finer grained matrix (Plates 2-12-6 and 2-12-7). Plate 2-12-7 shows aligned, closely spaced boudins that have not been as strongly transposed and rotated as those in Plate 2-12-6. Concretions are also rarely present within argillite; they are round to ovoid, concentrically zoned, and comprise about 10 to 30 per cent of the rock. Concretions are 3 to 15 centimetres in diameter, with monomineralic layers of pyrrhotite, light grey calcite and rare blebs of chalcopyrite, 3 to 10 millimetres thick (Plate 2-12-8).

Mineralization within the argillites consists predominantly of occasional, very fine to coarse-grained (up to 8 millimetres diameter), euhedral cubes of pyrite and/or fine-grained disseminated pyrrhotite. These appear to be secondary, and probably formed by diagenetic growth. Sulphide-rich beds and laminae occur in a few intersections; textural evidence indicates that these are primary. In some places, epigenetic sulphides occur as discrete beds or bands that have selectively replaced certain beds.

Argillites may have a well-developed foliation which is defined by pyrrhotite plates that are aligned in an axial planar orientation. A slatey cleavage is variably developed within

Plate 2-12-4. Normal graded bedding in argillite (sample 88-35; 115.5 m).

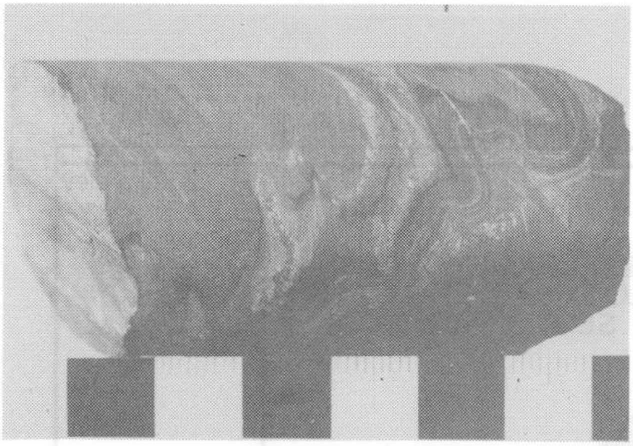


Plate 2-12-5. Soft-sediment deformation/slump structure in laminated, calcareous argillite (sample 88-36; 26.2 m).

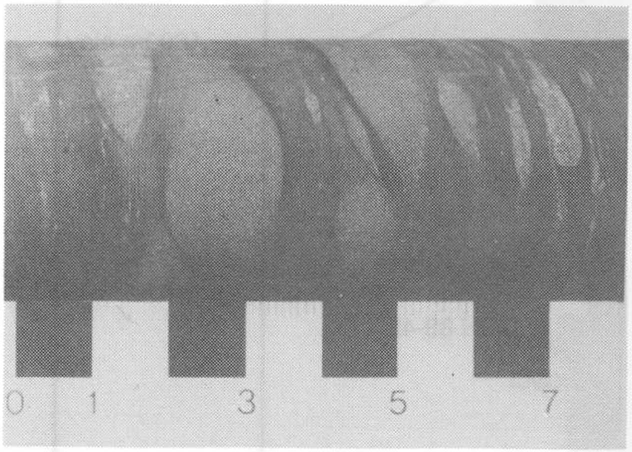


Plate 2-12-6. Light grey, calcareous boudins in finer grained, dark grey argillite groundmass (sample 88-44; 73.8 m).

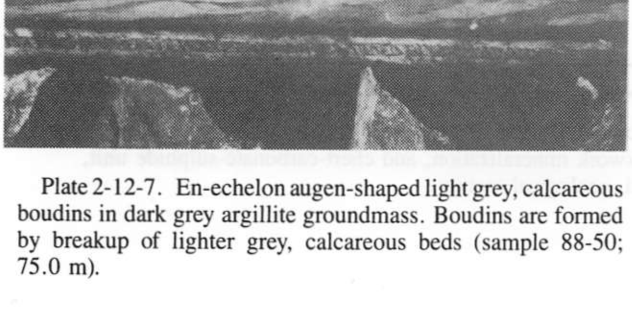


Plate 2-12-7. En-echelon augen-shaped light grey, calcareous boudins in dark grey argillite groundmass. Boudins are formed by breakup of lighter grey, calcareous beds (sample 88-50; 75.0 m).

Plate 2-12-8. Round to ovoid, concentrically zoned concretions in laminated to indistinctly bedded argillite. Concretions are 3 to 15 centimetres in diameter, with 3 to 10-millimetre-thick monominerallic layers of pyrrhotite, light grey calcite, and rare blebs of chalcopyrite. Location is in south wall of the main adit at 1780 metres.

graphitic argillite, axial planar to F_1 isoclinal folding (Gammon and Chandler, 1986).

DYKES AND INTRUSIVES

Subvolcanic dykes range from less than 10 centimetres to 25 metres wide, are light grey-green to dark green in colour, fine to coarse grained, and generally possess a 1 to 20-centimetre-wide chloritic chilled margin (Plate 2-12-9). The dykes are predominantly equigranular but occasionally contain hornblende (or chlorite pseudomorphs), plagioclase, and, rarely, quartz phenocrysts. Sulphides are invariably absent. In some places, dykes appear to be conformable with the adjacent lithologies and may actually be sills, but many are discordant and were emplaced after deposition of some volcanic flows and lithification of tuffs and argillites.

Several textural and compositional types of dykes are recognized: (1) fine-grained dykes of intermediate to mafic composition; (2) medium to coarse-grained diorites; (3) medium to coarse-grained gabbros; and (4) biotite-bearing, intermediate to mafic dykes (lamprophyres?).

Dioritic and gabbroic or diabase bodies are of limited extent and occur spatially (and stratigraphically) beneath massive mineralization. Their thickness in drill-hole intersections ranges from 1 to 40 metres. They are green-black in colour and medium to coarse grained. They have homogeneous meshwork textures of intergrown plagioclase, amphibole and pyroxene, and in part display an ophitic texture (Harris, 1988). They are moderately to extremely altered and contain abundant talc with minor to moderate amounts of calcite, chlorite and epidote. In one drillhole, gabbro or diabase is a host to stockwork mineralization and, therefore, predates mineralization. Biotite-bearing dykes are extremely rare and of limited extent. They contain medium to coarse-grained, dark brown to black biotite flakes in a finer grained groundmass.

Most of the dykes are poorly to well foliated and therefore predate folding and tectonism of the deposit. Both the fine-grained and biotite-bearing dykes intrude the massive mineralization and thus postdate the emplacement of sulphides.

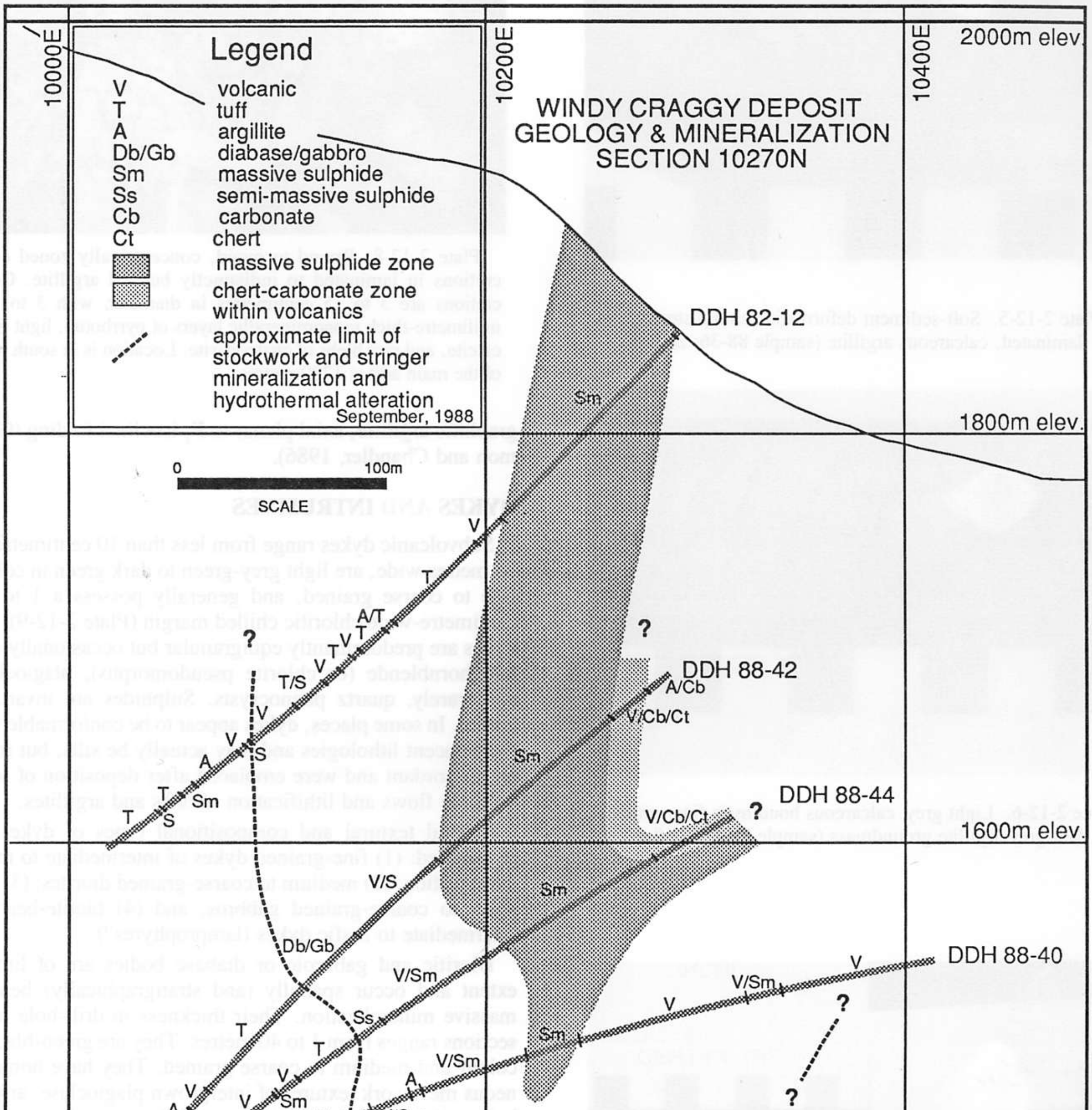


Figure 2-12-4. Section 10270N geology and mineralization showing location of adit, drill holes and lithologies noted in drill core. Also shown are boundaries of massive and stringer/stockwork mineralization, and chert-carbonate-sulphide unit, based on correlation between drill holes (after Geddes Resources Ltd. geological section).

MINERALIZATION

Drilling has identified two main sulphide masses, the North and South sulphide bodies (Figure 2-12-3) which lie along a strike length of about 500 metres. Figure 2-12-4 depicts the geology and mineralization on section 10270N shown on Figure 2-12-3. This section is probably the least structurally complicated of the sections drilled and is typical of the dimensions of the massive sulphide mass intersected in other sections. It also contains a well-developed stockwork alteration zone in the footwall of the deposit.

The following table summarizes some typical assay results from underground diamond drilling (Shareholders Progress Report, September 7, 1988).

TABLE 2-12-1
SELECTED ASSAY RESULTS, WINDY CRAGGY DEPOSIT

Hole	Intercept (m)	Interval (m)	Cu%	Au g/t	Ag g/t	Co%
North Sulphide Body						
88-46a	198-334	136	1.29	0.11	1.9	0.12
88-49b	180-332	142	2.02	0.08	3.9	0.10
88-49c	364-420	56	2.82	0.20	0.3	0.09
88-49	428-432	4	3.13	0.10	0.08	0.10
South Sulphide Body						
88-45d	156-304	148	2.00	0.09	0.1	0.11
88-47e	162-300	138	1.76	0.17	1.9	0.11
88-48f	272-314	42	1.22	0.05	0	0.12
88-43g, h	134-290	156	1.99	0.14	3.6	0.08
Gold Zone						
88-50	116-118	2	N/A	5.90	1.0	N/A
88-50i, j, k, l	128.85-147.40	18.55	0.62	4.47	3.6	N/A
88-52m	114.5-120.0	5.5	0.72	2.48	12.3	N/A

a contains an interval of 24 metres averaging 2.30% copper
b contains an interval of 76 metres averaging 2.56% copper
c contains an interval of 22 metres averaging 3.48% copper
d contains an interval of 72 metres averaging 2.87% copper
e contains an interval of 28 metres averaging 2.84% copper
f contains an interval of 28 metres averaging 1.47% copper
g contains an interval of 16 metres averaging 3.05% copper
h contains an interval of 24 metres averaging 3.07% copper
i contains an interval of 5.5 metres averaging 11.56 g/t gold
j contains an interval of 0.35 metres averaging 27.60 g/t gold
k contains an interval of 0.5 metres averaging 38.00 g/t gold
l contains an interval of 0.5 metres averaging 25.30 g/t gold
m contains an interval of 3 metres averaging 3.58 g/t gold

NORTH AND SOUTH SULPHIDE BODIES

MASSIVE SULPHIDE MINERALIZATION

The massive sulphide mass varies in thickness from about 70 to about 150 metres (for example, Figure 2-12-4); however, folding and deformation may have modified its morphology and these may not be original stratigraphic thicknesses.

Three principal types of massive sulphide mineralization exist: massive pyrrhotite with lesser chalcopyrite, massive pyrite with lesser chalcopyrite, and massive pyrrhotite and pyrite with lesser chalcopyrite and magnetite. Current indications are that the massive sulphide mass is miner-

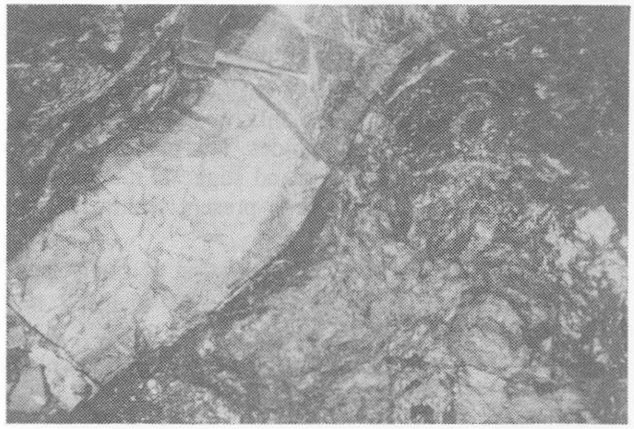


Plate 2-12-9. Mafic dyke, approximately 1 metre wide, with 10-centimetre-wide chloritized chilled margins; location is at end of North drift.

alogically zoned from massive pyrrhotite nearest the footwall to a massive pyrite zone at the stratigraphic top of the deposit. Magnetite occurs at the transition zone from pyrrhotite to pyrite, as fine-grained wisps, blebs, and patches. This zonation appears to be a primary feature unrelated to later metamorphism as only pyrrhotite-rich sulphides are associated with stockwork/stringer mineralization and pyrite-rich sulphides are absent. Figure 2-12-5 is a graphic log of drill-hole 88-44 showing the dominant lithologies intersected, the distribution of copper, cobalt, gold and silver, and estimates of pyrite and pyrrhotite abundances. Pyrrhotite occurs in the stringer/stockwork zone as well as within massive mineralization, but pyrite is not generally present within stockwork mineralization.

Previous preliminary investigations of the sulphide mineralogy (Harris, 1988; Buchan, 1983, 1984; Muir, 1980) have noted the presence of pyrrhotite, pyrite, chalcopyrite, with rare sphalerite, arsenopyrite, galena, valleriite, marcasite, cubanite and cobaltite. Gangue minerals include quartz, chlorite, calcite, ankerite, siderite, stilpnomelane, biotite and graphite.

There are a large variety of textures within the massive sulphide mass:

(a) fine-grained massive sulphides (pyrrhotite, pyrite, chalcopyrite, and magnetite) with minor chlorite along fractures.

(b) massive fine-grained sulphide (pyrrhotite, pyrite and chalcopyrite) with mottled, fine-grained carbonate (predominantly calcite with lesser ankerite and siderite) patches (Plate 2-12-10). Chalcopyrite occurs as discontinuous wisps, streaks and blebs associated with the carbonate.

(c) brecciated massive sulphides with angular, essentially monominerallic clasts of pyrite and/or pyrrhotite in a fine-grained sulphide matrix.

(d) foliated to gneissic sulphides with alternating, essentially monominerallic, discontinuous wisps, lenses and bands of chalcopyrite, pyrite, pyrrhotite, calcite and magnetite. This texture is relatively rare within massive mineralization and is probably due to recrystallization during folding and deformation.

(e) recrystallized, "spongy" medium to coarse-grained pyrite. This texture may be primary and unrelated to metamorphism.

(f) colloform-banded calcite, ankerite, and pyrite within fine-grained massive sulphides. This texture is indicative of open-space filling and suggests that cavities, pockets, and fractures were present within the sulphide mass.

(g) primary sulphide banding consisting of finely laminated to bedded pyrrhotite, magnetite, pyrite and chalcopyrite.

(h) soft-sediment deformation and slump structures within massive sulphide.

Stockwork and Stringer Mineralization

Stockwork and stringer mineralization consists of veinlets of fine-grained massive sulphide less than 1 millimetre to about 50 centimetres wide within brecciated host rock. Sulphides consist predominantly of pyrrhotite with lesser chalcopyrite and rare pyrite; gangue minerals include quartz and carbonate. This style of mineralization is not confined to any one particular lithology, although it appears to be most common within volcanic flows. The host rocks have been slightly to intensely chloritized and, in more extreme examples, have been strongly bleached and silicified. Host-rock breccia fragments are angular, 1 to 10 centimetres in diameter, and have been slightly to intensely chloritized and/or bleached and silicified (Plate 2-12-11). Silicified host-rock fragments are milky white, translucent, and resemble cryptocrystalline chert. The narrowest veinlets are generally associated with the most intense brecciation giving the overall appearance of a "crackle breccia".

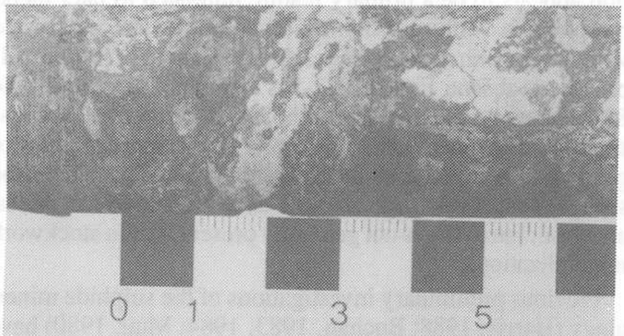


Plate 2-12-10. White calcite patches intergrown with massive pyrrhotite, pyrite and chalcopyrite (sample 88-49; 406.0 m).

Plate 2-12-11. Stockwork or stringer mineralization. Clasts and fragments are bleached milky white in colour and strongly silicified. Dark veinlets and matrix are predominantly fine-grained pyrrhotite with lesser chalcopyrite (sample 88-32; 234.9 m).

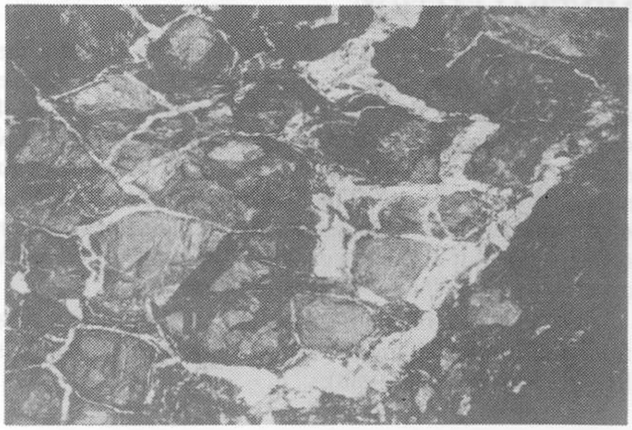


Plate 2-12-12. Stringer mineralization that has surrounded and, to a limited extent, brecciated pillowed mafic volcanics (basalt). Rims of pillows have been intensely chloritized. Mineralization consists of 70 per cent fine-grained pyrrhotite, 10 per cent chalcopyrite, and minor calcite and quartz. Location is approximately 150 metres north of adit in west wall of North drift. Pillow diameters are 30 to 50 centimetres.

Less intensely altered volcanic rock fragments are pervasively chloritized and medium to apple-green in colour, whereas moderately altered fragments are typically milky greenishwhite in colour. Plate 2-12-12 shows stockwork mineralization in brecciated pillow basalt in the North drift; sulphide veins are composed of 80 per cent pyrrhotite, 10 per cent chalcopyrite and 10 per cent each of calcite and quartz. Stockwork mineralization in argillite consists of light to dark grey fragments in a fine-grained sulphide matrix whereas similar mineralization in tuff generally contains dark grey-green fragments. Tuff fragments commonly contain more chlorite as a result of their original mineralogy. Intensely altered argillite and tuff fragments appear cryptocrystalline and milky white in colour. Pyrrhotite and chalcopyrite occur along select laminae and beds within individual fragments and as a breccia matrix between clasts. Relict lamination and bedding can be seen in both argillite and tuff (Plate 2-12-13). Sulphide laminae and beds are interconnected with matrix sulphides (Plate 2-12-14). It appears that sulphides have preferentially replaced coarser grained laminae and beds. In one place, stringer mineralization occurs within a diabase/gabbro intrusion.

Stockwork mineralization is localized within what is interpreted to be the stratigraphic footwall of the deposit and does

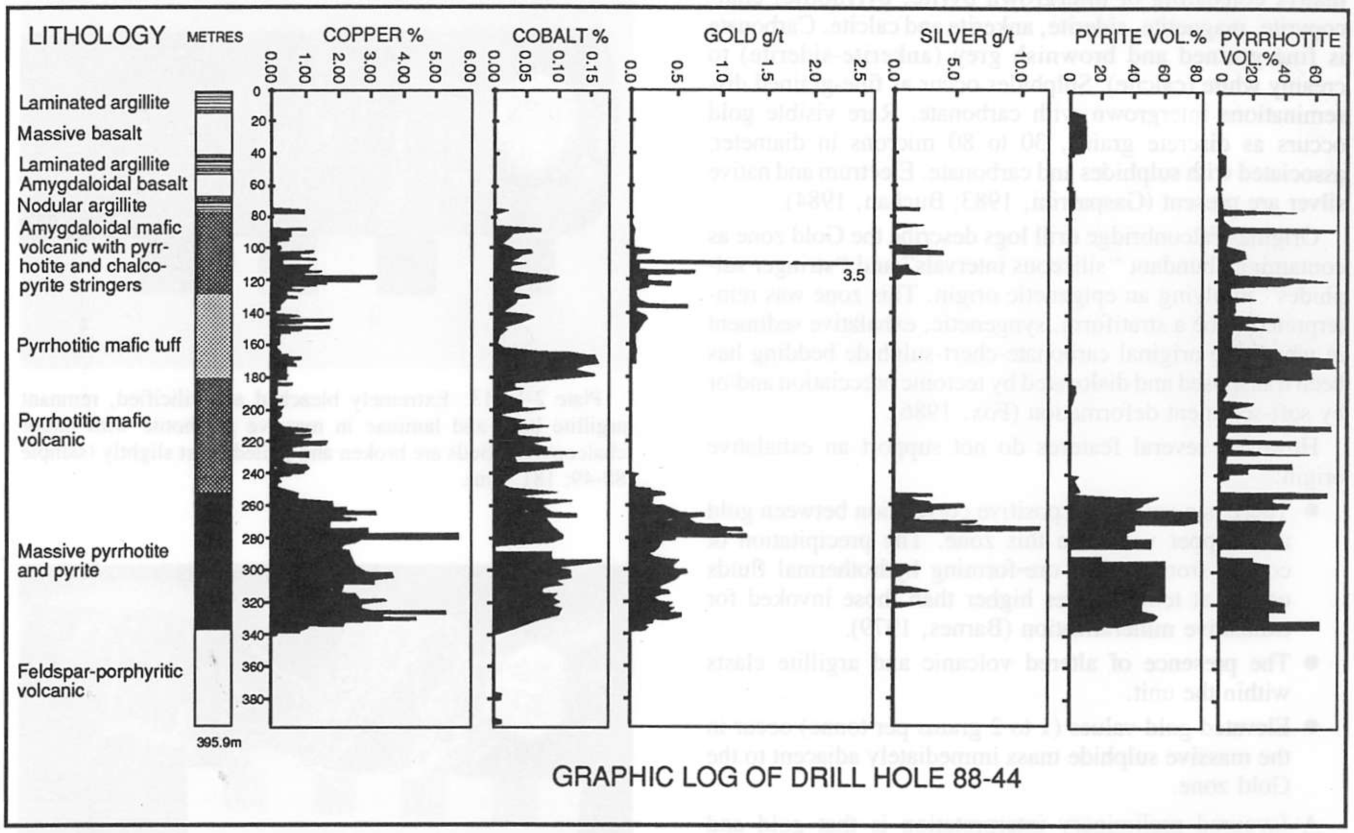


Figure 2-12-5. Graphic log of underground diamond-drill hole 88-44 shown on section 10270N in Figure 2-12-4. Shown are major lithologic units, copper, cobalt, gold and silver contents as well as estimates of pyrite and pyrrhotite abundances for adjacent 2-metre sample intervals (adapted from an original figure by R.J. Beckett and Geddes Resources Ltd. drill logs).

not appear to extend stratigraphically above massive mineralization. In the sections drilled to date (September, 1988), well-developed and recognizable stockwork and stringer mineralization extends about 100 metres beneath massive mineralization (Figure 2-12-4). However, as seen in Figure 2-12-5, significant copper (greater than 0.5 per cent), cobalt (greater than 0.05 per cent) (and even trace gold and silver) values occur well below this apparent boundary.

In many places stockwork/stringer mineralization is slightly to moderately foliated and individual clasts have been elongated and interstitial sulphide veinlets have been deformed to wisps and blebs.

Chert-Carbonate-Sulphide

This unit consists of finely interlaminated to interbedded (less than 1 millimetre to 5 centimetres) calcite, siderite, ankerite, chert, chlorite, sericite, hematite, magnetite, pyrrhotite, pyrite, chalcopyrite and, rarely, sphalerite (Plate 2-12-15). In places it contains a tuffaceous and/or argillaceous component. Individual units are generally narrow (0.1 to approximately 3 metres). In section 10270N (Figure 2-12-4) this unit consists of several thin carbonate-chert-sulphide bands within massive fine-grained mafic volcanic flows. Exhalite of similar appearance to the laminated chert-carbonate at Windy Craggy commonly overlies massive sulphide mineralization in a number of sulphide deposits. Possible analogues to this unit may be the "Tetsusekiei" of the Japanese Kuroko deposits (Kalogeropoulos and Scott, 1983), the Main Contact "C" tuff of the Noranda area (Gibson *et al.*, 1983) and the Key tuffite of Mattagami (Roberts, 1975). The chert-carbonate-sulphide unit at Windy Craggy does not typically carry gold, although in several places values between 1 and 3 grams per tonne were obtained.

Gold Zone

The Gold zone was first indicated from surface by diamond-drill hole 83-14 which intersected 61.3 metres of "cherty carbonate material" that assayed 4.46 grams gold and 3.43 grams silver per tonne and 0.62 per cent copper. Within this section 5.5 metres assayed 11.66 grams gold and 3.09 grams silver per tonne and 0.98 per cent copper. This width may not be a true stratigraphic width. Underground drilling has confirmed the presence of this gold-bearing zone (*see* Table 2-12-1).

The gold-bearing unit contains fragments and patches and bands of milky white, very fine-grained cherty-looking rock. Less commonly, clasts of fine-grained green volcanic rock and rare laminated to banded argillite fragments are also present. Volcanic clasts commonly display a thin rim of darker green chlorite indicative of hydrothermal alteration. Clasts comprise about 40 per cent of the rock and are supported by a fine-grained, mottled sulphide and carbonate matrix consisting of intergrown pyrite, pyrrhotite, chalcopyrite, magnetite, siderite, ankerite and calcite. Carbonate is fine grained and brownish grey (ankerite-siderite) to creamy white (calcite). Sulphides occur as fine-grained disseminations intergrown with carbonate. Rare visible gold occurs as discrete grains, 30 to 80 microns in diameter, associated with sulphides and carbonate. Electrum and native silver are present (Gasparrini, 1983; Buchan, 1984).

Original Falconbridge drill logs describe the Gold zone as containing abundant "siliceous intervals" and "stringer sulphides" implying an epigenetic origin. This zone was reinterpreted to be a stratiform, syngenetic, exhalative sediment in which the original carbonate-chert-sulphide bedding has been transposed and dislocated by tectonic brecciation and/or by soft-sediment deformation (Fox, 1986).

However, several features do not support an exhalative origin:

- There is a very good positive correlation between gold and copper values in this zone. The precipitation of copper from typical ore-forming hydrothermal fluids occurs at temperatures higher than those invoked for exhalative mineralization (Barnes, 1979).
- The presence of altered volcanic and argillite clasts within the unit.
- Elevated gold values (1 to 2 grams per tonne) occur in the massive sulphide mass immediately adjacent to the Gold zone.

A favoured preliminary interpretation is that gold and attendant sulphides and carbonates were introduced into bedded argillite and volcanics and possibly chert-carbonate-sulphide by later, high-temperature hydrothermal fluids. These fluids brecciated and altered (chloritized and/or silicified) the host rocks in part. This hypothesis is supported by the presence of clasts and fragments of volcanics and argillite that are rimmed by chlorite. As well, in some places, pyrrhotite and minor chalcopyrite bands occur in dark grey, fine-grained quartzose argillite. These bands are interconnected by narrow sulphide veinlets which crosscut the argillite. This texture, noted in drill hole 88-50, suggests that sulphides have selectively replaced pre-existing beds and laminae.

STRUCTURE AND METAMORPHISM

Multiple phases of deformation of the deposit have been noted since 1982 by Falconbridge geologists who recognized folded S_1 cleavage planes in drill core. Mapping of the north face of Windy Peak (Kelemen and Radford, 1983) verified the presence of two phases of folding within the deposit. F_1 isoclinal folds trend northwest and west-northwest. These are deformed by F_2 open folds which trend north to north-northeast. F_1 folds are often overturned towards the southwest and plunge 30° to 50° towards the northwest. The plunge of the F_1 axes varies due to the influence of the steeply north-plunging F_2 folds.

The north sulphide body is folded into a large, upright syncline plunging steeply to the northwest. The western limb of the syncline dips steeply north whereas the eastern limb has a more gentle dip to the south (Figure 2-12-4). Stockwork and stringer mineralization are most prevalent near the hinge

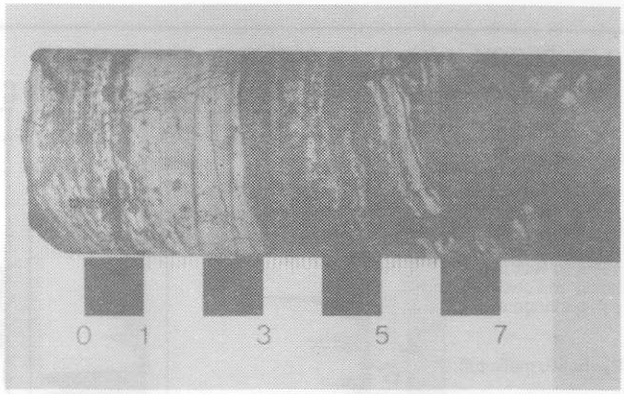


Plate 2-12-13. Extremely bleached and silicified, remnant argillite beds and laminae in massive pyrrhotite with minor chalcopyrite. Beds are broken and pulled apart slightly (sample 88-49; 181.4 m).

Plate 2-12-14. Beds of bleached and silicified tuffaceous argillite (black). Mixed white and black beds are pyrrhotite and minor chalcopyrite in coarser grained argillite. Sulphides appear to have replaced coarser grained beds. Note the veinlets of sulphide connecting the replaced beds (sample 88-49; 105.8 m).

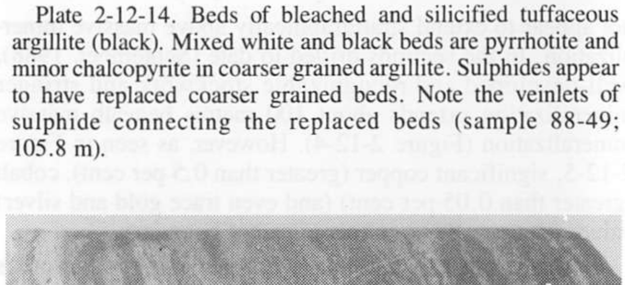


Plate 2-12-15. Chert-carbonate-sulphide unit consisting of finely interlaminated calcite, siderite, ankerite, chert, chlorite, sericite, hematite, magnetite, pyrrhotite, pyrite, chalcopyrite and rare sphalerite (sample 88-24; 305.7 m).

area of the syncline. Massive pyrrhotite is predominant in the western limb and massive pyrite is more common in the eastern limb.

The South sulphide body is monoclinal and plunges steeply southeast (Section 9910 on Figure 2-12-3). The monoclinal nature may be due to isoclinal folding as preliminary investigation indicates that stockwork mineralization occurs on either side of the massive sulphide mass. The two sulphide masses may in fact be part of a single, doubly-plunging structure.

Faulting is most prevalent within volcanic flows and gabbro/diabase units. Narrow zones of shearing and faulting with slickensided chlorite and/or talc and chloritic clay gouge are common in the diabase. All rock types contain narrow (1 to 3 millimetre) crosscutting veinlets of calcite and minor quartz. The orientation of these veinlets is generally random, but in several places they appear to be axial planar. Metamorphism of host rocks has not been intense, and primary textures and fabrics are preserved, except where the rocks have been affected by faulting or hydrothermal alteration. Host rocks are regionally metamorphosed to greenschist facies. All styles of mineralization bear some evidence of foliation.

CONCLUSIONS

The Windy Craggy deposit is a major resource of copper and cobalt with at least one gold-rich zone. It may prove to be one of the largest massive sulphide bodies in North America. The deposit is hosted by a sequence of interbedded volcanic flows, tuffs and argillites that have been intruded by dykes and sills. Mineralization consists of one or two massive sulphide bodies comprised predominantly of pyrrhotite, pyrite, chalcopyrite and magnetite. Significant stockwork/stringer mineralization is confined to hydrothermal alteration zones that are interpreted to stratigraphically underlie massive mineralization. The abundant argillaceous sediments, combined with basalts and synvolcanic dykes, indicate a setting similar to the present day seafloor sulphide deposits of Guaymas Basin in the Gulf of California (Peter and Scott, 1988).

ACKNOWLEDGMENTS

Dr. Steven Scott is gratefully acknowledged for supervision and guidance. The British Columbia Ministry of Energy, Mines and Petroleum Resources are thanked for generously providing a contract supporting research at Windy Craggy. Sincere gratitude is due to Mr. Douglas Little and Mr. Geddes Webster of Geddes Resources for generous logistical support and the ready exchange of data and ideas. Mr. Robert Beckett of Beckett Geological Services and Miss Mary P. Webster are thanked for many hours of fruitful discussion. Although they influenced the interpretations put forth in this paper, they do not necessarily support or agree with them. This paper has benefitted greatly from the incisive comments and editing of Robert Beckett, John Ricker and Mary Webster of Geddes Resources and John Newell of the British Columbia Geological Survey Branch.

REFERENCES

Barnes, H.L. (1979): Solubilities of Ore Minerals, *in* Geochemistry of Hydrothermal Ore Deposits, H.L. Barnes, Editor, *John Wiley and Sons, N.Y.*, pages. 404-460.

Buchan, R. (1984): Reconnaissance Petrographic Examination and Photomicrography of 18 samples from Windy Craggy, B.C., *Falconbridge Metallurgical Laboratories*, Unpublished report MR-1284.

Buchan, R. (1983) Mineralogical Examination of 20 DDH Core Samples from Hole 14-83, Windy Craggy, B.C., *Falconbridge Metallurgical Laboratories*, Unpublished report MR-1282.

Campbell, R.B., and Dodds, C.J. (1979): Operation Saint Elias, British Columbia, *in* Current Research, Part A, *Geological Survey of Canada*, Paper 79-1A, pages 17-20.

——— (1983): Geology of Tatshenshini River Map Area (114P), British Columbia, *Geological Survey of Canada*, Open File 926.

Dodds, C.J. (1988): Geological Mapping in Tatshenshini River Map Area, British Columbia, *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E, pages 65-72.

Fox, J.S. (1986): Geological Evaluation of the Windy Craggy Drill Core, *Geddes Resources Ltd.*, Unpublished Company Report, IREM P86-02.

Gammon, J.B., and Chandler, T.E. (1986): Exploration of the Windy Craggy Massive Sulphide Deposit, British Columbia, *in* Geology in the Real World – The Kingsley Dunham Volume, *The Institution of Mining and Metallurgy*, pages 131-141.

Gasparrini, C. (1983): Study of the Gold, Silver, and Cobalt Distribution in Two Samples of Core from the Windy Craggy Deposit, *Geddes Resources Ltd.*, Unpublished Company Report.

Gibson, H.L., Watkinson, D.H., and Comba, C.D.A. (1983): Silicification: Hydrothermal Alteration in an Archean Geothermal System within the Amulet Rhyolite Formation, Noranda, Quebec, *Economic Geology*, Volume 78, pages 954-971.

Harris, J.F. (1988): Petrographic Study of Rocks from the Windy Craggy Area, Atlin Mining District, B.C., *Geddes Resources Ltd.*, Unpublished Company Report.

Kalogeropoulos, S.I., and Scott, S.D. (1983): Mineralogy and Geochemistry of Tuffaceous Exhalites (Tetsusekiei) of the Fukazawa Mine, Hokuroku District, Japan, *Economic Geology* Monograph 5, pages 412-432.

Kelemen, P.B., and Radford, G.W. (1983): Geology of the North Face of Windy Peak, Windy Craggy Copper Deposit, *Falconbridge Limited*, Unpublished Company Report.

MacIntyre, D.G. (1983): A Comparison of Stratiform Massive Sulphide Deposits of the Gataga District with the Midway and Windy Craggy Deposits, Northern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1982, Paper 1983-1, pages 149-170.

——— (1984): Geology of the Alsek–Tatshenshini Rivers Area (114P), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 173-184.

——— (1986) The Geochemistry of Basalts Hosting Massive Sulphide Deposits, Alexander Terrane, Northwest British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1987-1, pages 197-210.

Muir, J.E. (1980): Mineralogical Examination of a Suite of Mineralized Samples from the Area of the Alsek (Windy Craggy) Copper Deposit, Northwestern B.C., *Falconbridge Metallurgical Laboratories*, Unpublished Report MR-1139.

Orchard, M.J. (1986): Conodonts from Western Canadian Chert: Their Nature, Distribution and Stratigraphic Application, *in* Conodonts: Investigative Techniques and Applications, *Ellis Horwood Ltd.*, pages 94-119.

Peter, J.M., and Scott, S.D. (1988): Mineralogy, Composition, and Fluid-inclusion Microthermometry of Seafloor Hydrothermal Deposits in the Southern Trough of Guaymas Basin, Gulf of California, *Canadian Mineralogist*, Volume 26, pages 567-587.

Prince, D.R. (1983): Report on Reconnaissance Geological Mapping of the Windy Craggy Area, B.C., NTS 114P, *Falconbridge Limited*, Unpublished Company Report.

Roberts, R.G. (1975): The Geological Setting of the Mattagami Lake Mine, Quebec: a Volcanogenic Massive Sulphide Deposit, *Economic Geology*, Volume 70, pages 115-129.

Industrial Minerals Studies

FLUORSPAR IN BRITISH COLUMBIA*

By Jennifer Pell and Janet Fontaine

KEYWORDS: Industrial minerals, fluorite, Rock Candy mine, Rock Canyon Creek, Deep Purple, Birch Island, Rexspar, Eaglet, Liard

INTRODUCTION

Fluorspar is the commercial name for the mineral fluorite, CaF_2. Fluorite is a very attractive mineral which often occurs in well-formed crystals ranging in colour from white to amber, green, blue, purple and black. It forms in a wide range of temperature and pressure conditions and therefore occurs in many geologic environments. It may be associated with calcite and barite in low-temperature, carbonate-hosted lead-zinc deposits; with quartz in granite-related silver-lead-zinc veins; with chalcedonic quartz and gold in epithermal vein systems; and with silver and lead in manto-type replacement deposits in carbonate rocks adjacent to granitic intrusions. Fluorine is also often enriched in carbonatites and related alkaline rocks, in specialized granites and complex pegmatites, and in skarns and greissens; consequently, fluorite and other fluorine-bearing minerals are often associated with the mineral deposits related to these rock types.

Fluorine is a useful pathfinder element for a wide range of deposit types; fluorite itself, has commercial importance, largely in the metallurgical and chemical industries. Mexico and China currently rank as the world's largest suppliers of fluorspar, together accounting for approximately 30 per cent of world production. The United States is the world's major consumer of fluorspar and a former significant producer. Canadian consumption of fluorspar is in the order of 170 000 tonnes per annum (Harben, 1985; Pelham, 1985).

In Canada, St. Lawrence Fluorspar Limited, at St. Lawrence, Newfoundland, is the only current producer. This mine was reopened in 1987 and produces approximately 60 000 tonnes per annum of high-purity fluorspar concentrate (Clarke, 1987). In the past, fluorspar was mined in the Madoc and Wilberforce areas of Ontario, at St. Lawrence, Newfoundland (from 1933 to 1978) and from the Rock Candy mine, north of Grand Forks, British Columbia (Dawson, 1985; Wilson, 1929). A small amount of fluorite (29.2 tonnes) was also shipped from the Gypo silica quarry, at Oliver, British Columbia (McCammon and James, 1959).

Fluorite occurrences are widespread throughout British Columbia. It has been found associated with mineral deposits in numerous geologic environments and in all tectonic belts except the Insular Belt (Figure 3-1-1). There are five major fluorite prospects and, though none are currently receiving any significant attention, one deposit, the Rock Candy mine, has a history of past production. A number of other deposits in the province also contain significant concentrations of fluorspar.

FLUORSPAR — USES AND ECONOMIC CONSIDERATIONS

Fluorspar is marketed in three major grades – acid, ceramic and metallurgical. Acid grade fluorspar (acidspar) contains no less than 97 per cent CaF_2 and limited silica, calcium carbonate, arsenic, lead, sulphide sulphur and phosphorous. Acidspar is used in the production of hydrofluoric acid, an essential feedstock in the manufacture of a wide range of chemicals, including synthetic cryolite used in aluminum smelting. Ceramic-grade fluorspar is generally marketed in two classes; No. 1 ceramic generally contains 95 to 96 per cent CaF_2 and No. 2 ceramic comprises 85 to 90 per cent CaF_2. An intermediate grade of approximately 92 to 93 per cent CaF_2 is also produeed. Impurity specifications vary, but commonly allow up to 3 per cent silica, 1.5 per cent calcite, 0.12 per cent iron oxide and traces of lead and zinc. Ceramic-grade flourspar has widespread application in the glass and ceramics industries, in the manufacture of enamels and in the production of calcium and magnesium metal and portland cement. Metallurgical grade fluorspar contains a minimum of 60 "effective" per cent CaF_2 and less than 0.3 and 0.5 per cent of sulphide sulphur and lead, respectively. The "effective" percentage is $\%CaF_2 - 2.5 \times \%SiO_2$. Metallurgical grade fluorspar is used as a fluxing agent in steel making.

In 1983, the primary consumers of fluorspar were the chemical industry (42 per cent), the aluminum industry (21 per cent), both of which utilize acid-grade spar, and the steel industry (31 per cent), which requires metallurgical-grade fluorspar. Forecasts predict greater increases in demand for acid-grade spar than for the lower purity products (Pelham, 1985). Current fluorspar prices, as quoted in Industrial Minerals, September 1988, are approximately US$70-77 per tonne for metallurgical-grade Mexican fluorspar, f.o.b. Tampico and US$115-120 per tonne for acidspar, f.o.b. source (Northern Europe, Tampico or Durban, South Africa). Acidspar produced in Illinois sells for US$168-173 per short ton.

Mineable grades vary depending on deposit type and mining method among other factors. Large, stratiform carbonate-hosted fluorite-barite-lead-zinc deposits in Illinois, Mexico, and South Africa are mined with CaF_2 grades of 15 per cent and up. Mineable vein deposits generally contain 25 to 80 per cent or more of CaF_2. Fluorspar occurs as a major gangue mineral in many lead-zinc vein and replacement deposits and is economically recoverable, as a by-product, when fluorspar grades are 10 to 20 per cent (Pelham, 1985).

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

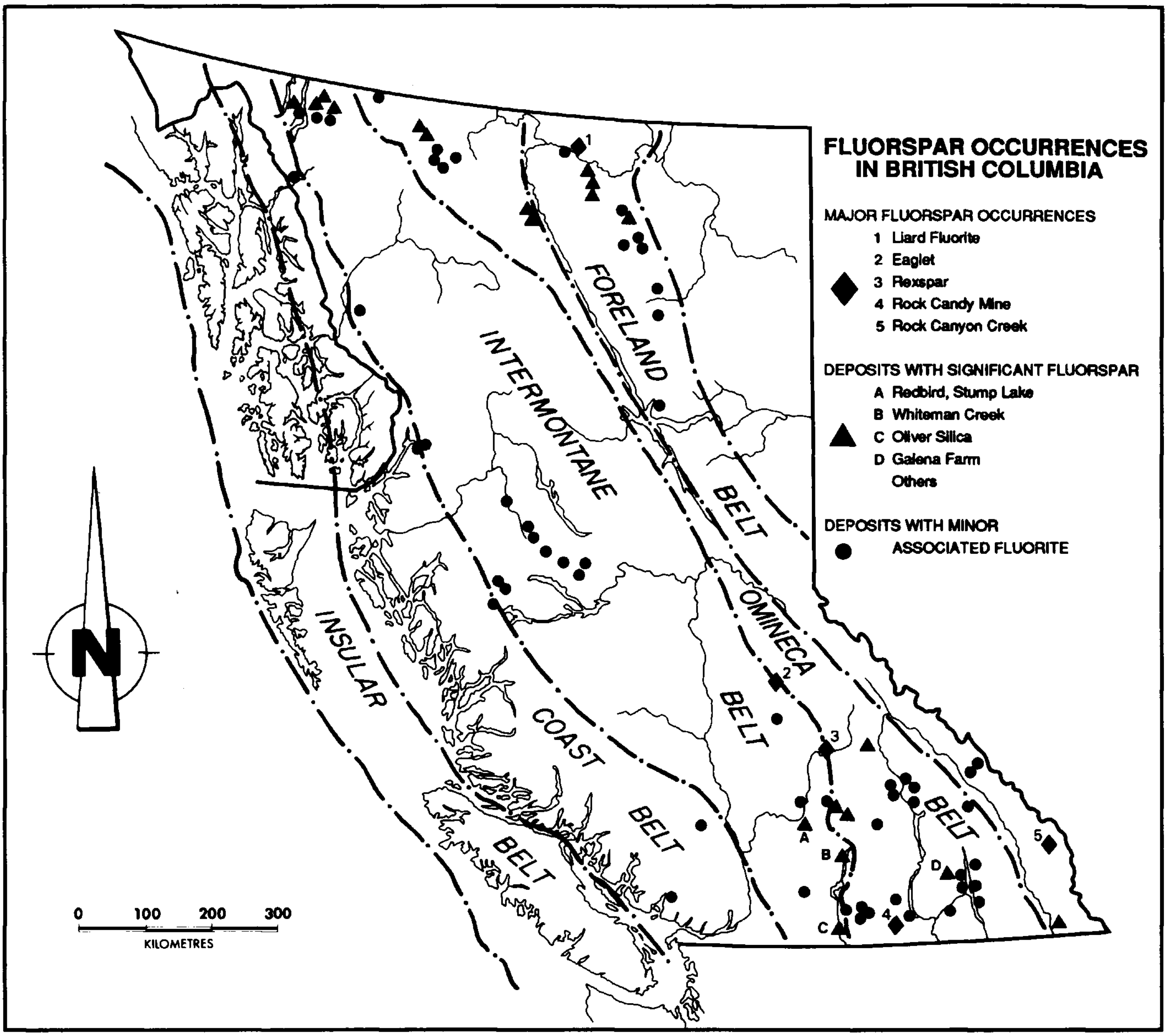


Figure 3-1-1. Location of fluorspar prospects and occurrences in B.C.

MAJOR FLUORSPAR DEPOSITS IN BRITISH COLUMBIA

ROCK CANDY MINE (MINFILE 082ESE070)

The Rock Candy fluorspar property is located on Kennedy Creek, approximately 27 kilometres north-northwest of Grand Forks, at the south end of the Omineca Belt, latitude 49°14′ north and longitude 118°29′ west. The main showing is exposed between 790 and 880 metres (2600 and 2900 feet) elevation.

History

The deposit was discovered in 1916 by two prospectors who mistook the green fluorite for a copper-bearing mineral (Dolmage, 1929). The property was acquired by Consolidated Mining and Smelting Company of Canada Limited (Cominco) in 1918, once the true nature of the mineralization was realized, and immediately put into production. It was in operation intermittently between 1918 and 1929, and a total of 51 500 tonnes of ore, with an average grade of 68 per cent CaF_2 and 22 per cent SiO_2 was mined and shipped to the Trail smelter. The two mine adits remained open until the early 1980s at which time they were blasted closed. It is estimated that approximately 12 300 tonnes of broken ore remain in the stopes and that 47 800 tonnes of probable ore remains in pillars and sills (Parsch, 1973). The mine was controlled by Cominco Ltd. until its recent acquisition by a mineral collector.

Geology

The Rock Candy fluorspar deposit consists of an intricate network of subparallel veins, which vary from a few centimetres to approximately 10 metres in width, occupying a silicified, northerly trending, moderate to steeply west-dipping fracture zone in Tertiary andesitic volcanics adjacent to a large syenitic intrusion (Figure 3-1-2). Fine-grained syenite dykes crosscut the andesites in the vicinity of the deposit (Parsch, 1973). Within the mine the veins were numerous and extremely closely spaced, with only narrow bands and isolated horses of altered country rock between them (Dolmage, 1929). The developed mineralized zone extends for approximately 200 metres north from Kennedy Creek and has a maximum width of approximately 15 metres. The vein reappears in outcrop approximately 1 kilometre north of the main developed zone (Figure 3-1-2).

Andesites which host the fluorite veins are predominantly fine to medium grained, greenish to grey in colour and contain albite, oligoclase and actinolite with minor magnetite and biotite. Quartz occurs as veinlets and as cavity fillings. Sericite, calcite and chlorite are locally developed alteration minerals. Immediately adjacent to the veins, the andesites are highly altered, weathering a pinkish buff colour, and contain abundant clay minerals (including kaolin), chlorite, sericite, quartz, calcite and pyrite (Parsch, 1973; Dolmage, 1929). These rocks are correlative with the Marron Formation of Paleocene or Eocene age. Outcropping to the east of the vein system are medium to coarse-grained, massive pink syenites which have been correlated with the Paleocene to Eocene Coryell intrusions (Dawson, 1985; Little, 1957). The syenites contain large pink and green feldspar crystals, predominantly orthoclase, with minor plagioclase. The centres of some orthoclase crystals have been identified as hyalophane, a barium-rich orthoclase (Dolmage, 1929). Biotite, hornblende, augite and magnetite, and traces of quartz, apatite, sphene and zircon are also present within the syenite. The ferromagnesian minerals are commonly altered to chlorite, and epidote is locally present (Dawson, 1985; McCammon, 1968a; Parsch, 1973). Microsyenite dykes locally crosscut the andesites and the coarse-grained intrusion. The dykes consist mainly of altered feldspars with some interstitial quartz and secondary calcite and chlorite. Fluorite has been reported from one such dyke (Dolmage, 1929). Granite and granodiorite, correlative with the Lower Cretaceous Nelson batholith, is present south of Kennedy Creek.

Excellent surface exposures of a large vein exist near the old workings (Figure 3-1-2), the eastern margin of which is covered by till. The outcrop consists of a 3 to 4-metre width of predominantly massive fluorite, bordered to the west by 1.5 to 2 metres of fluorite-matrix breccia and a thin composite-banded margin adjacent to altered volcanic country rocks. The massive portion of the vein consists of coarse-grained, pale apple to emerald-green fluorite and minor pale purple fluorite cut by numerous vuggy quartz veins. Within the mine, numerous large vugs, locally in excess of 1 metre in width, lined with crystals of barite, quartz, calcite and fluorite or containing white kaolin have been reported (Dolmage, 1929). The marginal breccia zone contains subangular, altered fragments of volcanic country rock in a matrix of purple and green fluorite, chalcedony, kaolin, pyrite, quartz and calcite. The banded western margin of the vein comprises both crystalline and massive banded barite with calcite, fluorite, chalcedony and quartz. Chalcopyrite, galena, chalcocite and covelite have been reported by early workers (Freeland, 1920), but are not evident in outcrop.

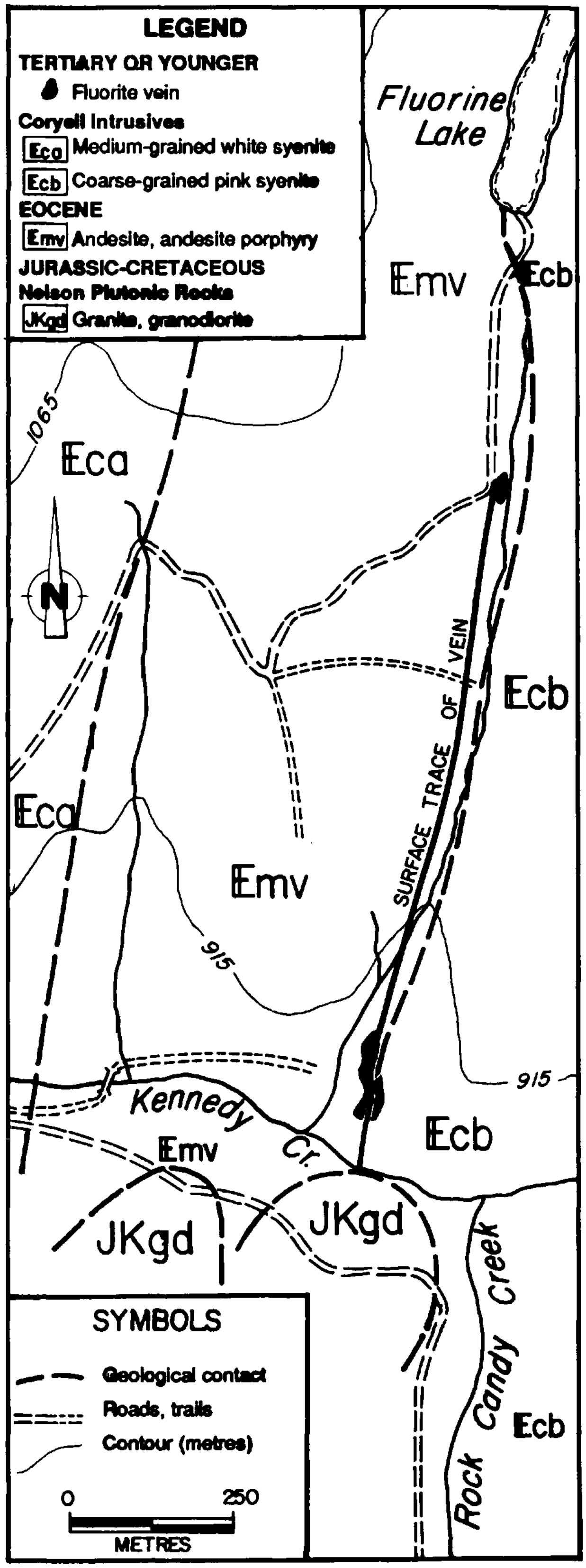


Figure 3-1-2. Geology of the Rock Candy Mine area. Compiled from field mapping by Pell, 1988.

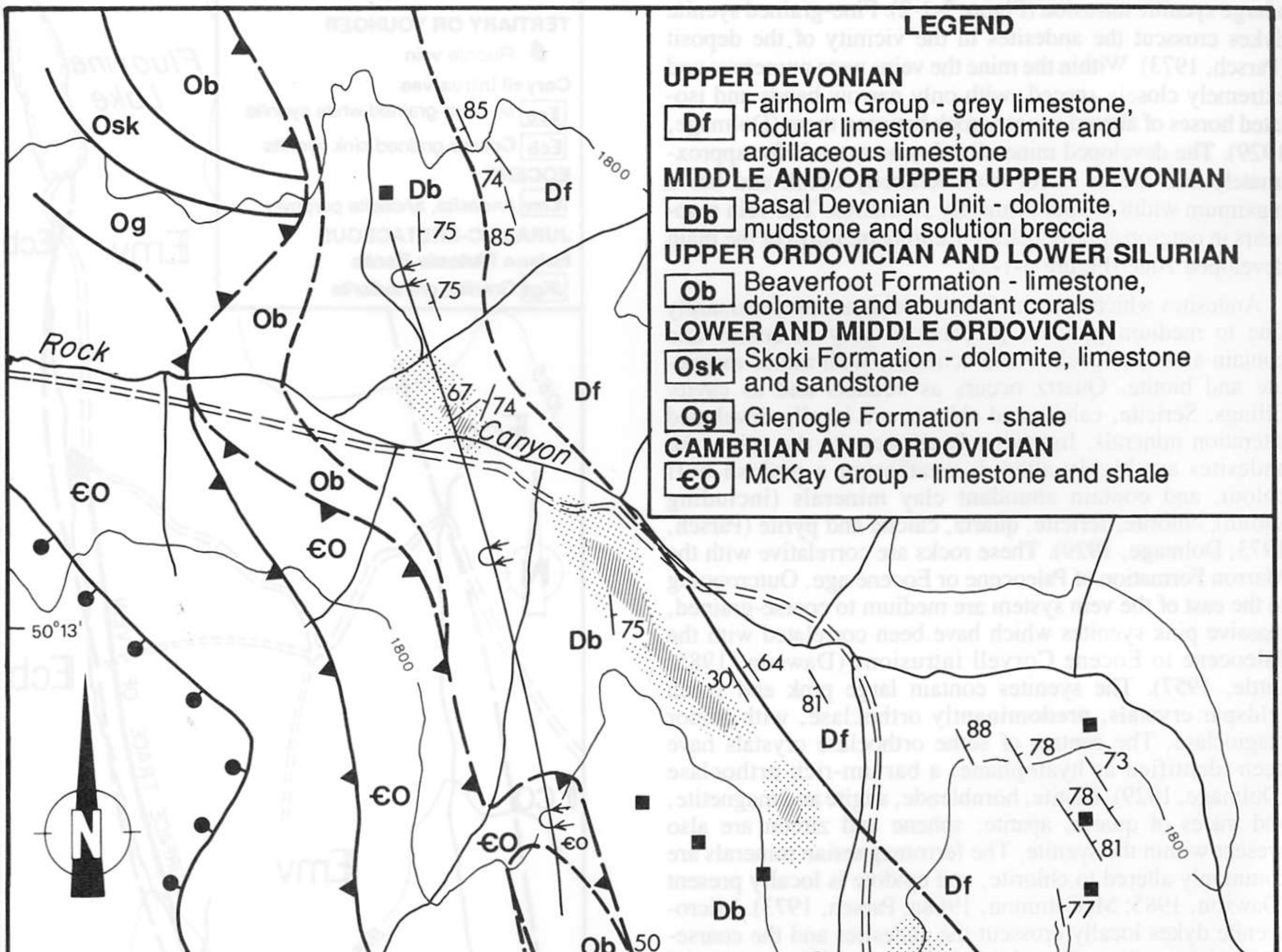


Figure 3-1-3. Geology of the Rock Canyon Creek fluorite rare-earth showing. Modified from Pell and Hora (1987) and Mott *et al.* (1986).

Numerous 4 to 5-centimetre fluorite veinlets, subparallel to the main vein, cut the altered volcanic rocks.

Approximately 1 kilometre north of the main showing, the fluorite mineralization is again exposed in outcrop. In this area a vein, 1 metre wide, cuts altered volcanics. The vein consists of massive pale purple and pale green fluorite cut by quartz veins and a breccia consisting of angular fluorite fragments, a few centimetres in size, in a matrix of small quartz crystals. Small vugs lined with quartz crystals are abundant. A significant linear structure connects this showing with the main workings and extends for some distance to the north and south. Drilling has indicated that fluorite mineralization is intermittently developed along the fracture zone; however, no economic grades were reported any distance from the main workings (Parsch, 1973).

Age and Genesis

The Rock Candy deposit is an epithermal vein system occupying dilatant fissures in a north-trending fracture system. Mineralization postdates the Paleocene to Eocene volcanic rocks in which it is hosted. Based on the fact that the Coryell syenite contained barium-rich feldspars and that fluorite had been found in related dykes, Dolmage (1929) suggested that the solutions from which the fluorspar veins were deposited were produced by fractionation and differentiation during the cooling and crystallization of the syenitic magma.

ROCK CANYON CREEK (DEEP PURPLE; MINFILE 082JSW018)

The Rock Canyon Creek property (Candy and Deep Purple claims) is located in the Main Ranges of the Foreland Belt, near the headwaters of Rock Canyon Creek approximately 40 kilometres east of Canal Flats, at 50°12′ north, 115°08′ west. It is accessible by conventional vehicles along the White River and Canyon Creek forestry roads, which join Highway 3A, 2 kilometres south of Canal Flats. The main mineralized zone lies between the 1525 and 2000-metre elevations in a valley that has been burnt-over and subsequently logged. Access is excellent, but exposure poor due to thick drift cover.

History

The prospect was discovered in 1977 during a regional exploration program carried out by Rio Tinto Canadian Exploration Limited in search of Mississippi Valley-type lead-zinc mineralization. Between 1977 and 1979, mapping, soil and rock geochemistry and trenching were done to assess the fluorspar-lead-zinc potential of the property (Bending, 1978; Alonis, 1979). More recent work (Graf, 1981, 1985) attempted to establish the economic potential of the property in terms of other commodities. During this latter work it was discovered that the property also contained anomalous rare-earth element (REE) concentrations. There has been no drilling on this property and the subsurface extent of mineralization is unknown.

Geology

The Rock Canyon Creek area is underlain by a Cambro-Ordovician to Middle Devonian carbonate-domiuated sequence (Leech, 1979). The southwestern boundary of the property is marked by a west-dipping thrust fault which places Cambrian and Ordovician strata over younger rocks (Figure 3-1-3). The remainder of the area is underlain by an overturned to upright homoclinal sequence, younging to the east. This succession comprises coral-rich limestones of the Ordovician Beaverfoot Formation in the northwest, unconformably overlain by buff-weathering dolomites and solution breccias of the basal Devonian unit which are, in turn, conformably overlain by fossiliferous and nodular grey limestones of the Fairholm Group. The fluorspar and rare-earth element mineralization is stratabound, hosted mainly by the basal Devonian unit.

Four main types of fluorite mineralization are identifiable in the field (Pell and Hora, 1987). The first and most widespread consists of disseminations and fine veinlets of dark purple fluorite in a dark brown to dark orange-brown-weathering dolomitic matrix. Fluorite content generally varies from 2 to greater than 10 per cent of the rock and chemical analyses indicate CaF_2 values of 2.5 to 12.78 per cent (Graf, 1985). Bastnaesite ($CeCO_3F$) often occurs along the margins of fluorite veins, as does coarse crystalline dolomite. Disseminated pyrite, gorceixite [$(Ba,Ca,Ce)Al_3(PO_4)_2(OH)_3H_2O$], calcite, limonite, illite and barite are common accessory minerals (Hora and Kwong, 1986). Parisite [$CaCe_2(CO_3)_3F_2$] has also been identified from fluorite veins with scanning electron microscopy, and may be associated with bastnaesite. Neutron activation analyses of up to 2.3 per cent rare-earth elements and 2.7 per cent barium have been reported (Graf, 1985). Niobium, strontium and yttrium are also present in measurable amounts (Pell, 1987). Contacts between mineralized and unmineralized dolomitic rocks are gradational; the amount of fluorite veining decreases and the colour of the rocks changes gradually from dark brown to buff, the characteristic colour of unaltered dolomites in the area. This type of mineralization defines a northwest-trending zone mappable for over a kilometre, subparallel to strike (Figure 3-1-3).

The second, and highest grade type of fluorspar mineralization consists of massive, fine-grained purple and white fluorite, which commonly comprises greater than 40 per cent of the rock, together with accessory prosopite [$CaAl_2(F,OH)_3$], gorceixite, pyrite and minor barite, calcite, rutile and kaolinite (Hora and Kwong, 1986). Chemical analyses (Graf, 1985; Pell, 1987) indicate CaF_2 contents for this type of mineralization of between 24.6 and 70.65 per cent. The rare-earth element and pyrite contents of these rocks are relatively low. Massive fluorite mineralization has not been found in place, but abundant float occurs at the southeast end of the zone of Type 1 mineralization, near the north-flowing branch of Rock Canyon Creek (Figure 3-1-3).

Fine-grained purple fluorite disseminated in white calcite, which is locally interbedded with buff-weathering dolomite and forms the matrix of solution breccias, constitutes the third type of mineralization. Fluorspar is present in concentrations from trace amounts to a few per cent. Minor rare-earth element enrichment is also reported (Graf, 1985). This type of mineralization is found randomly distributed throughout the basal Devonian unit.

The fourth type of fluorspar mineralization occurs in rocks tentatively assigned to the Devonian Fairholm Group and is

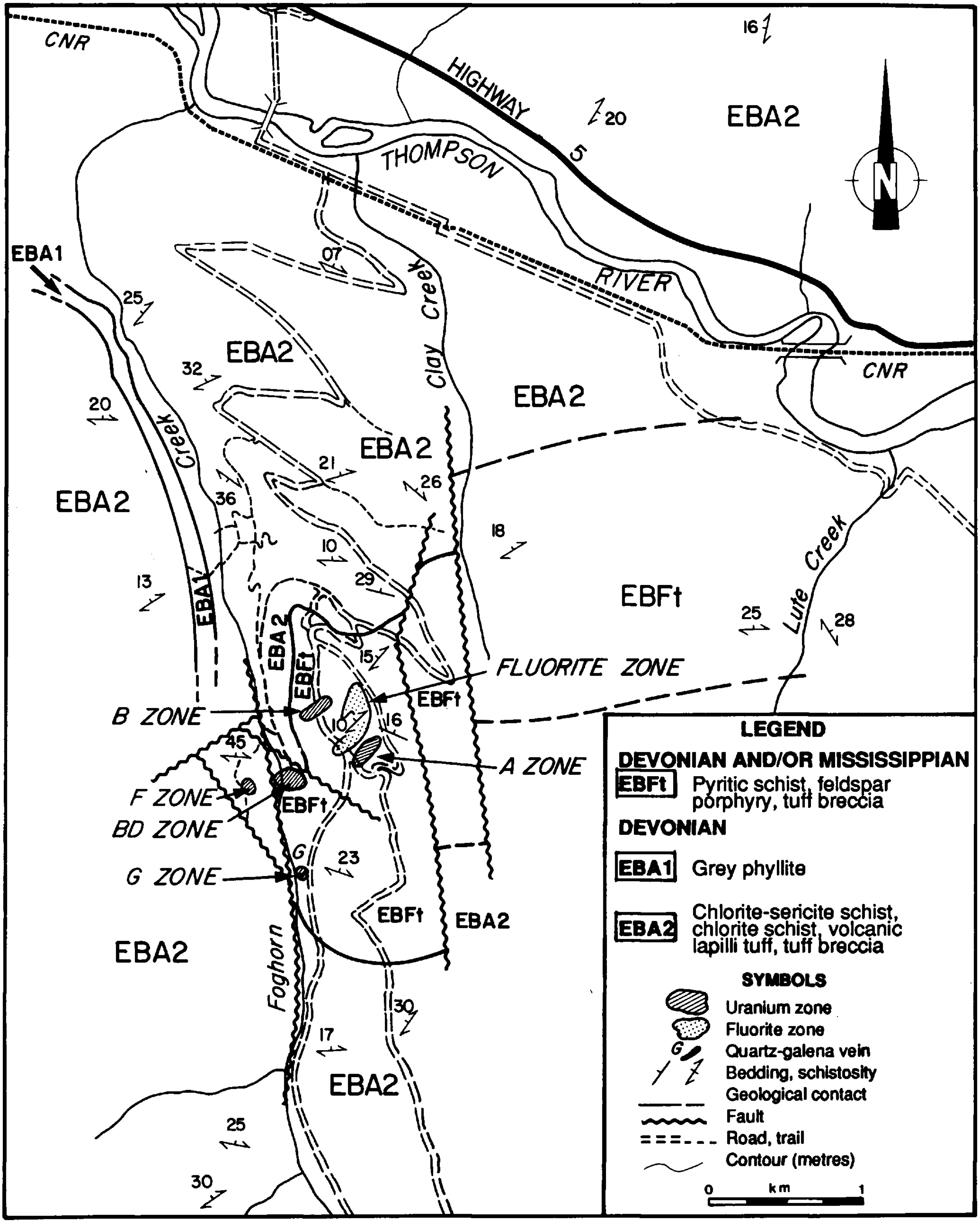


Figure 3-1-4. Generalized geology of the Rexspar property. Modifed from Descarreaux, 1986, Lund, 1973; Preto, 1978 and mapping by Pell, 1988.

found in one locality, at the 2135-metre elevation on the ridge east of the headwaters of Rock Canyon Creek (Figure 3-1-3). Massive purple fluorite forms the matrix of an intraformational conglomerate and constitutes greater than 20 per cent of the rock. Minor barite, pyrite and magnetite are also associated with this type of mineralization.

AGE AND GENESIS

A carbonatite-related origin has been suggested for the Rock Canyon Creek prospect (Graf, 1985; Hora and Kwong, 1986; Pell and Hora, 1987). This interpretation appears to be consistent with preliminary geochemical data. In addition to high fluorine, rare-earth elements and barium, the rocks are enriched in Fe_2O_3, MnO, MgO, strontium, yttrium, phosphorus and niobium, and have chondrite-normalized rare-earth element abundance patterns typical of carbonatites. Due to the lack of unequivocal igneous material and the gradational contacts of the mineralized zone with fresh carbonates, it is believed that it comprises metasomatically altered (fenitized) Devonian carbonate rocks, possibly related to a deep-seated alkaline intrusion.

Timing of metasomatism is poorly defined. Mineralization apparently occurred prior to the Jura-Cretaceous deformation, as no fluorite is observed west of the west boundary fault, and postdated at least part of the deposition of the basal Devonian unit. This broadly defines a time span of 280 Ma during which mineralization must have occurred. Some mineralization (Types 3 and 4, fluorite associated with solution breccias and intraformational conglomerate matrix) may have resulted from elemental remobilization, and therefore may postdate the Type 1 and 2 fluorite/rare-earth deposits. It has been suggested that mineralization may have been synchronous with deposition of the basal Devonian unit (Graf, 1985). A slightly younger age is favored as most other carbonatites in the province are Devono-Mississippian to Early Mississippian (*circa* 350 to 380 Ma) in age (Pell, 1987).

REXSPAR (MINFILE 082M 007, 21, 22, 34, 43)

The Rexspar deposit is located in the Omineca Belt, approximately 130 kilometres north of Kamloops and 5 kilometres south of the town of Birch Island, latitude 51°34′ north, longitude 119°54′ west. It is reached by the Foghorn Mountain logging road, south from Birch Island. The mineral deposits occur on Red Ridge, which leads down from Granite Mountain between Foghorn and Clay creeks, at elevations of 1250 to 1370 metres (4100 to 4500 feet). The terrain is rugged and forested; however, numerous outcrops are exposed along roads, trails, trenches, creeks and cliff sections.

HISTORY

Fluorite on the Rexspar property was originally discovered and staked in 1918; lead-silver showings were found in 1926 and a bog manganese prospect was discovered north of the other showings in 1929 (Joubin and James, 1957; McCammon, 1950, 1955; Wilson, 1929). Work on the property was sporadic until the 1940s when drilling was undertaken to define the extent of fluorite mineralization. The presence of uranium on the Rexspar property was discovered in 1949 after which extensive drilling and underground work, during the 1950s, outlined three zones of uranium mineralization, the A, B, and BD or Black Diamond zones, in addition to the original fluorite zone. From 1969 to 1976, surface work and diamond drilling was done on the property, after which time it has only received minor attention. Between 1943 and 1976, approximately 17 280 metres of drilling was completed which, together with underground work, defined combined reserves of 1 114 380 tonnes of 0.077 per cent U_3O_8 in the three uranium zones. The fluorite zone has an estimated 1 441 820 tonnes of ore averaging 23.46 per cent CaF_2 (Descarreaux, 1986; Preto, 1978).

GEOLOGY

The rocks in the vicinity of Birch Island are part of the Eagle Bay assemblage (Figure 3-1-4), which ranges in age from Lower Cambrian to Mississippian. The strata which host the Rexspar deposit are assigned to Unit EBFt of the Eagle Bay and are considered to be of Devono-Mississippian age (Schiarizza and Preto, 1987). These rocks are correlative with the strata which host the Rea Gold volcanogenic massive sulphide-barite deposit in the Adams Plateau area to the east (Schiarizza and Preto, 1987). They comprise a shallow-dipping package of pyritic lithic tuffs and breccias of trachytic composition, locally with some rhyolite and dacite members. These rocks are light greenish to rusty weathering and have white, light grey or light green fresh surfaces and may be massive to strongly foliated; the foliated varieties are best described as sericite-albite-quartz-pyrite schists. In thin section, they comprise albite and potassium feldspar phenocrysts in a fine-grained matrix of predominantly albite and sericite. Where lithic clasts are present, they are generally of similar composition to the enclosing schists. In the vicinity of the A and BD mineralized zones polylithic breccias with feldspar porphyry fragments and fragments of fine-grained dark rocks are present (Preto, 1978). To the south and east of G zone (Figure 3-1-4), fine to medium-grained massive rocks crop out and may represent intrusive phases. Coarse breccias are also locally present.

Underlying the trachytic tuff and breccia package (Unit EBFt) is a sequence of chlorite schists, spotted sericite schists, sericite-chlorite schists, argillaceous phyllites and sandstones (Unit EBA of Schiarizza and Preto, 1987). The schists are believed to be of metavolcanic origin; the clearly metasedimentary rocks are distinctly less abundant within this unit. No mineralization occurs within this lower package.

Uranium and fluorite mineralization are found exclusively in the upper part of the trachytic lithic tuff and breccia package (Unit EBFt). The fluorite zone measures approximately 400 metres by 50 metres, with an average true thickness of 24 metres (Descarreaux, 1986). It is hosted in a fine-grained, brecciated, tuffaceous trachyte which locally contains layers with abundant lithic fragments and is highly silicified, albitized and rich in pyrite. Fluorite occurs as dark purple, coarse-grained fragments or fine, disseminated grains, which give the rock an overall purple colour. On the weathered surface, the coarse-grained, dark purple fluorite fragments give the rock the appearance of a lithic tuff and could be replaced rock fragments. Fluorite veins, a few centimetres to tens of centimetres wide, containing banded white to purple fluorite ± quartz ± barite, are locally present within this zone. Molybdenite, celestite, strontianite, chalcopyrite, galena and bastnaesite have been identified from this zone. The fluorite deposit apparently grades laterally into a dark rock composed of mica, pyrite and 5 to 10 per cent fluorite.

The main zones of uranium mineralization loosely define a semicircular ring surrounding the fluorspar zone to the south, southwest and northwest (Figure 3-1-4). The high-grade uranium-bearing rocks are fine grained, dark grey to black and contain abundant pyrite and fluorphlogopite, up to 10 per cent fluorite and minor calcite (Preto, 1978; Descarreaux, 1986). This type of mineralization is generally conformable to layering and schistosity in the tuffs. Material from the A-zone dumps consists of strongly banded, pyrite-rich rocks that display textures not unlike those found in volcanogenic massive sulphide deposits; banded pyrite-fluorite and pyrite-fluorite-mica rocks locally show contorted bedding, fragmented sulphide layers and sulphide (rip up?) clasts. Locally fluorite veins crosscut the layered mineralization.

Low-grade uranium mineralization is characterized by coarse-grained, silver-grey fluorphlogopite in replacement zones with pyrite and minor fluorite and calcite. These replacement zones may be a few centimetres to a few metres in size, and may be either conformable or discordant, randomly oriented patches. In the G zone (Figure 3-1-4), fluorphlogopite replacements are associated with brown-weathering carbonate-filled fractures and larger carbonate pods or sweats in fragmental volcanic rocks. In this area, quartz-galena veins, up to a few tens of centimetres thick, and pyrite-filled shears or fracture zones are also present.

A number of uranium-thorium minerals are reported in uranium zones, including uraninite, torbernite, metatorbernite, thorianite and thorite. These minerals are commonly found as inclusions in fluorphlogopite crystals or as discrete grains in the pyrite-fluorphlogopite matrix. Other accessory minerals include monazite, bastnaesite (a rare-earth fluorocarbonate), niobian ilmenorutile, apatite, celestite, galena, sphalerite, chalcopyrite, molybdenite, scheelite and barite (Preto, 1978).

Age and Genesis

Mineralization at Rexspar is believed to be syngenetic with the host rocks, and therefore Devono-Mississippian in age. Preto (1978) suggests that the pyrite-mica zones and the uranium mineralization were formed by deuteric volatile-rich fluids during the late stage in the formation of the trachyte unit. The presence of related intrusive rocks, rhyolites and coarse breccias may indicate proximity to a volcanic vent. The distinct banded textures and sulphide clasts in the A zone support a volcanogenic origin. Discordant mineralization could have been produced by late fluids cutting slightly earlier formed rocks. Early workers had suggested the alternate hypothesis that mineralization was related to nearby Cretaceous granitoids.

Radiometric dating has not provided conclusive results. Potassium-argon analyses of mica from a coarse pyrite-mica rock indicated a 236 ± 8 Ma age; gas extraction during the analysis was poor, and this is considered to be a minimum age for mineralization (Morton *et. al.*, 1978). Although the data do not indicate a Middle Paleozoic age, they rule out any relationship with the Cretaceous granitic rocks. Lead-lead ages of galenas from the Rexspar deposit fall between Middle Jurassic and Tertiary (Goutier, 1986). These are considered problematic due to the highly radiogenic lead component generated by the nearby mineralization.

Studies of fluid inclusions in fluorite from the uranium zones (Morton *et al.*, 1978) indicate that two types of primary inclusions are present, one containing aqueous liquid plus vapour and one containing aqueous liquid plus liquid carbon dioxide plus vapour. It is considered likely that the uranium was transported as carbonate complexes in a weakly saline system charged with carbon dioxide of volcanic origin. As the solutions neared surface, the sudden pressure drop and concomitant effervescence and release of carbon dioxide would result in the precipitation of uranium minerals at or near the surface (Morton *et. al.*, 1978), supporting the volcanogenic hypothesis.

Only one type of fluid inclusion is present in fluorite from the fluorite zone; inclusions containing aqueous liquid plus vapour. There is no evidence for the presence of a carbon dioxide rich phase. The lack of carbon dioxide in the system probably resulted in the inability of the fluids to mobilize or transport uranium and therefore the absence of uranium in the fluorite zone. This apparent difference in the composition of the fluids also suggests that the fluorite zone may have formed at a slightly different time than the uranium zones, possibly after an incursion of meteoric water into the system (Morton *et. al.*, 1978).

EAGLET (MINFILE 093A 046)

The Eaglet fluorspar property is located in the Omineca Belt, on the east side of Quesnel Lake approximately 3.5 kilometres northeast of the junction of the North Arm and the main Lake, at latitude 52°33′ north and longitude 121°00′ west. Access is from Williams Lake by road, through the town of Horsefly, to the south shore of Quesnel Lake, a distance of 125 kilometres. From the south shore, a boat may be taken 8 kilometres across the lake to the mouth of Barrett Creek which is on the fluorspar property. Outcrops in the area are sparse; however, some fluorite mineralization is exposed on the slopes between Barrett Creek and Quesnel Lake, and in the Barrett Creek canyon at elevations of 760 to 915 metres (2500 to 3000 feet).

History

The fluorite showing on Barrett Creek was discovered by a prospector in 1946. Preliminary work was done on the property in the mid 1960s and from 1973 to 1983 extensive exploration involving surface work, drilling, driving of two adits and underground drilling was carried out (Ball and Boggaram, 1984; McCammon, 1966).

Geology

Fluorspar mineralization occurs in the Quesnel Lake gneiss, a granitic orthogneiss of Late Devonian to Early Mississippian age, (Mortensen *et al.*, 1987), near its contact

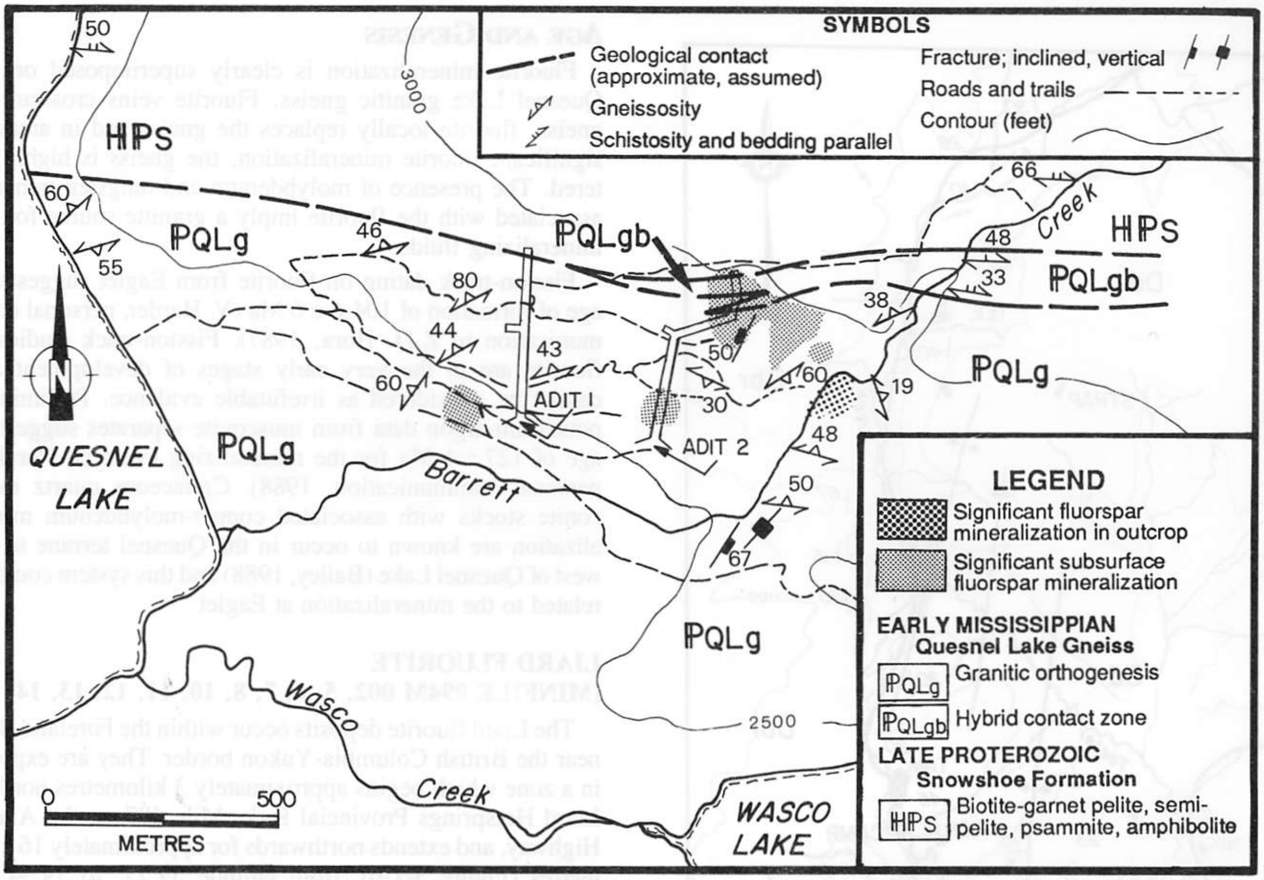


Figure 3-1-5. Geological map of the Eaglet Fluorspar Prospect. Compiled from field mapping by Pell, 1988 and drill data from Company and Assessment Reports.

with Late Proterozoic Snowshoe Group metasedimentary rocks (Figure 3-1-5). In the vicinity of the fluorite showings, the gneiss is medium grained, grey to rusty weathering, with a white to pink fresh surface. It is composed predominantly of feldspars and quartz with 5 to 10 per cent biotite and displays a weakly developed gneissosity. Biotite-rich bands, pegmatitic segregations and aplitic dykes are all locally present within the gneiss. At one locality, pink-weathering carbonate sweats were observed parallel to gneissosity. Fluorite is ubiquitous, occurring as grains disseminated throughout the gneiss in amounts from trace quantities to a few per cent, and traces of molybdenite are also locally present.

Near Barrett Creek, the Quesnel Lake gneiss is bordered to the north by biotite-garnet pelites, semipelites, garnet amphibolites and minor marbles of the Snowshoe Group. The contact of the gneiss and the metasediments strikes nearly east-west and has a shallow northerly dip, with the metasediments structurally overlying the gneiss. Relationships exposed in outcrops in the Barrett Creek canyon clearly show that this is an intrusive contact; apophyses of the granitic gneiss crosscut the metasediments and large xenoliths of metasediment are included within the gneiss near its margins.

Fluorite, in addition to disseminated grains, occurs as thin films on fractures in the gneiss, as veins up to 10 centimetres thick and as pods and irregular replacements up to 30 by 50 centimetres in size. Most fluorite exposed in outcrop varies from pale purple to black in colour. In Barrett Creek, near the contact of the gneiss and metasediments, coarse-grained calcite-fluorite-galena veins, 15 to 20 centimetres wide, are exposed. Sphalerite and tetrahedrite are reportedly associated with the calcite-fluorite-galena veins (Ball and Boggaram, 1984).

Economic concentrations of fluorspar are not evident at surface; however, drill holes and adits have encountered significant mineralization. A number of drill holes have intersections of between 9 and 21 metres of 11.5 to 19.5 per cent CaF_2. Adit 2 (Figure 3-1-5) also intersected significant mineralized zones and reserves in the vicinity of this adit are estimated at 1.8 million tonnes of 15 per cent CaF_2 (Ball and Boggaram, 1984). The fluorspar from the adit is medium to fine grained and predominantly white to cream in colour; some pale green, pale bluish grey and light to dark purple fluorite is also present. Texturally, the fluorspar varies from massive to sugary and interspersed with quartz and potassium feldspar. Associated minerals include muscovite, pyrite, molybdenite (up to 5 per cent), calcite, chalcopyrite and possibly barite. Galena, sphalerite, wolframite, scheelite and celestite have also been reported (Ball and Boggaram, 1984; McCammon, 1966). The sugary fluorite-quartz-feldspar rock grades into altered granitic gneiss which is generally pink to rusty in colour and contains pyrite, hematite, chlorite and, locally, a few per cent molybdenite.

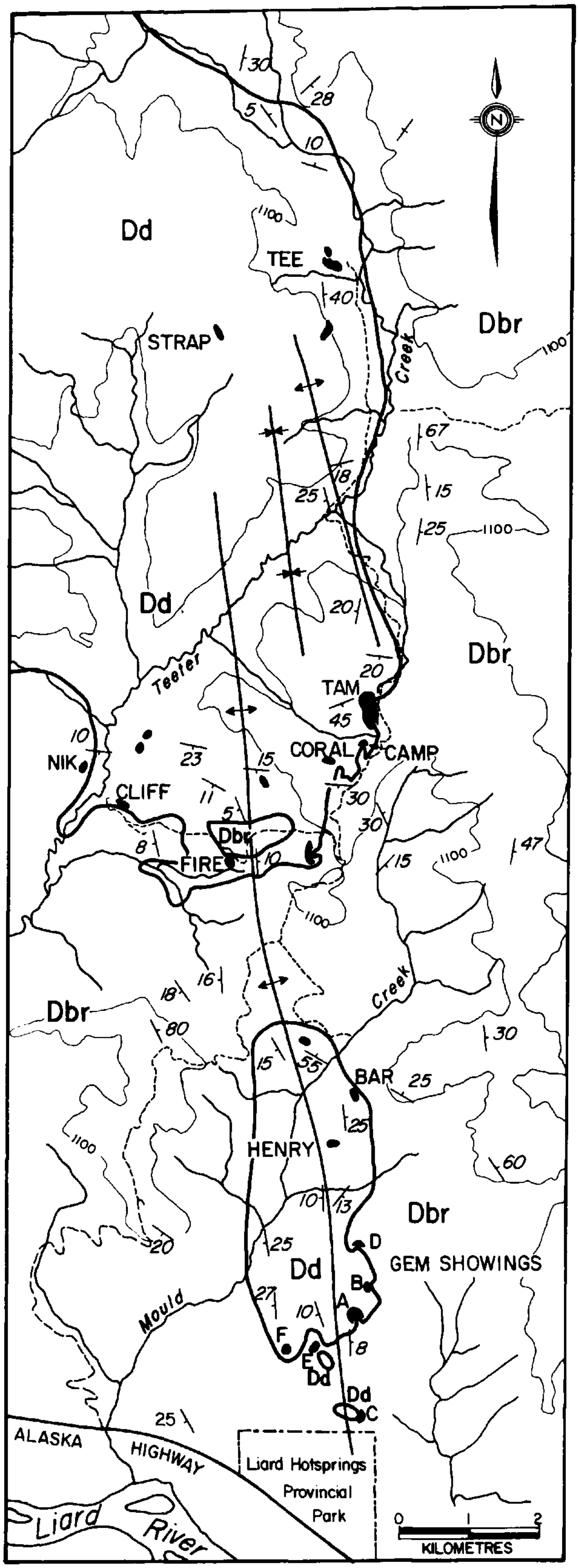


Figure 3-1-6. Generalized geology of the Liard Fluorspar showings. Modified from Woodcock, 1972 and Woodcock and Smitheringale, 1955.

Age and Genesis

Fluorite mineralization is clearly superimposed on the Quesnel Lake granitic gneiss. Fluorite veins crosscut the gneiss, fluorite locally replaces the gneiss and in areas of significant fluorite mineralization, the gneiss is highly altered. The presence of molybdenum and tungsten minerals associated with the fluorite imply a granitic source for the mineralizing fluids.

Fission-track dating on fluorite from Eaglet suggests an age of formation of 104.6 ± 6 Ma (V. Harder, personal communication to Z.D. Hora, 1987). Fission-track studies in fluorite are in the very early stages of development and cannot be considered as irrefutable evidence. Preliminary potassium-argon data from muscovite separates suggest an age of 127 ± 4 Ma for the mineralizing event (J. Harakal, personal communication, 1988). Cretaceous quartz monzonite stocks with associated copper-molybdenum mineralization are known to occur in the Quesnel terrane to the west of Quesnel Lake (Bailey, 1988) and this system could be related to the mineralization at Eaglet.

LIARD FLUORITE (MINFILE 094M 002, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15)

The Liard fluorite deposits occur within the Foreland Belt, near the British Columbia-Yukon border. They are exposed in a zone which begins approximately 3 kilometres north of Liard Hotsprings Provincial Park, Mile 497 on the Alaska Highway, and extends northwards for approximately 16 kilometres (Figure 3-1-6), from latitude 59°27′ to 59°34′30″ north at longitude 126°05′ west. The terrain consists of low, heavily drift-covered rolling hills of the Liard Plateau, and outcrop is sparse. Local karst topography is developed, with sink holes and isolated buttes sporadically distributed. Old roads and trails lead from the Alaska Highway to the showings which are at elevations ranging from 730 to 1100 metres (2400 to 3600 feet); however, in places the trails are so badly overgrown and covered with deadfall that they are virtually impassable, even on foot, and access to the showings is most easily gained by helicopter.

History

The Gem showings, the most southerly of the Liard Hotspring fluorspar occurrences, were discovered in 1953 by

LEGEND

FLUORSPAR SHOWINGS

DEVONIAN OR YOUNGER
BESA RIVER FORMATION

Dbr — Black shale, calcareous shale and minor dolomite

DUNEDIN FORMATION

Dd — Limestone and fossiliferous limestone

SYMBOLS

Bedding (inclined, vertical)

Geological contact

Anticline, syncline trace

Contour (metres)

prospectors in search of uranium mineralization (Holland, 1955). In 1954 work was begun, which included roadbuilding, stripping, drilling and geologic mapping. Regional prospecting in 1971 resulted in the discovery of the northern showings which were drilled and extensively explored during 1971 and 1972. Grades in excess of 30 per cent CaF_2 were encountered over excellent widths and thicknesses (Northern Miner, 1972); however, high predicted production and transportation costs resulted in little work being done after the early 1970s. In 1986, the Liard fluorspar showings were restaked as the Thor claims.

Geology

The area north of Liard Hotsprings is underlain by Middle Devonian Dunedin Formation fossiliferous limestones and Middle to Upper Devonian Besa River shales (Taylor and MacKenzie, 1970). The Dunedin Formation is exposed in the core of a broad, open antiform with an approximately north-trending axis (Figure 3-1-6). It is medium to dark grey in colour and locally extremely fossilliferous, containing abundant colonial corals as well as brachiopods and gastropods. The overlying Besa River Formation consists predominantly of black shales, some calcareous shales and minor, thin buff dolomitic layers. The contact between the shales and limestones is very irregular, possibly as a result of an erosional disconformity or structural complications (Woodcock, 1972).

Mineralization, which consists predominantly of fluorite and witherite, occurs at or near the contact between the shales and the limestones. In most of the showings, the major mineralization occurs in the limestones beneath the contact; in some cases, minor amounts of fluorite and witherite are found in the shales overlying mineralized limestone; and, rarely, such as at the Gem E showings, mineralization is confined to the shales (Woodcock, 1972; Woodcock and Smitheringale, 1955). Fluorite and witherite commonly occur as infillings and replacements in limestone or shale breccias, or as fracture infilling in the surrounding limestones and shales. In some cases, such as at the Tee showing, individual replacement pods, devoid of host rock fragments, are exposed over areas in excess of 50 by 15 metres; at the Tam showing mineralization is exposed over a distance of 275 metres by 50 to 165 metres.

In addition to fluorspar and witherite, mineralized zones contain barytocalcite, minor barite and silica. In most of the deposits the fluorite is purple to black in colour and may be fine or coarse grained. In the Gem A showing (Figure 3-1-6) the fluorite has been bleached to rose and white on exposed surfaces, but is dark purple on fresh surfaces. At the Tee showing, most of the fluorite is colourless, as is reportedly the case at the Cliff prospect (Woodcock, 1972). The witherite is usually white; however, when the mineralization is shale hosted, witherite tends to be grey in colour. In some locations, witherite is more abundant than fluorite, in others, the opposite is the case. Together, they commonly comprise 60 to 75 per cent of the rock. Barite rarely makes up over 10 per cent (Woodcock and Smitheringale, 1955).

Age and Genesis

Fluorspar deposits at Liard Hotsprings consist predominantly of carbonate-breccia-hosted infilling and replacement mineralization. The breccias do not appear to be clearcut paleokarst solution breccias, they may have formed as a result of small-scale dissolution or hydraulic fracturing. In terms of stratigraphic setting and the nature of the host breccias, these showings are similar to the lead-zinc deposits in the Robb Lake–Redfern Lake belt to the south (MacQueen and Thompson, 1978). They are probably genetically similar as well, formed from solutions originating during dewatering of the sedimentary basin, but represent fluorine-barium-rich, sulphur-deficient (barium carbonate rather than barium sulphate present) end-members as opposed to the lead-zinc-sulphur end-member. If this is the case, the Liard Hotspring deposits are probably approximately the same age as the carbonate-hosted lead-zinc deposits in the Robb Lake belt. Lead isotopic evidence suggests that mineralization associated with those deposits formed near 370 ± 30 Ma (Godwin *et al.*, 1982). Fission-track studies in fluorite from the Gem showing suggests an age of formation for the deposit of 332 ± 56 Ma (V. Harder, personal communication to Z.D. Hora, 1987) which, within errors, is in agreement with the lead-lead data from Robb Lake; however, as previously stated, this must be taken with certain reservations.

OTHER FLUORSPAR OCCURRENCES IN SOUTHERN BRITISH COLUMBIA

A large number of fluorspar occurrences exist within the province (Figure 3-1-1), but due to the unfavorable economics of mining in remote areas, only those in the southern part of the province are included in this report. Fluorspar occurrences in the Atlin area should be examined in future studies as proximity to tidewater could make them economically viable. A number of the occurrences in the southern part of the province will be briefly described.

Colonrless to pale green fluorite occurs as small pods near the centre of the Gypo or Oliver silica quarry (MINFILE 082ESW084), north of the town of Oliver at latitude 49°11′40″ north, longitude 119°33′20″ west. The quarry is located on a large quartz body which crosscuts quartz monzonite. It contains few impurities, other than the fluorite pods which have exposed surfaces of 0.5 to 1 metre by 1.5 to 2 metres in size. The silica quarry has operated intermittently since 1926, and in 1958 approximately 29 tonnes of fluorite were shipped from the quarry to markets in Washington (McCammon and James, 1959).

A fluorite occurrence on Whiteman Creek (MINFILE 082LSW001, latitude 50°20′ north, longitude 119°20″ west) near the west shore of Okanagan Lake across from Vernon, was explored for fluorite in the mid-1960s (McCammon, 1968b). Mineralization is exposed over an area of at least 300 by 700 metres and occurs as fracture infillings and drussy quartz-fluorite veins, 1 to 10 centimetres wide on average, in quartz monzonite. Veins are characterized by rapid pinching and swelling and rarely approach 1 metre in width. Open spaces are common and usually lined with small, well-formed fluorite crystals. The fluorspar is most commonly green in colour, although colourless, rose and pale purple varieties are sometimes intermixed with the green. Pyrite is a minor component of the veins and no other sulphides were observed or reported.

Fluorite is a common gangue mineral, together with quartz and siderite, in lead-zinc-silver veins of the Galena Farm mine at Silverton in the Slocan district (MINFILE 082FNW067, latitude 49°56′ north, longitude 117°22′ west). The veins occur predominantly within the Nelson granite, near its northern margin. Mineralization occurs as open-space fillings and fracture coatings. Within the gangue, quartz is present in amounts approximately equal to, or slightly greater than fluorite, and siderite is a minor constituent. The veins commonly have repeated layers of small quartz or fluorite crystals distributed parallel to vein margins; small well-formed fluorite crystals lining drussy openings; or, occasionally, botryoidal accumulations of fluorite adjacent to vein openings. The fluorspar at Galena Farm is colourless to very pale purple. Obvious sulphide minerals present are galena, sphalerite and pyrite, in that order of abundance.

Fluorite is abundant in veins cutting Triassic Nicola Group volcanics on the Redbird Claim, near Stump Lake, south of Kamloops (MINFILE 092ISE179, latitude 50°23′30″ north, longitude 120°22′ west), and has been exploited by mineral collectors since the mid-1960s. Veins in the area vary from a few centimetres to a few metres in width and may comprise crystalline quartz and fluorite, chalcedonic quartz and fluorite, chalcedonic quartz and fluorite breccias cemented by crystalline quartz, and banded chalcedonic quartz, pyrite and minor fluorite. Anomalous gold values have been found associated with some veins in this area (Dekker, 1983). Open spaces are common within the veins and are frequently lined with coarse, crystalline fluorspar. On the Redbird property, the fluorite is predominantly dark purple, but some dark green varieties are also present. In some veins, fluorite occurs along the vein margins adjacent to the Nicola volcanics, in others the fluorite forms the centre of veins with a vein border of chalcedonic quartz. In one vein, dark green fluorite forms a band adjacent to the vein margin, followed by purple fluorite, then banded chalcedony and the vein is cored by crystalline quartz.

A number of other occurrences where fluorspar is present in significant amounts are reported from southern British Columbia including the Tappen Creek (MINFILE 082LNW049) and To (MINFILE 082LNW034) properties near Shuswap Lake and the Howell Creek property (MINFILE 082GSE037), which is associated with syenites in the Flathead region of southeastern British Columbia. Fluorite also occurs as a minor or trace constituent in a number of areas including the Carmi molybdenum, Beaverdell silver-lead-zinc and Ainsworth silver-lead-zinc camps. Fluorite is also reported from Lower Cambrian carbonate-hosted stratiform lead-zinc deposits in the Monashee Complex near Revelstoke (the Ruddock Creek deposit) and from molybdenum deposits in the Jordan Creek–Mount Copeland area, also near Revelstoke.

CONCLUSIONS

Fluorspar mineralization in British Columbia occurs in a wide range of geologic environments, tectonic settings and ages. Fluids (volatiles) are always important in the mineralizing process. Where fluorspar deposits are associated with igneous systems, late-stage differentiated fluids released fractionated during crystallization and often enriched in incompatible elements (be it granitic or alkaline systems) play an important role.

In British Columbia, five significant fluorspar prospects are known. The Rock Candy orebody, a vein deposit of probable late Tertiary age associated with the Coryell intrusions, is in the southern Omineca Belt and has a history of past production. The Deep Purple prospect on Rock Canyon Creek, in the Foreland Belt, southern British Columbia, is a metasomatic replacement deposit interpreted to be related to a carbonatite-alkaline intrusive system. Mineralization at Deep Purple is probably Devono-Mississippian to Early Mississippian in age. The Rexspar deposit, which is located along the western margin of the Omineca Belt, south-central British Columbia, comprises separate zones of fluorspar and uranium mineralization of volcanogenic origin, related to alkaline tuffs. Mineralization at Rexspar is considered to be syngenetic with the host rocks which are Devono-Mississippian in age. The Eaglet fluorspar prospect consists of veins and replacements of Cretaceous age in the Quesnel Lake gneiss, at the western margin of the Omineca Belt in central British Columbia. The Foreland Belt of northern British Columbia contains the carbonate-hosted Liard fluorspar deposits which are apparently related to carbonate-hosted lead-zinc deposits further to the south and formed by dewatering of the sedimentary basin in the Late Devonian.

Numerous other showings occur throughout the province, but the major deposits are confined to the Omineca and Foreland belts, which suggests that these areas are most favourable for future exploration. Some deposits with abundant fluorspar are reported from the Atlin area in the Intermontane Belt; this area also warrants exploration attention. Of the known fluorspar deposits, the Rexspar property appears to have the best immediate potential. It is well located, close to the necessary infrastructure, has well-developed access and significant proven reserves of minable grades near surface. There are, however, environmental concerns due to proximity to known uranium mineralization.

In 1986, the United States imported 389 000 tonnes of fluorspar and 103 000 tonnes of hydrofluoric acid. About one half of these imports came from South Africa. Trade restrictions with South Africa may provide an opportunity for Canadian producers of low-phosphorous and low-arsenic fluorspar to penetrate the American market. Under the Free Trade agreement, the tariff on Canadian fluorspar imports to the United States will be removed in 1989 (Michel Prud'homme, personal communication to Z.D. Hora, 1988) which also will encourage new producers.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Canada/British Columbia Mineral Development Agreement for funding this project; Cominco Ltd. for providing access to company files on the Rock Candy mine; and Lee Whitney (Caretaker, Rock Candy mine) and Andy Halvorson (Caretaker, Eaglet Mines) for their helpfulness, chestnuts and cherry tomatoes.

REFERENCES

Alonis, E. (1979): Fluorite Claims, Golden Mining Division, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 7830.

Bailey, D.G. (1988): Geology of the Central Quesnel Belt, Hydraulic, South-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 147-153.

Ball, C.W. and Boggaram, G. (1984): Geology and Development of Eaglet Mines Limited, Quesnel Lake, British Columbia, Unpublished Report, 20 pages.

Bending, D. (1978): Fluorite Claims, Golden Mining Division, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 6978.

Clarke, G. (1987): The World's Fluorspar Industry: Following the Market, *Industrial Minerals*, March 1987, pages 17-39.

Dawson, K.R. (1985): Geology of Barium, Strontium and Fluorine Deposits in Canada, *Geological Survey of Canada*, Economic Geology Series, Report 34, 136 pages.

Dekker, L. (1983): Assessment Report, Drill Hole MG83-1, Microgold Claim, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 11397.

Descarreaux, J. (1986): The Rexspar Fluorite and Uranium Deposits, *in* Uranium Deposits of Canada, E.L. Evans, Editor, *Canadian Institute of Mining and Metallurgy* Special Volume 33, pages 305-308.

Dolmage, V. (1929): Rock Candy, *in* Fluorspar deposits of Canada, M.E. Wilson, Editor, *Geological Survey of Canada*, Economic Geology Series, No. 6, pages 23-28.

Freeland, P.B. (1920): Rock Candy Group, *B.C. Minister of Mines*, Annual Report 1919, pages 164-165.

Gabrielse, H. (1962): Geology, Rabbit River, British Columbia, *Geological Survey of Canada* Map 46-1962.

Godwin, C.I., Sinclair, A.J. and Ryan, B.D. (1982): Lead Isotope Models for the Genesis of Carbonate-hosted Zn-Pb, Shale-hosted Ba-Zn-Pb, and Silver-rich Deposits in the Northern Canadian Cordillera, *Economic Geology* Volume 77, pages 82-94.

Goutier, F.M. (1986): Galena Lead Isotope Study of Mineral Deposits in the Eagle Bay Formation, Southeastern British Columbia, Unpublished M.Sc. thesis, *The University of British Columbia.*

Graf, C. (1981): Geochemical Report, Candy Claim, Golden Mining Division, NTS 82J/3E, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 9960.

——— (1985): Geological Report on the DP 1, 2, 3 and Candy Claims, Rare-earth Element–Fluorite Prospect, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 14677.

Harben, P. (1985): North American Fluorspar, *Industrial Minerals*, November 1985, pages 37-43.

Holland, S.S. (1955): Fluorite-Witherite: Gem, *B.C. Minister of Mines*, Annual Report 1954, pages A178-179.

Hora, Z.D. and Kwong, Y.T.J. (1986): Anomalous Rare Earth Elements (REE) in the Deep Purple and Candy Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1985, Paper 1986-1, pages 241-242.

Joubin, F.R. and James, D.H. (1957): Rexspar Uranium Deposits, *in* Structural Geology of Canadian Ore Deposits, *Canadian Institute of Mining and Metallurgy* Congress Volume, pages 85-88.

Leech, G.B. (1979): Kananaskis Lakes Map Area, *Geological Survey of Canada*, Open File 634.

Little, H.W. (1957): Geology of Kettle River, East Half, British Columbia, *Geological Survey of Canada*, Map 6-1957.

MacQueen, R.W. and Thompson, R.I. (1978): Carbonate-hosted Lead-zinc Occurrences in Northeastern British Columbia with Emphasis on the Robb Lake Deposit, *Canadian Journal of Earth Sciences*, Volume 15, pages 1737-1762.

McCammon, J.W. (1950): Fluorite: Spar 1 and Spar 2, *B.C. Minister of Mines*, Annual Report 1949, pp 250-255.

——— (1955): Birch Island, fluorite-celestite-uranium, *B.C. Minister of Mines*, Annual Report 1954, pages 108-111.

——— (1966): Fluorite: Eaglet Group, *B.C. Minister of Mines*, Annual Report 1965, pages 263-264.

——— (1968a): Rock Candy, *B.C. Minister of Mines*, Annual Report 1967, pages 305-308.

——— (1968b): Whiteman Creek Fluorite, *B.C. Minister of Mines*, Annual Report 1967, pages 303-305.

McCammon, J.W. and James, A.R.C. (1959): Oliver Silica Quarry, *B.C. Minister of Mines*, Annual Report 1958, pages 104-106.

Mortensen, J.K., Montgomery, J.R. and Fillipone, J. (1987): U-Pb Zircon, Monazite and Sphene Ages for Granitic Orthogneiss of the Barkerville Terrane, East-central British Columbia, *Canadian Journal of Earth Sciences*, Volume 24, pages 1261-1266.

Morton, R.D., Abut, A. and Ghandi, S.S. (1978): Fluid Inclusion Studies and Genesis of the Rexspar Uranium-fluorite Deposit, Birch Island, British Columbia, *in* Current Research, Part B, *Geological Survey of Canada* Paper 78-1B, pages 137-140.

Mott, J.A., Dixon, J.M. and Helmstaedt, H. (1986): Ordovician Stratigraphy and the Structural Style at the Main Ranges-Front Ranges Boundary near Smith Peak, British Columbia, *in* Current Research, Part B, *Geological Survey of Canada*, Paper 86-1B, pages 457-465.

Parsch, K.O. (1973): Exploration Drilling, Cominco's Rock Candy Fluorspar Property. Unpublished Internal Report, *Cominco Ltd.*

Pelham, L. (1985): Fluorspar, *in* Mineral Facts and Problems, *United States Department of the Interior, Bureau of Mines*, Bulletin 675, pages 277-290.

Pell, J. (1987): Alkaline Ultrabasic Rocks in British Columbia: Carbonatites, Nepheline Syenites, Kimberlites, Ultramafic Lamprophyres and Related Rocks, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-17, 109 pages.

Pell, J. and Hora, Z.D. (1987): Geology of the Rock Canyon Creek Fluorite/Rare Earth Element Showing, Southern Rocky Mountains, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 255-258.

Preto, V.A. (1978): Geology of the Rexspar Deposit, *Canadian Institute of Mining and Metallurgy*, Bulletin 71, No. 800, pages 82-88.

Schiarizza, P. and Preto, V.A. (1987): Geology of the Adams Plateau-Clearwater-Vavenby Area, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1987-2, 88 pages.

Taylor, G.C. and MacKenzie, W.S. (1970): Devonian Stratigraphy of Northeastern British Columbia, *Geological Survey of Canada*, Bulletin 186.

Wilson, M.E. (1929): Fluorspar Deposits of Canada, *Geological Survey of Canada*, Economic Geology Series, No. 6, 97 pages.

Woodcock, J.R. (1972): Geology of the Liard Fluorspar Project, Mineral Claims TEE, TAM, FIRE, WEST, GEM, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 3975.

Woodcock, J.R. and Smitheringale, W.V. (1955): Geology of the Liard Fluorite Property, GEM Mineral Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 109.

FELDSPAR AND NEPHELINE SYENITE POTENTIAL IN BRITISH COLUMBIA

By G.V. White

KEYWORDS: Industrial minerals, feldspathic materials, pegmatite, feldspathic sand, nepheline syenite, phonolite, feldspar.

INTRODUCTION

Feldspathic materials are used in the glass and ceramic industries as a source of alkalis, alumina and silica. These elements affect the rate and temperature of melting, fluidity of the melt and physical properties of the finished product. Silica, sodium, potassium and alumina ratios in the feldspar product vary for each industrial user, however, iron must be limited to less than 0.1 per cent and other heavy metals such as copper and manganese must be virtually absent in the commercial product.

Glass manufacturers demand a product with grain-size in the range −40+100 mesh while ceramic producers require finer material at −200 or −325 mesh. The glass industry requires materials which are free of refractory minerals such as corundum, spinel or mica. Table 3-2-1 lists chemical analyses of some feldspathic and aluminous materials and demonstrates the wide range of products acceptable to manufacturers.

There is currently no production of feldspar or nepheline syenite in western Canada and British Columbia imports feldspathic sand from Idaho and nepheline syenite from Ontario. Market research indicates that, with an aggressive marketing strategy, there is good potential to replace imports and develop additional markets on the west coast and in Pacific Rim countries (MeVey, 1988).

During 1987 the Geological Survey Branch carried out a review of nine occurrences of feldspar-rich or nepheline syenite rocks. Seven sites are discussed in this report; two prospects, Hellroaring Creek and Lumby have been described previously (White, 1988a and b). The mapping and sampling program was followed by mineral processing tests at CANMET laboratories of Energy, Mines Resources Canada in Ottawa. The sites were chosen on the basis of access and the presence of pegmatite, feldspathic sand, nepheline syenite or phonolite.

This preliminary report describes these occurrences and their physical characteristics, and evaluates their potential as a commereial source of feldspar or nepheline syenite. A more detailed Open File report on feldspar/nepheline syenite is planned. All the sites are situated in southern British Columbia; most are near established transportation networks (Figure 3-2-1).

Results indicate the Scuzzy Creek and Trident Mountain sites can produce feldspathic product which will meet commercial specifications for glass and ceramic manufacturing and are similar to material currently imported (Table 3-2-1). The Lumby and Hellroaring Creek sites, which contain glass/ceramic grade feldspathic materials, (White, 1988a and b) are presently being evaluated by industry.

PEGMATITES

COPPER MOUNTAIN (MINFILE 092H 090)

Coarse-grained pegmatite occurs in an oval-shaped intrusive body which measures 1200 by 2000 metres, in the core of the Copper Mountain stock, approximately 16 kilometres south of Princeton (Figure 3-2-1; No. 3).

Ten grab samples selected from fresh-looking, coarse-grained (greater than 5 millimetres), orange to white perthosite, collected from outcrops west of the Similkameen River were analyzed with the following results:

Major oxides	Range Weight %
SiO_2	61.70 - 64.70
Al_2O_3	19.35 - 20.98
Fe_2O_3	0.21 - 1.19
CaO	0.18 - 1.93
Na_2O	4.54 - 8.49
K_2O	2.80 - 9.94

These results indicate the rock is potentially suitable as a source of feldspar and on this basis a 20-kilogram sample was sent to CANMET for beneficiation to further assess its potential. Results are summarized below.

Magnetic Separation Mesh	Weight %
−10 + 100 (magnetic)	2.0
−10 + 100 (nonmagnetic)	86.1
−100	11.9

The nonmagnetic fraction comprised 86 per cent of the sample, with a product size acceptable to industry. Consequently, a flotation test to reduce mica-iron levels followed with the following results:

Flotation Test Product	Weight %
Slimes	13.9
Mica-iron concentrate	0.4
Feldspar concentrate	18.2
Tailings	67.5

Approximately 80 per cent of the sample reported as slimes or tailings and only 18 per cent was recovered in the feldspar concentrate. The feldspar concentrate was passed over the magnetic separator and was then analyzed with the following results:

Major oxides	Feldspar concentrate Weight %	Nonmagnetic concentrate Weight %
SiO_2	61.70	61.40
Al_2O_3	18.60	18.80
Fe_2O_3	0.31	0.34
CaO	0.52	0.50
Na_2O	6.71	6.84
K_2O	6.14	5.99

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

TABLE 3-2-1
TYPICAL ANALYSES, FELSPATHIC AND ALUMINOUS MATERIALS*

Soda Flotation Feldspar, Spruce Pine, NC		Potash Flotation Feldspar, Kings Mountain, NC		Dry Ground Feldspar, Custer, SD	
SiO_2	67.54%	SiO_2	67.04%	SiO_2	71.84%
Al_2O_3	19.25	Al_2O_3	18.02	Al_2O_3	16.06
Fe_2O_3	0.06	Fe_2O_3	0.04	Fe_2O_3	0.09
CaO	1.94	CaO	0.38	CaO	0.48
MgO	Trace	MgO	Trace	MgO	Trace
K_2O	4.05	K_2O	12.10	K_2O	7.60
Na_2O	6.96	Na_2O	2.12	Na_2O	3.72
Loss	0.13	Loss	0.30	Loss	0.20
Feldspathic Sand, Bessemer City, NC		**Low Iron Aplite, Montpelier, VA**		**Canadian Nepheline Syenite Nephton, Ont., Canada**	
SiO_2	79.20%	SiO_2	63.71%	SiO_2	61.40%
Al_2O_3	12.10	Al_2O_3	21.89	Al_2O_3	22.74
Fe_2O_3	0.06	Fe_2O_3	0.09	Fe_2O_3	0.06
CaO	0.52	CaO	5.70	CaO	0.70
MgO	Trace	MgO	Trace	MgO	Trace
K_2O	2.62	TiO_2	0.43	K_2O	4.95
Na_2O	4.80	K_2O	2.37	Na_2O	9.54
Li_2O	0.35	Na_2O	5.60	Loss	0.60
Loss	0.35	Loss	0.21		

* From Lefond, 1983

Although the original samples are high in alumina (up to 20.98 per cent), beneficiation tests could not reduce the iron content below 0.31 per cent with liberation less than 100 mesh.

Economic Potential

Chemical analyses of grab samples collected from the core of the Copper Mountain stock indicate the rock is potentially a source of feldspathic material suitable to glass and ceramic manufacturers. However, benefication tests indicate a low recovery rate of nonmagnetic feldspar concentrate and an unacceptably high iron content in the final product. It is concluded that the stock has poor potential for the production of feldpsathic materials meeting industry requirements.

SUMAS MOUNTAIN (MINFILE 092G 037)

A white to light grey, fine-grained (less than 1 millimetre) aplite intrudes Middle Jurassic Harrison Lake acidic flows approximately 9 kilometres northeast of Abbotsford, near Sumas Mountain (Figure 3-2-1; No. 4). Examination of thin

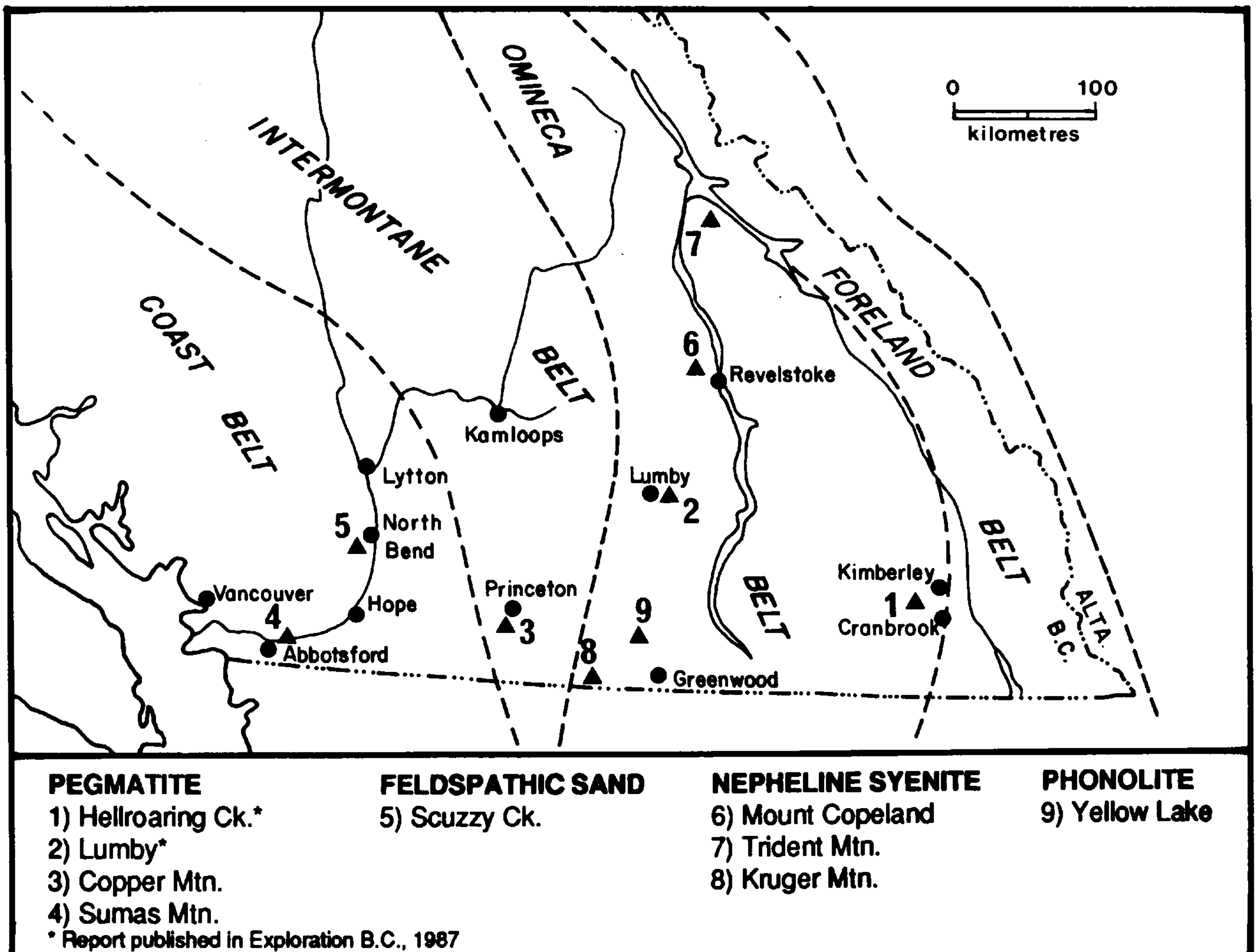


Figure 3-2-1. Feldspar and nepheline syenite occurrences in British Columbia.

sections identified albite and quartz as the main components of the aplite with trace amounts of chlorite also present. Limonite joint-filling is widespread and most likely deposited by circnlating meteoric waters. Incomplete chemical analyses on two samples, collected by Z.D. Hora, are as follows:

Oxides	Weight %
Al_2O_3	15 to 18
Na_2O	approximately 8
Fe_2O_3	0.15 to 0.40

Economic Potential

Preliminary analytical results indicated the aplite might be a potential source of feldspar for glass/ceramic applications. However, a sample sent to CANMET was considered too fine grained for processing tests. Without benefication, contaminants such as iron could not be reduced to levels acceptable to manufacturers.

FELDSPATHIC SAND

SCUZZY CREEK (MINFILE 092H 052)

Large sand deposits, of probable glaciolacustrine origin, are located along Scuzzy Creek and one of its tributaries near North Bend in the Fraser Canyon (Figure 3-2-1, No. 5). The feldspathic sand consists of unconsolidated material 0.06 to 2 millimetres in grain size. The sand is composed of plagioclase and quartz with minor mica and amphibole and ranges in colour from white to light grey or dark brown. The deposits may be up to 1800 by 440 metres in area and up to 60 metres thick. Samples analyzed had the following composition:

Major oxides	Weight %
SiO_2	73.75 - 76.90
Al_2O_3	14.43 - 15.40
Fe_2O_3	0.53 - 0.76
CaO	2.77 - 3.05
Na_2O	4.44 - 4.84
K_2O	0.44 - 0.49

Analyses indicate the sand is potentially suitable for glass applications. On this basis one sample was sent to CANMET for benefication. The first process step – screen analysis, produced the following results:

Screen Analysis Mesh	Weight %
+14	1.5
-14+28	17.1
-28+48	41.5
-48+100	28.1
-100+200	9.2
-200	2.6

Approximately 70 per cent of the grains are between -28 and +100-mesh, a size considered acceptable by glass manufacturers.

The sample was next scrubbed, deslimed and a mica, iron and feldspar float produced. The feldspar concentrate was run over a dry magnetic separator. Results are tabulated as follows:

Flotation Test	Test #1 (Weight %)	Test #2
+20 Mesh	-	4.40
Mica-iron concentrate	1.0	1.20
Feldspar concentrate 1	17.60	19.60
Feldspar concentrate 2	26.50	-
Cleaner tails	3.20	5.0
Tails	35.90	65.30
Slimes, losses	15.80	4.50

Magnetic Separation Major oxides	Test 1 Concentrate 1	Test 1 Concentrate 2 (Weight %)	Test 2
SiO_2	55.80	59.60	58.90
Al_2O_3	20.90	21.90	22.0
Fe_2O_3	0.084	0.084	0.94
CaO	5.52	5.53	4.53
Na_2O	8.41	8.39	8.43
K_2O	0.52	0.45	0.53

Recovery rates for feldspar concentrates are low. After magnetic separation, tested samples are high in alumina and calcium and contain moderate amounts of iron (but less than 0.1 per cent).

Economic Potential

Although recovery rates for feldspar are low, tests indicate the Scuzzy Creek deposits contain material meeting glass manufacturers' requirements. Large indicated volumes of sand available and relatively easy access give the site good potential to produce material for the glass industry.

NEPHELINE SYENITE

MOUNT COPELAND (MINFILE 082M 255)

Nepheline syenite and syenite gneisses crop out in a 6-kilometre band on the southern flank of Mount Copeland, 15 kilometres northwest of Revelstoke (Figure 3-2-1; No. 6). The rock consists of orthoclase with subordinate nepheline and albite and small amounts of amphibole, pyroxene and magnetite. It has a banded texture and contains both fine and coarse-grained zones. For detailed geological descriptions of the Mount Copeland area the reader is referred to Pell, 1987.

Thirty-four samples collected from the deposit were analyzed with the following results:

Major oxides	Weight %
SiO_2	51.30 - 61.26
Al_2O_3	17.27 - 24.38
Fe_2O_3	0.84 - 8.21
CaO	0.04 - 9.61
Na_2O	2.74 - 8.76
K_2O	7.49 - 10.14

These analyses indicate the rocks are a potential source of feldspathic material although most samples are high in iron. To better evaluate the material, two 20-kilogram samples, low in iron, were sent to CANMET for processing. At CANMET they were crushed, run through a dry magnetic separator (-10+100 mesh) and a mica-iron float produced with the following results:

Magnetic Separation (Weight %)	Magnetic	Nonmagnetic	-100 Mesh
Sample 1	40.0	51.0	9.0
Sample 2	23.4	66.3	10.3

Flotation (Weight %)	Slimes	Mica-Iron	Concentrate/float tails Magnetic	Nonmagnetic
Sample 1	15.6	27.9	19.1	36.5
Sample 2	20.0	3.8	28.6	46.6

The nonmagnetic concentrates were then analyzed with the following results:

Major oxides (Weight %)	Separation 1	Separation 2	Flotation 1	Flotation 2
SiO_2	56.20	47.1	54.80	50.70
Al_2O_3	19.20	20.50	18.30	21.10
Fe_2O_3	0.50	1.23	0.19	0.41
CaO	1.27	1.60	0.98	0.80
Na_2O	6.58	6.02	6.44	5.48
K_2O	8.40	9.45	8.76	10.57

Economic Potential

Full liberation is achieved at less than 100 mesh. Samples processed by CANMET contain high levels of iron and titanium which could not be reduced below 0.19 per cent and 0.40 per cent respectively. This makes it difficult to produce nepheline syenite meeting market specifications.

TRIDENT MOUNTAIN (MINFILE 082M 173)

Nepheline syenite gneiss occurs as a concordant lenticular mass at Trident Mountain, approximately 85 kilometres northeast of Revelstoke (Figure 3-2-1; No. 7). The rock is white to grey, medium (1 to 5 millimetres) to coarse-grained (greater than 5 millimetres) and consists of microcline, albite and nepheline with minor biotite, ilmenite, sodalite, cancrinite, calcite, apatite, sphene, pyrochlore and zircon (Pell, 1987). The composition of three samples collected is:

Major oxides	Weight %
SiO_2	55.59 – 63.70
Al_2O_3	20.73 – 24.69
Fe_2O_3	0.17 – 0.59
CaO	0.56 – 1.20
Na_2O	8.16 – 8.39
K_2O	3.12 – 8.22

A 20-kilogram sample sent to CANMET was crushed and passed through a magnetic separator with the following results:

Mesh	Magnetic concentrate (Weight %)	Nonmagnetic concentrate (Weight %)
-10+35	4.1	67.7
-35+100	1.3	19.8
-100	0.5	6.6

Analyses of the nonmagnetic concentrate are:

Major oxides	-10+35 mesh	-35+100 mesh (weight%)	-100 mesh
SiO_2	56.6	58.0	62.0
Al_2O_3	16.8	17.3	18.5
Fe_2O_3	0.07	0.03	0.10
CaO	0.75	0.76	0.95
Na_2O	6.11	5.79	5.63
K_2O	7.59	8.05	8.31

Processing results indicate the nepheline syenite is low in magnetic impurities, has a high recovery rate of nonmagnetic materials and therefore a very good potential to produce commercial grade nepheline syenite. Processing indicates a product brightness of 85 per cent can be obtained.

Economic Potential

Samples tested are comparable to nepheline syenite currently imported into western Canada from Ontario. Geological mapping by Pell (1987) has documented large lenticular bodies of nepheline syenite over a distance of 7 kilometres at Trident Mountain. This large body has excellent potential to contain nepheline syenite similar to the samples tested.

KRUGER MOUNTAIN (MINFILE 082ESW 106)

A large body of medium to coarse-grained nepheline syenite, several square kilometres in size, outcrops between Keremeos and Osoyoos (Figure 3-2-1; No. 8). The rocks are mafic phases of syenite with high iron content which is present mainly as very fine-grained (–200 mesh) disseminated magnetite. Analyses of three samples collected from outcrop of a salic, light-coloured phase exposed on a hilltop west of Kruger Mountain, approximately 9 kilometres west of Osoyoos, gave the following results:

Major oxides	Weight %
SiO_2	49.55– 74.04
Al_2O_3	14.27 - 15.13
Fe_2O_3	0.65 - 11.33
CaO	0.87 - 9.16
Na_2O	2.91 - 3.86
K_2O	4.68 - 5.91

One sample contained 0.65 per cent iron so a 20-kilogram sample was sent to CANMET for processing. It was crushed and middle-range screen fractions were passed through a dry magnetic separator with the following results:

Mesh size	End fractions	Middle-range screen fractions Magnetic (Weight %)	Nonmagnetic (Weight %)
+20	10.3	....	....
-20+28	....	4.1	11.2
-28+35	....	3.4	15.7
-35+140	....	5.5	37.5
-140	12.4	....	....
Totals	22.7	13.0	64.4

Moderate recovery (37.5 per cent) of nonmagnetic material was realized and analyses returned the following results:

Major oxides	-20+28 mesh	-28+35 mesh (Weights %)	-35+140 mesh
SiO_2	64.8	65.3	58.8
Al_2O_3	13.2	12.5	9.8
Fe_2O_3	0.15	0.12	0.09
CaO	0.76	0.75	0.68
Na_2O	4.08	4.02	3.59
K_2O	6.72	6.10	5.47

Economic Potential

The samples contain low alumina (up to 13.2 per cent) and high iron, indicating the rock has a limited potential to meet commercial specifications for glass and ceramic applications.

PHONOLITE

YELLOW LAKE (MINFILE 082E/SW-191)

Phonolite lava flows in the Yellow Creek member of the Eocene Penticton Group (Church, 1980, 1982; Figure 3-2-1, No. 9) outcrop north of Keremeos and Rock Creek. The rock consists of fine-grained pyroxene-rich mafic lava with locally well-developed plagioclase and aegirine-augite phenocrysts. Twelve samples collected from different outcrops were analyzed to evaluate whether the rock is a potential source of feldspar for industrial applications. Results are as follows:

Major oxides	Weight %
SiO_2	50.07 - 64.67
Al_2O_3	13.63 - 19.49
Fe_2O_3	3.30 - 6.93
CaO	1.46 - 8.47
Na_2O	3.05 - 5.86
K_2O	4.42 - 6.97

All samples tested contain high amounts of iron. The sample with the least iron was sent to CANMET for processing to determine whether impurities could be reduced to industry standards but the rock was considered to be too fine grained for mineral separation studies.

ECONOMIC POTENTIAL

Based on chemical analyses and evaluation by CANMET, the sites sampled have no potential for containing glass/ ceramic grade material.

SUMMARY AND CONCLUSIONS

Based on field investigations, chemical analyses and processing studies, on samples from the seven sites described here, one, Trident Mountain, has excellent potential to produce glass/ceramic feldspar/nepheline syenite. The Scuzzy Creek feldspathic-sand deposit offers a product suitable for coloured glass applications but at relatively low recovery rates. Two other sites reported on in an earlier publication have good to excellent potential – Lumby and Hellroaring Creek (White 1988a and b).

Results presented in this paper are based on limited field investigation and laboratory studies. Mapping and sampling of outcrops is required to fully evaluate the potential of each site.

ACKNOWLEDGMENTS

I would like to express thanks to the Mineral Processing Laboratories of CANMET in Ottawa, and in particular Grant Feasby, for carrying out mineral preparation and processing tests. I would also like to acknowledge Danny Hora of the British Columbia Geological Survey Branch for suggesting the study and for contributing to and reviewing the text of this paper. David Hannay provided capable and cheerful field assistance throughout the project.

REFERENCES

Church, B.N. (1980): Geology of the Rock Creek Tertiary Outlier, *B.C. Ministry of Energy, Mines and Petroleum Resources* Preliminary Map 41.

——— (1982): Geology of the Penticton Tertiary Outlier, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Revised Preliminary Map 35.

Lefond, S.J. (1983): Industrial Minerals and Rocks, *Society of Mining Engineers – American Institute of Mining, Metallurgical and Petroleum Engineers Inc.*, New York, Volume 1 and 2, 5th Edition.

McVey, H. (1988): A Study of Markets for British Columbia's Nepheline Syenite and Feldspathic Minerals, MDA Report 4, *B.C. Ministry of Energy, Mines and Petroleum Resources*, 92 pages.

Pell, J. (1987): Alkaline Ultrabasic Rocks In British Columbia; Carbonatites, Nepheline Syenites, Kimberlites, Ultramafics, Lamprophyres and Related Rocks, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1987-17.

White, G.V. (1988a): Hellroaring Creek Pegmatite, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, pages B109-B116.

——— (1988b): Lumby Pegmatite, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia 1987, pages B117-B125.

NOTES

WOLLASTONITE OCCURRENCES IN BRITISH COLUMBIA

By G.V. White

KEYWORDS: Industrial minerals, wollastonite, calc-silicate skarn, metasomatic, filler.

INTRODUCTION

Wollastonite is an important mineral filler in paints and ceramic products. Presently most wollastonite used in North America (approximately 1 million short tons per year) is supplied by NYCO a division of Processed Minerals Inc. from New York State (Power, 1986). With the restrictions on the use of asbestos in the United States, an increased demand for wollastonite for short-fibre filler applications should be anticipated.

There is no record of wollastonite production in British Columbia and deposits have not been systematically documented. Limited geological mapping, sampling, petrographic examinations and semiquantitve evaluations of wollastonite were undertaken at selected sites during the 1988 field season (Figure 3-3-1).

Five sites, Sechelt, Little Billy mine, Fintry Point, Silence Lake mine and Horsethief Creek have potential to contain mineable reserves of wollastonite. This paper describes these occurrences and documents their size and physical characteristics.

Analytical and processing tests on bulk samples collected from each site are required to evaluate the economic potential of each deposit. These tests will determine recovery rates, brightness, aspect ratio (ratio between length of the crystal and its width), loss-on-ignition, iron content and other chemical and petrographic parameters.

SNAKE BAY AND WORMY LAKE DEPOSITS (MINFILE 092G 052, 053)

Drilling by Tri-Sil Minerals Incorporated during 1987/88 on a wollastonite skarn near Snake Bay, 5 kilometres north of Sechelt, has outlined a continuous body of wollastonite mineralization approximately 150 metres wide and up to 100 metres in depth, along a strike length of 450 metres (Figure 3-3-2). Possible and probable drill-indicated reserves are 291 000 tonnes of wollastonite (Goldsmith and Kallock, 1988).

Near Wormy Lake (local name), approximately 2.5 kilometres north-northwest of the Snake Bay deposit, wollastonite crops out intermittently over a distance of 600 metres. Preliminary mapping has documented these outcrops but no further work has been done (Figure 3-3-3).

GEOLOGY

Both the Snake Bay and Wormy Lake wollastonite are hosted by a north-trending limestone belt (Karmutsen Formation?) in a roof pendant within the Coast plutonic complex. Calc-silicate assemblages include wollastonite, two types of garnet, and diopside, found in varying proportions and randomly distributed throughout the skarn. A brief description of rock types at Snake Bay follows:

Limestone: Light to dark grey, fine to medium-grained, thinly bedded to massive crystalline limestone crops out in the north half of the skarn. Discontinuous, alternating light and dark grey beds between 1 and 5 centimetres thick strike east to northeast, dipping 50 to 80 degrees north and northwest. In places beds are isoclinally folded, plunging 50 degrees west. In siliceous zones boudins of quartz may be replaced by wollastonite, garnet or calcite, most often near contacts with intrusive rocks.

Skarn: Green, grey, brown to brownish black, fine to medium-grained banded skarn crops out throughout the property. Associated minerals include wollastonite, brown and black garnets, diopside, epidote, and occassionally pyrite and chalcopyrite. Remnant limestone beds up to 10 centimetres thick strike east to northeast and dip north or south 50 to 85 degrees.

Diorite: Diorite crops out east, west and south of the skarn and apophyses extend into the sediments. It is medium to coarse grained and consists of 60 to 70 per cent hornblende and biotite with minor pyrite and chalcopyrite.

Dykes: Greenish black to black andesite dykes between 0.5 and 3 metres wide intrude skarn, limestone and diorite. They generally strike west to southwest, dip steeply northwest at 65 and 90 degrees, and consist of a fine-grained groundmass with phenocrysts of plagioclose and/or hornblende. Contacts with host rocks are well defined. Where dykes intrude limestone, rock is thermally altered to marble (within 3 metres) and may contain wollastonite and/or garnet.

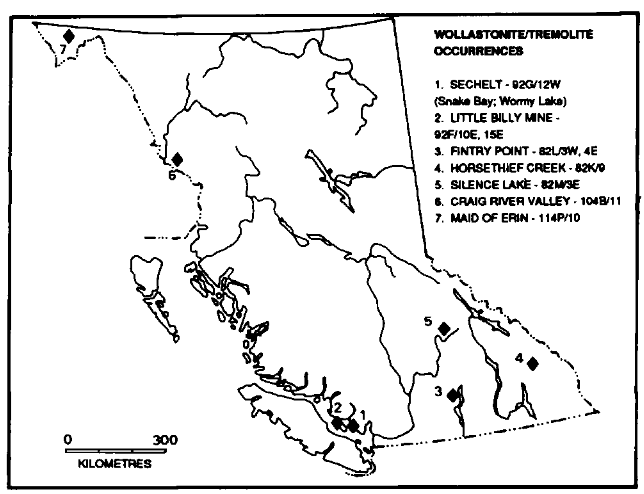


Figure 3-3-1. Wollastonite/tremolite occurrences in British Columbia.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

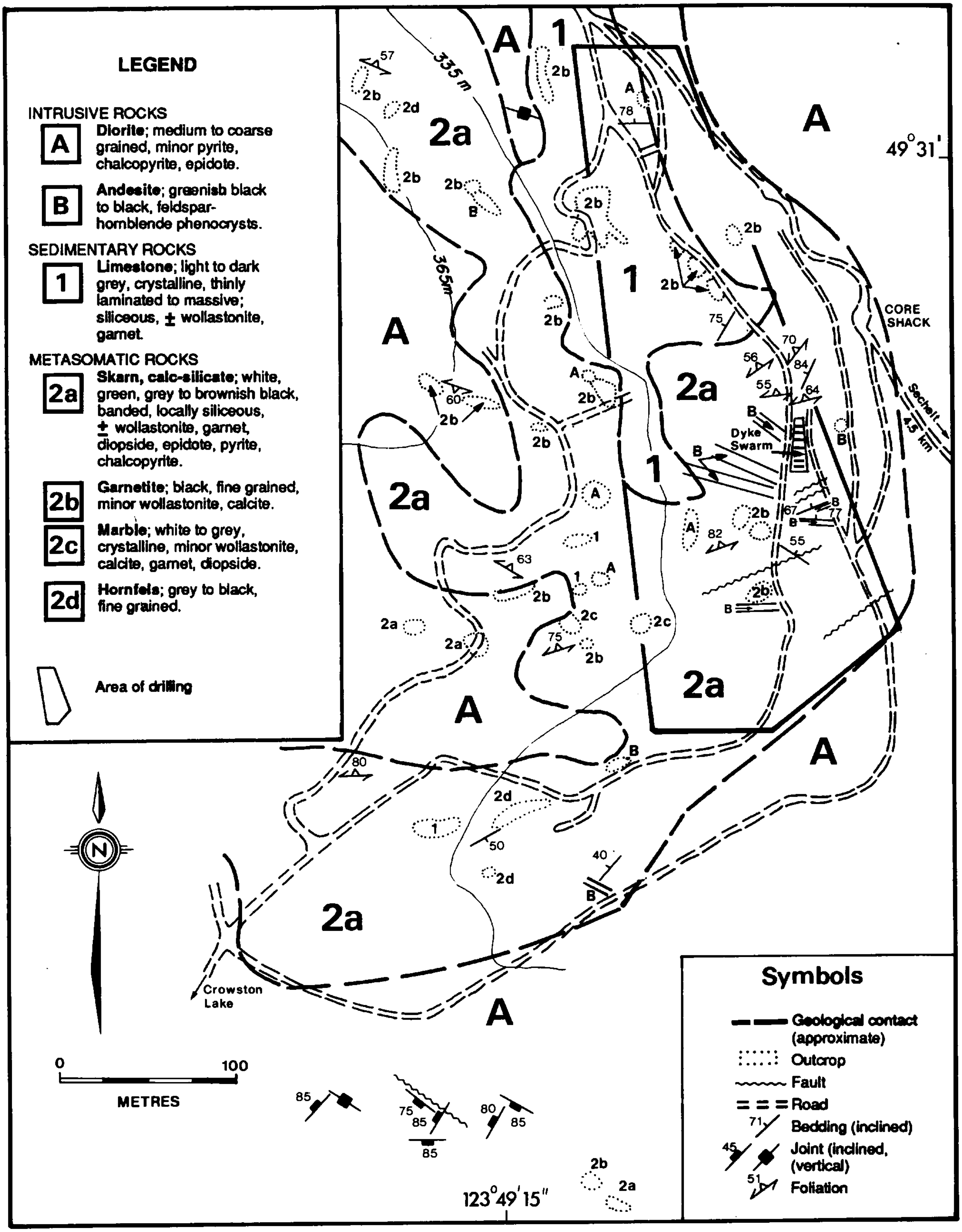


Figure 3-3-2. Snake Bay wollastonite-garnet skarn.

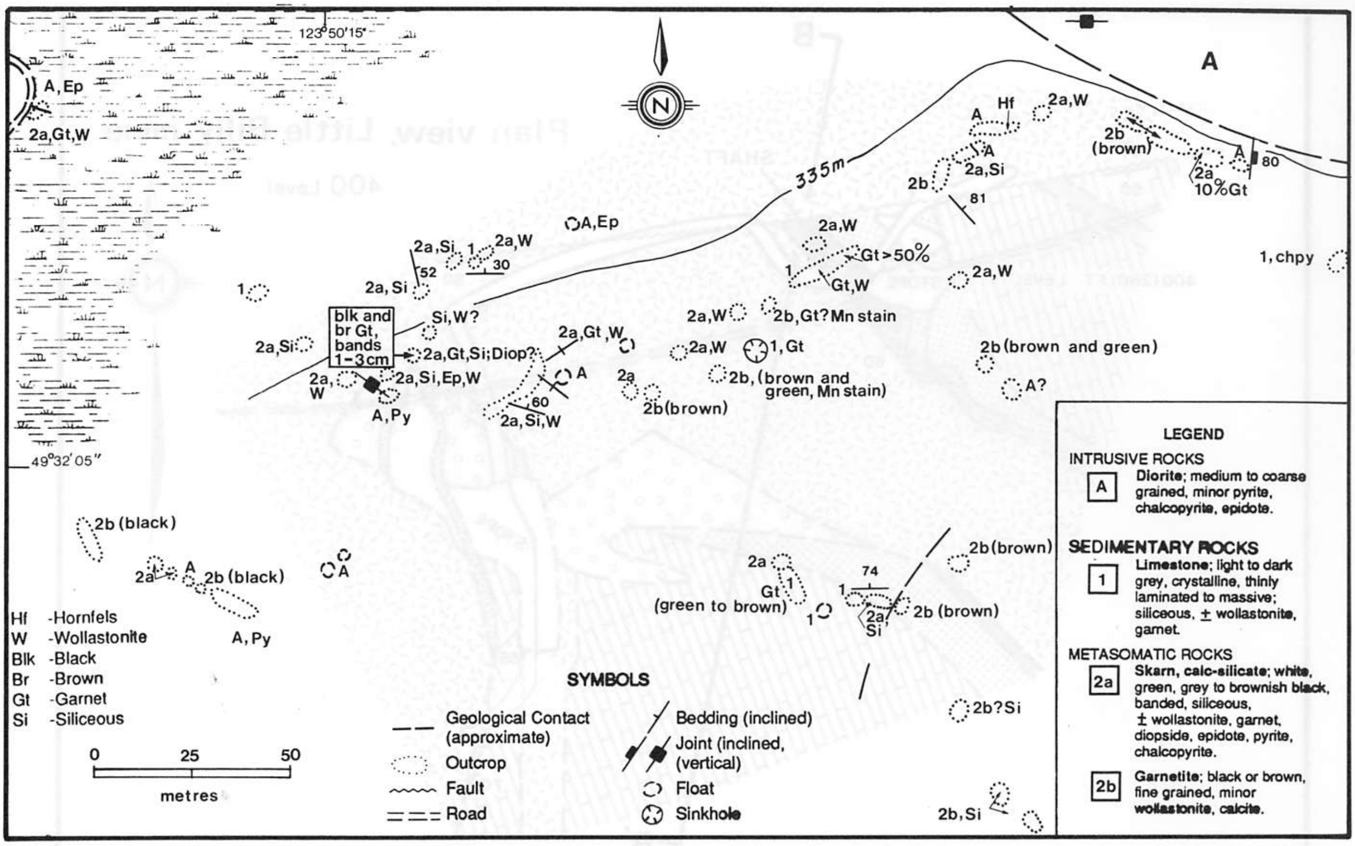


Figure 3-3-3. Wormy Lake – geological ourcrop map.

Plate 3-3-1. Snake Bay – white wollastonite and brown garnet (dark grey in photo) replacing limestone.

Plate 3-3-2. Snake Bay – white "augens" of wollastonite replacing grey crystalline limestone.

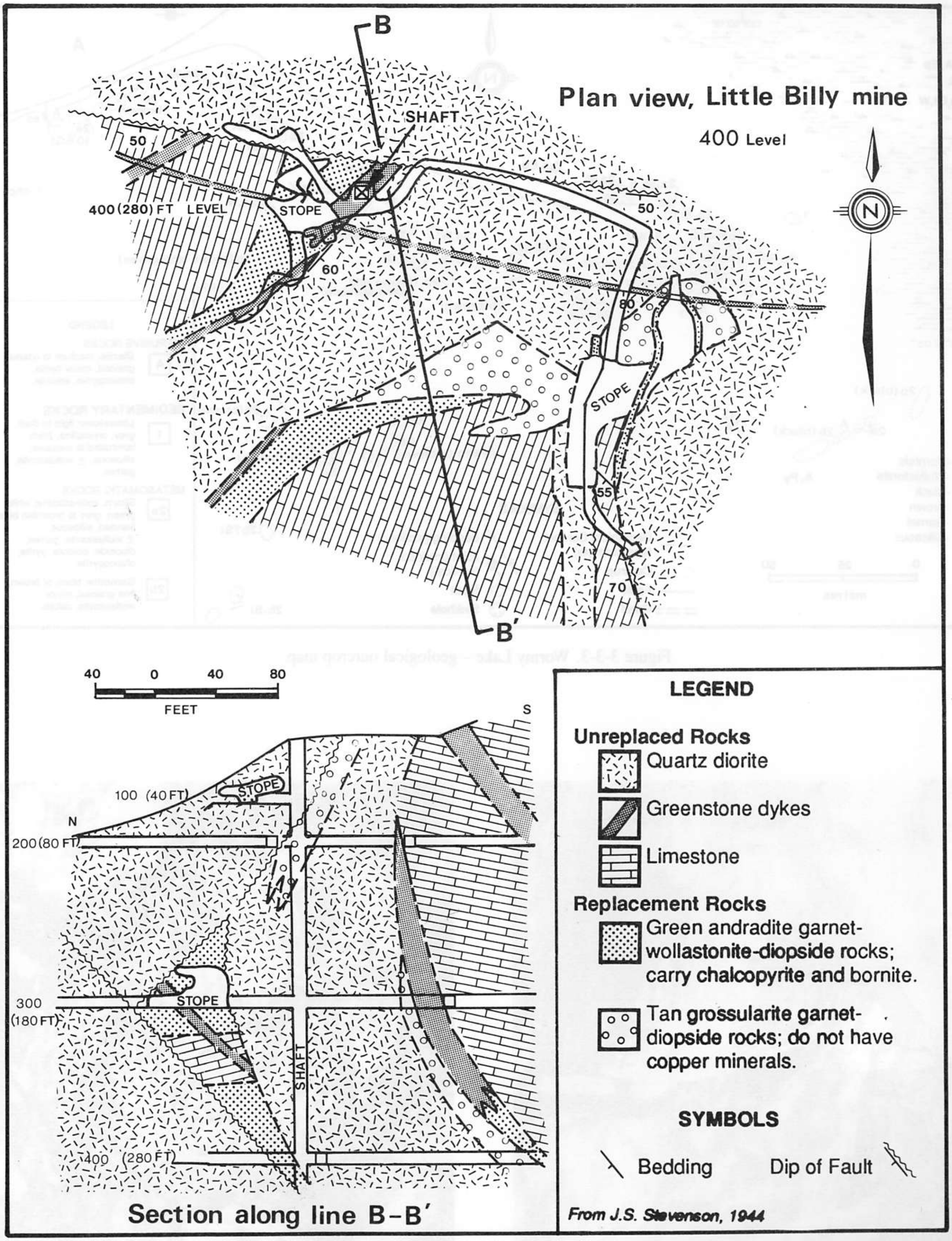


Figure 3-3-4. Little Billy mine – wollastonite occurs in replacement rocks.

Calc-silicate rocks: Wollastonite and garnet occur in parallel alternating bands which suggests preferential replacement of carbonate beds of slightly different chemical composition. The more siliceous units form wollastonite and the argillaceous beds are replaced by garnet (Plates 3-3-1 and 3-3-2). Wollastonite replaces carbonate randomly; fibres less than 1 millimetre long occur in bands up to 8 centimetres thick. Determining the percentage of wollastonite relative to carbonate in the field is difficult, and grade varies from 5 to 75 per cent. Brown to green garnet (grossularite?) forms bands up to 20 centimetres thick. A fine-grained black variety, andradite(?), occurs in isolated pods and lenses of garnetite.

Rocks at Wormy Lake are similar to those at Snake Bay. Outcrop distribution in the mineralized area at the southeast end of the Lake is shown in Figure 3-3-3.

LITTLE BILLY MINE (MINFILE 092F 105)

A 30-kilogram sample of massive white wollastonite was collected for processing studies from waste dumps at the abandoned Little Billy mine near Vananda on the northeast shore of Texada Island (Figure 3-3-1).

No wollastonite mineralization crops out at the mine but J.S. Stevenson (1945) reports zones of wollastonite skarn are present in the mine between the 100 and 400-foot levels, along the contacts between quartz diorite and limestone of the Quatsino Formation (Figure 3-3-4). The zone plunges 45 degrees south along the contact and consists of coarse-bladed wollastonite, garnet, diopside, bornite, chalcopyrite, pyrite, molybdenite, magnetite, sphalerite, galena, scheelite, gold and silver. Wollastonite-garnet textures indicate these phases crystallized simultaneously and are of metasomatic origin (Ettlinger and Ray, 1988). Reserve estimates based on Stevenson's 1944 report, indicate approximately 100 000 tonnes of wollastonite-rich skarn is present in the old mine workings.

FINTRY POINT (MINFILE 082L 014)

Wollastonite skarn crops out 6 kilometres west of Fintry point on the west shore of Okanagan Lake approximately 27 kilometres southwest of Vernon. It is hosted in Permo-Carboniferous limestone of the Thompson assemblage (formerly Cache Creek Group), approximately 100 metres west of a large granitic body and occurs along a zone 30 to 80 metres wide having a strike length of 850 metres and an exposed vertical extent of 500 metres (Figure 3-3-5). The site was first described by Hallisey (1963). A description of the rock types follows:

Calc-Silicate Rocks: Wollastonite occurs as irregular lenses, clusters and stringers in steeply-dipping grey to black crystalline limestone and forms up to 35 per cent of the host rock.

Fibres range to 12 centimetres in length but average 2 to 3 centimetres. Associated minerals include calcite and quartz in stringers and lenses, minor garnet and diopside and clinopyroxenes along the limestone-granodiorite contact. In hand specimen wollastonite is easily identified by its radial crystal growth. Examined in thin section it forms fibrous aggregates randomly speckled by fine-grained diopside crystals. Boundaries between wollastonite skarn and its carbonate host are sharp with only minor crosscutting veinlets of calcite and quartz. A zone of garnet-quartz skarn 1 to 2 metres wide crops out along the limestone-granodiorite contact. The rock is brown, fine grained and in sharp contact with both sediments and the intrusive. Hallisey reports it is composed of 65 per cent grossularite, 25 per cent quartz and 10 per cent altered diopside (tremolite-actinolite).

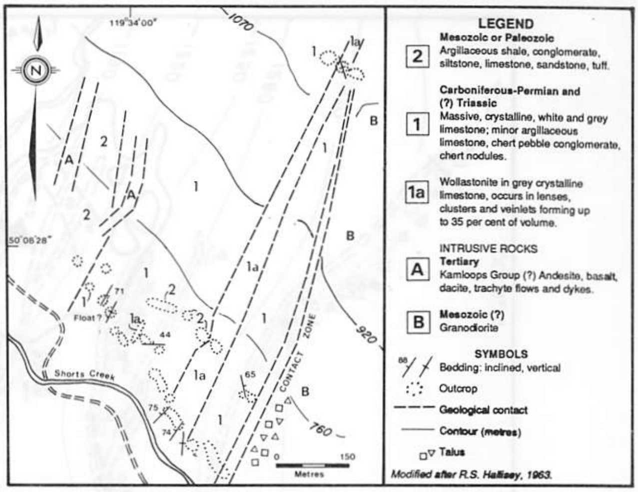


Figure 3-3-5. Fintry Point wollastonite skarn.

Unaltered Sedimentary Rocks: White to grey to black, fine to medium-grained crystalline limestone crops out immediately west of the skarn contact zone and west of the wollastonite zone. Remnant beds strike north and dip steeply east or west between 60 and 90 degrees. Interbedded black argillite and fine-grained sandstone with minor pockets of conglomerate are exposed at lower elevations.

Intrusive Rocks: A large body of fresh-looking, coarse-grained granodiorite outcrops immediately east of the sedimentary package. It contains 40 per cent plagioclase, 30 per cent orthoclase, 10 to 15 per cent quartz and 10 to 20 per cent biotite and hornblende.

Sills of porphyritic basalt intrude the sedimentary package along bedding planes, west of the limestone-granodiorite contact. The basalt is fine grained, with small, randomly spaced plagioclase phenocrysts in a brown groundmass. Hallisey (1963), identified the groundmass as mainly fine-grained sercitized plagioclase feldspar with finely disseminated pyrite throughout. He found occassional remnants of augite, usually altered to chlorite and sericite.

SILENCE LAKE (MINFILE 082M 123)

Dimac Resource Corporation's open-pit tungsten mine, approximately 30 kilometres northeast of Clearwater, operated briefly during 1981/82. The area is underlain by calcareous and non-calcareous biotite schist, marble and quartz-feldspar-biotite gneiss that are thermally and metasomatically altered by intrusions of quartz monzonite, quartz diorite and related granitic phases (Figure 3-3-6).

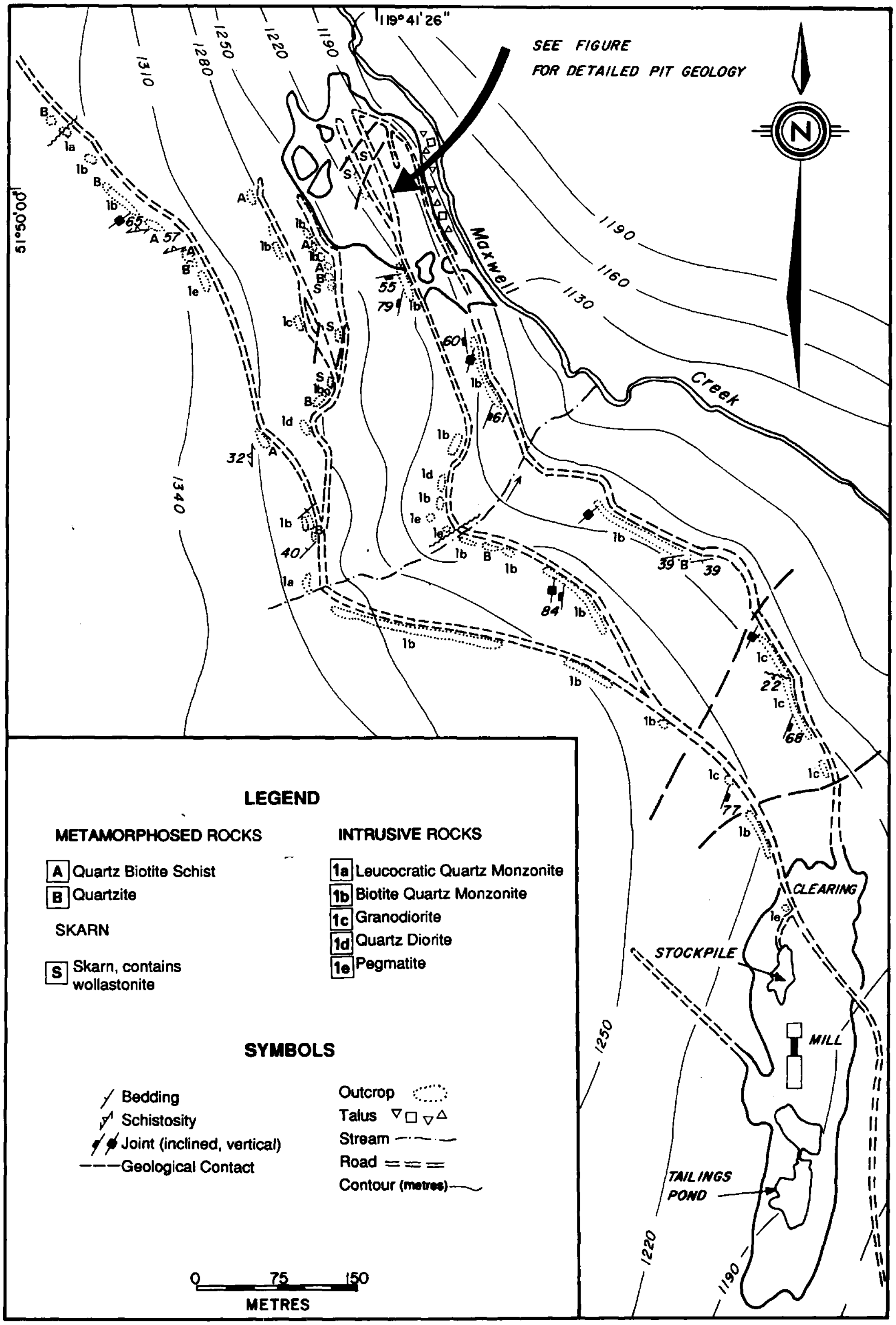


Figure 3-3-6. Geological outcrop map – Silence Lake mine.

At the mine, skarn rocks are hosted in quartz biotite schist and quartzite close to an intrusion of massive biotite-muscovite quartz monzonite (Figure 3-3-7). A brief description of these rock types follows:

Wollastonite Skarn: The mining operation exposed a 15 to 20-metre section of siliceous skarn containing up to 35 per cent wollastonite (Plate 3-3-3). Poor rock exposure along strike prevents detailed examination but similar wollastonite skarn outcrops 170 metres south-southwest of the main showing (Figure 3-3-6).

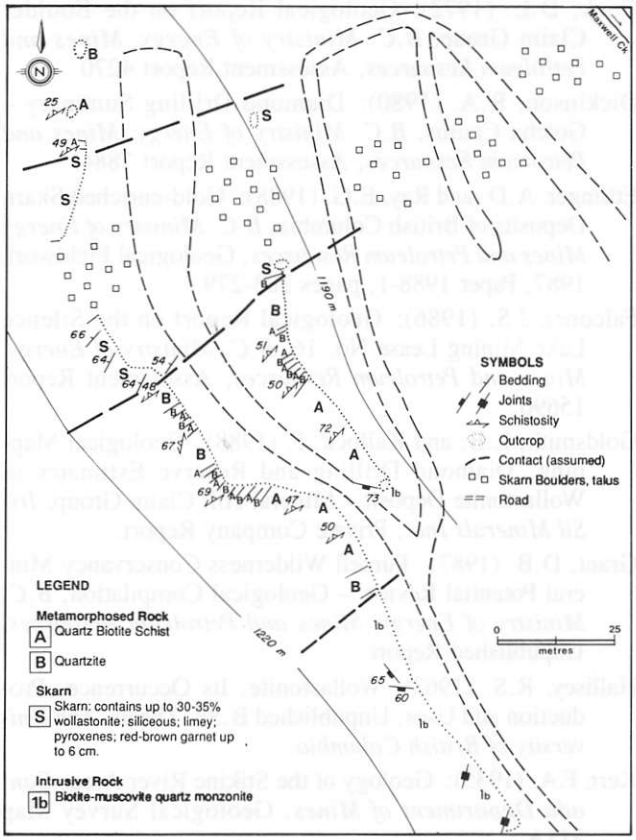


Figure 3-3-7. Geological sketch – open pit area of Silence Lake mine.

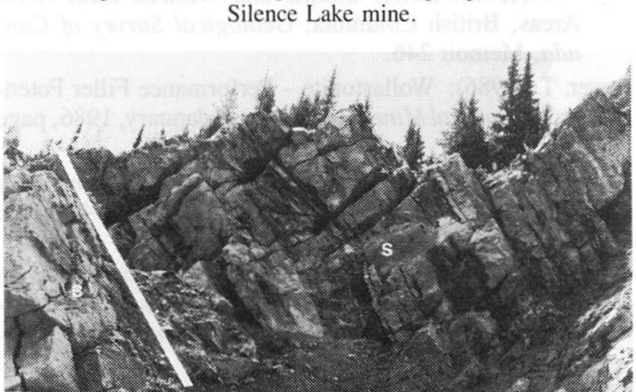


Plate 3-3-3. Silence Lake mine – Looking west-southwest.

S = Zone contains wollastonite, garnet, quartzite
B = Quartzite

In the pit wollastonite occurs in calc-silicate zones which strike northeast and dip 60 to 70 degrees northwest. Individual wollastonite bands are up to 100 centimetres wide and consist of massive fresh-looking white wollastonite with fibres up to 3 centimetres long. Clusters of red-brown garnet (grossularite) commonly form 20 to 30 per cent of the rock volume. Thin quartzite beds are intercalated with the calc-silicates, with contacts clearly defined and sharp. Accessory minerals include diopside and relict calcite. Two other skarn mineral assemblages have been identified by Dimac, (Dickinson, 1980; Falconer, 1986) a siliceous garnet skarn, consisting of coarsely crystalline garnet (andradite-grossularite), diopside, idocrase, scheelite and quartz, and a pyroxene skarn consisting of medium to coarsely crystalline garnet (iron and manganese-rich grossularite), actinolite, vesuvianite, diopside and pyrrhotite.

Schist and Quartzite: Brown to grey, medium-grained biotite schist crops out north, south and west of the skarn zone. The schist contains 40 to 50 per cent quartz, 20 per cent feldspar, 20 per cent biotite. A well-developed foliation strikes northeast. The schist is intercalated with massive beds of grey medium-grained quartzite.

Intrusive Rocks: A medium-grained, equigranular, orange-brown-weathering quartz monzonite crops out south of the skarn along the mine access road. In places biotite may form up to 15 per cent of the rock.

HORSETHIEF CREEK (MINFILE 082K 031)

A recently discovered calc-silicate occurrence approximately 30 kilometres west of Invermere and immediately south of Horsethief Creek was staked by G. Plassmann and B. Bechel in June, 1988 (Figure 3-3-1). The property is underlain by dolomitic sediments of the Proterozoic Dutch Creek and Mount Nelson formations which consist of

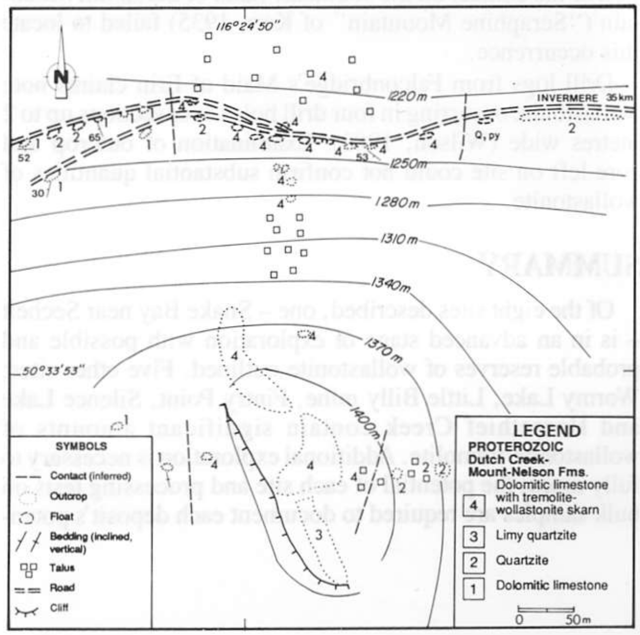


Figure 3-3-8. Geological sketch of the Horsethief Creek calc-silicate prospect.

argillites, limestone and dolomite (Grant, 1987). Brief rock-type descriptions follow:

Calc-silicate Rocks: Tremolite and wollastonite(?) occur in clusters of radiating fibres up to 10 centimetres long and in lenses or veins in siliceous dolomitic limestone. The more massive occurrences are found at the top of a prominent hill and along a 30-metre cliff. Massive white to pale green calc-silicate skarn outcrops over an area measuring approximately 110 by 175 metres (Figure 3-3-8). In this area calc-silicate occurs in veins 15 to 20 centimetres wide which strike northwest and are intercalated with beds of quartzite and cut by occassional veinlets of calcite.

Dolomitic Limestone: Dark grey to black dolomitic limestone crops out west of the hill and along Horsethief Creek. Beds strike generally north and dip between 30 and 65 degrees west.

Quartzite: Pale brown to light grey, massive, sometimes cherty quartzite crops out east of the hill and along the road. This unit marks the eastern extent of the calc-silicate zone.

Intrusive Rocks: No intrusive rocks were found in place on the property. Only occasional large boulders of a coarse-grained, grey to mauve granite were observed and these probably originate from a large granitic body immediately to the north-northwest.

MISCELLANEOUS OCCURRENCES

Reports of wollastonite-bearing skarns in the Craig River valley in the Iskut River area, (MINFILE 104B 005) and the Maid of Erin claims north of Rainy Hollow (MINFILE 114P 007) 5 kilometres west of the Haines-Whitehorse Highway, were checked briefly in the field.

At Craig River, Kerr (1948) reported: "In Craig Valley, near the masses of hornblende granodiorite, the limestone is largely converted into wollastonite and silica". An examination of the contact on the southeast flank of Seraphim Mountain ("Seraphine Mountain" of Kerr, 1935) failed to locate this occurrence.

Drill logs from Falconbridge's Maid of Erin claims note wollastonite occurring in four drill holes over sections up to 2 metres wide (Wilson, 1983). Examination of outcrop and core left on site could not confirm substantial quantities of wollastonite.

SUMMARY

Of the eight sites described, one – Snake Bay near Sechelt – is in an advanced stage of exploration with possible and probable reserves of wollastonite outlined. Five other sites; Wormy Lake, Little Billy mine, Fintry Point, Silence Lake and Horsethief Creek contain significant amounts of wollastonite/tremolite. Additional exploration is necessary to fully assess the potential of each site and processing tests on bulk samples are required to document each deposit's potential to produce wollastonite which will meet industry specifications.

ACKNOWLEDGMENTS

I would like to acknowledge Z.D. Hora for suggesting the study and reviewing the paper. Bob Paul provided capable and cheerful field assistance. Figures were drafted by Janet Fontaine.

REFERENCES

Cook, D.L. (1972): Geological Report on the Boulder Claim Group, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 4270.

Dickinson, R.A. (1980): Diamond Drilling Summary – Gotcha Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 7884.

Ettlinger, A.D. and Ray, E.G. (1988): Gold-enriched Skarn Deposits of British Columbia, *B.C. Ministry of Energy Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 263-279.

Falconer, J.S. (1986): Geological Report on the Silence Lake Mining Lease No. 16, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 15696.

Goldsmith, L.B. and Kallock, P. (1988): Geological Mapping, Diamond Drilling and Reserve Estimates of Wollastonite Deposit – Mineral Hill Claim Group, *Tri-Sil Minerals Inc.*, Private Company Report.

Grant, D.B. (1987): Purcell Wilderness Conservancy Mineral Potential Review – Geological Compilation, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Unpublished Report.

Hallisey, R.S. (1963): Wollastonite, Its Occurrence, Production and Uses, Unpublished B.Sc. Thesis, *The University of British Columbia*.

Kerr, F.A. (1935): Geology of the Stikine River Area, *Canada Department of Mines*, Geological Survey Map 311A.

——— (1948): Lower Stikine and Western Iskut River Areas, British Columbia, *Geological Survey of Canada*, Memoir 246.

Power, T. (1986): Wollastonite – Performance Filler Potential, *Industrial Minerals Magazine*, January, 1986, page 19.

Stevenson, J.S. (1945): Little Billy Mines, *B.C. Ministry of Energy, Mines and Petroleum Resources*, 1944 Annual Report, page A162.

Wilson, J. (1983): Diamond Drilling Assessment Report on the ME2 and ME7 Group Mineral Claims, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 11835.

GYPSUM IN BRITISH COLUMBIA
(82G, J, 83E)
By S.B. Butrenchuk

KEYWORDS: Industrial minerals, gypsum, Stanford Range, Mayook, Joffre Creek, Forgetmenot Creek, Burnais Formation, Starlight evaporite.

INTRODUCTION

Gypsum ranks third in value of production, behind asbestos and sulphur, among industrial minerals produced in British Columbia. In 1986, 527 200 tonnes of gypsum valued at $5,460,700 were produced. Production comes primarily from quarries located on Windermere Creek operated by Westroc Industries Limited (Plate 3-4-1) and on the Lussier River operated by Domtar Construction Materials (Plate 3-4-2). There is also some intermittent production by Canada Cement Lafarge Limited from its quarries near Falkland. Most of the gypsum produced is used in the manufacture of wallboard; smaller quantities are used in the cement industry. Gypsum is shipped by rail and truck to plants in Vancouver, Calgary and Edmonton. Minor tonnages of anhydrite-gypsum mixture are also produced by Westroc Industries at Windermere and are exported to the United States to be used in the manufacture of portland cement.

While gypsum has been known in the province since the early 1900s, there has been no comprehensive report on gypsum deposits in British Columbia. A program to study gypsum deposits in the province was initiated during the summer of 1988. Fieldwork focused on the Stanford Range where extensive gypsum is present in the Devonian Burnais Formation. Some time was spent examining Devonian gypsum in the Joffre Creek and Mayook, Bull River and Chipka Creek areas (Figure 3-4-1). In addition to the work in southeastern British Columbia, a gypsum occurrence of Triassic age in the Forgetmenot Creek area was evaluated.

Gypsum occurrences were assessed for their resource potential and quality. Wherever possible, stratigraphic relationships and structural controls were also examined. Samples were routinely collected for major oxide analyses and specimens were collected for petrographic study. In addition to evaluating known deposits the fieldwork also involved a search for new occurrences. The program was successful in locating three major, previously undocumented, gypsum localities in the Coyote Creek area.

STRATIGRAPHY OF THE STANFORD RANGE

Gypsum in the Stanford Range occurs in rocks of Devonian age (Figure 3-4-2). Early work by Henderson (1954) assigned the name Burnais Formation to a sequence of evaporites and associated carbonate rocks and Harrogate Formation to the overlying limestone and shale sequence. Leech (1958, 1960) retained the same nomenclature and added the term "basal Devonian unit" to a sequence of quartzites, argillaceous limestone and limestone of Devonian age underlying the evaporites. More recent work by Belyea and Norford (1967) proposed the term "Cedared Formation" for a sequence of dolomites, sandstones and limestones that is, in part, stratigraphically equivalent to the Burnais Formation and possibly part of the basal Devonian unit. They retained the name Harrogate Formation. These stratigraphic relationships are shown in Figure 3-4-3.

This study attempted to delinate areas underlain by gypsum from those underlain by carbonate rocks. Much of the carbonate strata previously included in the Burnais Formation are now tentatively assigned to either the Cedared or Harrogate formations. This designation is primarily based on lithological similarities.

Devonian strata unconformably overlie or are in structural contact with the Ordovician-Silurian Beaverfoot-Brisco Formation. This unit consists primarily of thin to medium-bedded light grey dolomite and limestone. Ovular chert nodules and lenses in a carbonate matrix are characteristic of the unit. The upper contact was not seen in the study area.

Strata of the basal Devonian unit were only observed in the Coyote Creek area. It consists of orthoquartzite and sandstone low in the section and limestone, argillaceous limestone, dolomite and minor shale in the upper part. Ar-

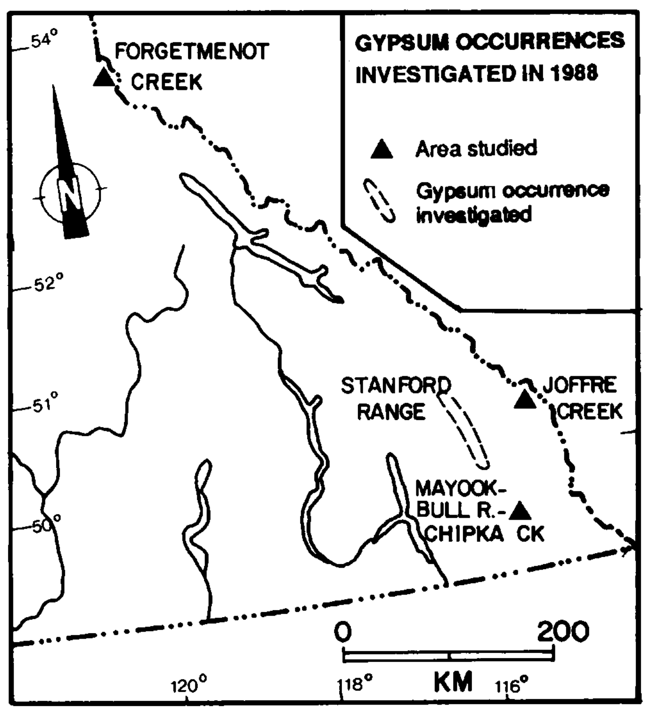


Figure 3-4-1. Location map showing areas studied.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

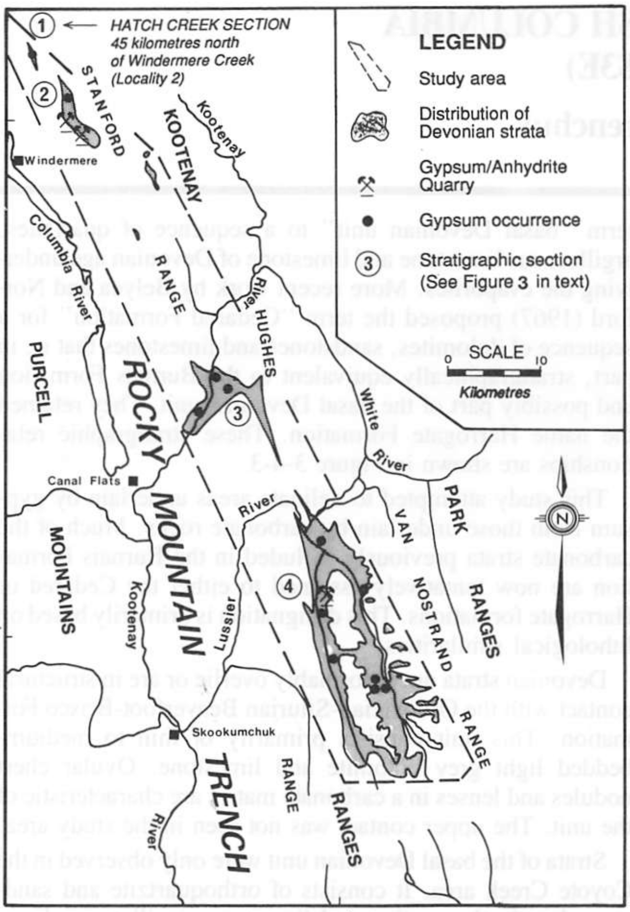


Figure 3-4-2. Location map showing the distribution of Devonian strata and gypsum occurrences in the Stanford Range.

Plate 3-4-1. Elkhorn quarry operated by Westroc Industries Limited, Windermere Creek.

Plate 3-4-2. Lussier quarry operated by Domtar Construction Materials, Lussier River.

gillaceous limestones are easily recognized by their pale maroon to pale green colour. Lithologically similar strata, tentatively assigned to the Cedared Formation, outcrop in the Windermere Creek area near the Elkhorn deposits. Limestone and dolomite in the upper part of the section are generally grey to dark grey, thin to medium bedded, aphanitic and void of fossils.

The Cedared Formation, at its type locality, consists of a sequence of dolomite, limestone, argillaceous limestone, mudstone, sandstone and breccia. These rocks are typically grey to yellowish brown and weather light grey, light yellowish grey and light brownish grey to light brown (Belyea and Norford, 1967). In the Stanford Range the Cedared Formation comprises dolomite with minor limestone and argillaceous limestone. These rocks are generally light grey to grey and weather grey to pale maroon and green. They are thin to medium bedded and aphanitic to finely crystalline. No fossils were found.

The Burnais Formation is restricted to an evaporite sequence consisting of gypsum and anhydrite that occurs at a number of localities throughout the Stanford Range. Although anhydrite does not outcrop, it occurs in drill holes at depths ranging from 20 to 40 metres. Very little is known about the thickness of the anhydrite as very few holes penetrate its entire thickness. A black fetid limestone and thin grey aphanitic limestone bands in fault contact with the gypsum are also included in the Burnais Formation. Estimates of thickness range from 50 to 300 metres, with the thickest sections occurring in the Windermere Creek area. There is a general thinning of the formation southward toward Coyote Creek where thickness rarely exceeds 60 metres. This study suggests gypsum deposits are not as widespread as previously thought. Much of the area previously mapped as Burnais Formation is now interpreted as underlain by carbonate rocks of the Cedared and Harrogate formations.

The Harrogate Formation is the youngest Devonian unit in the Stanford Range. It consists of a sequence of dark grey to black, typically nodular limestones. Minor shale and dolomite are present locally. The nodular limestone unit, which can be traced throughout the study area, is a useful marker horizon. Fossils, mainly brachiopods, were found at two localities, near the Elkhorn quarry and in the Coyote Creek area. In the Coyote Creek–Lussier River area, the Devonian sequence is overlain by a shale unit and carbonate strata of the Banff Formation. These rocks are Mississippian in age.

Plate 3-4-3. Laminated gypsum from the Windermere quarry on Windermere Creek.

GYPSUM DEPOSITS

Primary gypsum was discovered on Windermere Creek in 1947 (Henderson, 1954). Production, which began in 1950, has been continuous to the present day totalling in excess of 6.8 million tonnes.

Seven areas underlain by the Burnais Formation were identified by Henderson (1954) and Leech (1958) mapped the formation over a large area near the Lussier River. Much of the subcrop of the Burnais Formation is inferred from the presence of sinkholes; the scarcity of outcrop makes interpretation of the gypsum distribution extremely difficult.

Gypsum throughout the Stanford Range is typically laminar to thin bedded (Plate 3-4-3), with laminations and bedding varying in thickness from a fraction of a millimetre to 3 millimetres. Laminations are generally crenulated or intricately folded. The colour of the gypsum varies from white through various shades of grey to occasionally black. Pale brown to pale brownish grey laminae are very often present. White selenite is common as massive blebs but may also occur as well-formed crystals or along fractures and fault surfaces. Crosslaminations and cut-and-fill structures, indicative of periodic high-energy events in an overall shallow-water facies, are observed locally. Native sulphur is present in trace amounts at many localities, most commonly as crystalline masses associated with selenite along fractures. Occasionally it is smeared along slickenside surfaces giving the impression of greater abundance.

Anhydrite is rarely observed in outcrop. In the Windermere Creek area anhydrite occurs at an average depth of 30 to 40 metres while in the Lussier River area it occurs at a depth of 20 to 25 metres. Very often there is an accumulation of salts at or very near the anhydrite-gypsum contact.

Gypsum deposits are more structurally complex than the enclosing carbonate rocks. Some of the structural features may have formed at the time of deposition, others are interpreted as enterolithic (Plate 3-4-4) and related to swelling and expansion during conversion of anhydrite to gypsum. This process involves a volume increase of 30 to 50 per cent.

WINDERMERE CREEK

Gypsum deposits are best developed in the Windermere Creek area where thicknesses in excess of 100 metres have been reported. These deposits trend northwesterly along a strike length of 3 kilometres (Figure 3-4-4). Two gypsum horizons are interpreted, separated by dolomite and limestone tentatively assigned to the Cedared Formation. The lower gypsum bed has a minimum thickness of 50 metres

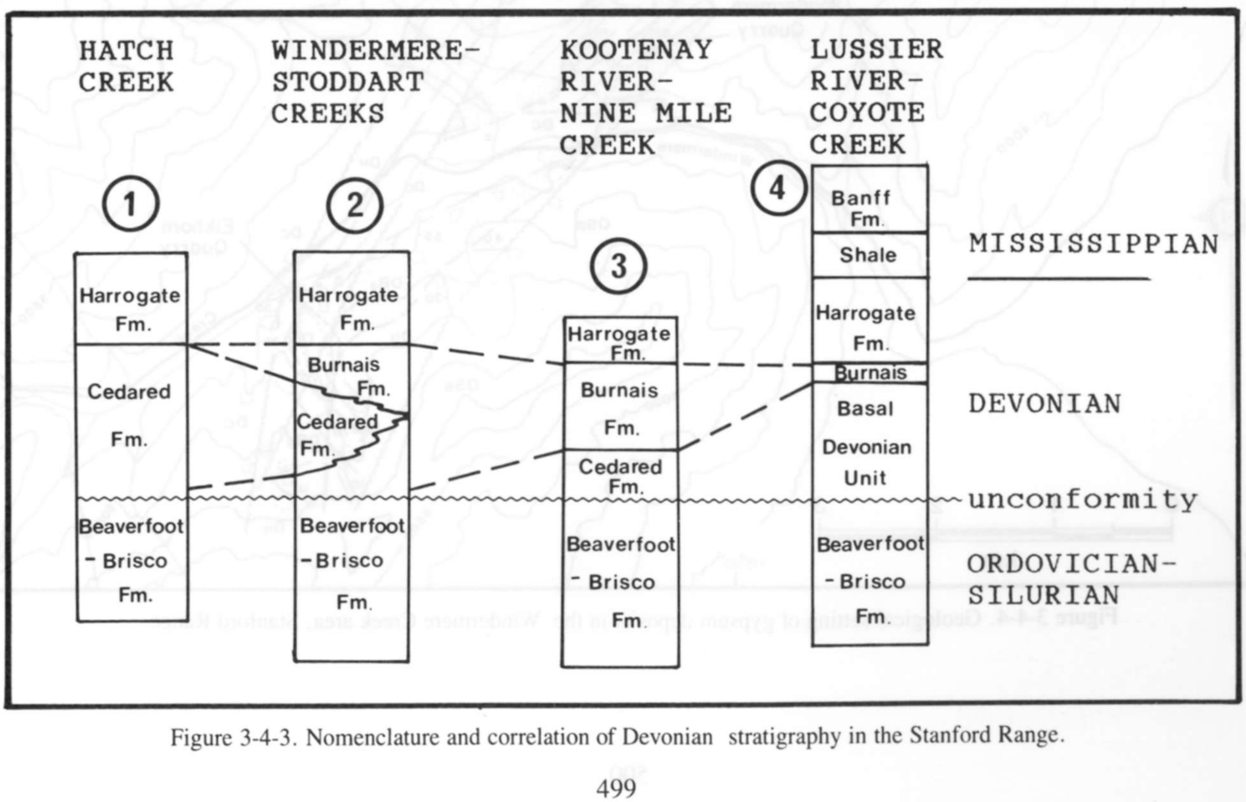


Figure 3-4-3. Nomenclature and correlation of Devonian stratigraphy in the Stanford Range.

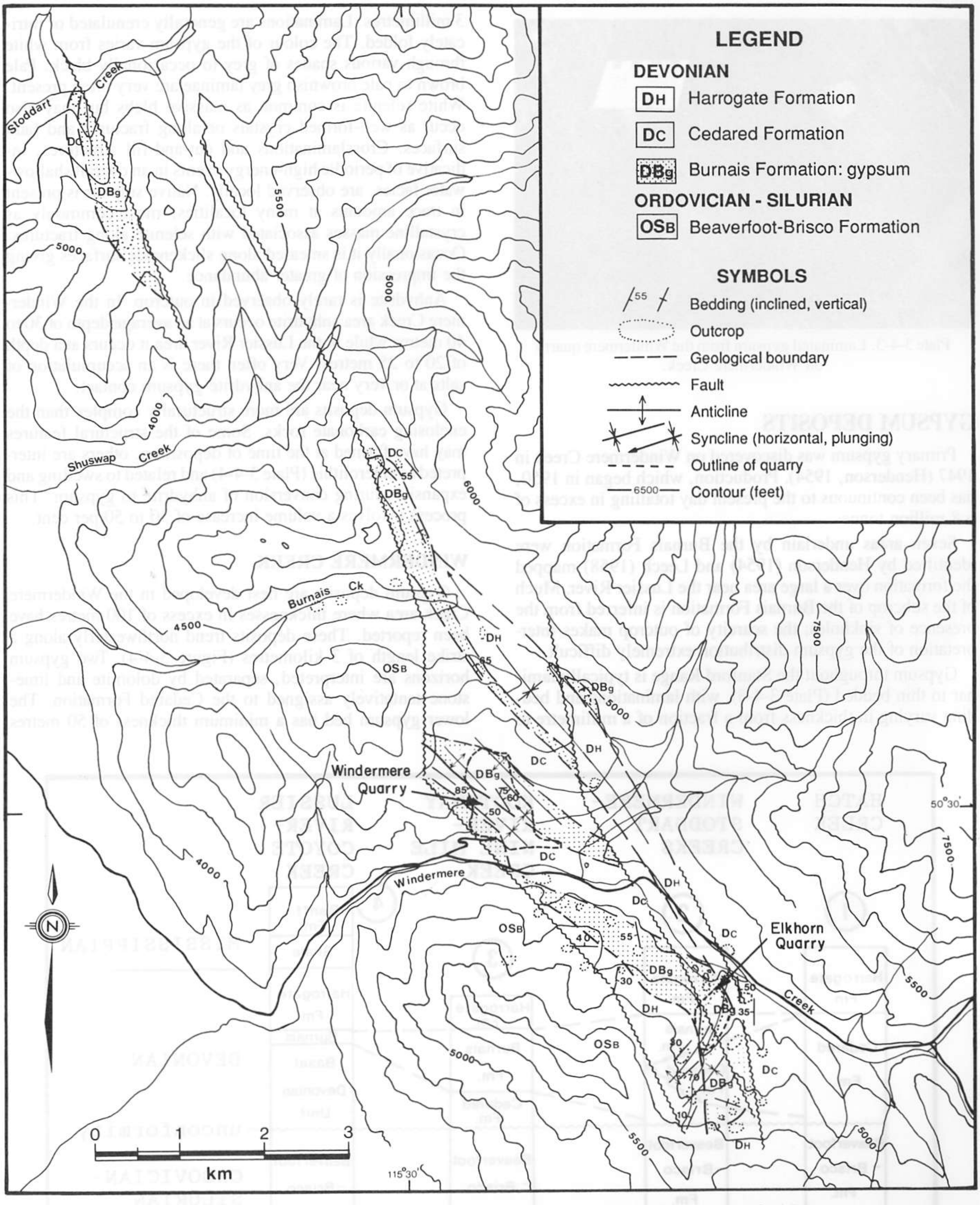


Figure 3-4-4. Geological setting of gypsum deposits in the Windermere Creek area, Stanford Range.

Plate 3-4-4. Enterolithic folding of gypsum, Lussier River quarry.

while the upper bed ranges from 50 to 100 metres thick. The upper bed is structurally more complex and therefore determining an accurate thickness is difficult. Contact relationships between the gypsum and underlying strata were not observed but it is inferred the lower gypsum bed is in fault contact with the underlying Beaverfoot-Brisco Formation. Contacts with the Cedared Formation and overlying Harrogate Formation, where observed, appear to be conformable. The quality of the ore is good, ranging between 83 and 93 per cent gypsum.

Gypsum can be traced northward from Windermere Creek to north of Burnais Creek where it thins and disappears under thick overburden and carbonate strata of the Cedared Formation. Further north a small lens of gypsum outcrops south of Stoddart Creek. Here the rock is of lower quality, containing approximately 75 per cent gypsum (F.W. Jarrett, Westroc Industries Ltd., personal communication, 1988). No gypsum is known to occur north of Stoddart Creek.

Anhydrite is distinguished from gypsum by its hardness and light blue colour. At the nearly depleted Windermere quarry anhydrite is present in a breccia zone that is 30 metres

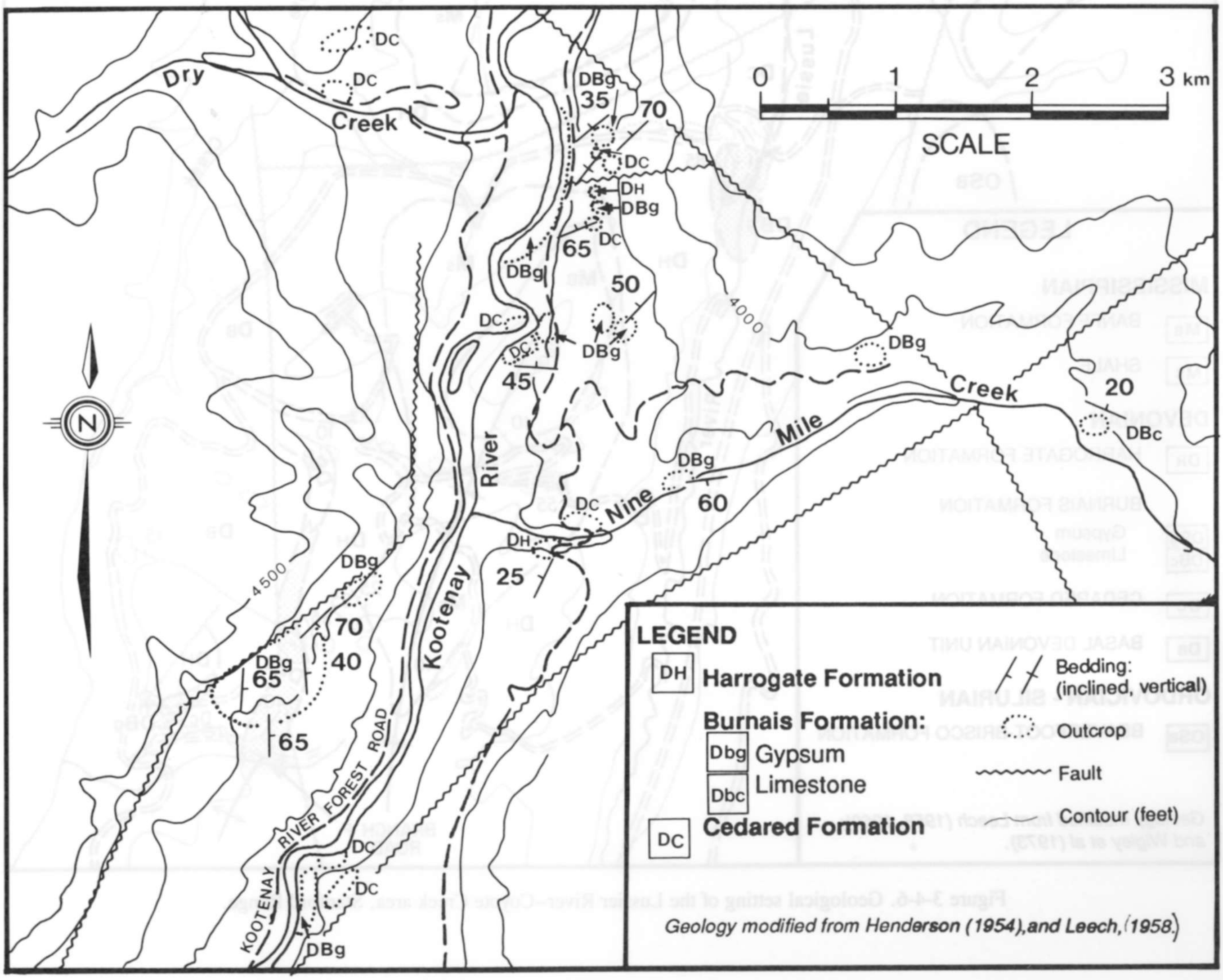


Figure 3-4-5. Geological setting of the Kootenay River–Nine Mile Creek area, Stanford Range.

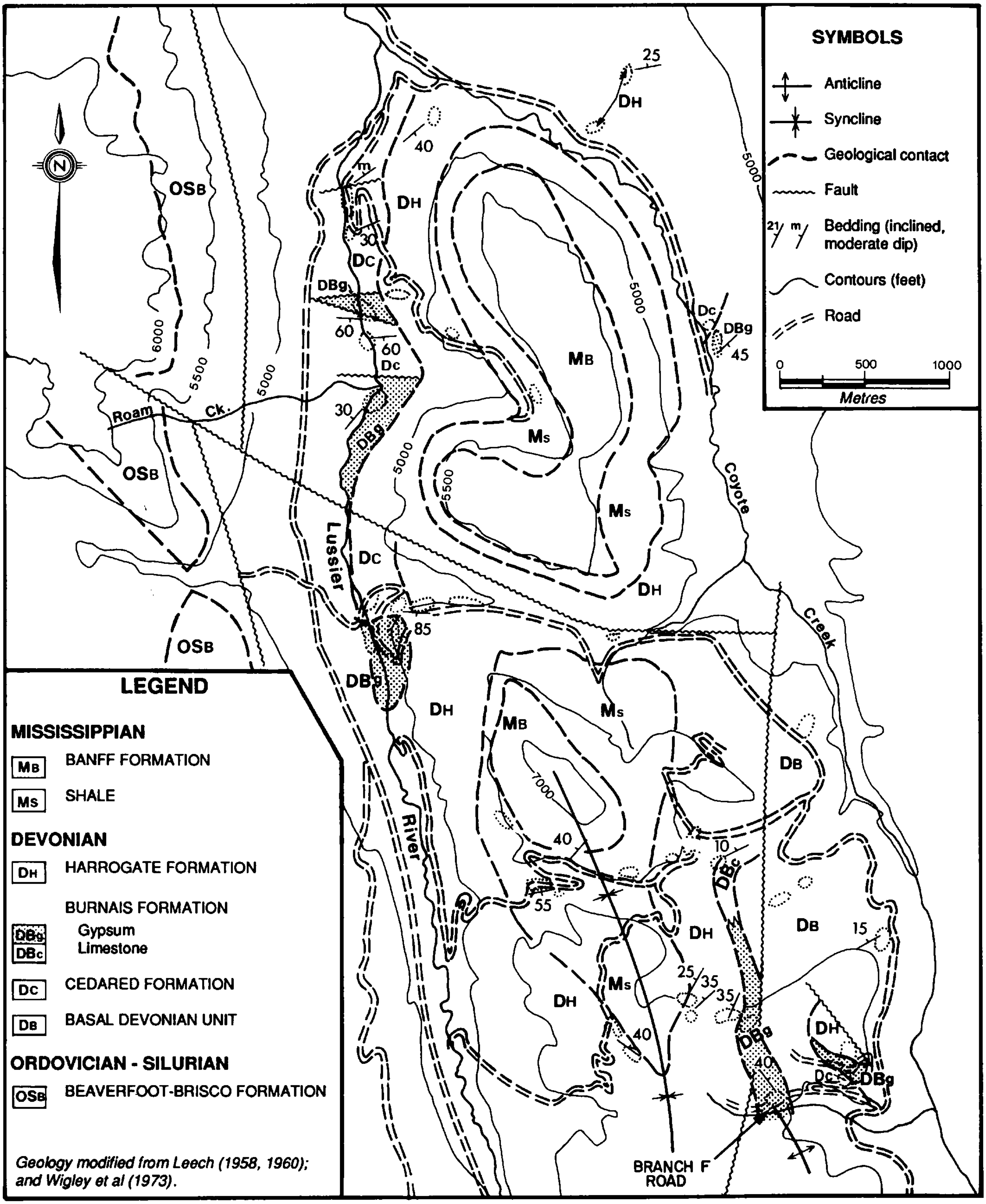


Figure 3-4-6. Geological setting of the Lussier River–Coyote Creek area, Stanford Range.

wide. The breccia consists of angular anhydrite and gypsum fragments in an anhydrite matrix. Also, the anhydrite tends to be more massive than the surrounding gypsum.

KOOTENAY RIVER–NINE MILE CREEK

In the Kootenay River–Nine Mile Creek area gypsum outcrops extensively on the west side of the river north of the bridge at kilometre 10.5 on the Kootenay River logging road (Figure 3-4-5). Gypsum is very well exposed in an area approximately 1.5 kilometres in length across an average width of 400 metres. Bedding generally strikes north to northeasterly with moderate to steep dips to the east. The gypsum is pale grey to grey in colour and is typically laminated to thin bedded. Pure white gypsum is present locally. To the west the gypsum is in fault contact with older rocks; to the east it disappears under extensive overburden in the Kootenay River valley. A minor amount of gypsum has been produced from a small quarry at the north end of this deposit.

There are several large exposures of gypsum along the east bank of the Kootenay River and in the Nine Mile Creek area. The gypsum is intercalated with carbonate strata of the Cedared Formation. A black fetid limestone of the Burnais Formation is present in more easterly localities. Nodular limestone of the Harrogate Formation is also present. East of the Kootenay River the structure is more complex and the bedding strikes east to northeasterly with moderate dips to the northwest, north and south. Structural relationships east and west of the Kootenay River suggest that a synclinal axis, with or without associated faulting, may be present.

In the Nine Mile Creek area laminated to thin-bedded gypsum varies from cream to pure white in the north to the more typical pale grey to grey in southerly exposures. Northern exposures contain abundant white selenite with lesser rounded gypsum fragments and a few angular limestone fragments. To the south the gypsum retains its laminar appearance but does not contain any gypsum or carbonate fragments. Bedding thickness ranges up to 5 centimetres, but thicknesses less than 1 centimetre are more usual. Native sulphur was observed in a single outcrop immediately north of Nine Mile Creek. The quality of the rock is variable with gypsum content varying from 44 to 94 per cent (Henderson, 1954).

LUSSIER RIVER–COYOTE CREEK

The southernmost exposures of gypsum in the Stanford Range occur in the Lussier River–Coyote Creek area (Figure 3-4-6). In the Lussier River valley all known occurrences are located east of the river. Extensive and very thick overburden preclude tracing the gypsum over any significant distance, but drilling by Domtar Construction Materials in recent years has helped to delineate its distribution. Where observed, the gypsum is steeply dipping to vertical. Faulting may have played an important role in the localization and preservation of these deposits.

Domtar's Lussier River gypsum deposit occurs in a northwest-trending anticline. It is truncated on the south by a fault and probably abuts a fault to the north, although evidence for this is lacking. Carbonate strata of the Cedared Formation outcrop immediately north and south of the deposit but nowhere are contact relationships observed. The deposit is overlain by nodular limestone of the Harrogate Formation. Structure within the deposit is complicated by numerous faults with minimal displacement and intricate small-scale folds. A fault with considerable but undetermined displacement near the southern end of the quarry has a carbonate band adjacent to it. These structures are the locus of sinkholes and other karst features.

There are two other significant gypsum occurrences on the east side of the Lussier River, south of the Lussier quarry. The South quarry is a small deposit located 750 metres south of the main producing quarry, but there has been limited production from this locality. Gypsum is again exposed south of Roam Creek, over a length of 200 metres, in steep bluffs 60 to 90 metres high along the east side of the Lussier River. The gypsum is steeply dipping and cut by numerous near-vertical faults. Some breccia material and a thin limestone band adjacent to a fault are present at the northern end. Traces of native sulphur occur locally. Work by Trurock Gypsum Products Ltd. on this deposit suggests a reserve potential of 40 million tonnes with a gypsum content averaging 80 per cent (Korun, 1980).

Three occurrences of gypsum were located immediately east of the height of land separating the Lussier River from Coyote Creek. To the author's knowledge these are new discoveries although nearby sinkholes were mapped by Leech (1960). Two of them are located on a logging road locally known as Branch F; the third outcrops north of the westernmost of these two showings. Gypsum is similar in appearance to that seen elsewhere in the Stanford Range and is probably of similar quality. The easternmost showing is exposed in an outcrop measuring 45 by 20 metres. Small sinkholes, many of which contain gypsum or possibly anhydrite, are present over an area measuring 300 by 100 metres. It is estimated that the gypsum bed is approximately 30 metres thick, suggesting potential for a 2 to 3-million-tonne deposit.

To the west gypsum is exposed in two outcrops approximately 1 kilometre apart along a northerly trend, and small sinkholes, some of which contain gypsum, are commonly present in the intervening area. The northern occurrence is exposed across an outcrop width in excess of 30 metres and 60 metres of elevation. Gypsum is laminated, pale grey to dark grey with some black laminations. Traces of native sulphur are also present. The southern occurrence is exposed in a roadcut across a width of 60 metres in the nose of an anticline. The gypsum is similar in appearance to the northern showing. These two localities are estimated to have a combined potential for 6 million tonnes and all three of these occurrences are ideally situated for future exploitation.

MAYOOK–CHIPKA CREEK–BULL RIVER AREA (82G)

There are four gypsum occurrences in the Rocky Mountain Trench area east of Cranbrook and they represent the southernmost occurrences of gypsum in southeastern British Columbia. Two of them, Sunrise and Mayook, are located north and south respectively of Highway 3 near Mayook and the third is along Chipka Creek, south of Wardner. Gypsum is also reported from a locality on the Bull River approximately 4 kilometres from its mouth.

Approximately 95 000 tonnes of gypsum has been produced from the Sunrise quarry and there has been limited production from the Mayook occurrence.

Gypsum in these deposits varies from white to grey and is bedded to laminated, although bedding is largely obscured; surface exposures are generally soft and granular and very often covered by a coating of gypsite. Angular, pale brownish grey fragments of limestone are present locally. At the Chipka Creek locality limestone and chert are reported in sufficient quantities to make parts of the deposit unworkable (Cole, 1930). Intricate minor structures, present throughout much of the Stanford Range further to the north, are rare in this area. Native sulphur was observed only at Chipka Creek although Cole reports native sulphur at the Mayook and Sunrise deposits.

The stratigraphic position of these deposits is still uncertain but it is believed they are Devonian and may be equivalent to the Burnais Formation.

Gypsum in the Bull River area is described as dark grey in colour with indistinct bedding. Rocks are reported to be highly folded. A small bulk sample was taken from this locality in 1937 for testing.

JOFFRE CREEK (82J/11)

Gypsum was reported in the basal Devonian unit in the Joffre Creek area by Leech (1979) and Mott *et al.*, (1986). The basal Devonian unit consists of brown to orange dolostone with white orthoquartzite. Minor sandstone and shale are also present.

A single gypsum occurrence located along a westerly flowing tributary of Joffre Creek was examined during this study. Gypsum is exposed along the bank of the creek at an elevation of 1830 metres.

Gypsum varies from cream to grey in colour and is laminated to thin bedded. Both the laminations and bedding are highly contorted, possibly the result of soft-sediment deformation. Thin black laminae are present locally. Selenite is locally abundant but native sulphur is absent. Approximately 20 metres above the base of the gypsum, the rock is distinctly conglomeratic in appearance. This unit is 5 metres thick and consists of egg-shaped gypsum fragments in a gypsum matrix, possibly representing a period of emergence of the evaporite deposit. Above this horizon the gypsum reverts to its normal appearance.

The gypsum has a minimum thickness of 40 metres and a strike length of less than 100 metres. Bedding strikes east-northeast with shallow north dips into the mountain. The area is structurally complex with several faults. Neither the upper nor lower gypsum contacts were observed and therefore stratigraphic relationships could not be determined. The gypsum is probably equivalent to the Burnais Formation.

FORGETMENOT CREEK (83E/13)

Gypsum of Triassic age occurs at a single locality straddling the Alberta boundary at the headwaters of Forgetmenot and Fetherstonhaugh creeks. This occurrence was first reported by Henderson (1954) and later described in detail by Govett (1961). Gypsum intercalated with dolomite and minor limestone is present in several beds in the Starlight evaporite member of the Whitehorse Formation. This unit is assigned a Karnian age and is correlated with the Charlie Lake Formation which is host to extensive anhydrite deposits further north (Figure 3-4-7).

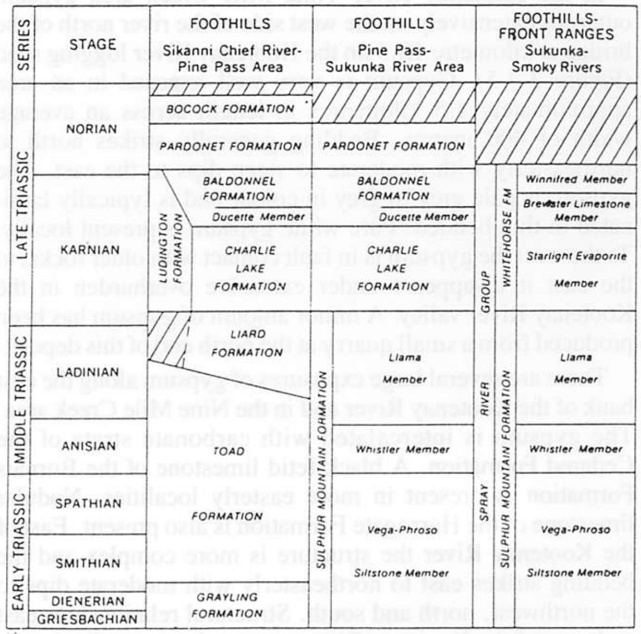


Figure 3-4-7. Nomenclature and correlation chart of Triassic stratigraphy (from Gibson, 1972).

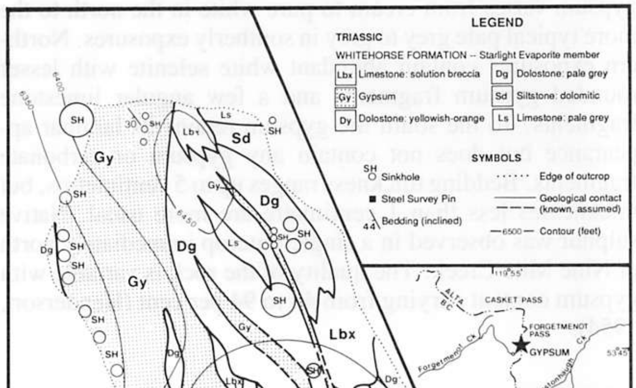


Figure 3-4-8. Geological setting of the gypsum deposit in the Forgetmenot Creek area.

The Starlight evaporite, the lowermost unit of the Whitehorse Formation, has been described by Gibson (1972, 1975) as consisting of a recessive buff to light grey weathering sequence of interbedded dolostones, limestones, siltstones and intraformational or solution breccias. In the Forgetmenot Creek area pale grey and yellowish brown to orange dolostone is intercalated with several gypsum beds (Figure 3-4-8). Also present are lenses of dolomitic and calcareous siltstone and pale grey limestone. Solution breccia comprised of a vuggy calcareous matrix with subangular to subrounded fragments of limestone occurs in a number of outcrops.

There are at least four gypsum beds ranging in thickness from 2 metres to greater than 26 metres (Figure 3-4-9) with the uppermost bed being the thickest and most persistent. Locally, it contains solution breccia and lenses of dolostone of variable thickness. The gypsum is typically white to pale pink in colour but may also be pale grey to grey. It is laminated to thin bedded and locally massive. Anhydrite was not observed in outcrop. Trace amounts of pyrite are present but native sulphur is absent. The quality of the gypsum is good.

The beds strike northwest with dips of 25 to 30 degrees southwest; the gypsum outcrop can be traced 500 metres along strike. The presence of sinkholes suggests it may extend some distance further south. Gypsum occurs over a minimum stratigraphic thickness of 100 metres and contacts between gypsum and overlying or underlying rocks are invariably marked by sinkholes up to several metres in diameter.

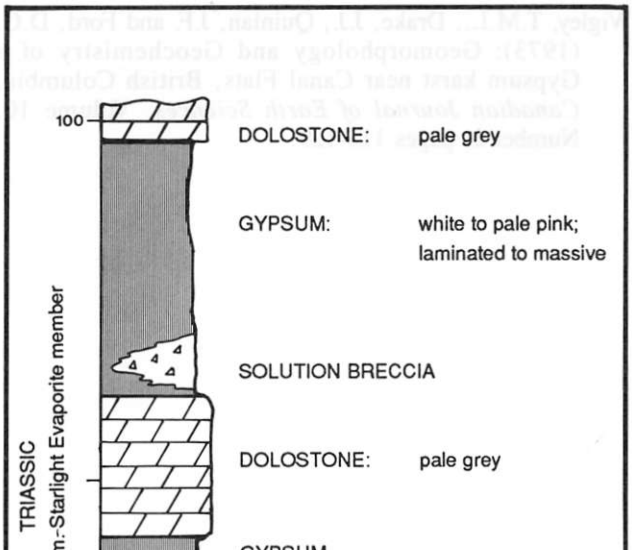


Figure 3-4-9. Stratigraphic section of upper portion of gypsum-bearing sequence, Forgetmenot Creek.

Drilling by Domtar Chemicals Ltd. (1968) indicated that the gypsum grade at depth was more variable than in surface exposures. Gypsum content in the subsurface varied between 75 and 80 per cent while surface sampling yielded assays greater than 90 per cent gypsum. Reserves estimated by Domtar (Hamilton, 1984) are 2.3 million tonnes with a potential for 25 to 30 million tonnes if the gypsum persists along its projected length.

DISCUSSION

Evaporite deposits in the Rocky Mountains are sedimentary in origin. Henderson (1954) concluded that the gypsum deposits in the Stanford Range were primary and not the result of hydration of anhydrite. He based his conclusions on the absence of anhydrite at depth and the absence of expansion-type fold structures. It is now apparent that gypsum only occurs near surface and expansion-related folding is present at many localities. This author concludes that the deposits in the Stanford Range formed by the hydration of anhydrite by the action of meteoric waters.

Further to the south in the Mayook–Chipka Creek–Bull River area, at Joffre Creek, and at Forgetmenot Creek, the enterolithic folding present in the Stanford Range is not present. No anhydrite is seen at surface, but it may be present at depth. Gypsum in these areas may be primary but evidence for this is inconclusive.

CONCLUSIONS

The Burnais and Cedared formations are interpreted by Belyea and Norford (1967) to have been deposited in a gently subsiding basin. Accumulation took place in a long, relatively narrow depression. The Cedared Formation was probably deposited in a tidal-flat environment that may have been emergent at times. Contemporaneous deposition of the Burnais Formation evaporites was limited to areas with restricted circulation.

The gypsum resource potential of the Stanford Range originally estimated at 450 million metric tonnes by Henderson (1954) is now thought to be substantially reduced and may be in the order of 160 million tonnes, including all past production. The most favourable areas for future exploitation are the west side of the Kootenay River, along the Lussier River south of the Lussier quarry, and the area near Coyote Creek which contains the three new occurrences.

There is a potential for 2 to 3 million tonnes of good quality gypsum in the Forgetmenot Creek area, but because of its inaccessibility and location near the Willmore Wilderness Reserve in Alberta it will probably be some time before this deposit is developed.

Deposits in the Joffre Creek area appear to be poddy although probably of good quality. Extensive overburden and rugged terrain will inhibit development and their resource potential is small.

Substantial amounts of gypsum remain in deposits in the Mayook–Chipka Creek–Bull River area, but they contain varying amounts of carbonate and are subeconomic under current market conditions.

ACKNOWLEDGMENTS

The author gratefully acknowledges Westroc Industries Limited, Kenelly Contracting Ltd. and Mountain Minerals Ltd. for providing information and logistical support; and S. Preto for providing able assistance throughout the field season.

REFERENCES

Belyea, H.R. and Norford, B.S. (1967): The Devonian Cedared and Harrogate Formations in the Beaverfoot, Brisco and Stanford Ranges, Southeast British Columbia, *Geological Survey of Canada*, Bulletin 146, 64 pages.

Cole, L.H. (1930): The Gypsum Industry of Canada, *Department of Mines*, Ottawa, Number 714, pages 64-68.

Domtar Chemicals Ltd. (1968): Report on Work Done on the Fetherstonehaugh Creek Gypsum Deposit, *Alberta Research Council*, Unpublished Report, Economic Minerals File GYP-AF-02, 20 pages.

Gibson, D.W. (1972): Triassic Stratigraphy of the Pine Pass–Smoky River Area, Rocky Mountain Foothills and Front Ranges of British Columbia and Alberta, *Geological Survey of Canada*, Paper 71-30, 108 pages.

_______ (1975): Triassic Rocks of the Rocky Mountain Foothills and Front Ranges of Northeastern British Columbia and West-central Alberta, *Geological Survey of Canada*, Bulletin 247, 61 pages.

Govett, G.J.S. (1961): Occurrence and Stratigraphy of some Gypsum and Anhydrite Deposits in Alberta, *Alberta Research Council*, Bulletin 7, pages 10-15.

Hamilton, W.N. (1984): Salt and Gypsum in Alberta, *in* The Geology of Industrial Minerals in Canada, *Canadian Institute of Mining and Metallurgy*, Special Volume 29, pages 230-237.

Henderson, G.G.L. (1954): Stanford Range, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 35, 84 pages.

Korun, B. (1980): Report on Drilling and Geological Evaluation of Mineral Property at Lussier River, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 8076, 27 pages.

Leech, G.B. (1958): Canal Flats, *Geological Survey of Canada*, Map 24-1958.

_______ (1960): Fernie (West Half), *Geological Survey of Canada*, Map 11-1960.

_______ (1979): Kananaskis Lakes Map Area, *Geological Survey of Canada*, Open File 634.

Mott, J.A., Dixon, J.M. and Helmstaedt, H. (1986): Ordovician Stratigraphy and Structural Style at the Main Ranges – Front Ranges Boundary near Smith Peak, British Columbia, *Geological Survey of Canada*, Paper 86-1B, pages 457-465.

Wigley, T.M.L., Drake, J.J., Quinlan, J.F. and Ford, D.C. (1973): Geomorphology and Geochemistry of a Gypsum karst near Canal Flats, British Columbia, *Canadian Journal of Earth Sciences*, Volume 10, Number 2, pages 113-129.

MOUNT BRUSSILOF MAGNESITE PROJECT, SOUTHEAST BRITISH COLUMBIA (82J/13E)

By M.E. MacLean
University of Calgary

KEYWORDS: Industrial minerals, magnesite, Mount Brussilof, Baymag, Cathedral Formation, Cambrian carbonates, Simpson Pass thrust.

INTRODUCTION

The Mount Brussilof magnesite deposit (MINFILE 082JNE 001) is located in the East Kootenay region of the southern Rocky Mountains, about 30 kilometres northeast of Radium Hot Springs (Figure 3-5-1). The world-class deposit has been mined by open pit methods by Baymag Mines Co. Ltd. since 1982.

A proposed 2-year, 1:50 000-scale geological mapping project commencing in 1989, will outline the extent of the magnesite mineralization and the Cambrian hostrocks. The depositional controls for the magnesite will be established to serve as an exploration tool for similar deposits in the Rocky Mountains.

A preliminary examination of the property was carried out in September 1988. Samples of the magnesite from the main pit and the host dolomites and limestones were collected for petrographic study.

Support for this project is provided by a British Columbia Ministry of Energy, Mines and Petrolenm Resources Geoscience Research Grant. Cooperation by Baymag staff is gratefully acknowledged. The project will form the basis of a Master's thesis at the University of Calgary.

HISTORY AND PRODUCTION

The Mount Brussilof magnesite deposit was discovered in 1965 by a Geological Survey of Canada field party led by G.B. Leech. Baykal Minerals Ltd. and Brussilof Resources Ltd. subsequently staked over 300 claims in the area and drilling was carried out in 1970 and 1971. In 1971, Baykal and Brussilof amalgamated to form Baymag Mines Co. Ltd. and further drilling followed. The reserves were increased to 19 million tonnes grading 95.7 per cent magnesium oxide. In 1979, Baymag was acquired by Refratechnik GmbH. of Germany and production began in 1982. Proven and probable geological reserves calculated in 1980 were 9.5 million tonnes of 95 per cent (and greater) magnesium oxide in calcined product and 13.6 million tonnes of 93 to 95 per cent magnesium oxide in calcined product. Additional possible reserves were estimated at 17.6 million tonnes averaging 92.44 per cent magnesium oxide in calcined product (Schultes, 1986).

The magnesia being produced is caustic-calcined; the primary ore is roasted and then hydrated. The main uses for this product are in acid-neutralization processes in the pulp and paper industry, and as an animal feed supplement. A more refined, high temperature product, "fused" magnesia, was introduced in 1983, and is used as a refractory in steel making.

PREVIOUS MAPPING

The Cambrian formations of the southern Rocky Mountains have been extensively studied, most notably by Aitken (1966, 1968) and Cook (1970, 1975). Geological mapping by G.B. Leech (1966a, b) covers the west half of the Kananaskis Lakes sheet at a scale of 1:126 720 and includes the Mount Brussilof area (Figure 3-5-2). Since this time, several people have mapped the area immediately surrounding the magnesite showings, with significant contributions being made by Grove (1975), Baykal (1969), Godfrey (1969) and Leech (1977). Geological mapping at a scale of 1:50 000 will tie in these detailed studies to the regional setting and provide a framework for magnesite exploration.

GEOLOGY

REGIONAL SETTING

The Mount Brussilof area is in the southern Main Ranges of the Rocky Mountains. The area lies in the Simpson Pass

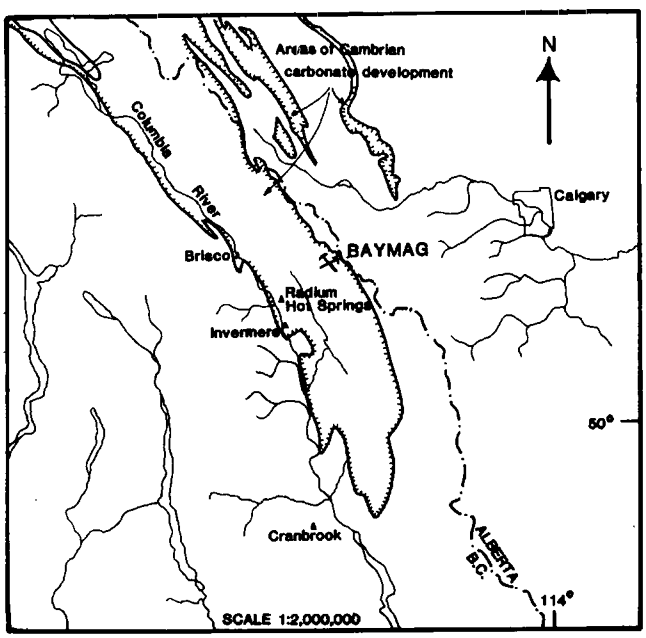


Figure 3-5-1. Location of Baymag Mount Brussilof magnesite mine.

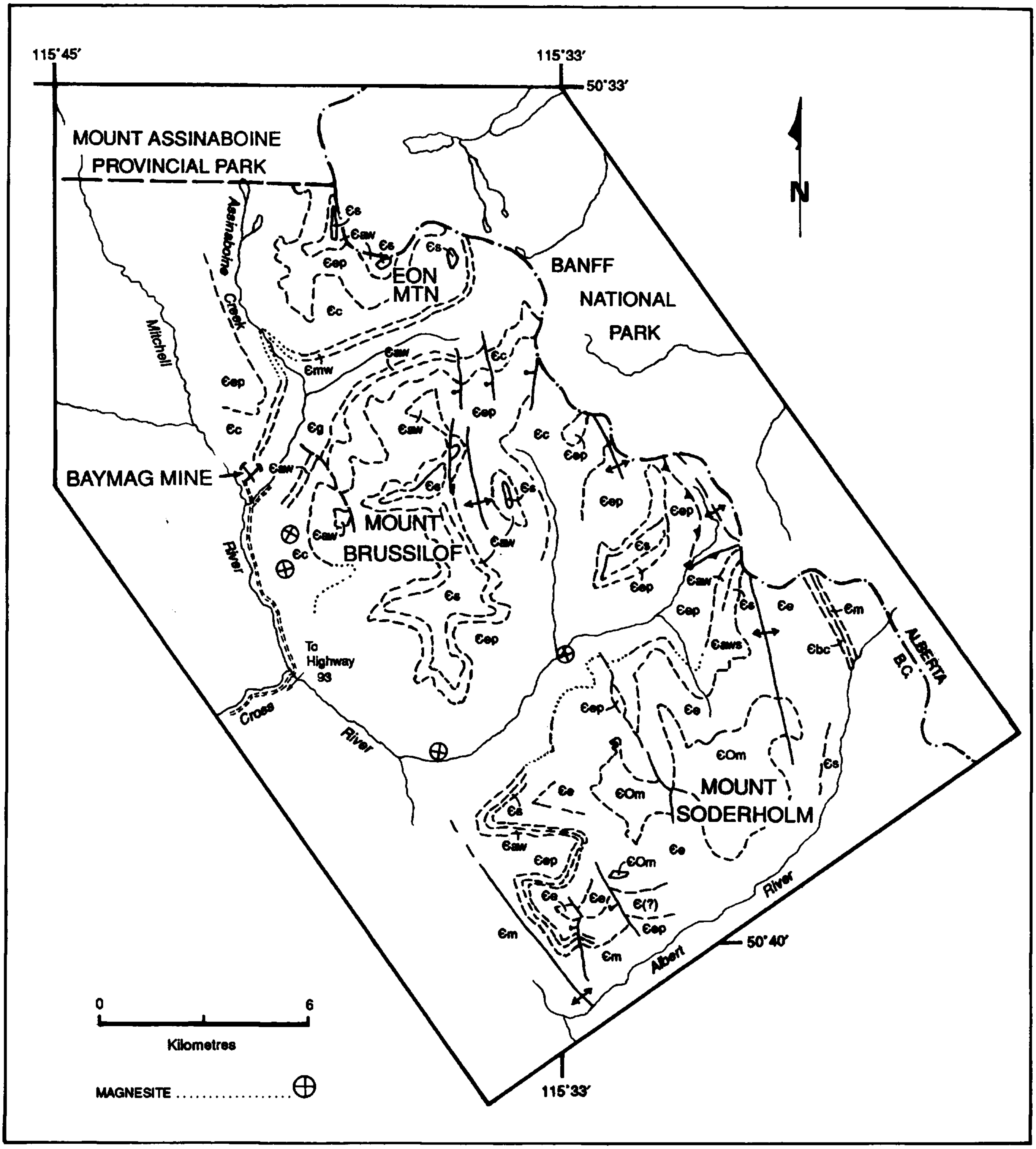


Figure 3-5-2. Geology of the project area (from Leech, 1966b). For map unit symbols refer to Table 3-5-1.

thrust sheet and contains rocks ranging in age from Early Cambrian to Early Ordovician (Table 3-5-1, Figure 3-5-2). Middle Cambrian deposits are extensive as they represent the period of maximum Lower Paleozoic marine transgression. Cook (1970) studied the Cambrian sequence in detail in the Kicking Horse Pass region northeast of the study area. He correlated the eastern, mainly carbonate, facies with western shales, depicting a basin deepening to the west. The western correlative facies (Chancellor Formation) occurs west of the western boundary (Mitchell River) of the study area.

TABLE 3-5-1
TABLE OF FORMATIONS*

Period	Epoch	Formation	Lithology	Map Symbols (Fig. 3-5-2)
Ordovician	Lower Ordovician	Survey Peak Fm. min. 240 m	green shale, siltstone, limestone, limestone nodules at top	€Osp
		McKay Group,	undivided shale, limestone	€Om
Cambrian	Upper Cambrian	Mistaya Fm. 150 m	thin-bedded limestone, dolomite partings, stromatolites	€m
		Bison Creek Fm. 120 m	brown, grey shale, limestone interbeds	€bc
		Lyell Fm. 300 m	thick-bedded limestone, dolomite, silty in part	€l
		Sullivan Fm. 90 m up 210 m md 150 m lw	shale limestone, dolomite shale, minor limestone, base silty	€s
	Middle Cambrian	Waterfowl Fm. 150-210 m	thick-bedded dolomite, limestone	€aw
		Arctomys Fm. 60-150 m	shale, siltstone, dolomite, purple at base	
		Pika Fm. 240 m	limestone, dolomite, flaggy limestone with shale partings	€ep
		Eldon Fm. 360-460 m	massive dolomite, limestone	
		Carbonate	facies, undivided	Em
		Stephen Fm. 0-105 m	green siliceous argillites, shale, thin-bedded limestone	€st
		Cathedral Fm. 240-580 m	massive dolomite, limestone, minor magnesite	€c
		Mount Whyte Fm. 0-180 m	altered green silty shale, dark grey limestone, minor siltstode	€mw
	Lower Cambrian	Gog Group 600-900 m	thick-bedded quartz siltstone, shale interbeds, limestone at top	€g

* From Cook (1970) Table 1. Eastern facies only. Map units from Leech (1966).

STRUCTURE

The rocks in the Mount Brussilof area, east of the Mitchell River, are broadly concentrically folded, with axes trending northwest. The Baymag magnesite deposit lies on the western limb of one of these folds. Crumpling in the core of an anticline east of the deposit displays tighter folding and anomalously steep-dipping strata in an otherwise very gently dipping sequence.

MAGNESITE DEPOSITS

The magnesite occurs with limestones and dolomites of the cliff-forming Middle Cambrian Cathedral Formation (Table 3-5-1) which ranges from 240 to 580 metres in thickness. The magnesite is coarse grained, white to buff coloured, weathering buff to rusty. At the Baymag deposit, the main pit contains very pure white magnesite. Several other magnesite beds were mapped in the area by Leech (1966b), and those opposite the mine, on the flanks of Mount Brussilof, were studied in detail by Godfrey (1969).

The magnesite is stratabound, forming bands 65 to 75 metres thick separated by well-bedded limestone and dolomite. The discrete beds have led to speculation whether the magnesite is primary in origin or the result of complete replacement of the original sediments by either hydrothermal or diagenetic processes.

Baykal (1969) and Jenkins (1973) both support a sedimentary origin for the magnesite, that is, deposition from concentrated brines in a shallow, saline environment. Evidence for a sedimentary origin is seen in the sharp conformable contacts between magnesite and dolomite and limestone beds. Cook (1975) also noted that the thickness of the magnesite bed varies similarly to the other strata, which may reflect cycles of sedimentary deposition. Cook proposes, however, that the magnesite is secondary, and that the conformity results from preferential replacement of specific beds.

Leech (1977) noticed frequent lenticular pods of pyritized, coarse-grained white to pinkish dolomite within the magnesite, and Schultes (1986) also comments on the occurrence of dolomite and dolomite/limestone lenses. In September of 1988, the open-pit operation at Mount Brussilof had exposed a lens of well-bedded dolomite and silty limestone in sharp but irregular contact with the surrounding magnesite. Original bedding remains visible, coarse-grained magnesite crystals are seen growing in the sediments and locally completely replace the original dolomite. The dolomite/limestone beds form a discontinuous lens in the centre of the main mass of magnesite, suggesting it is a remnant of an original complete sequence which has been almost totally replaced. Further evidence for the magnesite being secondary is the presence of pyrite-filled veins which may indicate hydrothermal activity (Schultes, 1986).

REFERENCES

Aitken, J.D. (1966): Middle Cambrian to Middle Ordovician Cyclic Sedimentation, Southern Rocky Mountains of Alberta, *Canadian Petroleum Geology*, Bulletin, Volume 14, pages 405-41.

——— (1968): Cambrian Sections in the Eastermost Southern Rocky Mountains and the Adjacent Subsurface, Alberta, *Geological Survey of Canada*, Paper 66-23, 96 pages.

Baykal, O. (1969): Preliminary Geological Report on the Mag 1 to 36 Mineral Claims, Mount Brussilof, Radium, British Columbia, Assessment Report 2040, 13 pages.

Cook, D.G. (1970): A Cambrian Facies Change and its Effect on Structure, Mount Stephen–Mount Dennis Area, British Columbia, *in* Structure of the Southern Canadian Cordillera, J.O. Wheeler, Editor, *Geological Association of Canada*, Special Paper 6, pages 27-39.

——— (1975): Structural Style Influenced by Lithofacies, Rocky Mountain Main Ranges, Alberta–British Columbia, *Geological Survey of Canada*, Bulletin 233, 73 pages.

Godfrey, J.O. (1969): The Mount Brussilof Magnesite Project, British Columbia. A Preliminary Field Investigation, for *Baykal Minerals Ltd.*, Private report, December 1969, 63 pages.

Grove, E.W. (1975): Summary Report, Mount Brussilof Magnesite Deposit (NTS 82J/13E), *Canex Placer Inc.*, Private Report, 10 pages.

Jenkins, D.M. (1973): Baymag Property, 1972 Summary Report on Geology, for J.W. Ondrack, Private Report February 1973, 35 pages.

Leech, A.P. (1977): Assessment Report, Yelo Claims, Cross River–Mitchell River Area of British Columbia, Assessment Report 6565, 10 pages.

Leech, G.B. (1966a): Geological Map, Kananaskis Lakes West Half NTS 82J, *Geological Survey of Canada*, Open File 634.

——— (1966b): Kananaskis Lakes Area West Half, *Geological Survey of Canada*, Paper 66-1, pages 65-66.

Schultes, H.B. (1986): Baymag - High Purity MgO from Natural Magnesite, *Canadian Institute of Mining and Metallurgy*, Bulletin, May 1986, pages 43-47.

INDUSTRIAL ZEOLITES IN THE PRINCETON BASIN (92H)

By Virginia V. Marcille
University of Guelph

KEYWORDS: Economic geology, zeolites, Princeton basin, Allenby Formation, clinoptilolite, x-ray diffraction, cation exchange capacity.

INTRODUCTION

Recent developments in the agricultural, horticultural and industrial applications of natural zeolites have sparked interest in the occurrence of these minerals in the Princeton basin of south-central British Columbia. A previous study conducted by Read (1987) reported the occurrence of zeolites in five distinct tephra lenses of the Allenby Formation of the Princeton basin: Sunday Creek tephra, Snowpatch ash, Asp Creek ash, Tailings ash and Bromley Vale tephra. The zeolites, formed in an open hydrologic system, replace original glass shards in waterlain rhyolite tuff and volcanic breccia layers. The objectives of this study are twofold: to determine the extent of zeolitization in selected horizons of the Allenby Formation, and to investigate their potential for economic application, particularly in agriculture and horticulture.

Based on the results of Read's study, Tailings ash and Bromley Vale were chosen for further research. During fieldwork in September 1988, two Tailings ash sections (VM88-9 and VM88-10) and one Bromley Vale section (VM88-11) were sampled (Figure 3-6-1). These sections correspond to Z7, Z4 and Bromley Vale Adit No. 1 respectively in Read (1987). This report summarizes the results of the fieldwork and preliminary laboratory characterization. Future work will include further laboratory, greenhouse and field studies.

GENERAL GEOLOGY

Encompassing 170 square kilometres of south-central British Columbia, the Princeton basin is a half-graben bounded on the east by the north-northeasterly trending, west-dipping Boundary fault (Figure 3-6-1), and filled with Tertiary sediments of the Princeton Group. As proposed by Hills (1965), the stratigraphy of the Princeton Group consists of the Lower Volcanic Formation and the Allenby Formation. The Lower Volcanic Formation, predominately intermediate in composition, is comprised of greater than 1370 metres of interbedded flows, breccias, tuffs and volcaniclastic sediments. It is overlain by the Allenby Formation: a 1600 to 2000-metre sequence of sandstone, shale, waterlain rhyolite tephra and coal. Broken by northwesterly to westerly trending folds and faults south of Princeton, the shallower northern half of the trough is sediment dominated, while the southern half is predominantly volcanic (Read, 1987).

STRATIGRAPHY

The geology of the basin has been mapped at 1:50 000 scale (McMechan, 1983), and the zeolitized tephra horizons and the surrounding sedimentary stratigraphy at 1:25 000 (Read, 1987). Fieldwork conducted in 1988 for this project concentrated on producing finer stratigraphic detail on the selected exposures, and obtaining representative samples across each section: in each case, samples were taken at 1.0-metre intervals, with the exception of the upper 10 metres of VM88-10 where the interval was 2.5 metres. The stratigraphic sections are summarized in Table 3-6-1.

Detailed correlation of the Tertiary rocks in the basin is restricted by the rarity of good exposures. It has been suggested, however, that Bromley Vale tephra should correlate with Tailings ash if the Asp Creek fault (Figure 3-6-1) has a right-lateral strike-slip displacement of roughly 1200 metres (Read, 1987).

Tailings ash is exposed on the south limb of the westerly trending Tailings syncline, from the left bank of the Similka-

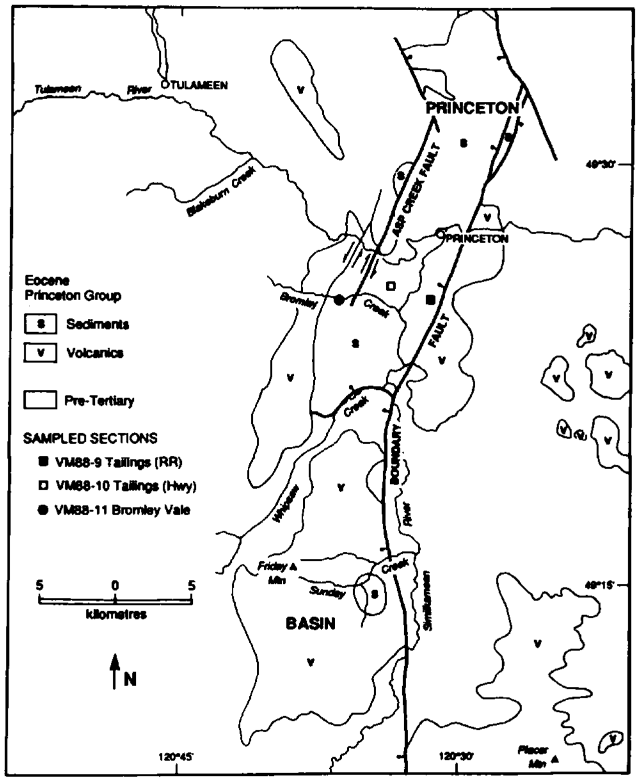


Figure 3-6-1. Simplified geological map of the Princeton basin showing location of studied exposures. Modified from Read (1987).

Section: VM88-9 (Tailings ash on Railway)

BED	DESCRIPTION	THICKNESS(m)	HEIGHT(m)*
3	tuff, vitric rhyolite, buff; massive; ze, pl, ksp, qz, bi, mm; no fossils	10	4.05
2	mudstone, grey, fine; thin bedded, ripple marks, flame structures, nodules; qz, ksp, pl, mm clc; no fossils	0.05	4
1	tuff, vitric-crystal, buff to light grey; massive; ze, pl, ksp, qz, mm; no fossils	4	0

Section: VM88-10 (Tailings ash on Highway)

BED	DESCRIPTION	THICKNESS(m)	HEIGHT(m)*
5	tuff, vitric-crystal, light grey to buff; coarse bedded to blocky, fining upward; ze, mm, mus, pl, ksp, qz, bi; no fossils	12	11
4	ash, unconsolidated, light grey,; ze, mm, pl, ksp, qz, bi; no fossils	2	9
3	tuff, vitric-crystal, light grey; medium to coarse bedded, fining upward; pumice; ze, qz, pl, ksp, mm, mus; wood fragments (.5 to 5cm)	3	6
2	breccia, rhyolitic, buff, fine; massive; rock fragments (to 2cm), pumice; ze, pl, ksp nt, qz; wood fragments (to 10cm)	2	4
1	tuff, mixed, grey; massive; subangular rock fragments; pl, ksp, ze, qz, nt; no fossils	1	3

Section: VM88-11 (Bromley Vale)

BED	DESCRIPTION	THICKNESS(m)	HEIGHT(m)*
3	tuff, vitric-crystal, light grey to cream; thin to medium bedded, few rock fragments; ze, qz, pl, ksp, mm, bi; wood fragments (.1 to 1cm)	8	1
2	ash, unconsolidated, buff; pumice, angular rock fragments; ze, ksp; wood fragments	0.2	0.8
1	tuff, fine, dark grey, massive; ze, pl, ksp, mm, qz; no fossils	0.8	0

* Height refers to height above base of exposure.
N.B. Refer to Table 2 for mineral abbreviations.

Table 3-6-1. Stratigraphic sections.

meen River to the abandoned Copper Mountain railway grade. VM88-9 corresponds to a 14-metre section of this outcrop along the grade. The section consists of 4 metres of vitric crystal tuff overlain by 10 metres of vitric rhyolite tuff. Both tuffs contain zeolite (clinoptilolite), but the thin mudstone unit separating them does not. Expandable clays are present throughout the section.

On the opposite limb of the syncline, VM88-10 is exposed in a roadcut on the northwest side of Highway 3, approximately 600 metres east of a side-road along Bromley Creek and 100 metres northeast of a gravel pit. Due to obliteration by slumping, 3 metres at the base of the exposure were not included in this section.

A mixed tuff underlies a 2-metre-thick, fine rhyolite breccia which is overlain by a thick montmorillonite-bearing vitric crystal tuff.

VM88-11 corresponds to an exposed section of Bromley Vale tephra along Bromley Creek upstream from Adit No. 1. With the exception of a massive tuff and an ash layer at the base of the outcrop, the section consists of an 8-metre-thick, thin to medium-bedded, vitric crystal tuff. As in VM88-10, the presence of wood fragments in some strata indicates deposition by water (Read, 1987), and neither the top nor the bottom contact of the zeolitized horizon is exposed.

MINERALOGY

The mineralogy of the samples (Table 3-6-2) was determined by a Rigaku Geigerflex x-ray diffractometer under the following operating conditions: copper K-alpha radiation, step scan mode, 4 second count time, 0.02° step width. In order to prepare powder presses, the samples were first powdered using a Retsch pulverizer.

Contrary to earlier findings of clinoptilolite and lesser amounts of stilbite (Z.D. Hora, personal communication, 1988), clinoptilolite is the only zeolite present in the samples studied. Plagioclase and potassium feldspars, quartz and mica (biotite, muscovite) are the most common accessory minerals. The presence of natrolite in some samples and ill-defined peaks intermediate to those for clinoptilolite and feldspar indicate the possible presence of poorly crystalline feldspathoidal minerals. Diffraction peaks associated with expandable clay minerals have been attributed to montmorillonite, however, further x-ray diffraction studies are necessary for the precise characterization of the clay mineralogy.

ZEOLITE CONTENT

Although x-ray diffraction permits the identification of the zeolite species, quantitative analysis is restricted by the interference of other phases and the non-proportional nature of peak intensities. As a result, the zeolite content of the samples was estimated from their cation exchange capacity (CEC); that is, the availability of exchangeable cations loosely held within the tetrahedral framework of their crystal structure (Mumpton, 1984). Natural zeolites have characteristically high cation exchange capacities.

In this study, the method for determining cation exchange capacity is based on clinoptilolite's high selectivity for

SAMPLE	CEC (meq/100g)	MINERALOGY*
VM88-9 (Tailings ash on Railway):		
13-14m	157	ze,pl,ksp,qz,mm
12-13m	170	ze,ksp,qz
11-12m	123	ze,pl,ksp,bi,mm
10-11m	149	ze,pl,ksp,mm
9-10	129	ze,pl,qz,bi,mm
8-9m	159	ze,ksp,pl,qz,mm
7-8m	145	ze,ksp,pl,qz,mm,nt
6-7m	155	ze,ksp,mm
5-6m	146	ze,ksp,qz
4-5m	133	ze,ksp,qz,mm
3-4m	147	ze,pl,ksp,qz,mm
2-3m	156	ze,pl,ksp,qz,mm
1-2m	157	ze,pl,ksp,qz
0-1m	152	ze,pl,ksp,qz,mm
VM88-10 (Tailings ash on Highway):		
17.5-20m	89.3	qz,pl,ksp,bi,mm
15-17.5m	105	ze,pl,mus
12.5-15m	91.1	ze,pl,mus
10-12.5m	83.5	ze,pl,ksp,mm,mus
9-10m	75.0	ze,pl,ksp,qz mus,mm,
8-9m	64.3	pl,ksp,ze,bi,ksp
7-8m	83.1	ze,mm
6-7m	78.1	pl,ksp,ze,mus,qz
5-6m	137	ze,pl,ksp,qz,mm
4-5m	110	ze,pl,ksp
3-4m	109	ze,pl,ksp,qz
2-3m	118	alb,ze,pl,ksp,qz
1-2m	114	ze,pl,ksp,qz,nt
0-1m	104	kspm,ze,pl,ksp,qz,
VM88-11 (Bromley Vale):		
8-9m	125	ze,pl,ksp,qz,mm
7-8m	139	ze,pl,ksp,qz
6-7m	139	ze,pl,ksp,qz
5-6m	132	ze,pl,ksp,mm
4-5m	135	ze,pl,ksp,mm
3-4m	103	ze,pl,ksp,mm,bi
2-3m	142	ze,pl,bi,mm
1-2m	153	ze,ksp
0-1m	78.1	ze,pl,ksp,qz,mm

* alb=albite, bi=biotite, ksp=K feldspar, kspm= microcline, mm=expandable clay mineral,possibly montmorillonite, mus=muscovite, nt=natrolite, pl=plagioclase, qz=quartz, ze=clinoptilolite. Underlined mineral is predominant.

Table 3-6-2. Mineralogy of samples from stratigraphic sections (*See* Table 3-6-1).

NH_4^+. One gram of powdered sample was shaken for five days in 50 millilitres of 1 molar NH_4Cl. After washing out the excess NH_4^+ with distilled water, the ammonium-saturated samples were twice exchanged with 50 millilitres of 1 molar KCl. The supernatants from both exchanges were collected in a 250-millilitre volumetric flask and brought up to volume with 1 molar KCl. The solutions were then analysed for NH_4^+-N using a Technicon colorimetric auto-analyser. The cation exchange capacity was calculated from this concentration. Values for duplicates of each sample were averaged and are presented in Table 3-6-2 and illustrated in Figure 3-6-2.

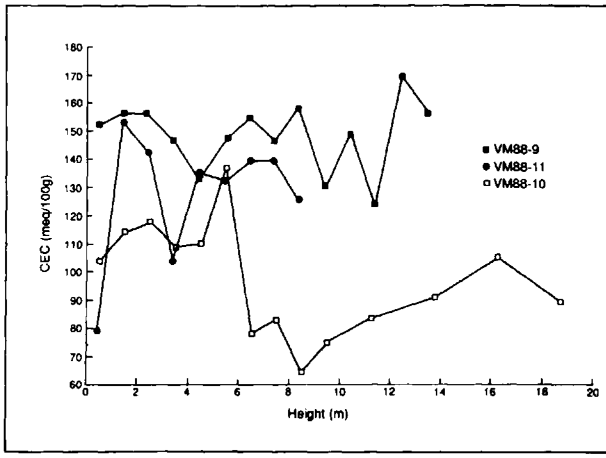


Figure 3-6-2. Plot of cation exchange capacity versus height illustrating extent and uniformity of zeolitization across VM88-9, VM88-10 and VM88-11.

The accuracy of zeolite content, as estimated by this method, is restricted by the presence of such minerals as feldspars, feldspathoids and expandable clays which contribute to the total cation exchange capacity of the sample. Furthermore, exchange capacity is a function of the degree of Al^{3+} substitution for Si^{4+} in the crystal framework of the zeolite; yet the ratio of Si:Al is not constant (Mumpton, 1984). It is possible, however, to estimate the zeolite content by assuming a cation exchange capacity of 220 meq per 100 grams for pure clinoptilolite, and disregarding the effects of secondary minerals.

The zeolite content of the studied samples ranges from 29 to 77 per cent. VM88-9 shows the least variability with 56 to 77 per cent clinoptilolite across the section, excluding the mudstone layer which is not zeolitized. In Tailings ash on Highway 3 (VM88-10), the rhyolitic breccia has the highest zeolite content (50 per cent), and that of the vitric crystal tuff in VM88-11 is about 60 per cent, generally decreasing upwards. As previously noted, however, these estimates may be high due to the presence of secondary minerals, particularly expandable clay minerals.

ECONOMIC GEOLOGY

In 1980, world production of natural zeolites was 270 000 tonnes: European production accounted for one-half of this total and Japanese for 80 000 tonnes (Sersale, 1985). The industrial applications of natural and synthetic zeolites differ owing to the uniformity, efficiency, performance quality, design parameters and high cost of synthetic zeolites; natural zeolites are better suited for less sophisticated, large-scale uses.

The most profitable applications of zeolites utilize their adsorption, ion exchange and molecular sieve properties. Present applications are in the following fields: construction industry as pozzolan; agriculture as soil conditioners, fertilizer regulators, deodorizers and feed supplements; aquaculture in filtering systems; treatment of heavy metals and waste water; oxygen separation; solar energy storage; and domestic use as deodorizers and pet litter. Clinoptilolite has demonstrated varied success in each of these applications:

proper utilization requires careful characterization of the material with respect to type and amount of zeolite, variability within the deposit and associated mineralogy.

CONCLUSIONS

Tailings ash and Bromley Vale horizons of the Allenby Formation are potential economic deposits of natural zeolite owing to their high clinoptilolite content (estimated 26 to 77 per cent), uniformity, thickness and accessibility. Samples taken across VM88-9 (Tailings ash on railway) show the least variability and the highest cation exchange capacity values.

The preliminary results of this study warrant further characterization of the deposits, including clay mineralogy and zeolitization using scanning electron microscopy and x-ray diffraction. The potential application of these zeolites in agronomy and horticulture, based on their high cation exchange capacity and affinity for NH_4^+, will also be investigated.

ACKNOWLEDGMENTS

This project is supported by British Columbia Geoscience Research Grant RG88-01. I thank Danny Hora for his encouragement and field assistance, and Dr. Peter van Straaten and Dr. Ward Chesworth of the University of Guelph for their guidance and support. Special thanks to Peter Smith for his invaluable technical contributions and to Debbie Wilson for her graphics expertise.

REFERENCES

Hills, L.V. (1965): Source of the Allenby Formation, Princeton Coalfield, British Columbia, *Canadian Petroleum Geology*, Bulletin, Volume 13, pages 271-279.

McMechan, R.D. (1983): Geology of the Princeton Basin, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1983-3, 52 pages.

Mumpton, F.A. (1984): Natural Zeolites in Zeo-agriculture: Use of Natural Zeolites, *in* Agriculture and Aquaculture, W.G. Pond and F.A. Mumpton, Editors, *Westview Press*, Boulder, Colorado, pages 33-43.

Read, P.B. (1987): Industrial Minerals in Some Tertiary Basins, Southern British Columbia (92H, 92I), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 247-254.

Sersale, R. (1985): Natural Zeolites: Processing, Present and Possible Applications, *in* Zeolites, B. Drzaj and S. Pejovnik, Editors, *Elsevier Science Publishers*, Amsterdam, pages 503-512.

MIOCENE STRATIGRAPHY AND INDUSTRIAL MINERALS, BONAPARTE TO DEADMAN RIVER AREA, SOUTHERN BRITISH COLUMBIA* (92I/14, 15; 92P/2, 3)

By P.B. Read
Geotex Consultants Ltd.

KEYWORDS: Industrial minerals, diatomaceous earth, pozzolan, Chilcotin Group, Deadman River Formation, Chasm Formation, Miocene.

INTRODUCTION

This report summarizes results from 49 days of fieldwork spent investigating the distribution of Miocene rocks, their stratigraphy, and the occurrence of industrial minerals in the area between Bonaparte and Deadman rivers. In the Miocene, the principle industrial minerals are diatomaceous earth and volcanic ash. In addition to the regional geology of the area of Monger (1982) for the Ashcroft area (92I), and Campbell and Tipper (1971) for the Bonaparte Lake area (92P), McCammon (1960) described volcanic ash and its pozzolanic properties at Sherwood Creek; Cockfield (1948) and Hora (1986) reported on the Red Lake diatomite; and Read (1988) discovered diatomite north of the junction of Gorge Creek and Deadman River. Laboratory investigations of samples are in progress, but tests of materials relative to ASTM specifications have not yet started.

MIOCENE STRATIGRAPHY

Within the mapped area (Figure 3-7-1), the Miocene succession consists of up to 350 metres of fluviatile rhyolite ash and fine clastic sediments underlying a minimum thickness of 500 metres of olivine basalt flows. The core from two drill holes east of Chartrand Lake indicates that the basalt flows and sediments are intercalated over a thickness of 150 metres. All of these rocks belong to the Chilcotin Group, which Mathews (*in press*) defined as consisting of Neogene basalt, and intercalated sedimentary and pyroclastic strata in south-central British Columbia. The rhyolite ash, and fluviatile and lacustrine sediments up to the first appearance of basalt belong to the Deadman River Formation (Campbell and Tipper, 1971), and the overlying olivine basalt flows and intercalated rhyolite ash and sediments belong to the newly proposed Chasm Formation.

The Deadman River Formation outcrops in a few roadcuts, slide scarps and stream bottoms on the western side of the map area, along sections of Bonaparte River, and Loon and Scottie creeks. On the east side of the map area, it underlies parts of the valley walls of Deadman River and the north-trending valley containing Young Lake. White to buff-weathering, unbedded rhyolite ash dominates, and white tuffaceous sandstone, siltstone and shale occur near the top of the sequence. Although there are only a few exposures of carbonaceous shale and siltstone near the top, two drill holes near Chartrand Lake show layers up to few metres in thickness are scattered throughout the formation. In the Deadman River valley, Campbell and Tipper (1971) suggested that diatomaceous layers up to 4 metres thick occur near the bottom of the succession, but in Loon Creek, diatomaceous earth outcrops near the base and at the top. In Loon Creek, pebble conglomerate and sandstone form a minor part of the formation, and according to Campbell and Tipper, similar rocks occur near the mouth of Chasm Creek and within a few kilometres south and west of Clinton.

Most of the sediments are fluviatile and partly fill deeply incised, steep-walled valleys very similar to the present valleys of Deadman and Bonaparte rivers and Chasm Creek. Local debris-flows from the steep valley walls form some of the fill. North of the junction of Gorge Creek and Deadman River, a cross-section of the Miocene Deadman channel, abbreviated as Mio-Deadman, is 2 kilometres wide and 380 metres deep with the lower 200 metres filled mainly with rhyolite ash of the Deadman River Formation. The northwest side of Loon valley, near Wohlleben Creek, has a few exposures of Deadman River Formation that outline the cross-section of the Mio-Bonaparte channel which is 5 kilometres wide and more than 400 metres deep, with a fill of more than 365 metres of rhyolite ash, conglomerate and diatomaceous earth. The Mio-Bonaparte channel is still more than 2 kilometres wide along the bottom of Loon Creek which indicates that the channel depth not only exceeds 400 metres but could easily approach 500 metres. The Miocene interfluves were probably similar to the present rolling hills of the map area. East of Deadman River, in the southeast corner of the map area, unbedded airfall rhyolite tephra covers the interfluves to depths approaching 20 metres. The restricted areal distribution and up to 20-metre thickness of tephra on the interfluves imply proximity to local rhyolite vents rather than the distant calcalkaline arc volcanoes lying to the southwest, as suggested by Bevier (1983). About 4 kilometres north of Red Lake, diatomaceous earth exposed at the Western Clay Products deposit, formerly the DEM deposit, is part of a lacustrine succession that lies on Eocene basic volcanics. The base of the succession is perched about 300 metres above the base of the nearby Miocene channels and is clearly not part of the fluviatile channel fillings.

The Chasm Formation typically forms a chain of cliffs up to 50 metres in height at the top of the present valley sides.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

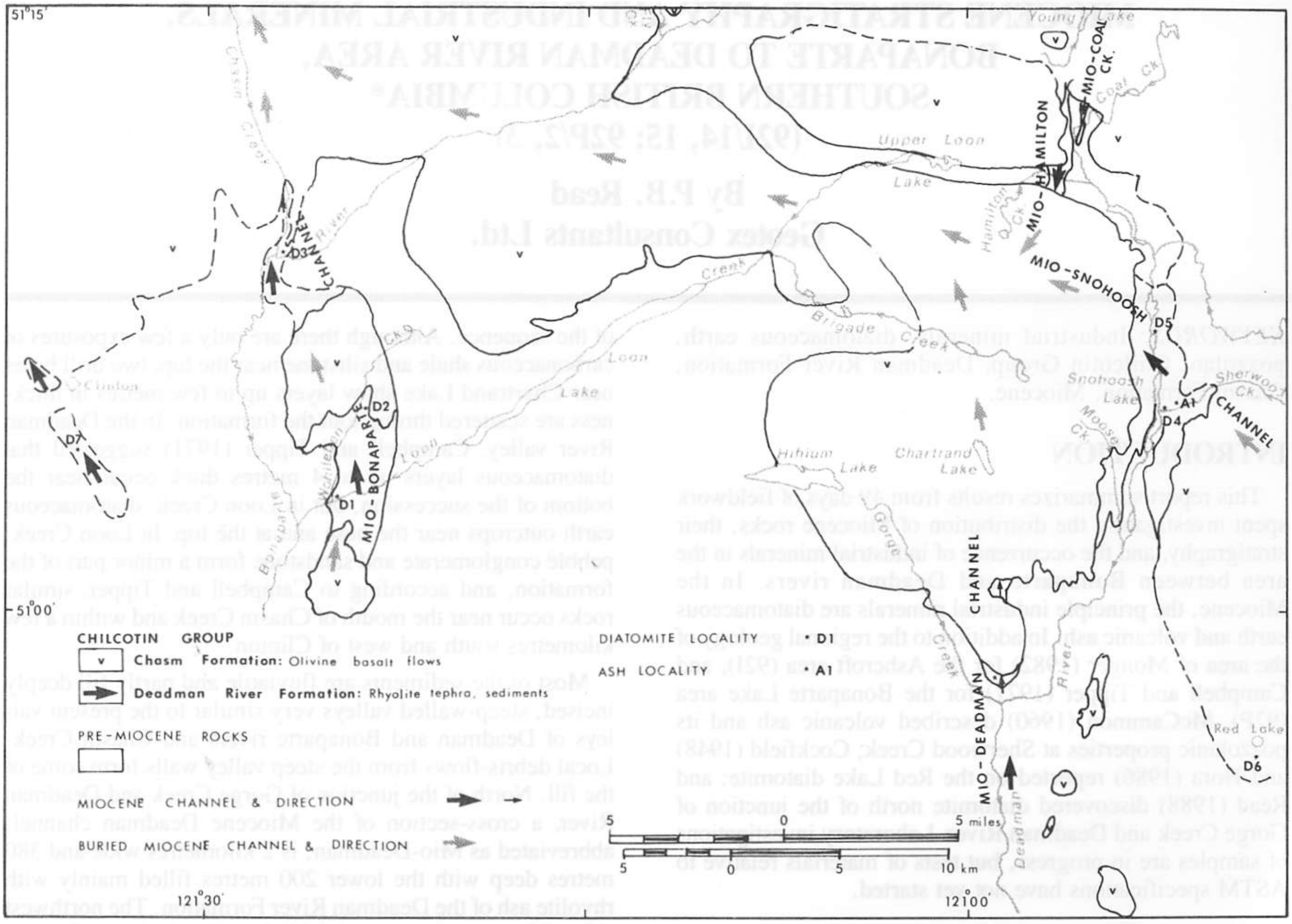


Figure 3-7-1. Simplified geological map of the area between Bonaparte and Deadman rivers showing the distribution of the Chilcotin Group, exhumed and buried Miocene drainage channels, and industrial mineral occurrences. Geological boundaries are dashed where taken or modified from Campbell and Tipper (1971).

The postglacial channel of Chasm Creek, ringed by cliffs of 100 metres or more, exposes up to a dozen olivine basalt flows ranging in thickness from 1 to 15 metres. Only near the margins are the flows vesicular or amygdaloidal with zeolites as the common filling. Away from the margins, most of the flows are medium to dark grey with prominent olivine and plagioclase. The outcrops are blocky to columnar jointed, and lack platy jointing or flow layering. These outcrop characteristics distinguish the Miocene olivine basalt flows from the typically grey, aphanitic and platy jointed flows of the Eocene Kamloops Group. In addition, Miocene volcanic breccias are very local in contrast to the widespread distribution of breccias in the Eocene. Near the base of the formation, some of the Miocene basalt flows have a weak platy jointing and contain ultramafic nodules such as those near the mouth of Fly Creek, or olivine xenocrysts as in basal flows near Moose Creek. Drill holes east of Chartrand Lake show that the lower 150 metres of the formation consists of olivine basalt flows with intercalations of rhyolite ash, siltstone, shale and carbonaceous sediments ranging from 2 to 9 metres thick. Ten kilometres to the south, Bevier (1983) noted a few airfall silicic tephra layers between basalt flows. The base of the Chasm Formation is set at the first appearance of olivine basalt and thus the formation includes the overlying silicic tephra and sediment layers among the olivine basalt flows.

Within the map area, the succesion of flat-lying olivine basalt flows is nearly 500 metres thick as exposed in the valleys of Bonaparte River, Loon Creek, and Deadman River. Such a thickness must contain dozens of flows and is many times the average thickness of 67 metres for the Chilcotin Group or the thickest section of 141 metres measured by Bevier (1983) in her regional study. Because the flows form a third or less of the Miocene channel fills, most spread out over a rolling topography that had more than 800 metres of relief, but which lacked the deeply incised valleys that the Deadman River Formation had already filled.

MIOCENE DRAINAGE

Bevier (1983) noted that the present courses of the Fraser and Chilcotin rivers were established during the Late Miocene. The near coincidence of the Mio-Bonaparte channel and present Bonaparte river, Mio-Deadman and present Deadman, and Mio-Snohoosh with Snohoosh Lake may have the same implication of Late Miocene development. However, the fascinating observation of Mathews and Rouse

(1984) is that the Miocene sediments in the vicinity of Gang Ranch on the Fraser River have current directions indicating a flow to the north or northwest.

In the mapped area, because massive rhyolite ash dominates the Deadman River Formation, current indicators are extremely rare. At four different locations in cliffs of conglomerate in the Mio-Bonaparte channel on the south side of Loon Creek, pebble imbrication indicates northerly flow. Other sites for the measurement of current indicators are present near Clinton but uncooperative landowners will not allow access. In the absence of other current indicators, the angle of intersection of Miocene channels and the differences in elevations along the channel bases provide relevant information (Table 3-7-1).

TABLE 3-7-1
CHARACTERISTICS OF MIOCENE CHANNELS

Channel	Channel	Angle of Intersection
Mio-Deadman	Mio-Bonaparte	Acute towards northwest
Mio-Snohoosh	Mio-Hamilton	Inferred acute towards west
Mio-Snohoosh	Mio-Deadman	Inferred acute towards northwest
Mio-Hamilton	Mio-Coal Creek	Acute towards south
Channel	**Elevations**	**Direction of Elevation Decrease**
Mio-Coal Creek	1020 m (3350′) 975 m (3200′)	Southward
Mio-Bonaparte	850 m (2800′) <700 m (2800′)	North-northwestward

In the mapped area, these data indicate that most of the Miocene channels drained to the north and west, in contrast to the present drainage system which is to the south and southwest. In the Mio-Bonaparte channel, pebble imbrication, and a northward decrease in the elevation of the channel prove north-northwest flow in a channel that is subparallel to, but about 4 kilometres east of Bonaparte River. Deadman valley exposes parts of four Miocene channels which from south to north are Mio-Deadman, Mio-Snohoosh, Mio-Hamilton and Mio-Coal Creek. Of these, the southward decrease in the elevation of the base of the channel of Mio-Coal Creek and its angle of intersection with Mio-Hamilton Creek require a southward flow in both channels. The elevation of the base of Mio-Hamilton Creek, at less than 930 metres (3050 feet) in Hamilton Creek where the Miocene channel is 0.5 kilometre wide in the creek bottom, implies that Mio-Deadman and Mio-Snohoosh cannot be part of a south-flowing Mio-Hamilton channel because Mio-Deadman and Mio-Snohoosh bases are not less than 915 metres (3000 feet) and 925 metres (3025 feet) respectively. If Mio-Deadman and Mio-Snohoosh are not part of a south-flowing system, then the channels must be north flowing and join with Mio-Hamilton beneath a thick cover of basalt flows under the mid-course of Brigade Creek. The low elevation of the base of olivine basalt flows in Loon Creek where it is less than 915 metres (3000 feet) and in Bonaparte River at less than 715 metres (2350 feet) provides evidence of a west-northwest-flowing Miocene channel which joins the four Miocene channels exposed in Deadman valley with the Mio-Bonaparte near the mid-course of Chasm Creek. The regional distribution of Miocene rocks and the elevations of the underlying basement preclude an eastward drainage of any significant Miocene channel toward the North Thompson River.

INDUSTRIAL MINERALS IN THE CHILCOTIN GROUP

Industrial minerals in the Chilcotin Group are restricted to diatomaceous earth and volcanic ash which are found only in the Deadman River Formation. Because much less than 1 per cent of the area underlain by the formation contains outcrops, it cannot be adequately prospected for industrial minerals without trenching or drilling.

DIATOMACEOUS EARTH

The Mio-Bonaparte channel contains diatomaceous earth. A 3-metre-high roadcut on Tomlin Road within 100 metres of its junction with the Loon Lake Road at 700 metres (2300 feet) elevation and UTM coordinates FM0610050mE, FM5655900mN (**D1**) (Figure 3-7-1) exposes diatomaceous earth near the bottom of the channel fill. Roadcuts on an old logging road shown on NTS sheet 92P/3 just east of Wohlleben Creek expose diatomaceous earth between 1030 and 1045 metres (3375 and 3425 feet) at FM0612350mE, FM5660250mN (**D2**) which lies within 30 metres of the top of the channel fill. The potential for further occurrences of diatomaceous earth in Mio-Bonaparte channel exist near the junction of Chasm Creek and Bonaparte River but uncooperative landowners will not permit access to the area. Mio-Deadman channel has float of diatomaceous earth exposed in roadcuts at FM0648100mE, FM5648200mN (**D3**) (Read, 1988). Near the bottom of Mio-Snohoosh channel, Campbell and Tipper (1971) reported two layers of diatomaceous earth 2 to 3 metres thick on the east side of Snohoosh Lake, north of Sherwood Creek close to FM0649200mE, FM5661200mN (**D4**). Farther north along the channel, both McCammon (1960) and Campbell and Tipper (1971) noted three diatomaceous layers ranging from 2 to 5 metres in thickness near FM0648700mE, FM5664300mN (**D5**). The sparse outcrops of the Mio-Hamilton and Mio-Coal Creek channel fills show no diatomaceous layers. Of all the diatomaceous earth occurrences only the deposit of Western Clay Products Ltd. (**D6**) near Red Lake at 1235 metres (4000 feet) and FM0653700mE, FM5645150mN has been an intermittent producer of pet litter. Drilling has outlined a lacustrine accumulation of diatomaceous earth which is up to 37 metres thick and covers an area of more than 65 hectares. Campbell and Tipper (1971) found gravel, sand and some diatomaceous silts in logging roadcuts about 2 kilometres south of Clinton and the British Columbia Railway (**D7**). Because of proximity to rail transportation, this area is worth prospecting.

VOLCANIC ASH

Massive rhyolite ash of the Deadman River Formation is the dominant rock filling the Miocene channels. To date, prospecting efforts and testing have concentrated on the north side of Sherwood Creek at 915 metres (3000 feet) and FM0649300mE, FM5661000mN (**A1**) where McCammon

(1960) tested the ash for its pozzolanic properties. Although it meets ASTM specifications, it has not been used as a pozzolan nor has it found use as a cream glaze on ceramicware (McCammon, 1960), or as an abrasive (Eardley-Wilmot, 1924 and 1927). Similar appearing but untested ash is widespread and localities in the Mio-Bonaparte channel, such as the south side of Loon Creek, might be closer to major transportation routes or the cement plant in Marble Canyon.

REFERENCES

Bevier, M.L. (1983): Regional Stratigraphy and Age of Chilcotin Group Basalts, South-central B.C., *Canadian Journal of Earth Sciences* Volume 20, pages 515-524.

Campbell, R.B. and Tipper, H.W. (1971): Geology of Bonaparte Lake Map-area, B.C., *Geological Survey of Canada*, Memoir 363, 100 pages.

Cockfield, W.E. (1948): Geology and Mineral Deposits of Nicola Map-area, B.C., *Geological Survey of Canada*, Memoir 249, 164 pages.

Eardley-Wilmot, V.L. (1924): Natural Abrasive Materials in Canada, *in* Investigations of Mineral Resources and the Mining Industry, 1923, *Mines Branch, Canada Department of Mines*, Publication Number 616, pages 14-15.

——— (1927): Abrasives, Part I, Siliceous Abrasives, *Mines Branch, Canada Department of Mines*, Publication Number 673, pages 85-89.

Hora, Z.D. (1986): New Developments in Industrial Minerals, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1985, Paper 86-1, pages 239-240.

Mathews, W.H. (*in press*): Neogene Chilcotin Basalts in South-central British Columbia: Geology, Ages and Geomorphic History, *Canadian Journal of Earth Sciences*.

McCammon, J.W. (1960): Pozzolan, *B.C. Minister of Mines*, Annual Report 1959, pages 178-184.

Mathews, W.H. and G.E. Rouse: (1984): The Gang Ranch - Big Bar Area, South-central British Columbia: Stratigraphy, Geochronology, and Palynology of the Tertiary Beds and Their Relationship to the Fraser Fault, *Canadian Journal of Earth Sciences*, Volume 21, pages 1132-1144.

Monger, J.W.H. (1982): Bedrock Geology of Ashcroft (92I) Map Area, *Geological Survey of Canada*, Open File 980, Sheet 1.

Read, P.B. (1988): Industrial Minerals in the Tertiary of the Bonaparte to Deadman River Area, Southern B.C., *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 417-419.

STRUCTURE, STRATIGRAPHY AND INDUSTRIAL MINERALS IN THE GANG RANCH AREA, SOUTHERN BRITISH COLUMBIA*
(92O/8, 9)

By K.C. Green and S. Trupia
University of Calgary

KEYWORDS: Industrial minerals, Spences Bridge Group, Kamloops Group, zeolite, bentonite, perlite, Frenier mine, diatomaceous earth.

INTRODUCTION

This project is part of a regional investigation into the occurrence of industrial minerals in Tertiary basins of southern British Columbia. The field area is located along the west side of the Fraser River approximately 100 kilometres west of Clinton. Mapping was restricted to the west side of the Fraser fault where Cretaceous to Pleistocene rocks are exposed (Figure 3-8-1). Industrial minerals of interest include zeolite, bentonite, perlite and diatomite.

STRUCTURE

Volcanic, volcaniclastic and sedimentary rocks ranging in age from Early Cretaceous to Pleistocene underlie the field area. To the east, right-lateral strike-slip movement on the Fraser fault has juxtaposed these rocks against Pennsylvanian to Triassic rocks of the Cache Creek complex (Tipper, 1978). The stress regime associated with movement on the Fraser fault has controlled the development of folds and faults within the map area. Northwest-trending upright folds have developed in Eocene sediments immediately west of the Fraser fault. Minor east-dipping reverse faults have accommodated compression in the more brittle Eocene volcaniclastic rocks exposed further west along Churn Creek (Figure 3-8-1). Dips flatten and strata become near horizontal toward the western half of the map area. From Lone Cabin Creek northward along the Empire Valley, Lower Cretaceous volcanic and sedimentary rocks are uplifted and exposed along a major northwest-trending fault (referred to as the Empire Valley fault). Correlation of stratigraphy across this fault indicates approximately 300 metres of west-side-up vertical displacement with no significant horizontal movement. Near-vertical slickensides measured along the Fraser and Empire Valley faults indicate the most recent movement was dip-slip. Vertical motion along these faults may have taken place in response to a decrease in southwest-directed compression as strike-slip movement along the Fraser fault ceased.

STRATIGRAPHY

PENNSYLVANIAN – TRIASSIC

East of the Fraser fault, siliceous volcanic tuffs, black and green ribbon chert and sheared, siliceous black argillite comprise the major part of the Cache Creek Group (Figure 3-8-1). To the south, where the Fraser fault enters the map area, a 150-metre-thick lens of light grey to buff recrystallized limestone is interbedded with black argillite and chert. At the northern end of the map area, near the mouth of Gaspard Creek, green chert and tuff are underlain by mafic flows and gabbro.

CRETACEOUS

West of the Fraser fault the oldest unit exposed is a package of maroon, green-brown and grey, porphyritic to aphanitic volcanic rocks at least 700 metres thick. Potassium-argon dating by Mathews and Rouse (1984) has identified these volcanics as Middle Cretaceous, Albian to Cenomanian in age (90.9 ± 3.2 to 97.4 ± 3.4 Ma). They are assigned to the Spences Bridge Group which has been mapped to the south by Read (1988).

Immediately west of the Empire Valley Ranch headquarters, hornblende-bearing dacite and flow-laminated aphanitic volcanic rocks locally form part of the Cretaceous strata. The presence of pumpellyite, calcite, zeolite and silica in veins, on fracture coatings, and in amygdules throughout the unit indicates that these volcanic rocks have been subjected to subgreenschist grade metamorphism. On the south side of Churn Creek, west of a large landslide (Figure 3-8-1), light green lithic tuff and an underlying sequence of well-bedded conglomerates, gravels, sandstones and mudstones approximately 180 metres thick lie beneath or within the maroon volcanic unit.

EOCENE

Eocene volcanic and sedimentary rocks of the Kamloops Group, approximately 1000 metres in thickness, unconformably overlie Spences Bridge Group volcanics. North of Churn Creek and west of Table Mountain, the contact crops out and is defined by Eocene volcanic breccia overlying amygdaloidal, zeolite-bearing flows of the Spences Bridge Group. The absence of subgreenschist alteration in the Eocene strata is an important distinguishing characteristic between otherwise similar-looking volcanic rocks of the two units. Cross-section X-X′ (Figure 3-8-2) shows a schematic Eocene stratigraphic sequence. Many of the units are discontinuous and pinch out laterally, but four generalized units can be identified over most of the map area.

The lowest (Unit 1) is composed of varicoloured volcanic breccias and minor interlayered laminated and vesicular flows ranging from mafic to dacitic in composition. Unit 1 is thickest in the northern part of the map area around Churn Creek and Gaspard Creek and thins southward, becoming

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

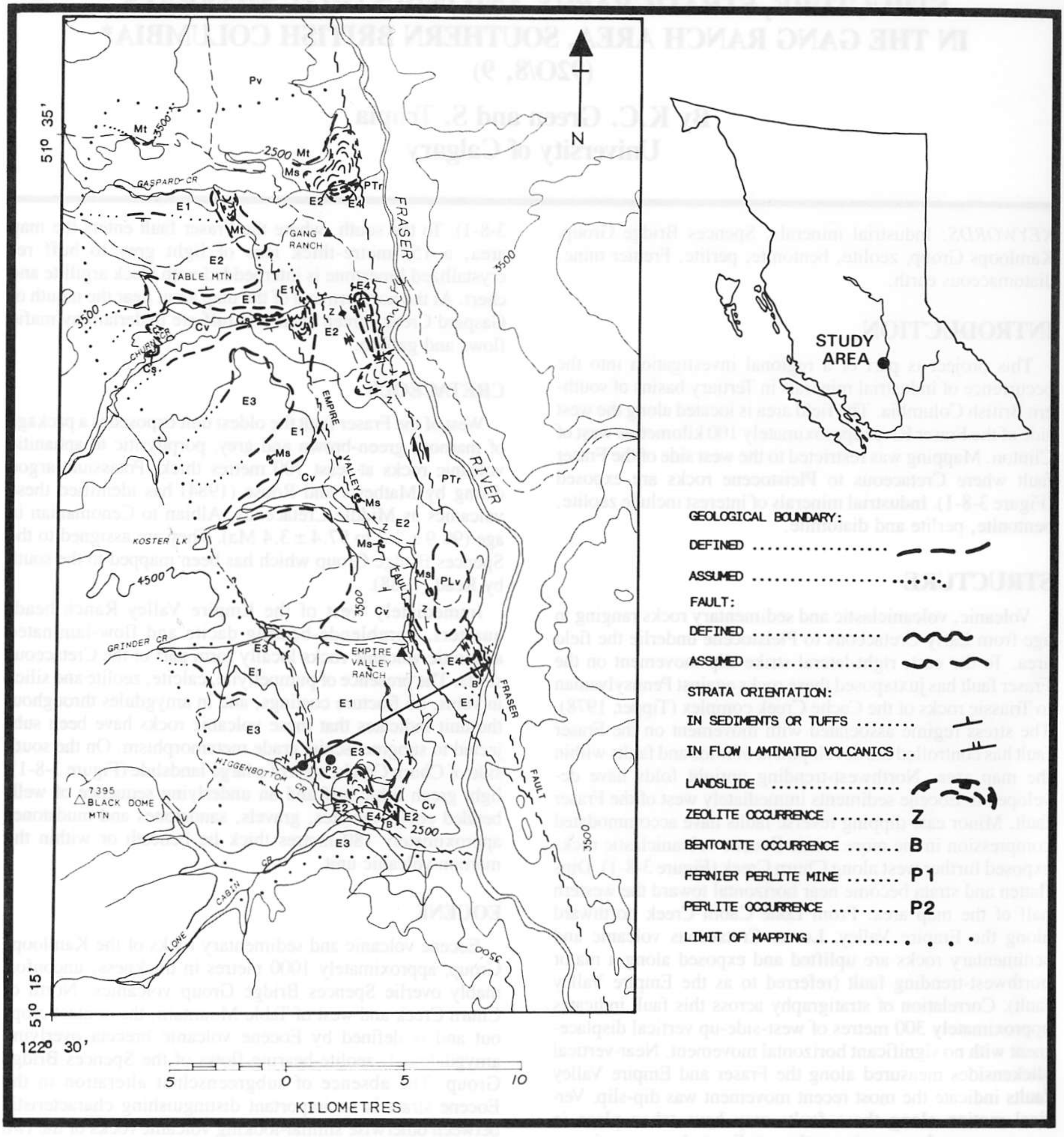


Figure 3-8-1. Generalized geology and location map. *See* Table 3-8-1 for description of rock units and key to symbols.

replaced by predominantly laminated flows with minor volcanic breccia.

The division between Units 1 and 2, east of the Empire Valley fault and north of Churn Creek, is placed arbitrarily at the first occurrence of rhyolitic tuff. Unit 2 is a succession of volcanic breccias and flows interlayered with rhyolitic lithic to ash tuffs. In places the lithic tuffs show graded bedding and sharp basal contacts typical of waterlain deposits.

Unit 3, west of the Empire Valley fault and south of Churn Creek, consists of pink to white feldspar and quartz porphyry rhyolite flows overlain by a thick accumulation of welded and crystal tuffs. From the junction of Black Dome and Koster Lake roads southward to Higgenbottom Creek, a thin layer (1 to 2 metres) of volcanic glass lies between the rhyolite flows and crystal tuffs. At Higgenbottom Creek the volcanic glass is perlitic and appears to be intrusive into the underly-

TABLE 3-8-1
TABLE OF LITHOLOGIC UNITS

Name	Age	Symbol	Industrial Minerals	Description
Chilcotin Group	Pleistocene Pliocene Miocene	Plv Pv n/a		Plateau basalt flows with well-developed columnar jointing.
Fraser Bend Formation	Miocene	Mt Ms	Diatomite	Cream-coloured volcanic ash overlying rhyolitic pyroclastic breccia and well-bedded gravels and conglomerates.
Kamloops Group	Eocene (56.7±2.0 to 49.9±1.7 Ma)	E1		Red, yellow-beige and brown volcanic breccia with interlayered flows.
	(46.8±1.6 to 45.9±1.6 Ma)	E2	Zeolite Bentonite	As above with interlayered rhyolitic tuffs and ashes.
	(48.1±1.7 Ma to ?)	E3	Perlite	Pink to white rhyolite flows overlain by welded and crystal tuffs.
	(45.9±1.6 Ma to ?)	E4	Bentonite	Well-bedded conglomerates, sandstones and siltstones overlain by bentonite layers and minor coal seams.
Spences Bridge Group	Cretaceous (Albian to Cenomanian)	Cv Cs		Massive maroon volcanics with local hornblende porphyry and laminated flows underlain (?) by well-bedded conglomerates, gravels, sandstones and mudstones.
Cache Creek Complex	Pennsylvanian to Triassic	PTr		Siliceous volcanic tuffs, black and green ribbon chert with minor interbedded limestone underlain by basalt and gabbro.

ing rhyolite flows. The rhyolite flows or, where they are absent, the crystal tuffs of Unit 3, directly overlie the volcanic breccias and flows of Unit 1 along a well-defined contact. The presence of perlite clasts in the lithic tuffs and ashes of Unit 2 indicates that they are distal equivalents of the tuffs of Unit 3.

Unit 4 is a sedimentary sequence composed of well-bedded, yellow-brown conglomerates, sandstones and siltstones overlain by bentonitic ash layers and minor coal seams. These sediments overlie Unit 2 and are exposed at three locations immediately west of the Fraser fault and a fourth location on the north side of Lone Cabin Creek near its confluence with the Fraser River (Figure 3-8-1).

Potassium-argon dating of the Eocene volcanics by Mathews and Rouse (1984) determined that the volcanics of Unit 1 range from 56.7±2.0 to 49.9±1.7 Ma and represent the oldest of the Eocene volcanics. The volcanics of Unit 2 range from 46.8±1.6 to 45.9±1.6 Ma and the rhyolite flows of Unit 3 give a date of 48.1±1.7 Ma. The palynomorph assemblage identifies Unit 4 as Early to Middle Eocene (Mathews and Rouse, 1984). The stratigraphic position of Unit 4 with respect to Unit 2 suggests the sediments are actually younger than 45.7±1.6 Ma, the youngest of the Unit 2 volcanics.

MIOCENE

Mathews and Rouse (1984) identified two occurrences of Miocene strata, in the vicinity of the Gang Ranch headquarters, on the basis of palynology. A third occurrence was mapped in the northwestern corner of the map area. The most extensive exposure, located on the north side of Gaspard Creek, consists of a lower 130-metre-thick package of bedded conglomerates and gravels, overlain by a 2 to 5-metre layer of cream to white, semiconsolidated rhyolitic ash. The second occurrence of Miocene strata is located approximately 3 kilometres west of the ranch headquarters. In this area the white to cream ash layer thickens to approximately 75 metres and a recent roadcut at its eastern extent reveals that it locally overlies a rhyolitic pyroclastic breccia approximately 100 metres thick. Clasts within the breccia include blocks of Eocene volcanic rocks near the base of the exposure. White to black pumice fragments and a heterogeneous assortment of clasts, including diatomite and mudstone, are present throughout most of the breccia. Poorly sorted conglomerates are exposed beneath the ash layer, in an irrigation ditch directly north of Table Mountain, but it is not clear if these conglomerates are part of the same unit exposed north of Gaspard Creek. Miocene strata mapped in the northwestern corner of the map area are an isolated occurrence of ash which directly overlies Eocene Unit 1 flow-laminated volcanics. Mathews and Rouse (1984) correlate these sediments on the basis of similar lithology with Fraser Bend Formation sediments in the Quesnel area to the north.

A poorly sorted conglomerate has been mapped at the southeast end of the Empire Valley, approximately 2 kilometres north of the ranch headquarters. It grades into well-sorted and bedded conglomerates and sands which crop out at four different locations along the northwest-trending Empire Valley (Figure 3-8-1). Pebble imbrication in the conglomerate indicates a northwest transport direction which is in agreement with the transport direction determined in the sediments north of Gang Ranch (Mathews and Rouse, 1984). On this basis these rocks are mapped as Miocene in age.

PLIOCENE AND YOUNGER

Plateau basalt remnants of the Chilcotin Group (Mathews and Rouse, 1984; Read, 1988) which yield Pleistocene

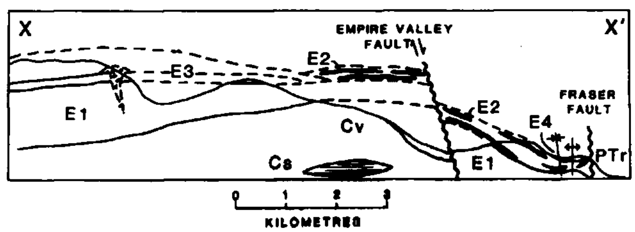


Figure 3-8-2. Schematic cross-section X-X' (Figure 3-8-1) of Eocene and Cretaceous lithologic units (vertical exaggeration X 2).

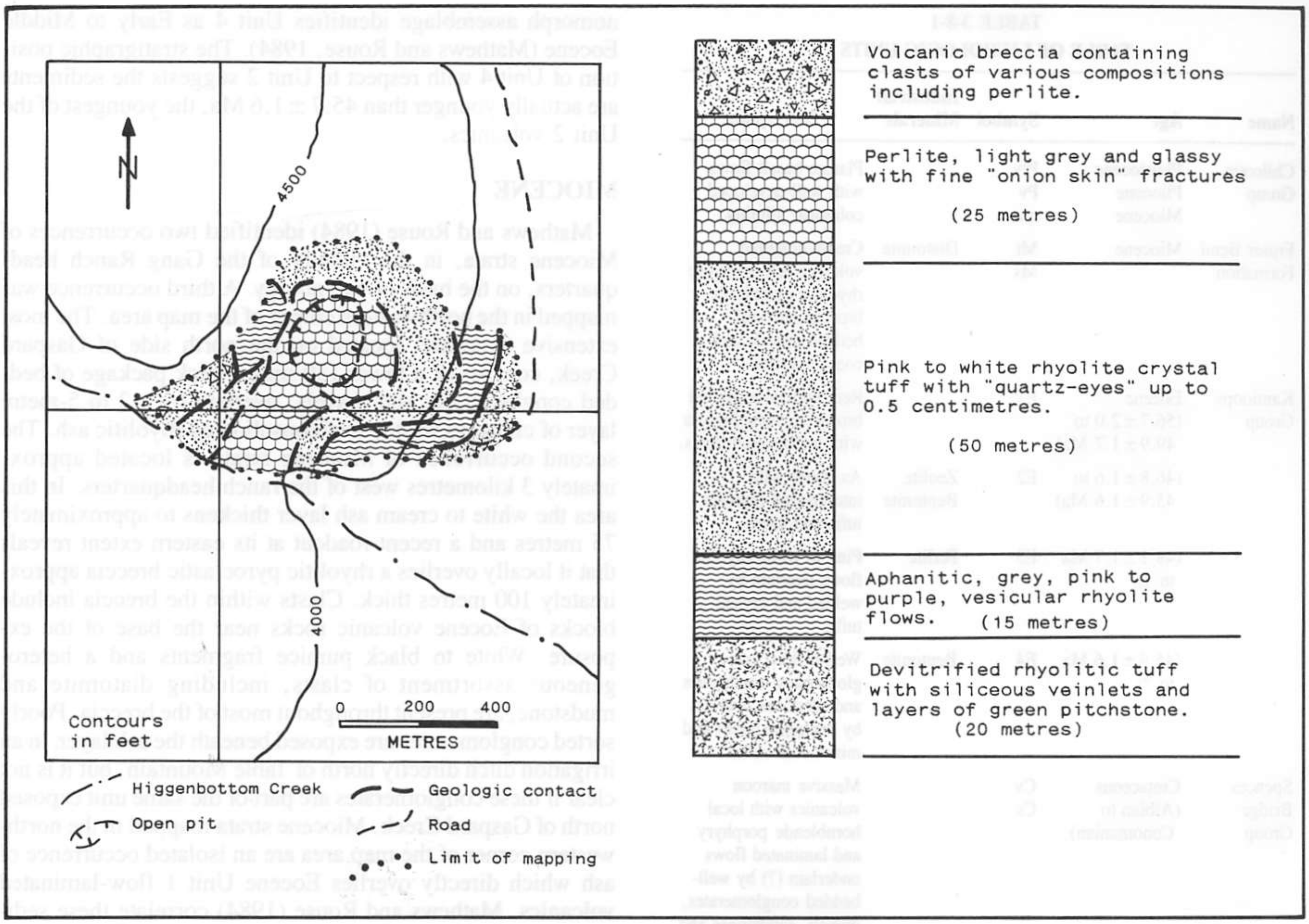


Figure 3-8-3. Geological sketch map of the Frenier perlite deposit and surrounding area.

(1.3 ± 0.1 Ma) potassium-argon ages outcrop north of Gaspard Creek at the northern end of the map area. They are composed of fine-grained, dark grey to black lavas with well-developed columnar jointing. Northeast of the Empire Valley Ranch headquarters the Fraser fault is overlain by plateau basalts dated at 0.78 Ma (Mathews, unpublished data). A number of other occurrences of columnar basalt were mapped in the Empire Valley area but they have not been dated.

INDUSTRIAL MINERALS

ZEOLITES

Preliminary bulk analysis on the rhyolite tuffs of Unit 2 by X-ray diffraction identified heulandite-group zeolites in significant quanitities. These rhyolitic tuffs range from 2 to 10 metres in thickness and can be traced discontinuously from Churn Creek to the Empire Valley Ranch. Further analyses are required to assess the extent of zeolitization and whether the deposits meet industrial standards.

BENTONITE

Layers of white bentonitic ash occur interbedded with the tuffs of Unit 2 and as individual layers in exposures close to the Fraser fault. Layers 1 to 2 metres thick occur along the fault in the Churn Creek area and to the south where the fault trace enters the map area. In both areas the bentonite layers can be followed for at least a kilometre along strike. In outcrop the bentonite has a typical "popcorn" appearence on exposed surfaces. Analysis by X-ray diffraction shows it is composed of montmorillonite and illite. Further work is being done on approximately 40 samples, to assess the quantity and composition of the clays present.

PERLITE

Two occurrences of perlite have been mapped in the field area. One of the occurrences, the Frenier deposit (P1, Figure 3-8-1), was developed by Aurun Mines Limited as an open-pit mine in 1983. The second occurrence (P2, Figure 3-8-1) is located approximately 1 kilometre east of the Frenier deposit.

THE FRENIER PERLITE DEPOSIT

Aurun Mines Limited currently holds the mineral rights to the deposit. Reserves have been estimated at 450 000 tonnes of perlite with an average expandability factor of 22 times (Aurun Mines Limited, 1986).

Detailed geological mapping in the vicinity of the deposit identified five lithological subdivisions within Unit 3 (Figure

3-8-3). The lowest unit is a white to grey devitrified rhyolite tuff, approximately 20 metres thick, that contains abundant siliceous veinlets and layers of waxy, green volcanic glass (pitchstone). This tuff is overlain by 15 metres of grey, pink to purple vesicular rhyolite flows. Above the flows and directly below the perlite is a unit of pink to grey rhyolite crystal tuff approximately 50 metres thick which contains quartz phenocrysts up to 0.5 centimetre in size. Perlite flows, approximately 25 metres thick, overlie the previously mentioned units in the vicinity of the open pit, however, immediately south of the pit, in Higgenbottom Creek, it crosscuts the underlying lithologies. In outcrop the perlite is a homogeneous, light grey, glassy rock, crosscut by veins of opalline silica and pitchstone. Fine fractures are visible in hand-sample which impart an onion-skin texture to the perlite. A volcanic breccia containing clasts of various composition and size in a light green, siliceous rhyolitic matrix overlies the perlite and grades laterally and vertically into a welded pink rhyolite tuff.

The second perlite occurrence, mapped directly east of the Frenier deposit, appears similar in general character and stratigraphic position to the Frenier deposit. The similarities between the two occurrences suggest there is potential for a second perlite deposit in the area.

DIATOMACEOUS EARTH

As previously mentioned, clasts of diatomite have been identified in Miocene pyroclastic breccias. Due to the fissile nature of diatomite it is unlikely this material has travelled far from its source. Locating the source will be one of the objectives of the 1989 field season.

ACKNOWLEDGMENTS

The project owes its success in part to the ideas expressed by Peter Read, Edward Ghent and Leonard Hills, and the cooperation and hospitality of Robert and Eitha Pepperlling, owners of the Empire Valley Ranch. The British Columbia Ministry of Energy, Mines and Petroleum Resources is acknowledged for technical support and partial financial support in the form of a Geoscience Research Grant.

REFERENCES

Aurun Mines Limited (1986): Annual Report.

Mathews, W.H. and Rouse, G.E. (1984): The Gang Ranch – Big Bar area, South-central British Columbia: Stratigraphy, Geochronology and Palynology of the Tertiary Beds and their Relationship to the Fraser Fault, *Canadian Journal of Earth Sciences,* Volume 21, pages 1132-1144.

Read, P.B. (1988): Industrial Minerals in Tertiary Rocks, Lytton to Gang Ranch, Southern British Columbia (92I/05, 12, 13; 92O/01, 08; 92P/04), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 411-415.

Tipper, H.W. (1978): Taseko Lakes (92O) Map Area, *Geological Survey of Canada,* Open File 534.

NOTES

NEARSHORE MORPHOLOGY AND HEAVY MINERAL DEPOSITS, JUAN DE FUCA STRAIT, SOOKE TO PORT RENFREW (92B/5; 92C/8, 9)

By C.E. Kilby, E. Van der Flier-Keller,
University of Victoria

B.D. Bornhold
Pacific Geoscience Centre, Geological Survey of Canada

and

J.V. Barrie
Centre for Cold Ocean Resources Engineering,
Memorial University of Newfoundland

KEYWORDS: Marine geology, offshore placers, heavy minerals, Strait of Juan de Fuca.

INTRODUCTION

The purpose of this study is to examine the nearshore morphology, geology and evolution of northern Strait of Juan de Fuca between Sooke Basin and Port Renfrew, from the beach seawards to the edge of the prominent platform (near the 100-metre isobath). Various field and analytical techniques have been and will be employed, including: offshore dredging and grab sampling, sidescan sonar, high-resolution bottom profiling (seismic), magnetic susceptibility, textural analyses and mineralogical determinations. A determination of the heavy mineral assemblages and their distribution in the area will be completed as well as an evaluation of the potential for nearshore placer deposits.

Preliminary work on this 2-year study began in the summer of 1988. Grab and dredge sampling from various oceanographic vessels produced a total of 186 samples from three cruises in 1979, 1981 and 1988. Eight transects of French Beach provided 104 samples corresponding to magnetic susceptibility survey stations. Samples were collected or obtained from archives at the Pacific Geoscience Centre and subjected to textural analysis. A study of information obtained from the first 1988 cruise, which included sidescan sonar and bottom profiling, has begun.

PREVIOUS WORK

The glacial history of the Strait of Juan de Fuca, as well as a general description of the character of its sediments, was discussed by Anderson (1968) and Mayers and Bennett (1973). The geomorphology of southwestern Vancouver Island and its late Pleistocene history are described by Alley and Chatwin (1979). A study of the nearshore surficial geology along the northern Strait has not been done, though north of Port Renfrew numerous studies of the shelf sediments have been completed. The surficial geology of the continental shelf off northwestern Vancouver Island was examined by Bornhold and Yorath (1984), and off south-central Vancouver Island by Herzer and Bornhold (1982).

A summary of investigations of beach sand magnetite content was completed by Holland and Nasmith (1958) for several locations on the British Columbia coast, including Graham Island where placer gold was also of interest. Nearshore heavy mineral assemblages and the potential for nearshore placer gold deposits on the shelf off Vanconver Island have not, however, been previously examined. Recent work by Barrie *et al.* (in press) studied the heavy mineral deposits of Hecate Strait and Queen Charlotte Sound. A study of the magnetic susceptibility of shelf sediments off central Vancouver Island revealed areas of anomalously high readings (Currie and Bornhold, 1983) which could be of potential economic interest due to the association between magnetite and heavy mineral placers.

GEOLOGIC SETTING

Southwest Vancouver Island is underlain by Tertiary Metchosin volcanics and the Jura-Cretaceous Leech River Formation, both of which are juxtaposed against the Leech River complex by the Leech River fault (Muller, 1980). Along the coast these older rocks are overlain by a narrow fringe of Tertiary clastic strata of the Carmanah Group. At the southeastern edge of the study area intrusions of the Tertiary Sooke gabbro are present.

Late Wisconsinian (Fraser) glaciation produced the major Pleistocene deposits and landforms on southwestern Vancouver Island (Alley and Chatwin, 1979). During the maximum extent of glaciation (Vashon stage), southern Vancouver Island lay completely under a cover of ice which moved in a south-southwesterly direction across the Strait of Juan de Fuca to the edge of the continental shelf. Deglaciation resulted in downwasting of the glacial debris onto the continental shelf and subsequent reworking of these sediments has concentrated heavy minerals locally.

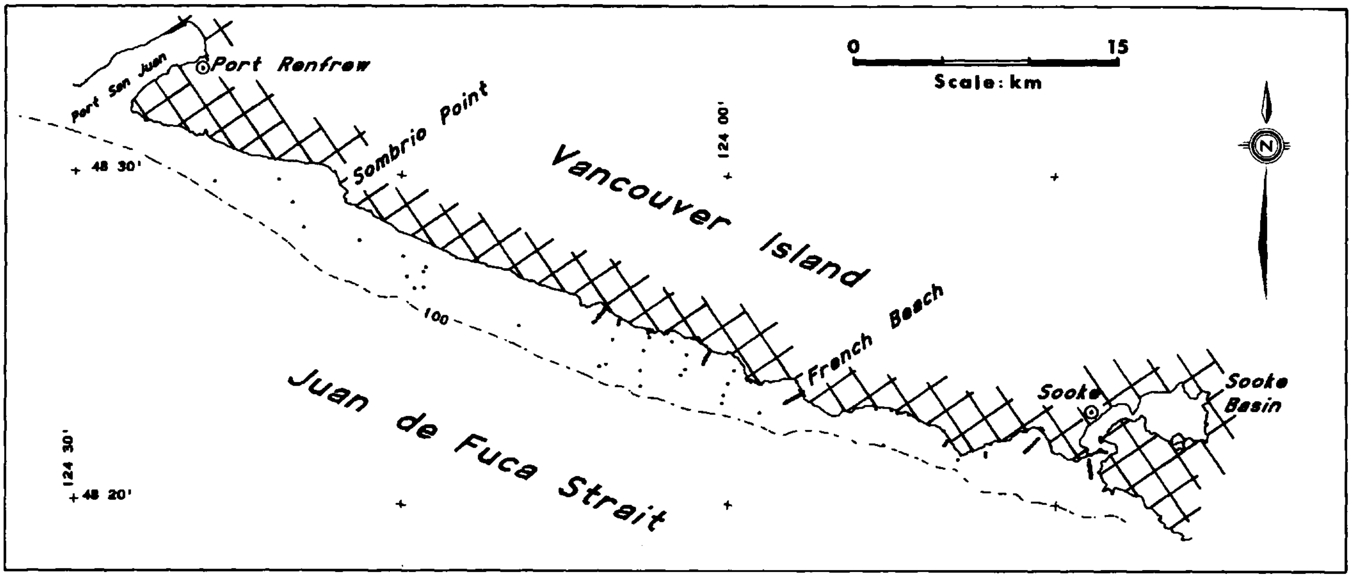


Figure 3-9-1. Samples in study area collected from cruises and beach reconnaissance in 1979, 1981 and 1988 (186 samples). Bathymetry is in metres.

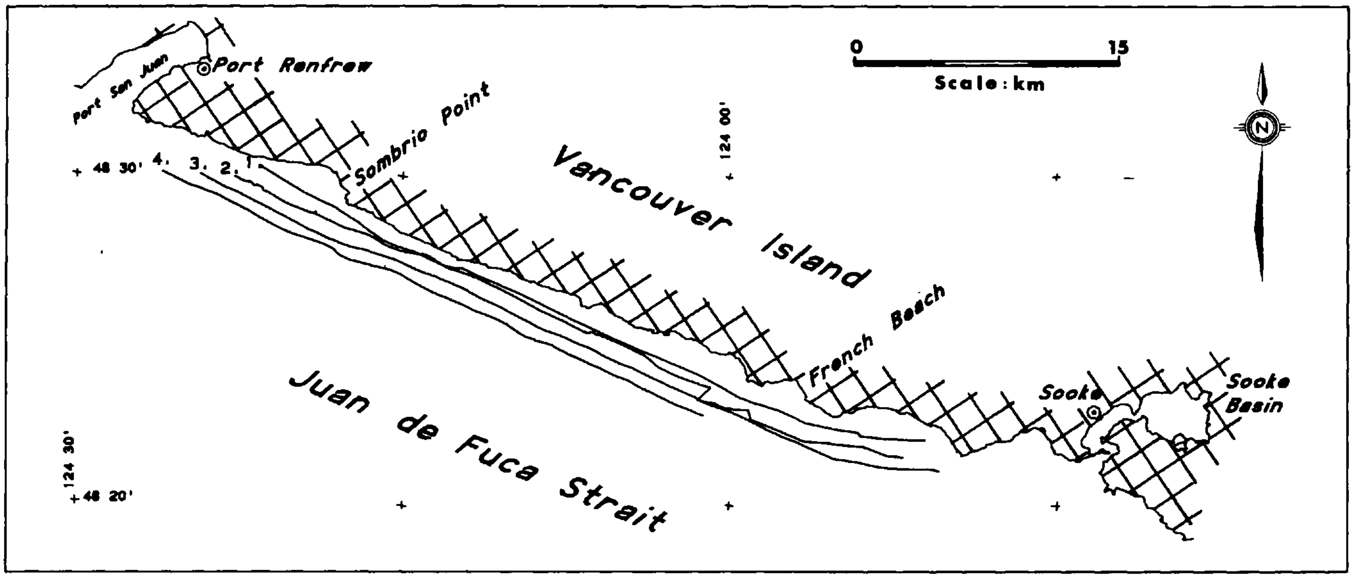


Figure 3-9-2. Four survey lines of C.S.S. Tully in January 1988. Information obtained included sidescan swaths and sub-bottom profiles (3.5 kHz).

Heavy mineral placer potential off the British Columbia coast is uncertain. Beach deposits are mined in the Gulf of Alaska, and gold has been successfully mined offshore from the Stephens Passage area in southeastern Alaska (Clifton and Luepke, 1987). Offshore mineral-related exploration in the State of Washington has centred on areas of titanium and iron-rich black sands (Lasmanis, 1988). However, gold and platinum were mined from beach placers earlier in this century on the northern Washington coast, south of Cape Flattery. These placer deposits are thought to have been derived from glacial sediment brought southward from British Columbia (Clifton and Luepke, 1987).

METHODS

Samples were collected from 175 sites during two survey cruises off the southwestern coast of Vancouver Island in 1979 and 1981. These samples are stored in the marine sample archives of the Pacific Geoscience Centre and were utilized for this study. An additional 11 samples were obtained during a cruise in January 1988 (Figure 3-9-1). During this cruise (Tully 88A) four survey lines of detailed high-resolution sidescan sonar, sub-bottom profiling and echo-sounding were completed (Figure 3-9-2). In November 1988 an additional 2-week cruise (Tully) is scheduled for fill-in sampling and to complete additional geophysical surveys in the study area.

Preliminary provenance studies of unconsolidated beach material were initiated in the summer of 1988. A magnetic susceptibility survey was completed along eight transects across French Beach. Specific volume samples (154 cubic centimetres, approximately 250 grams) were collected at every second site to determine density values for the sediments and to examine mineralogy. Shallow hand-trenches were excavated at sites of relatively high magnetic susceptibility. Till bluffs were sampled above the beach berm at Sombrio Beach where such deposits remain abutting the active beach.

Offshore samples were analysed for complete grain-size distribution.

DISCUSSION

At this preliminary stage sample analysis is still in progress. The physical laboratory analyses, including textural studies, have been completed for the 186 offshore samples collected to date. Heavy mineral separation will be performed together with petrological, mineralogical and elemental analyses on the sand-size fraction. A map of detailed bathymetry has been compiled and examination of the sea floor morphology using sidescan sonar is in progress.

In the spring of 1989 sediment transport investigations using tracer techniques (pollucite) in the nearshore and beach zone are planned. Several additional beaches within the study area will be surveyed by transects where sand accumulation is sufficiently thick for examination of magnetic susceptibility. Bulk stream sampling at selected sites above the high tide mark is also planned.

Visual inspection of beach samples from French Beach indicates distinct fining of sands seaward together with a constant decrease of magnetic susceptibility. Highest susceptibility readings coincided, in a general sense, with the high dark-mineral content in the medium-sand-size area which was usually only 1 or 2 metres seaward of the steep gravel berm.

Offshore samples were either predominantly gravel or sand. Twenty-five per cent of the samples contained 50 per cent gravel or more, and had little or no mud. Nearly two-thirds of the samples contained over 75 per cent sand with either low mud content, or more often, with about 20 per cent mud. No distinctly dark sands from the offshore have been sampled to date; vibracoring is planned for future cruises in the area to investigate the possibility of buried heavy mineral concentrations.

Ultimately an interpretation of heavy mineral transport paths from source to deposit will be attempted, along with the sediment distribution, sediment thickness, heavy mineral concentration, mineralogy and zonation of economically interesting placer minerals. Results will provide a detailed description of heavy mineral distribution and help to construct geological models for exploration programs.

ACKNOWLEDGMENTS

This study forms part of the senior author's M.Sc. research at the University of Victoria. Financial support from the British Columbia Ministry of Energy, Mines and Petroleum Resources Geoscience Research Grant Program and the Geological Survey of Canada in the form of summer employment is gratefully acknowledged. The authors are grateful for the assistance offered by R. Currie, T. Forbes and the staff at Pacific Geoscience Centre. We also thank the British Columbia Ministry of Environment and Parks for permission to sample various beach sites.

REFERENCES

Alley, N.F. and Chatwin, S.C. (1979): Late Pleistocene History and Geomorphology, Southwestern Vancouver Island, British Columbia, *Canadian Journal of Earth Sciences*, Volume 16, Number 9, pages 1645-1657.

Anderson, F.E. (1968): Seaward Terminus of the Vashon Continental Glacier in the Strait of Juan de Fuca, *Marine Geology*, Volume 6, pages 419-438.

Barrie, J.V., Emory-Moore, M., Luternauer, J.L. and Bornhold, B.D. (in press): Origin of Modern Heavy Mineral Deposits, Northern British Columbia Continental Shelf, *Marine Geology*.

Bornhold, B.D. and Yorath, C.J. (1984): Surficial Geology of the Continental Shelf, Northwestern Vancouver Island, *Marine Geology*, Volume 57, pages 89-112.

Clifton, H.E. and Luepke, G. (1987): Heavy-mineral Placer Deposits of the Continental Margin of Alaska and the Pacific Coast States, *in* Geology and Resource Potential of the Continental Margin of Western North America and Adjacent Ocean Basins – Beaufort Sea to Baja California, *Circum-Pacific Council for Energy and Mineral Resources*, Earth Science Series, Volume 6, pages 691-738.

Currie, R.G. and Bornhold, B.D. (1983): The Magnetic Susceptibility of Continental-shelf Sediments, West Coast Vancouver Island, Canada, *Marine Geology*, Volume 51, pages 115-127.

Herzer, R.H. and Bornhold, B.D. (1982): Glaciation and Post-glacial History of the Continental Shelf off Southwestern Vancouver Island, British Columbia, *Marine Geology*, Volume 48, pages 285-319.

Holland, S.S. and Nasmith, H.W. (1958): Investigation of Beach Sands, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Special Report, pages 3-8.

Lasmanis, R. (1988): Washington Offshore Mineral Resources, *Washington Geologic Newsletter*, Volume 16, Number 3, pages 5-10.

Mayers, I.R. and Bennett, L.C., Jr. (1973): Geology of the Strait of Juan de Fuca, *Marine Geology*, Volume 15, pages 89-117.

Muller, J.E. (1980): Geology–Victoria Map Area, Vancouver Island and Gulf Islands, British Columbia, *Geological Survey of Canada*, Open File 701.

NOTES

NATIVE SULPHUR OCCURRENCES IN DEVONIAN EVAPORITES, NORTHEASTERN BRITISH COLUMBIA (O94)

By B.J. Thompson

KEYWORDS: Industrial minerals, sulphur, Devonian, evaporite, Elk Point Group, Slave Point Formation.

INTRODUCTION

Most of Canada's current supply of sulphur is produced as a byproduct of "sour" natural gas, by removal and processing of hydrogen sulphide. During the 1960s and 70s an imbalance of supply and demand resulted in the build-up of a stockpile of 21 million tonnes of unsold sour-gas sulphur in western Canada. The stockpile has been gradually worked down during the last decade and is expected to be exhausted by 1991. This will result in a sudden drop of 25 per cent in the Canadian share of the world sulphur market from the present level of 40 per cent.

Potential for native sulphur deposits in western Canada was recognized many years ago. Caron (1976) and Hollister (1977, 1984) pointed out exploration opportunities for Frasch sulphur deposits in Alberta and British Columbia. This report results from a compilation of occurrences of native sulphur in Middle Devonian strata in northeastern British Columbia as reported in oil and gas drill-hole logs. Over 600 drill-hole logs intersecting Devonian beds have been reviewed and 27 sulphur occurrences identified (Figure 3-10-1); the four considered to be the most significant are briefly described. Potential sulphur deposits in Middle Devonian rocks beneath the Great Plains are too deep to recover using available Frasch mining technology, however, technological advances are improving mining methods from year to year and the recovery techniques may reach these depths in the foreseeable future.

It became apparent during the course of this study that native sulphur is also present in evaporite facies of Upper Triassic age. Triassic occurrences are not covered by this report but are shallower and more accessible and therefore offer potential for less costly exploration and development. To document sulphur occurrences in their stratigraphic interval will require the review of approximately 600 additional drill hole logs.

GEOLOGICAL SETTING

The Middle Devonian evaporites in northeastern British Columbia are a significant source of sour gas and petroleum shows are known in the Keg River, Muskeg and Sulphur Point formations of the Elk Point Group. This carbonate reef complex represents the most promising environment for the development of sulphur deposits.

The lower Elk Point sedimentary deposition was initiated by slow submergence of the land mass and resultant marine transgression from the northwest. An evaporite basin formed when barrier reef build-up restricted the circulation of marine water from the northwest. Reef growth was by a combination of organic build-up and the trapping of debris in and around the organic lattice. Local subsidence of the Keg River reef platform was commonly matched by reef build-up. Minor

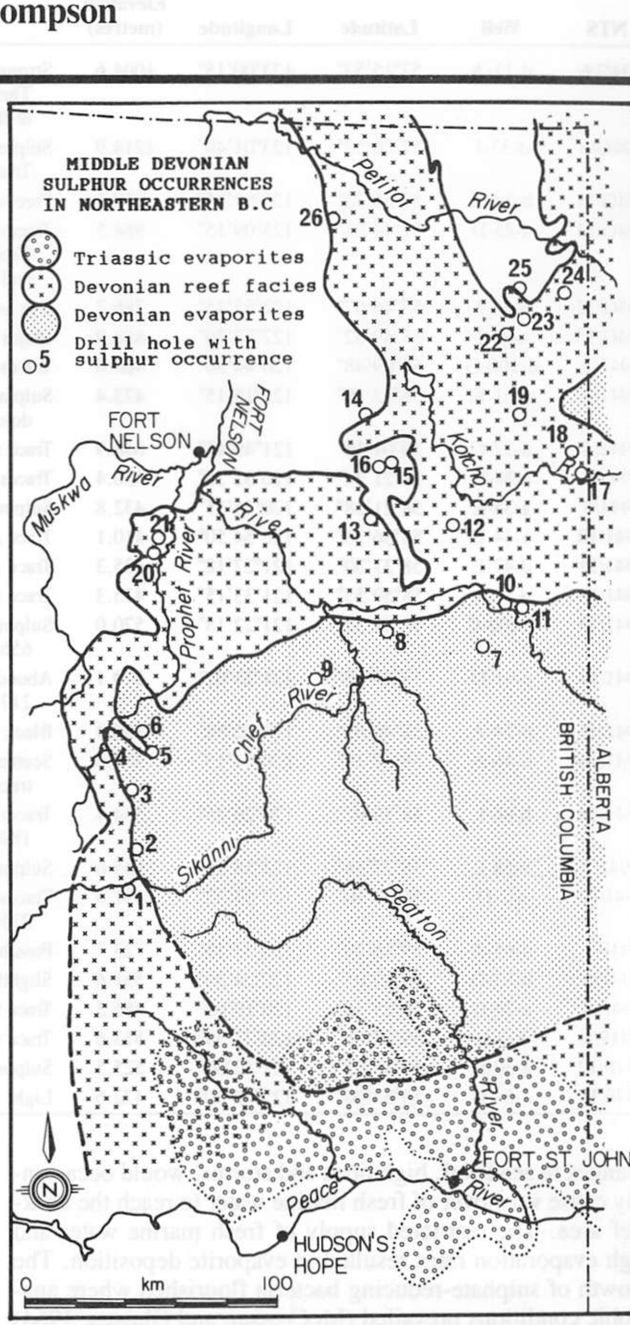


Figure 3-10-1. Middle Devonian sulphur occurrences and geological environments in northeastern British Columbia.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

TABLE 3-10-1
SULPHUR OCCURRENCES IN OIL AND GAS WELLS, NORTHEASTERN BRITISH COLUMBIA

NTS	Well	Latitude	Longitude	Elevation (metres)	Remarks
94G/6	d-11-A	57°15'53"	123°00'15"	1004.6	Strong sulphurous odours and yellow sulphur in sandstones of the Triassic Halfway Fm. The sands have poor porosity and are well cemented with silica and carbonate. The top of the Halfway sands is @ 699.8 m.
94G/6	d-33-1	57°26'53"	123°01'40"	1214.9	Sulphur coatings on fractures lined with white dolomite in sandstone and siltstone of the Triassic Halfway Fm. @ 475.5 m.
94G/11	b-34-H	57°36'32"	123°02'25"	970.8	Free sulphur in dolomitic siltstone of the Triassic Toad/Grayling beds @ 588.2 - 591.3 m.
94G/11	a-25-D	57°44'05"	123°09'15"	984.5	Traces of sulphur in microfractures in Triassic siltstone and anhydrite of the Schooler Creek beds. Crystalline sulphur in Devonian Pine Point dolomite @ 3197.4 - 3211.6 m. and in underlying anhydrite. Traces sulphur in dolomite continue to 3334.5 m.
94G/15	a-83-J	57°46'07"	122°55'45"	786.7	6 m solid sulphur in Devonian Presqu'ile Fm. (*see* text).
94G/15	a-83-J	57°49'52"	122°57'30"	858.9	Major sulphur showing in Devonian Elk Point evaporites (*see* text).
94I/2	d-100-G	58°09'48"	120°44'30"	460.6	Traces of sulphur throughout the Devonian Keg River Fm. @ 2284.0 - 2289.4 m.
94I/3	d-61-K	58°13'10"	121°15'15"	473.4	Sulphur in Mississipian limestone. Slave Point carbonates and Elk Point anhydrite and dolomite (*see* text).
94I/4	d-27-C	58°01'18"	121°49'45"	648.9	Trace sulphur in Devonian Presqu'ile dolomite @ 2563.4 - 2571.0 m.
94I/7	a-34-H	58°21'34"	120°32'30"	430.4	Traces of sulphur in Devonian Lower Keg River dolomites from 2209.8 - 2246.4 m.
94I/8	a-35-E	58°21'38"	120°25'35"	432.8	Sulphur in Devonian dolomites of Upper Keg River Fm. (*see* text).
94I/10	a-34-E	58°36'38"	120°54'50"	410.1	Trace sulphur in Devonian Presqu'ile dolomite from 2130.6 - 2145.8 m.
94I/11	d-47-E	58°37'30"	121°27'18"	435.3	Trace sulphur in Devonian Sulphur Point limestone @ 1950.7 m.
94I/13	d-95-1	58°59'55"	121°33'15"	435.3	Trace sulphur in Devonian Elk Point dolomites @ 2407.9 - 2417.1 m.
94I/14	c-100-C	58°49'52"	121°22'15"	570.0	Sulphur staining in Devonian Pine Point limestone @ 627.9 - 647.7 m and in dolomite @ 656.8 - 673.6 m.
94I/14	c-91-D	58°49'55"	121°23'02"	570.1	Abundant H_2S odor and minor black sulphur solids in Devonian Presqu'ile dolomite @ 2178.1 - 2180.8 m.
94I/16	b-24-A	58°46'07"	120°02'58"	358.4	Black sulphur staining common in dolomite @ 1859.3 - 1889.8 m.
94I/16	b-46-A	58°47'10"	120°04'15"	359.0	Scattered traces sulphur in Devonian Elk Point dolomites between 1869.3 and 1941.6 m. traces of black sulphur in anhydrite of Chinchaga Fm. @ 1962.9 - 1969.0 m.
94I/16	b-86-L	58°59'07"	120°26'45"	534.4	Traces and occasional crystals of sulphur in Devonian Presqu'ile dolomite @ 1887.6 - 1898.9 m, 1923.3 - 1932.4 m and associated with pyrite @ 1941.6 - 1947.7 m.
94J/7	b-58-L	58°27'38"	122°58'15"	545.6	Sulphur staining in Devonian Muskeg evaporite @ 2383.5 - 2398.8 m.
94J/10	a-2-D	58°30'10"	122°53'32"	491.6	Traces of sulphur in dolomite interbeds in Watt Mountain Fm. @ 2340.9-2342.4 m. and 2350.0-2360.7 m.
94P/7	d-65-A	59°18'20"	120°33'15"	723.7	Possible reddish sulphur with ZnS in Devonian Slave Point dolomite @ 1950-1980 m.
94P/8	b-83-D	59°19'05"	120°24'30"	531.6	Slightly sulphurous Devonian Elk Point dolomite @ 2039.1 - 2069.9 m.
94P/8	a-74-G	59°23'35"	120°10'00"	456.5	Trace free sulphur in Devonian Keg River dolomite @ 1630.7 - 1633.7 m.
94P/8	b-7-L	59°25'05"	120°27'38"	513.6	Trace sulphur in fractures in Devonian Keg River dolomite @ 2048.3 - 2054.4 m.
94P/12	a-30-K	59°41'05"	121°52'00"	525.5	Sulphur fills hairline fractures in Devonian Slave Point dolomite @ 2079.3 - 2080.3 m.
94O/16	a-64-H	59°53'06"	122°02'30"	422.6	Light yellow sulphurous infill in Jean Marie limestone @ 1445.0 - 1446.4 m.

changes in sea level, high tides and storms, would occasionally cause washover of fresh marine water to reach the back-reef area. The restricted supply of fresh marine water and high evaporation rates resulted in evaporite deposition. The growth of sulphate-reducing bacteria flourished where anaerobic conditions prevailed (McCrossan and Glaister, 1964) and promoted the precipitation of sulphur. As deposition continued, more evaporites precipitated and a reflux process began. The concentrated brine then flowed towards the seaward side of the reef through the porous limestone. This resulted in some dolomitization, but more importantly, the barrier reef provided microniches in which sulphate-reducing bacteria could thrive. Thus the contact area between the reef and the evaporite basin is favoured for the entrapment of sulphur.

The Middle Devonian assemblage in the study area comprises the Elk Point Group and Slave Point Formation. The Elk Point Group ranges in thickness from 600 metres in the Great Plains to 1000 metres in the northern Rocky Mountains. It comprises a cyclical sequence of evaporites, reefoid carbonates and thin beds of clastic rocks.

The Chinchaga Formation, at the base of the Elk Point Group, consists mainly of anhydrite interbedded with dolostone. The lower Keg River Formation comprises a thick reefal facies and thinner platform carbonates. The formation ranges from less than 15 metres thick in inter-reef areas, to some 200 metres thick at the rim of the barrier reef complex. The barrier complex comprises a massive carbonate bank, mainly of crystalline dolomite with occasional patches of limestone, and commonly contains thick sections with vuggy porosity.

Muskeg Formation evaporites overlie the relatively thin Keg River sequence behind the barrier, filling depressions between the Keg River reefs, and are in turn overlain by limestones of the Sulphur Point Formation and a thin unit of interbedded shales, siltstones and occasional sandstones about 10 metres thick, the Watt Mountain Formation. The Watt Mountain Formation is not present in areas where reef growth continued from Elk Point into Slave Point time.

SULPHUR OCCURRENCES

This study was limited to reports from companies drilling exploratory oil and gas wells, and the research was done without benefit of field examination. It was not possible to verify inconsistent or questionable information. A few assumptions were consistently made when the source information was obscure. The description of sulphurous odors, often used in well reports, was assumed to be either hydrogen sulphide or sulphur dioxide gas as elemental sulphur is odorless. The term "black sulphur" in reports was taken to mean dark sulphur containing carbon impurities. A listing of 27 sulphur occurrences is provided in Table 3-10-1 and locations are plotted on Figure 3-10-1; the four wells considered most significant are briefly described below.

WELL a-25-D; 94G/15

This exploration well, located at latitude 57°46′07″ north, 122°55′45″ west, elevation 787 metres, reached the top of Presqu'ile bedding, equivalent to the Keg River barrier, at a depth of 3094.0 metres. A drillstem test run for the interval 3189.7 to 3264.4 metres (10 465 to 10 710 feet) intersected 6.1 metres (20 feet) of solid sulphur. No other details are given.

WELL c-97-D; 94G/15

A major sulphur showing was intersected in this well within Elk Point evaporites and located at latitude 57°49′52″ north, 122°57′30″ west, elevation 858.9 metres. The drillstem test for the interval 3200 to 3262 metres (10 500 to 10 701 feet) recovered specks of free sulphur, 9.1 metres (30 feet) of muddy sulphur and 27.4 metres (90 feet) of native sulphur. Descriptions of 3-metre (10-foot) drilling samples, beginning at 3234 metres (10 610 feet) are as follows: dolomite and minor anhydrite with considerable native sulphur; dolomite with some scattered native sulphur; dolomite and trace sulphur; dolomite with minor amounts of sulphur; dolomite with traces of sulphur as above for the next 6.1 metres (20 feet); dolomite with rare trace sulphur for the following 9 metres (30 feet); dolomite with abundant sulphur in samples; dolomite with some sulphur; dolomite and trace brown chert with some sulphur contamination; dolomite with sulphur in samples; and dolomite samples contain elemental sulphur.

The Chinchaga beds, immediately beneath the Elk Point strata, and the pre-Devonian assemblage also contain sulphur in this hole. The interval 3302.2 to 3371.1 metres (10 834 to 11 060 feet) consists of dolomite and sandstone beds with "some elemental sulphur" to "trace sulphur staining".

WELL d-61-K; 94I/13

Sulphur occurrences were found in Mississipian limestone and Slave Point carbonates in this exploration hole located at latitude 50°13′10″ north, 121°15′15″ west, elevation 473.4 metres. The Mississipian limestone contains free sulphur over the 3-metre interval from 798.6 to 801.6 metres (2620 to 2630 feet). The Slave Point Formation has trace sulphur in limestone over the interval 2094.0 to 2097.0 metres. A strong odor of sulphur dioxide is noted from the Elk Point interbedded anhydrite and dolomite at 2283.0 to 2286.0 metres.

WELL a-35-E; 94I/8

The upper member of the Upper Keg River Formation contains sulphur in this hole located at latitude 58°21′38″ north, 120°25′35″ west, elevation 432.8 metres. The interval from 2138.2 to 2141.5 metres contains approximately a metre of possible 30 per cent sulphur followed by a 9-metre interval of dolomite and anhydrite interbeds with a heavy sulphurous odor and possible native sulphur. The interval 2161.0 to 2173.2 metres (7090 to 7130 feet) is comprised of dolomite and possible thin sulphur-bearing beds. The native sulphur is yellow, coarsely orytstalline to amorphous, and burns out of the samples as sulphur dioxide. It can be seen sparsely over the shaker table in daylight.

ACKNOWLEDGMENTS

My appreciation is extended to everyone in the Geological Survey Branch and Petroleum Section of the British Columbia Ministry of Energy, Mines and Petroleum Resources who shared both their work space and their knowledge and expertise. Particular thanks are due to Keith McAdam for his help from beginning to end, and Sylvia Chicorelli who shared her office space with me and helped assemble the database. The help and support of John Macrae, Sharon Ferris, Sharon Foofat, Louise Kadar and Stephen Glover is also much appreciated. I would also like to thank Danny Hora for his patience and understanding throughout the project. John Newell is acknowledged for his efforts in improving the draft manuscript.

REFERENCES

Caron, M.E. (1976): Sulphur in Aberta and Northeastern British Columbia–Proposed Target areas; *Unpublished Inter-office Memorandum for Duval Corporation*, 15 pages.

Hollister, V.F. (1977): Potential for the Occurrence of Sedimentary Sulphur Deposits in Northeastern British Columbia, *Canadian Institute of Mining and Metallurgy* Bulletin, November 1987, pages 97-106.

——— (1984): Sulphur Potential of the Wabamun Group, Alberta, The Geology of Industrial Minerals in Canada, *Canadian Institute of Mining and Metallurgy*, Special Volume 29, pages 238-243.

McCrossan, R.G. and Glaister, R.P. (1964): Geological History of Western Canada, *Alberta Society of Petroleum Geologists*, Calgary, 217 pages.

NOTES

Coal
Studies

NUMERICAL DEPOSITIONAL MODELLING OF THE ELK VALLEY COALFIELD*
(82G, J)

By D.A. Grieve

KEYWORDS: Coal geology, computer methods, depositional modelling, Elk Valley stratigraphy, statistical analysis, coal.

INTRODUCTION

With the completion in 1987 of 1:10 000-scale mapping of the north half of the Elk Valley coalfield (Morris and Grieve, 1988 and in preparation), the last stage of the Elk Valley project, preparation of a bulletin, is under way. Statistical analysis of stratigraphic sequences in core logs and measured sections from the coalfield is now in progress. This article summarizes results to date.

The locations of drill cores used in this study are shown in Figure 4-1-1. A total of 3284.4 metres of core was logged, comprising ten separate holes. Some of these were described by Grieve and Elkins (1986). All holes penetrated mainly the Mist Mountain Formation, principal coal-bearing unit of the Jurassic-Cretaceous Kootenay Group (Gibson, 1985). The Mist Mountain Formation averages 500 metres in thickness in the study area. The minor proportion of the logged core is from the underlying Morrissey Formation and overlying Elk Formation (the other two formations within the Kootenay Group) and is omitted in this statistical analysis.

The overall depositional environment of the lower Mist Mountain Formation is believed to have been an extensive deltaic-interdeltaic coastal plain and, for the upper Mist Mountain Formation, a fluvial-alluvial plain (Gibson, 1985). It was deposited conformably and abruptly on the subaerial beach ridge – eolian dune lithofacies of the underlying Moose Mountain member of the Morrissey Formation. Fluvial channels within the Mist Mountain Formation were dominantly of the meandering type.

An embedded, first-order Markov chain analysis of the sedimentary sequence was carried out. This method is based on a test of the assumption that the occurrence of a particular sedimentary unit at any given position within the stratigraphic column is dependent on the nature of the immediately underlying unit. Thicknesses of individual units are not taken into account. The frequency of occurrence of upward transitions from one rock type to another is tallied and displayed in matrix form. A second matrix is then generated, containing predicted frequencies of occurrences of upward transitions, based on a theoretical totally random sequence. The difference between these two matrices gives an indication of which upward transitions are occurring more often than at random.

Substitutability analysis was also carried out (Davis, 1973). This analysis examines the tendency for two rock types to occur in a similar stratigraphic setting with respect to overlying and underlying units. Two rock types with high substitutability are usually assumed to have been deposited in similar sedimentary environments (Kilby and Oppelt, 1985).

METHODS OF STUDY

Thicknesses of individual units within core were measured to the nearest centimetre. Intervals representing sampled coal horizons were taken from company lithological and geophysical logs. Units thinner than 5 centimetres were generally not measured separately.

The core logging system of Research Planning Institute, Inc. (RPI) was utilized in this study (Ruby *et al.*, 1981). The RPI system uses three-digit codes to represent rock type, composition/colour, and sedimentary structures; suffixes modify sedimentary structures, and identify penecontemporaneous deformation, cement type, and presence of coal banding or spar. This system is readily applicable to Kootenay Group strata, and offers adequate degrees of detail, speed and consistency.

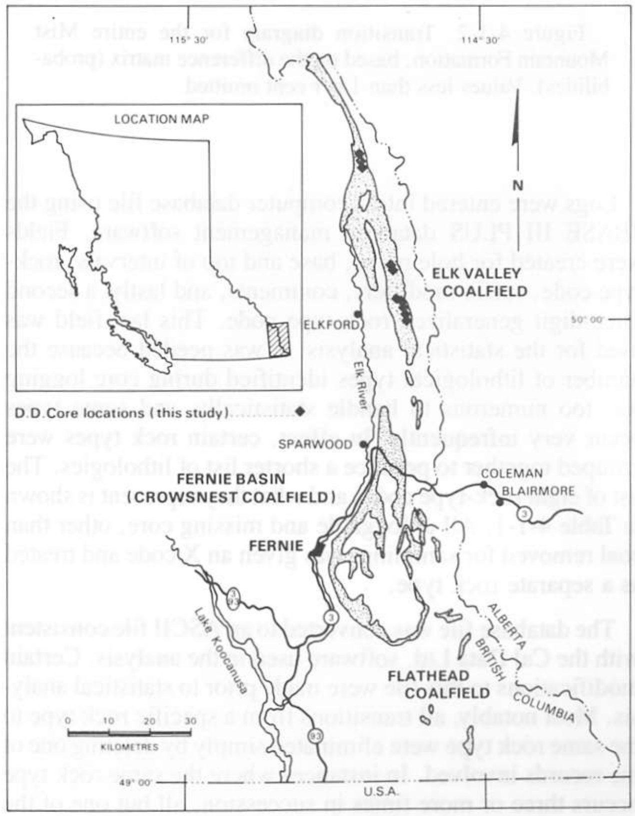


Figure 4-1-1. Locations of the three East Kootenay coalfields and drill cores used in this study.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

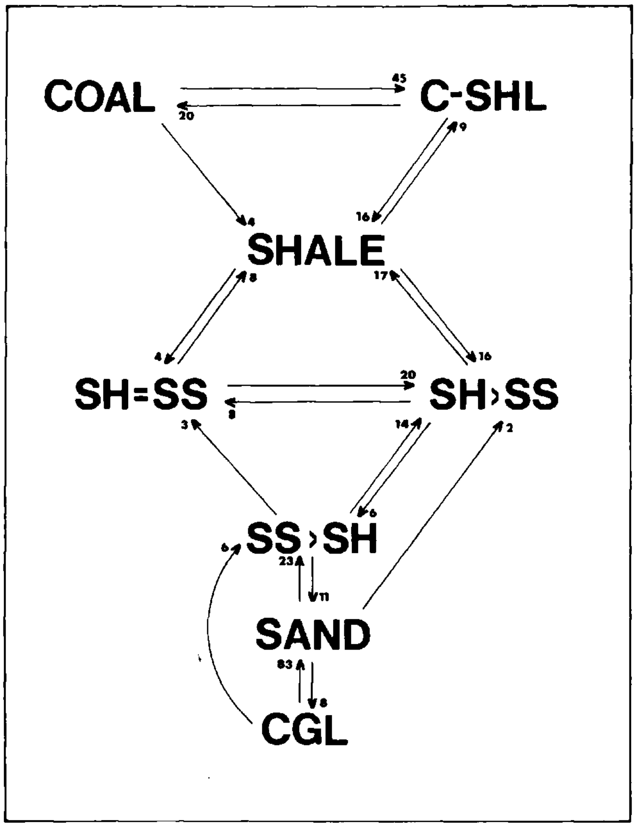


Figure 4-1-2. Transition diagram for the entire Mist Mountain Formation, based on the difference matrix (probabilities). Values less than 1 per cent omitted.

TABLE 4-1-1
ROCK-TYPE CODES USED FOR STATISTICAL ANALYSIS
(Derived from Ruby *et al.*, 1981)

Code	Explanation
CGL	**Conglomerate.** Generally chert-pebble composition.
SAND	**Sandstone.** Generally medium to very coarse grained. May be massive, flat bedded, or crossbedded.
SS>SH	**Intermixed shale and sandstone,** with sandstone in greater abundance than shale. Includes flaser-bedded sandstone, and wavy-bedded sandstone with interbedded shale. Sandstones generally fine grained.
SS=SH	**Intermixed shale and sandstone,** with both in roughly equal amounts. Predominantly lenticular-bedded sandstone with interbedded shale. Sandstone generally fine or very fine grained.
SH>SS	**Intermixed shale and sandstone,** with shale in greater abundance than sandstone. Includes shale with lenticular sandstone streaks, and sandy shales. Sandstone generally fine or very fine grained.
SHALE	**"Shale series".** Generally non-carbonaceous, grey siltstone, silty mudstone or mudstone. May be massive or laminated.
C-SHL	**Carbonaceous shale.** Generally dark grey to black mudstone or shale with coal streaks, bands or spar.
COAL	**Coal series.** Most often missing from core. Where observed it includes banded coal, dull massive coal, and coal with shale interbeds or streaked with shale.
X	**Missing core** (other than coal) and unloggable core.

Logs were entered into a computer database file using the dBASE III PLUS database management software. Fields were created for hole name, base and top of intervals, rock-type code, suffix modifiers, comments, and lastly, a second three-digit generalized rock-type code. This last field was used for the statistical analysis. It was needed because the number of lithological types identified during core logging was too numerous to handle statistically, and some types occur very infrequently. In effect, certain rock types were grouped together to produce a shorter list of lithologies. The list of eight rock-type codes and what they represent is shown in Table 4-1-1. All unloggable and missing core, other than coal removed for sampling, was given an X code and treated as a separate rock type.

The database file was converted to an ASCII file consistent with the Cal Data Ltd. software used in the analysis. Certain modifications to this file were made prior to statistical analysis. Most notably, all transitions from a specific rock type to the same rock type were eliminated simply by deleting one of the records involved. In instances where the same rock type occurs three or more times in succession, all but one of the records were deleted. This was necessary because the type of Markov chain analysis employed (embedded) is based on changes in lithology, irrespective of unit thickness. Another modification was the elimination of all records not belonging to the Mist Mountain Formation.

Subfiles of the overall modified database were defined, each subfile representing one core log. This was necessary to avoid inclusion of the transitions from the end of each core to the beginning of the next.

The modified database, which contains 3707 legitimate transitions, was then subjected to statistical analysis. The statistical computer programs developed and described by Kilby (in Kilby and Oppelt, 1985) were used and these, in turn, were based on techniques described by Siemers (1978) and Davis (1973). The first step in the procedure is generation of a count-transition matrix (Table 4-1-2) which displays the number of occurrences of each possible type of upward transition in the data. Next, an expected matrix is generated, which represents the number of upward transitions of each type which would occur in a totally random sedimentary sequence containing the same quantities of the various rock types. The difference matrix is then generated by subtracting the second matrix from the first (Table 4-1-2).

At this point it is possible to analyse the difference matrix to discover which upward transitions occur more frequently than at random, that is, those which are represented by positive values. Two outstanding examples include transitions from *SHALE* to *SH>SS* and vice versa, with positive difference values of 153 and 145, respectively (Table 4-1-2). Caution must be used in considering these numbers, however, because these two rock types occur most frequently in the database, and hence the number of transitions involving them is automatically high. To provide a more balanced analysis of the difference matrix, it is necessary to convert the positive frequency values in the difference matrix to probabilities based on the total number of transitions each unit is involved in, that is, to divide each positive element in the difference matrix by the sum of all the elements in the

TABLE 4-1-2

Transition, expected, difference and substitutability matrices for the entire Mist Mountain Formation.

Transition Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	15	2	0	1	0	0	0	0
SAND	15	0	58	21	47	32	10	1	0
SS>SH	2	48	0	47	114	76	15	1	7
SS=SH	0	21	34	0	196	159	39	2	3
SH>SS	0	43	125	173	0	377	137	8	9
SHALE	1	40	71	162	383	0	242	64	18
C-SHL	0	17	15	43	105	252	0	158	7
COAL	0	1	2	4	11	73	146	0	5
X	0	0	3	4	12	19	7	4	0

Expected Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	0	1	2	4	4	2	1	0
SAND	0	9	15	22	43	49	29	11	2
SS>SH	1	15	25	37	72	82	49	19	4
SS=SH	2	22	37	55	106	121	73	29	6
SH>SS	4	43	72	106	204	232	140	56	11
SHALE	4	48	82	120	230	261	157	63	12
C-SHL	2	29	49	73	139	159	96	38	7
COAL	1	12	20	29	56	64	38	15	3
X	0	2	4	6	11	13	7	3	0

Difference Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	15	1	-2	-3	-4	-2	-1	0
SAND	15	-9	43	-1	4	-17	-19	-10	-2
SS>SH	1	33	-25	10	42	-6	-34	-18	3
SS=SH	-2	-1	-3	-55	90	-38	-34	-27	-3
SH>SS	-4	0	53	67	-204	145	-3	-48	-2
SHALE	-3	-8	-11	42	153	-261	85	1	6
C-SHL	-2	-12	-34	-30	-34	93	-96	120	0
COAL	-1	-11	-18	-25	-45	9	108	-15	2
X	0	-2	-1	-2	1	6	0	1	0

Difference Matrix (Positive values converted to % probabilities)

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL		83.6	5.6					
SAND	8.2		23.4		2.2			
SS>SH	0.3	10.6		3.2	13.5			
SS=SH					19.8	8.4		
SH>SS			6.1	7.7		16.6		
SHALE				4.3	15.6		8.7	0.1
C-SHL						15.6		20.1
COAL						3.7	44.6	

Upward Substitutability Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL	1.000							
SAND	0.125	1.000						
SS>SH	0.358	0.680	1.000					
SS=SH	0.147	0.751	0.908	1.000				
SH>SS	0.129	0.620	0.584	0.597	1.000			
SHALE	0.150	0.662	0.754	0.690	0.322	1.000		
C-SHL	0.010	0.545	0.697	0.749	0.729	0.376	1.000	
COAL	0.010	0.321	0.368	0.462	0.649	0.501	0.378	1.000

Downward Substitutability Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL	1.000							
SAND	0.109	1.000						
SS>SH	0.389	0.705	1.000					
SS=SH	0.152	0.837	0.891	1.000				
SH>SS	0.188	0.709	0.521	0.644	1.000			
SHALE	0.010	0.681	0.741	0.663	0.303	1.000		
C-SHL	0.010	0.644	0.722	0.824	0.714	0.448	1.000	
COAL	0.010	0.406	0.295	0.442	0.531	0.514	0.308	1.000

Mutual Substitutability Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL	1.000							
SAND	0.010	1.000						
SS>SH	0.139	0.479	1.000					
SS=SH	0.010	0.629	0.809	1.000				
SH>SS	0.010	0.440	0.304	0.384	1.000			
SHALE	0.010	0.452	0.559	0.458	0.010	1.000		
C-SHL	0.010	0.362	0.503	0.618	0.521	0.168	1.000	
COAL	0.010	0.130	0.108	0.204	0.344	0.258	0.116	1.000

corresponding row in the count-transition matrix. (This may also be accomplished by expressing the values in the first two matrices as probabilities, and simply subtracting the second from the first to generate the difference matrix). The difference matrix with positive values expressed as probabilities (percentages) is shown in Table 4-1-2. Examination of this matrix shows that, for example, the 15 transitions from *CGL* to *SAND*, representing an 83.3 per cent probability, are more significant than the seemingly impressive 153 transitions from *SHALE* to *SH>SS*, representing a 15.6 per cent probability, referred to earlier.

All transitions involving missing or unloggable core were ignored.

The probability-difference matrix was converted to graphic form for easier interpretation (Figure 4-1-2). All positive upward transitions, except those below an arbitrary cut-off of 1 per cent, are displayed as an arrow connecting the two lithologies. The positions of the various lithologies on the diagram were selected to simulate a general fining-upward sequence and to show the upward transitions in as simple a manner as possible.

The count-transition matrix is tested for the Markov property by means of a chi-square test, as described by Davis (1973). In this application, rejection of the null hypothesis implies that the transitions observed are dependent to a significant degree (not random) and thus form a Markov chain.

The process was repeated twice, once for each of two subsets of the database. The first represents all strata within 200 metres of the base of the Mist Mountain Formation, and the second strata more than 200 metres above the base. The first contains 2216 transitions and the second 1485 transitions. These were generated to see if there are any sedimentological differences between the lower and upper parts of the formation in the study area.

Three further matrices (Table 4-1-2), known as the substitutability matrices, were generated for the entire formation data following the methods of Davis (1973). Values in the upward-substitutability matrix indicate the tendency of any two lithologic units to be overlain by a similar lithological unit (maximum value 1). The downward-substitutability matrix is the same except that the values indicate the degree of similarity for two lithologic units to be underlain by a similar lithological unit. The mutual-substitutability matrix measures the degree to which two units are overlain and underlain by similar units. The upward-substitutability matrix is calculated from the transition matrix for each pair of lithologies by calculating the cross-product ratio of the respective rows (*see* Davis, 1973). The downward-substitutability matrix is calculated in the same manner but using columns instead of rows. The mutual-substitutability matrix is obtained by multiplying the corresponding values from the upward and downward-substitutability matrices.

RESULTS AND DISCUSSION

Matrices related to the entire Mist Mountain Formation are shown in Table 4-1-2, those related to the lowest 200 metres in Table 4-1-3, and those related to strata more than 200 metres above the base in Table 4-1-4. Corresponding transition diagrams based on the probability-difference matrices are shown in Figures 4-1-2, 3 and 4. Results for the entire Mist Mountain Formation will be discussed first, followed by a comparison of the lower and upper portions of the formation. Rock-type abbreviations will be used throughout. Explanations of the abbreviations are given in Table 4-1-1.

Starting at the base of the transition diagram (Figure 4-1-2), *CGL*, although a rare rock type, shows a very strong trend (83 per cent probability) to be overlain by *SAND*. *SAND* is most likely to be overlain by *SS>SH* (23 per cent). *SS>SH* is most often overlain by *SH>SS* (14 per cent), but is almost as likly to be overlain by *SAND* (11 per cent). *SS = SH* tends to be overlain by finer units, especially *SH>SS* (20 per cent). *SH>SS* is most likely to be overlain by *SHALE* (17 per cent). SHALE shows a stronger trend to be overlain by coarser rock types, especially *SH>SS* (16 per cent), than by *C-SHL* (9 per cent). *C-SHL* shows roughly equal likelihood of being overlain by *SHALE* (16 per cent) or *COAL* (20 per cent). *COAL* is most likely to be overlain by *C-SHL* (45 per cent).

The chi-square test of the transition matrix for the Markov property yielded a value of 452 321. This represents a very strong rejection of the null hypothesis that the observed rock-type transitions are produced by random events.

Fluvial sediments in general can be subdivided into those derived from point-bar deposition and those deposited in the floodplain (Walker and Cant, 1984). In the Mist Mountain Formation the point-bar environment is represented by prominent fining-upward "channel" sandstone bodies, which consist predominantly of medium-grained or coarser sandstone, together with rare conglomerate which forms as basal channel-lag deposits, and fine and very fine-grained sandstone to siltstone, in the upper parts.

The floodplain environment in the Mist Mountain Formation, which is the more common, includes levee, crevasse-splay and flood-basin deposits (Gibson, 1985). As pointed out by Dunlop and Bustin (1987), levee deposits are difficult to recognize in the Mist Mountain Formation, especially in vertical sections, and may be indistinguishable from cre-

TABLE 4-1-3

Transition, expected and difference matrices for the lowest 200 metres of the Mist Mountain Formation.

Transition Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	12	2	0	0	0	0	0	0
SAND	12	0	39	10	34	22	7	1	0
SS>SH	2	34	0	27	80	57	6	0	2
SS=SH	0	9	22	0	118	91	27	0	1
SH>SS	0	33	84	107	0	220	93	7	2
SHALE	0	28	51	92	231	0	132	31	7
C-SHL	0	9	8	29	71	137	0	83	4
COAL	0	0	1	1	5	45	74	0	0
X	0	0	1	1	4	6	3	1	0

Expected Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	0	1	1	3	3	2	0	0
SAND	0	7	11	15	30	32	19	6	0
SS>SH	1	11	19	25	50	54	32	11	1
SS=SH	1	15	25	32	65	69	41	14	1
SH>SS	3	30	51	65	133	142	84	30	3
SHALE	3	32	53	68	140	149	88	31	4
C-SHL	2	19	32	41	83	88	52	18	2
COAL	0	7	11	15	30	32	19	6	0
X	0	0	1	1	3	4	2	0	0

Difference Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	12	1	−1	−3	−3	−2	0	0
SAND	12	−7	28	−5	4	−10	−12	−5	0
SS>SH	1	23	−19	2	30	3	−26	−11	1
SS=SH	1	−6	−3	−32	53	−22	−14	−14	0
SH>SS	−3	3	33	42	−133	78	9	−23	−1
SHALE	−3	−4	−2	24	91	−149	44	0	3
C-SHL	−2	−10	−24	−12	−12	49	−52	65	2
COAL	0	−7	−10	−14	−25	13	55	−6	0
X	0	0	0	0	1	2	1	1	0

Difference Matrix (Positive values converted to % probabilities)

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL		85.7	7.1					
SAND	9.6		22.4		3.2			
SS>SH	0.5	11.1		1.0	14.4	1.4		
SS=SH					19.8	8.2		
SH>SS		0.5	6.0	7.7		14.3	1.6	
SHALE				4.2	15.9		7.7	
C-SHL						14.4		19.1
COAL						10.3	43.7	

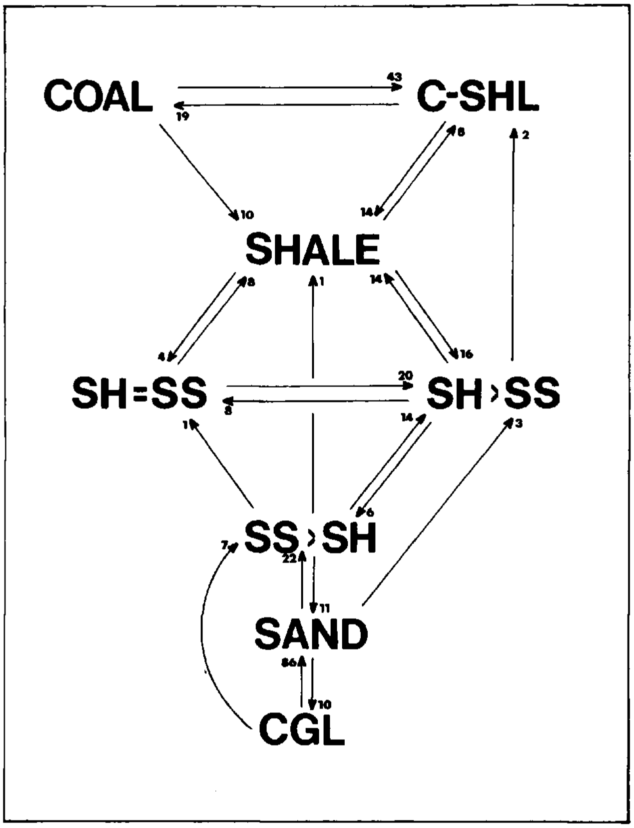


Figure 4-1-3. Transition diagram for the lowest 200 metres of the Mist Mountain Formation, based on the difference matrix (probabilities). Values less than 1 per cent omitted.

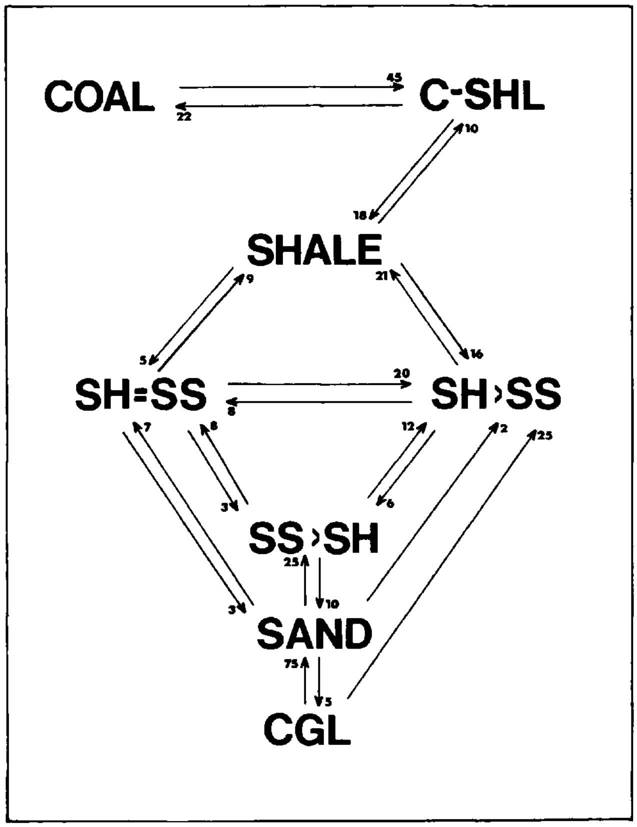


Figure 4-1-4. Transition diagram for strata more than 200 metres above the base of the Mist Mountain Formation, based on the difference matrix (probabilities). Values less than 1 per cent omitted.

TABLE 4-1-4

Transition, expected and difference matrices for strata more than 200 metres above the base of the Mist Mountain Formation.

Transition Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	3	0	0	1	0	0	0	0
SAND	3	0	19	11	13	10	3	0	0
SS>SH	2	14	0	20	34	19	9	1	5
SS=SH	0	12	12	0	78	68	12	2	2
SH>SS	0	10	41	66	0	157	44	1	7
SHALE	1	12	20	70	152	0	107	33	11
C-SHL	0	7	7	14	34	115	0	74	3
COAL	0	1	1	3	6	28	71	0	5
X	0	0	2	3	8	13	4	3	0

Expected Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	0	0	0	0	1	0	0	0
SAND	0	2	4	7	12	16	9	4	1
SS>SH	0	4	7	12	22	28	17	7	2
SS=SH	0	7	12	23	40	51	31	14	4
SH>SS	0	12	22	41	71	90	54	25	7
SHALE	1	16	27	51	89	112	68	31	9
C-SHL	0	10	17	32	55	70	42	19	5
COAL	0	4	7	14	25	31	19	8	2
X	0	1	2	4	7	9	5	2	0

Difference Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	3	0	0	1	-1	0	0	0
SAND	3	-2	15	4	1	-6	-6	-4	-1
SS>SH	0	10	-7	8	12	-9	-8	-6	3
SS=SH	0	5	0	-23	38	17	-19	-12	-2
SH>SS	0	-2	19	25	-71	67	10	-24	0
SHALE	0	-4	-7	19	63	-112	39	2	2
C-SHL	0	-3	-10	-18	-21	45	-42	55	-2
COAL	0	-3	-6	-11	-19	-3	52	-8	3
X	0	-1	0	-1	1	4	-1	1	0

Difference Matrix (Positive values converted to % probabilities)

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL		75			25			
SAND	5.1		25.4	6.8	1.7			
SS>SH		9.8		7.8	11.8			
SS=SH		2.7			20.4	9.1		
SH>SS			5.8	7.7		20.6		
SHALE				4.7	15.5		9.6	
C-SHL						17.7		21.7
COAL							45.2	

vasse-splay deposits. All rock types finer than and including fine-grained sandstone are included in the floodplain environment with the finest units deposited in the flood basin.

The results suggest a fining-upward depositional sequence with sandstone (or conglomerate) at the base and coal at the top, with numerous combinations of transitional events possible within the sequence. It must be reiterated here that although the transition diagrams were deliberately drawn to simulate a general fining-upward sequence, the results of the analysis are definitely consistent with this model. For example, *CGL* (channel lag) is nearly always overlain by *SAND*. *SAND* is overlain by an intermixed sandstone and shale unit, usually *SS>SH*. Interestingly, the direct fining-upward transition from *SAND* to *SHALE* is not observed to a significant degree. If *SAND* is assumed to be the characteristic component of a point-bar deposit, and *SHALE* is taken as the major component of the flood-basin deposit, then it is apparently not possible to make the transition from one environment to the other without the intermediate lithologies. This suggests that either the intermixed sandstone and shale rock types are an imegral part of the point-bar deposits, or that another floodplain environment must first be "passed through" before reaching the flood basin. The possibilities for the latter suggestion are levees and crevasse splays, which as was pointed out earlier, are difficult to distinguish. The intermixed sandstone and shale rock types are expected to be characteristic of both (Dunlop and Bustin, 1987).

Deposition of distal crevasse-splay deposits on the floodplain is believed to have occurred in the instances where intermixed shale and sandstone units, either *SS=SH* or *SH>SS*, directly overlie *SHALE*. These results suggest that this is more likely to occur than the transition from *SHALE* to the carbonaceous units, *C-SHL* and *COAL*. Interestingly, *COAL* only occurs overlying *C-SHL*, suggesting a gradual transition to the coal-forming environment, and perhaps a relatively isolated environment for coal deposition. *COAL* is most often overlain by fine-grained units, either *C-SHL* or *SHALE*, sugesting that coal deposition is terminated by invasion of flood-basin sediments, perhaps related to increased rate of subsidence in the swamp.

The results are also interesting in that they do not indicate how the depositional sequence described above begins. In other words, there is no evidence of *SAND* or *CGL* overlying units finer than *SS>SH*. It is known from field evidence that channel sandstones frequently overlie fine-grained sequences and in many instances they are observed to directly overlie carbonaceous units, including coal. This transition, in effect, would represent the end of one cycle and the start of the next. The only comment which can be made here is that the transition matrix (Table 4-1-2) does indicate instances where *SAND* overlies either SHALE, *C-SHL* or *COAL*, but the number of occurrences is less than that expected in random situations (expected matrix). This may be partly a function of the high degree of detail in which these cores were logged; the significance of single large-scale events has perhaps been lost in the process of distinguishing such a large number of transitions, most of which represent fairly subtle changes in environment. In effect, the significance of a thick point-bar sandstone body directly overlying a coal-bearing zone depends on whether the latter zone is defined as one unit or as a series of several alternating rock types, as was done here, including *COAL*, *C-SHL* and *SHALE*. It is hoped that similar statistical analysis of sections measured in the field in the same area will yield results which favour large-scale changes.

Analysis of the three substitutability matrices for the entire formation (Table 4-1-2) is both instructive and somewhat confusing. For example, they show that the rock types *SS=SH* and *SS>SH* have a very high degree of substitutability, suggesting their depositional environments were similar. Given the lithological similarity of these two units (Table 4-1-1), and their common presumed association with the upper part of point-bar and/or crevasse-splay depositional environments, this result is not srprising. More unexpected, however, are the relatively high substitutabilities for such pairs of rock types as *C-SHL* and *SS=SH*, *SHALE* and *SS>SH*, and *C-SHL* and *SS>SH*. The depositional model derived from the Markov analysis does not suggest that any of these pairs would be highly substitutable, as their presumed depositional environments are significantly different. Further work will be necessary to explain these results.

The results for the lowest 200 metres of the Mist Mountain Formation and the overlying portion of the formation are presented in Tables 4-1-3 and 4; Figures 4-1-3 and 4. They are in general similar to those for the whole formation, and will not be described in detail. Moreover, the results for the two subsets of data are not markedly different from each other, suggesting the same depositional processes apply to both. This is somewhat surprising given the different depositional settings postulated for the lower and upper parts of the formation (*see* Introduction). There are in fact some subtle differences, such as the fairly weak tendency for *SAND* to overlie and be overlain by *SS=SH* in the upper part of the formation, which did not appear in the lower part or in the formation as a whole. This may suggest a subtle contrast in the deposition of the upper part of point-bar deposits between the upper and lower parts of the formation. Another contrast is in the roof-rock of coal seams. *COAL* in the upper part of the formation is always overlain by *C-SHL* (Figure 4-1-4), in contrast with the lower part of the formation in which *COAL* is overlain by both *C-SHL* and *SHALE*. This may suggest a more gradual "choking out" of coal deposition by shale in the upper part of the formation.

Chi-square tests of the count-transition matrices for the lower and upper parts of the formation also yield high values.

CONCLUSIONS

Statistical analysis of detailed core logs of the Mist Mountain Formation from the Elk Valley coalfield indicates that the sequence has a first-order Markov property. An overall fining-upward sequence is suggested, typical of deposition within a meandering fluvial channel and associated floodplain. Some interesting features of the sequence defined here include:

- *CGL* is closely associated with *SAND*, consistent with a channel-lag deposit.
- *SAND* is generally overlain by intermixed sandstone and shale units, suggesting a gradual transition from a point-bar to a flood-basin environment which is charac-

terized by *SHALE*. These transitional strata may represent an integral part of the point-bar facies or may be part of transitional environments, such as levees or crevasse splays.

- *SHALE* is more likely to be overlain by intermixed sandstone and shale, probably representing distal crevasse-splay deposits, than by carbonaceous units.
- *C-SHL* (carbonaceous shale) is the only rock type which is overlain by *COAL* to a significant degree. This suggests a gradual transition to the coal-forming environment.
- *COAL* is most often overlain by *C-SHL*, and, to a much lesser degree, *SHALE*. This suggests that coal deposition is usually terminated gradually, by invasion of flood-basin sediments.

On the basis of this analysis, the lowest 200 metres of the formation does not differ markedly from the remainder of the formation.

ACKNOWLEDGMENTS

I would like to thank Ward Kilby for providing and patiently explaining the Cal Data Ltd. software used in this study, and for introducing me to this type of statistical analysis.

REFERENCES

Davis, J.C. (1973): Statistics and Data Analysis in Geology, *John Wiley and Sons*, New York, 550 pages.

Dunlop, R.L. and Bustin, R.M. (1987): Depositional Environments of the Coal-bearing Mist Mountain Formation, Eagle Mountain, Southeastern Canadian Rocky Mountains, *Canadian Petroleum Geology*, Bulletin, Volume 35, pages 389-415.

Gibson, D.W. (1985): Stratigraphy, Sedimentology and Depositional Environments of the Coal-bearing Jurassic-Cretaceous Kootenay Group, Alberta and British Columbia, *Geological Survey of Canada*, Bulletin 357, 108 pages.

Grieve, D.A. and Elkins, P.R. (1986): Correlation and Comparison of Two Coal-bearing Zones Between Ewin Pass and Bare Mountain, Elk Valley Coalfield, Southeastern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 17-23.

Kilby, W.E. and Oppelt, H.P. (1985): Numerical Depositional Modelling–Gething Formation along the Peace River, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 233-249.

Morris, R.J. and Grieve, D.A. (1988): Elk Valley Coalfield, North Half, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 187, Paper 1988-1, pages 427-434.

——— (in preparation): Geology of the North Half of the Elk Valley Coalfield, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map.

Ruby, C.M., Horne, J.C. and Reinhart, P.J. (1981): Cretaceous Rocks of Western North America–A Guide to Terrigenous Clastic Rock Identification, *Research Planning Institute, Inc.*, 100 pages.

Siemers, C.T. (1978): Generation of a Simplified Working Depositional Model for Repetitive Coal-bearing Sequences Using Field Data: An Example from the Upper Cretaceous Menefee Formation (Mesaverde Group), Northwestern New Mexico, *in* Proceedings of the Second Symosium on the Geology of Rocky Mountain Coal, H.E. Hodgson, Editor, *Colorado Geological Survey*, pages 1-22.

Walker, R.G. and Cant, D.J. (1984): Sandy Fluvial Systems, *in* Facies Models, Second Edition, R.G. Walker, Editor, *Geoscience Canada*, Reprint Series 1, pages 71-89.

NOTES

VITRINITE REFLECTANCE STUDY OF NANAIMO GROUP COALS OF VANCOUVER ISLAND (92F)

By Candace Kenyon and Corilane G.C. Bickford Bickford Consulting Ltd.

KEYWORDS: Coal geology, vitrinite reflectance, Vancouver Island, Nanaimo, Comox, sub-basins, stratigraphy, coal rank.

INTRODUCTION

Preliminary results of a vitrinite reflectance study on Nanaimo Group coals are presented in this report. This study is part of an ongoing project begun in 1987 to provide an update of critical geologic relationships of the Vancouver Island coal deposits. The objective of the project is to provide sufficient data and analysis to assist industry and government in assessing the potential of the Island coals with respect to utilizing this resource for the production of coal-seam gas, coal-water fuel and the traditional thermal and metallurgical applications.

Vitrinite reflectance data will provide a quick and effective method for determining coal rank distribution over the study area. Because vitrinite is abundant in coal, easy to isolate, and undergoes changes consistently, it is an excellent medium for rank studies (Teichmuller and Teichmuller, 1966). Reflectance data can aid in stratigraphic correlation and can also provide information relevant to structural interpretations. Rank variations assist in determining the relative timing of coalification and provide information which is critical in the evaluation of coal deposits.

Previous work involved compiling and analysing existing data as well as reconnaissance mapping and sampling during the 1987 field season. Details of this work have been published previously (Bickford and Kenyon, 1988). During the 1988 field season additional outcrops were sampled in the Comox sub-basin and detailed geological mapping was completed in the Quinsam area. Details of this mapping are presented in Bickford *et al.* (this volume).

The study area is located on the east side of Vancouver Island (Figure 4-2-1). The Comox sub-basin is approximately 1230 square kilometres in area and the Nanaimo sub-basin covers nearly 780 square kilometres. Elevations range from sea level to 500 metres but the topography is fairly gentle. Exposures in both sub-basins are limited to creeks and roadcuts throughout most of the area, due to dense forests and thick underbrush. Logging roads provide the main access.

GEOLOGICAL SETTING

The coal measures of eastern Vancouver Island are found in Nanaimo Group rocks of Santonian to Maastrichtian age (Muller and Jeletsky, 1970). They lie unconformably on a basement of Paleozoic to middle Mesozoic volcanic, intrusive and sedimentary rocks. The Nanaimo Group consists of a sequence of conglomerates, sandstones, shales and coals. They occupy the western erosional margin of the Late Cretaceous Georgia basin within the Insular Belt of the Canadian Cordillera.

Two distinct sub-basins, Comox and Nanaimo, contain Nanaimo Group rocks. These basins are separated by a northeast-trending basement uplift, the Nanoose arch (Figure 4-2-1). Sediments in both sub-basins generally dip 5 to 14 degrees in a northeasterly direction and numerous faults contribute to the structural complexity. Economic coal measures in the Nanaimo sub-basin are found in the Pender and Extension formations and in the Comox sub-basin they occur in the Comox Formation, specifically in the Dunsmuir and Cumberland members (Table 4-2-1). Detailed coal-measure stratigraphy and the relationship of the Nanaimo Group rocks across the sub-basins can be found in Bickford and Kenyon (1988).

TABLE 4-2-1
STRATIGRAPHIC UNITS OF THE NANAIMO GROUP

Maastrichtian	Spray Fm.	Dark shale: COAL
Late Campanian	(Boundary within Spray Fm.)	Classic turbidites, mostly shales
	Geoffrey Fm.	Conglomerate and sandstone
	Northumberland Fm.	Classic turbidites, mostly shales
	De Courcy Fm.	Sandstone and conglomerate
	Cedar District Fm.	Classic turbidites, mostly shales
Early Campanian	Protection Fm.	(Subdivided in Nanaimo coalfield)
	McMillan Mbr.	Sandstone and siltstone
	Reserve Mbr.	Siltstone and sandstone: COAL
	Cassidy Mbr.	Sandstone and conglomerate
	Pender Fm.	(Subdivided in Nanaimo coalfield)
	Newcastle Mbr.	Shale and conglomerate: COAL
	Cranberry Mbr.	Sandstone and siltstone
	Extension Fm.	(Subdivided in Nanaimo coalfield)
	Millstream Mbr.	Conglomerate: COAL
	Northfield Mbr.	Siltstone and sandstone: COAL
	East Wellington Fm.	Sandstone (Nanaimo sub-basin only)
	Haslam Fm.	Classic turbidites, mostly shales
	Comox Fm.	(Subdivided in Comox sub-basin)
	Dunsmuir Mbr.	Sandstone: COAL
	Cumberland Mbr.	Siltstone and sandstone: COAL
	Benson Mbr.	Conglomerate and red beds

UNCONFORMITY

Older basement rocks, chiefly volcanics

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

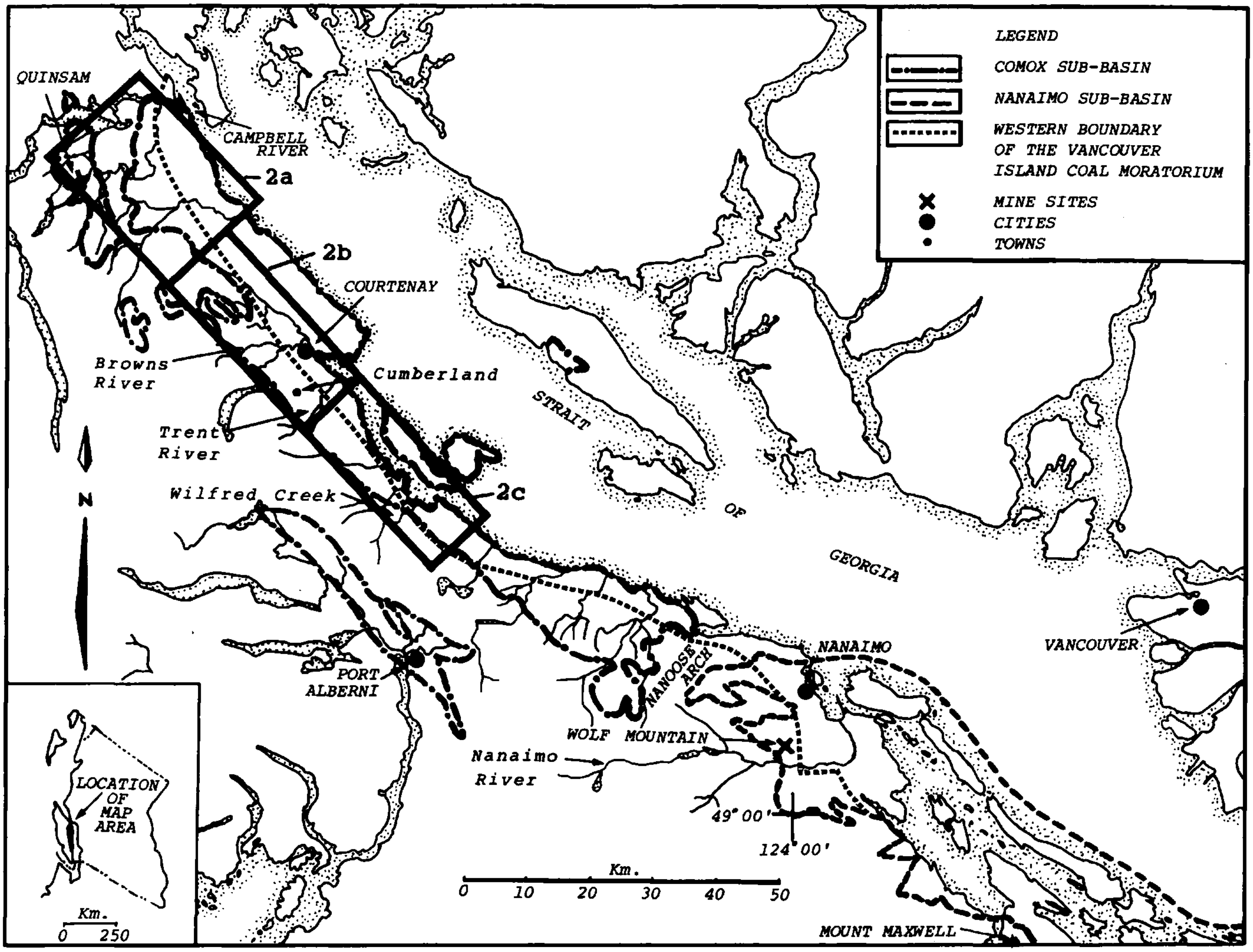


Figure 4-2-1. Location map, Vancouver Island coal basins.

FIELDWORK AND METHODS OF STUDY

Preparation for sampling coal on Vancouver Island involved a search of archived information to obtain outcrop, adit and mine locations. An exploration map from 1914 (no author) indicated possible outcrop locations throughout the Comox sub-basin and was used as a guide in this area. Exposures of coal in the Nanaimo sub-basin are limited and generally confined to the Newcastle seam (Table 4-2-1). Exposures of the Comox Formation coal measures are more readily accessible. Logging activities have contributed to the disappearance of many old coal showings either by stream diversion or sediment build-up behind dams.

Limited exposure results in difficulties placing outcrops accurately in the stratigraphic section. Borehole information in these areas is being used for data interpretation. Sections along Browns River, Trent River and Wilfred Creek were measured and sampled in detail (Figure 4-2-1). Sampling is continuing.

Sample locations were plotted on 1:20 000 air photographs and transferred to 1:20 000 base maps. UTM coordinates and elevations for each location were picked from the base maps and recorded (Tables 4-2-2 and 4-2-3). Geological maps of the Comox sub-basin (Bickford and Kenyon, 1988) were modified by data collected during the 1988 field season. Sample locations were plotted on these maps and also on a map depicting coal seam traces in the Nanaimo sub-basin (Figures 4-2-2a, 2b, 2c and 3).

All coal intervals were sampled and multiple samples were taken at most locations. Weathered material was cleaned off and, whenever possible, a channel sample was taken across the total seam thickness. Partings more than 1 centimetre thick were not included. One sample from each location was chosen for a vitrinite reflectance test. In addition, channel samples for proximate analysis were taken from fresh coal at the Quinsam mine. A tonstein contained in a coal seam outcropping along the Iron River was sampled (No. 46, Figure 4-2-2a) and has been sent to The University of British Columbia for zircon uranium-lead dating.

Coal samples selected for vitrinite reflectance tests were crushed using a mortar and pestle. The −20 mesh fraction was combined with epoxy and pelletized. A Leitz MPV-3 reflecting-light microscope was used to determine the reflectance of the polished coal surfaces. On each sample, 50

TABLE 4-2-2
SAMPLE LOCATION AND REFLECTANCE DATA
COMOX SUB-BASIN

Sample No.	UTM EASTING	UTM NORTHING	ELEVATION (m)	% R_oMax
30	323490	5534650	239	0.59
32	323350	5534100	242	0.63
18	322525	5533200	351	0.80
44	322280	5531420	314	0.72
45	322185	5530880	338	0.77
46	325065	5532420	274	0.85
67	325400	5528230	501	0.72
16	326750	5527350	526	0.71
15	326770	5526320	564	0.81
17	331250	5530000	210	0.73
83	334360	5526900	145	0.74
61	340380	5518560	135	2.52
33	346100	5509100	195	1.19
12	343600	5506270	478	1.76
13	343620	5506180	450	1.81
74	346640	5506230	178	1.63
75	346660	5506260	176	1.63
76	346720	5506350	170	1.55
77	346780	5506390	168	1.31
78	346820	5506400	165	1.38
79	346850	5506400	164	1.31
81	347060	5506250	155	3.21
82	347320	5506100	150	1.51
39	347770	5506220	138	1.09
38	347822	5506200	135	1.05
72	348920	5506240	110	0.88
70	349600	5506440	90	0.79
10	349500	5495880	555	0.88
11	351960	5497100	180	0.98
49	352100	5496860	190	0.99
9	351900	5493290	475	0.84
48	354200	5493410	270	0.89
47	354345	5493490	255	0.81
51	354100	5493760	250	0.82
50	354260	5493650	240	0.83
36	354590	5493770	235	0.79
42	354820	5493940	228	0.76
41	355090	5494290	198	0.65
40	355480	5494410	190	0.73
34	355700	5494580	175	0.75
69	362430	5486170	170	0.96
60	363610	5484740	142	0.87
86	366420	5481220	115	0.97
85	366830	5481410	80	0.85
84	366990	5481480	70	0.98

TABLE 4-2-3
SAMPLE LOCATION AND REFLECTANCE DATA
NANAIMO SUB-BASIN

Sample No.	UTM EASTING	UTM NORTHING	ELEVATION (m)	% R_oMax
22	432160	5449985	0	0.68
25	431410	5449525	20	0.69
24	431340	5449480	40	0.67
23	432860	5448525	0	0.65
26	431630	5446490	10	0.64
27	433060	5439280	102	0.66
5	433625	5439800	60	0.68
4	433670	5439675	60	0.72
6	425575	5440625	570	0.71

randomly oriented vitrinite particles were measured for maximum and minimum apparent reflectance. Histograms and reflectance crossplots were prepared for data interpretation using computer programs developed by Kilby (1986). The graphic data, produced by the reflectance crossplot technique, provide a method for determining the three principal reflectance axes which describe the shape of the vitrinite reflectance-indicating surface, using a new technique developed by Kilby (1988). Samples were assigned an ASTM rank following the classification of McCartney and Teichmuller (1972).

RESULTS

Preliminary vitrinite reflectance data in the Nanaimo sub-basin are limited to the Newcastle seam, except for one value from the Wellington seam, due to limited exposures (Figure 4-2-3). A composite section indicates the position of the coal seams in the Pender and Extension formations (Figure 4-2-4). Detailed geology of the Nanaimo sub-basin can be found in Buckham (1947). Mean maximum reflectance values from the Newcastle seam range from 0.64 per cent to 0.72 per cent while the single value from the Wellington seam is 0.71 per cent A summary of this information is presented in Table 4-2-3. Results indicate little variation in rank within the sub-basin. Interpretation of crossplots for eight samples produced reflectance-style values (R_{ST}) of -3.0 to $+3.81$ indicating the coals have biaxial-even reflectance-indicating surfaces.

Sample locations in the Comox sub-basin are more numerous due to better exposure. Reflectance values for this area are summarized in Table 4-2-2. Mean maximum reflectance data throughout the sub-basin exhibit values ranging from 0.59 to 3.21 per cent. The lowest value is from an outcrop close to the top of the Comox Formation (No. 30, Figure 4-2-2a) while anomalous values are found north of the Puntledge River, specifically at sample locations 61, 12, 13, 33, and along the Browns River (Figure 4-2-2b, Section A-A'). Excluding anomalous values, there is a trend of increasing coal rank from north to south in the Comox sub-basin, contrasting with a lack of variation in the Nanaimo sub-basin. Crossplots examined to the time of writing have produced R_{ST} values ranging from -7.0 to $+7.2$. Data again suggest that the reflectance-indicating-surface patterns are biaxial-even.

Detailed sampling of a 200-metre section along Browns River (Section A-A', Figure 4-2-2b) produced mean maximum reflectance values ranging from 0.79 to 3.21 per cent. The lowest value is from the top of the section and the highest value is located adjacent to a porphyritic dacite sill (Figure 4-2-5). The high rank sample has been coked and shows strong mosaic anisotropy and devolatilizing bubbles. The trend down-section illustrates that the temperature gradient increases approaching the sill, decreases beyond it and increases again near the basement volcanics. Crossplot data interpretation has not been completed for this section.

Reflectance values range from 0.65 to 0.89 per cent over a 280-metre section along the Trent River (Section B-B', Figure 4-2-2b). Some data scatter is present, but the reflectance

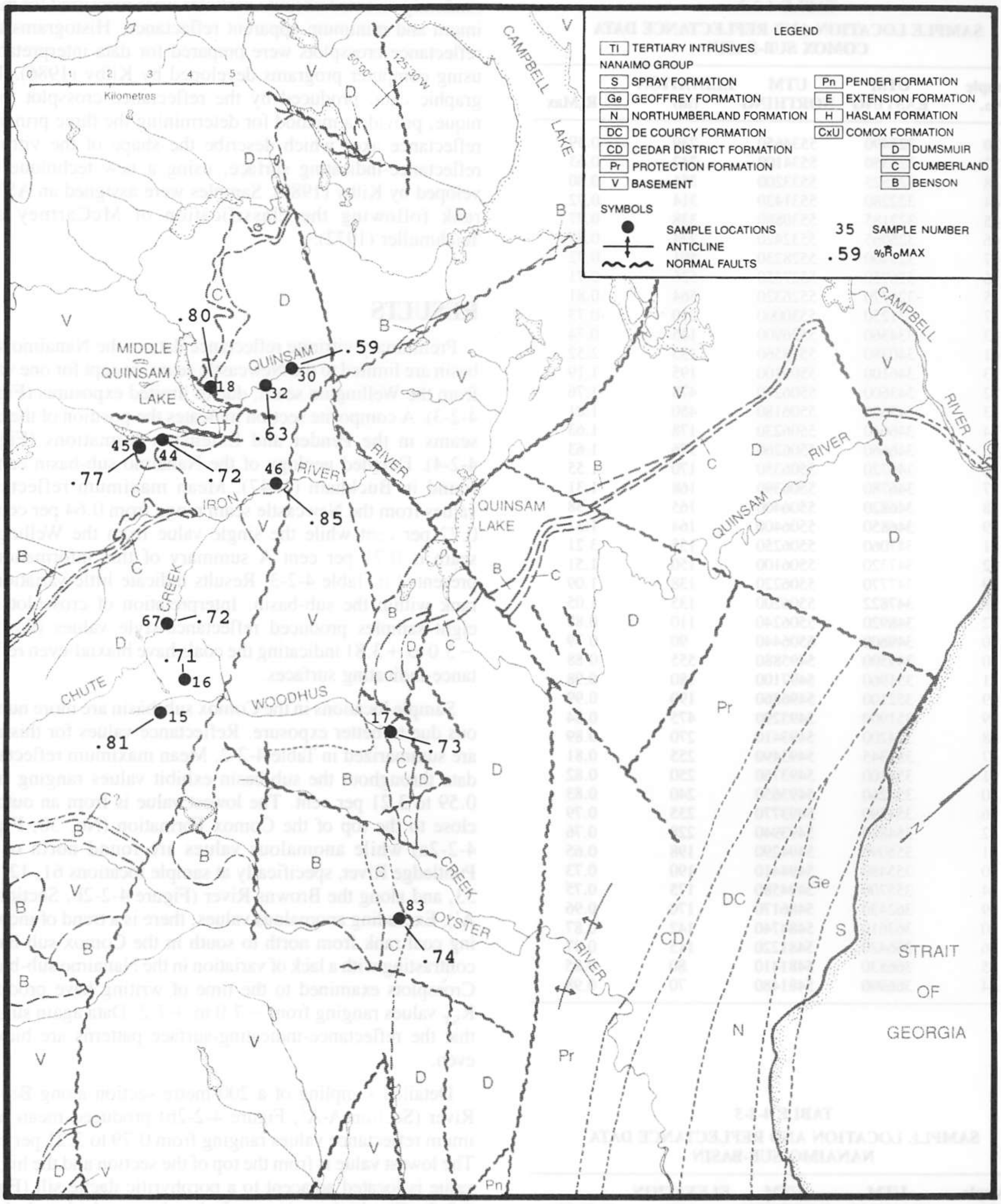


Figure 4-2-2a. Geology of the Comox sub-basin (revised, 1988) with coal sample locations and R_o max values. Refer to Figure 4-2-1.

gradient generally increases down-section (Figure 4-2-6). A depth-reflectance profile of this section is presented in Figure 4-2-7. As in the Browns River section, this illustrates an obvious increase in temperature gradient close to the basement. Crossplot interpretations from these sample locations yielded R_{ST} values from -6.0 to $+7.2$. The majority of values were negative but fairly low, illustrating biaxial-even reflectance patterns.

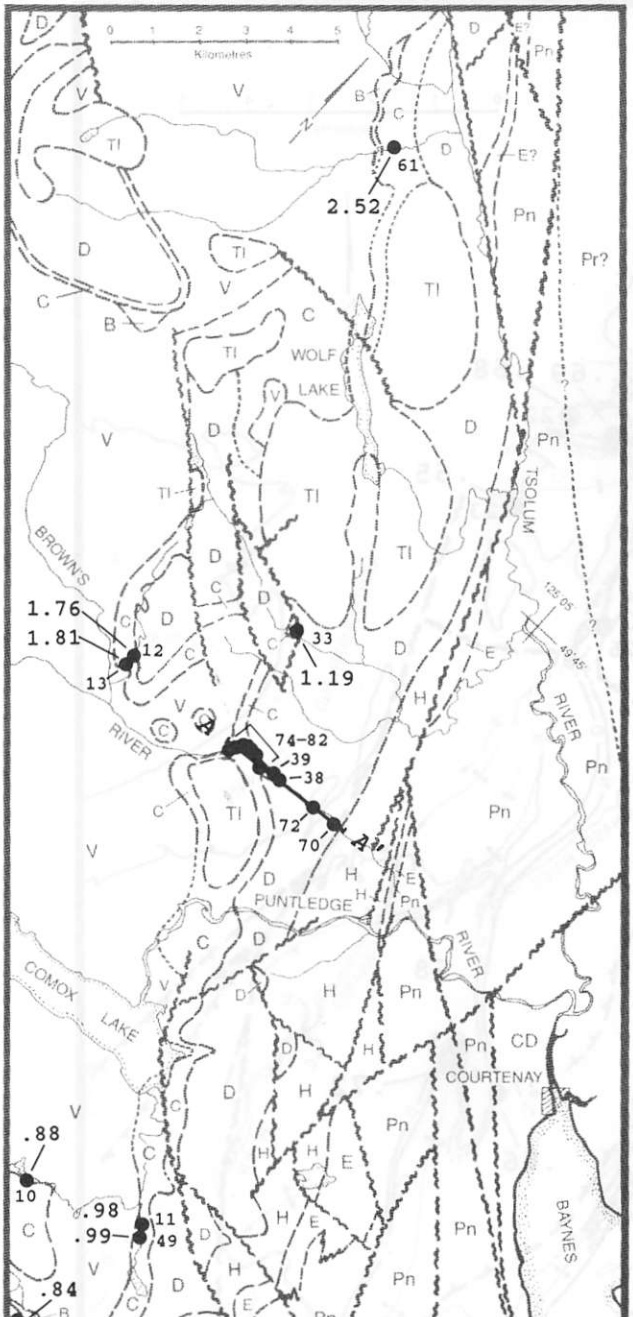


Figure 4-2-2b. Geology of the Comox sub-basin (revised, 1988). Refer to Figure 4-2-2a for legend and also to Figure 4-2-1.

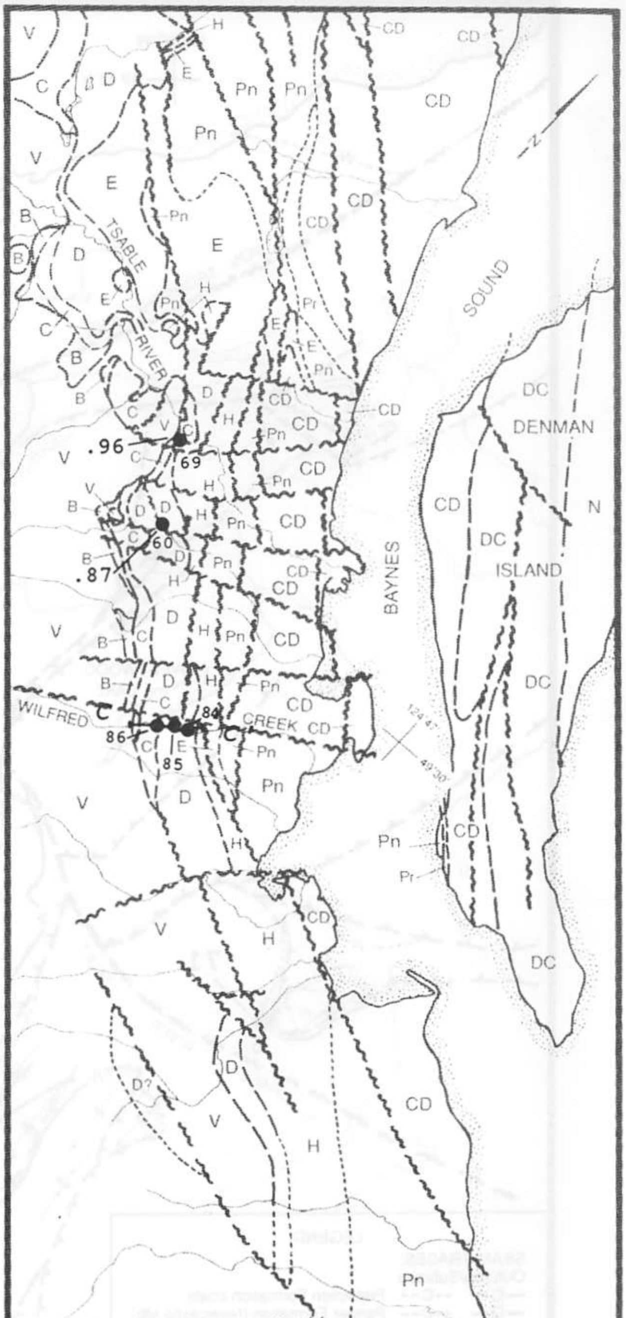


Figure 4-2-2c. Geology of the Comox sub-basin (revised, 1988). Refer to Figure 4-2-2a for legend and also to Figure 4-2-1.

The Comox Formation on Wilfred Creek is approximately 210 metres thick (Section C-C', Figure 4-2-2c). There are fewer coal seams in this section than along the Trent and Browns rivers to the north (Figure 4-2-8). Mean maximum reflectance values ranged from 0.85 to 0.98 per cent with no obvious trend in the reflectance gradient. Reflectance values obtained from coals in the Dunsmuir member are higher in Wilfred Creek than in Trent River. Crossplots have not been interpreted for Wilfred Creek.

The one location available for obtaining a fresh coal sample for detailed quality analysis was at the Quinsam mine (No. 18, Figure 4-2-2a). Two channel samples were taken on a 2.27-metre section. Sample 1, over 1.28 metres, was obtained above a 3-centimetre mudstone parting and Sample

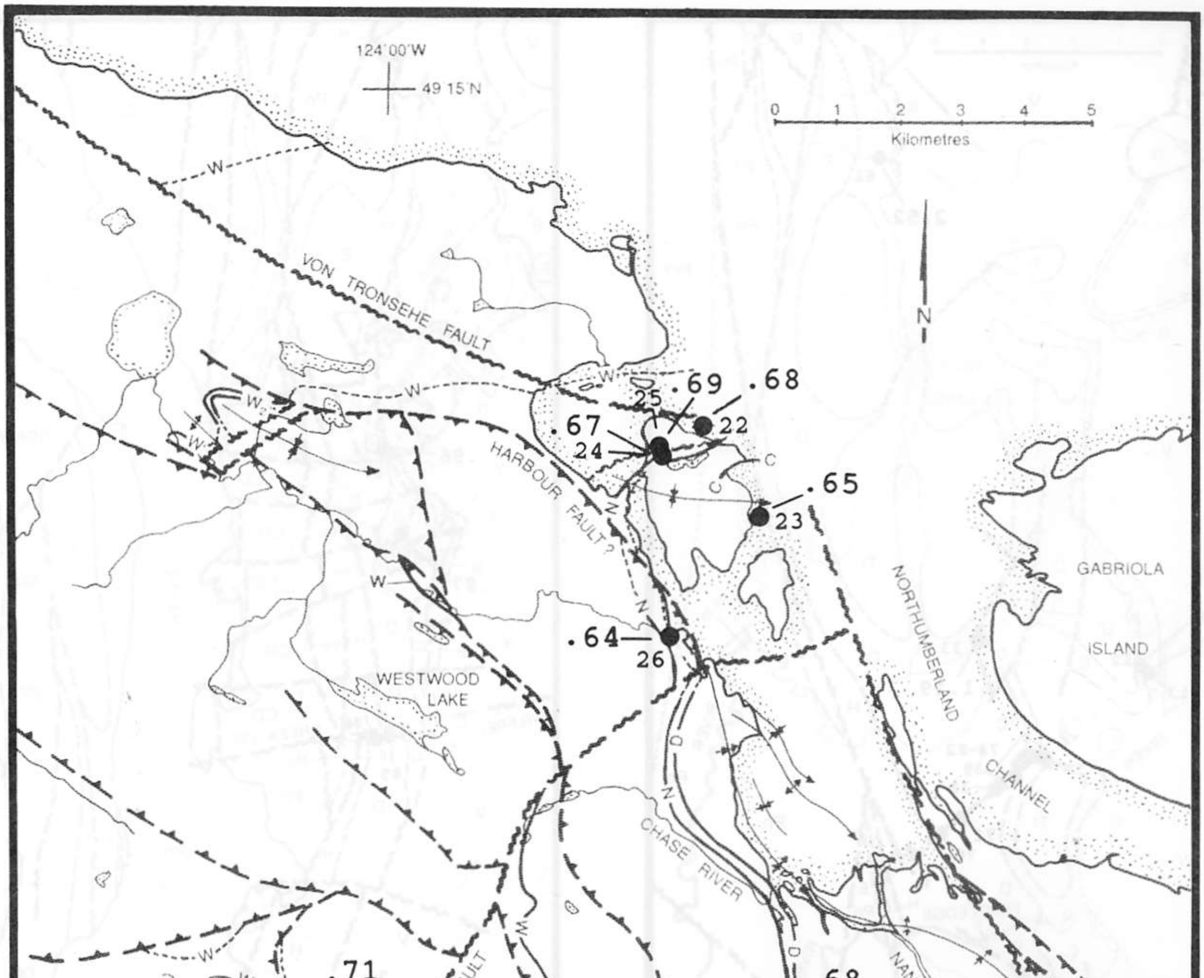


Figure 4-2-3. Coal seam traces, coal sample locations and R_o max values, Nanaimo sub-basin.

2, over 0.95 metre, was taken below the parting. The samples were analysed by Commercial Testing and Engineering Company in Vancouver. Test results are included in Table 4-2-4 because vitrinite reflectance from bituminous coal is correlatable with other parameters such as volatile matter, carbon content, and the hydrogen:carbon ratio used in determining rank distribution (McCartney and Teichmuller, 1972). These data indicate a high-volatile bituminous coal and are supported by the R_o max measurements (Table 4-2-2 and Figure 4-2-2a).

TABLE 4-2-4
ANALYSIS DATA FROM QUINSAM MINE

Proximate Analysis (dry basis)	**Sample 1**	**Sample 2**
% Ash	9.97	8.50
% Volatile matter	40.35	39.62
% Fixed carbon	49.68	51.88
	100.00	100.00
% Sulphur	1.24	0.46
Calorific value (Btu/lb)	11 862	12 318
Sulphur forms (dry basis)		
% Pyritic sulphur	0.51	0.05
% Sulphate sulphur	0.04	0.01
% Organic sulphur (difference)	0.69	0.40
% Total sulphur	1.24	0.46
Ultimate Analysis (dry basis)	Composite of 1 + 2	
% Carbon	72.42	
% Hydrogen	5.13	
% Nitrogen	0.97	
% Chlorine	0.02	
% Sulphur	0.92	
% Ash	9.33	
% Oxygen (difference)	11.21	
	100.00	

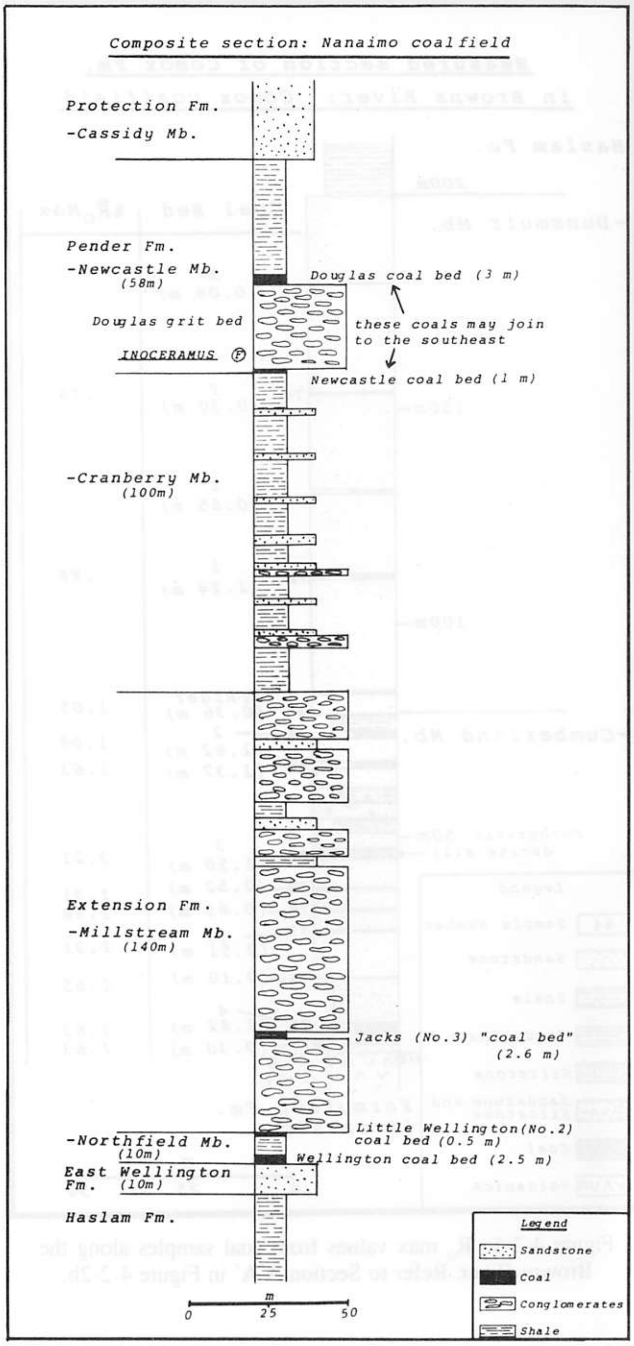


Figure 4-2-4. Composite section of the coal measures in the Nanaimo sub-basin.

DISCUSSION

Preliminary studies indicate that regional coalification patterns differ between the two sub-basins. In the Nanaimo sub-basin, evidence suggests structural changes occurred before final coalification. Data obtained from the Comox sub-basin indicate coalification was pre-deformational with localized post-tectonic thermal overprinting. Evidence supporting these ideas follows in this discussion.

Lateral variation of coal-rank distribution is not apparent in the Nanaimo sub-basin whereas there is a rank gradient increase from north to south in the Comox sub-basin. Reflectance studies indicate the presence of high-volatile bituminous A and B coals in the Nanaimo sub-basin. The same coal ranks exist in the Comox sub-basin, however, anomalous data obtained from samples north of Puntledge River (Figure 4-2-2b) provide rank values ranging from high-volatile bituminous to anthracite (Table 4-2-2).

The absence of lateral rank variation in the Nanaimo sub-basin is evidenced by the R_o max values from the Newcastle and Wellington seams. Coal rank distribution is essentially uniform at surface. Taking into account that the Wellington seam is more than 225 metres below the Newcastle seam (Figure 4-2-4), it is inferred that an isorank line would be horizontal in cross-section (Bustin *et al.*, 1983). This could indicate a fold-thrust deformation of the coal-measures into the pattern we see today, followed by deep burial by Tertiary sediments which have subsequently been eroded. Further work is expected to indicate an increase in reflectance with depth along the seams. Biaxial negative reflectance-indicating-surface data obtained on samples from the Newcastle seam can be interpreted as a product of random scatter, or evidence of tectonic stress in addition to overburden loading.

Complex coalification patterns are apparent in the Comox sub-basin due to overprinting by thermal events. The re-

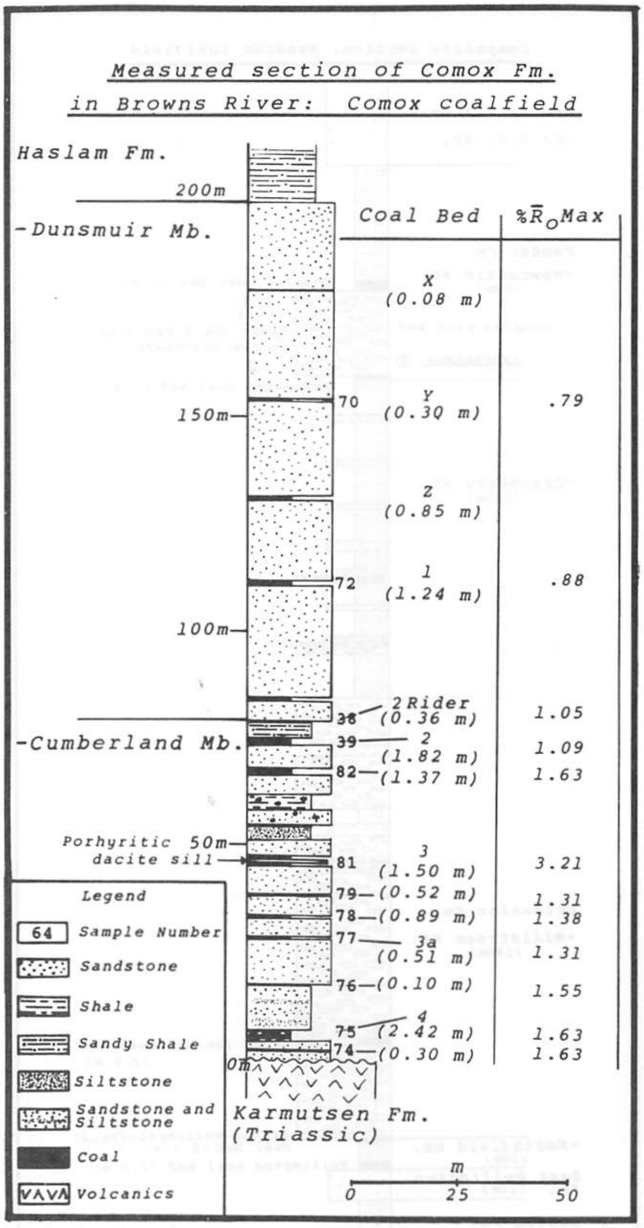


Figure 4-2-5. R_o max values from coal samples along the Browns River. Refer to Section A-A′ in Figure 4-2-2b.

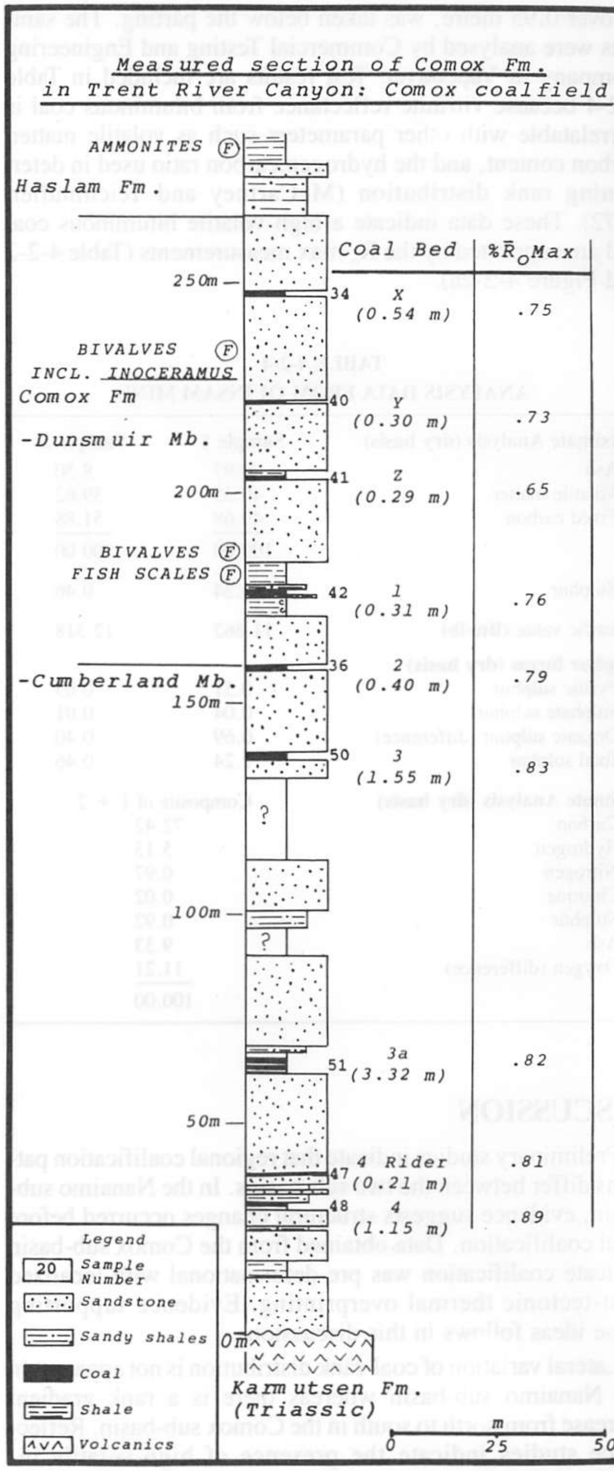


Figure 4-2-6. R_o max values from coal samples along the Trent River. Refer to Section B-B′ in Figure 4-2-2b.

gional increase in rank from north to south has two possible explanations: progressively deeper burial towards the south of the basin (now eroded) may have caused the rank gradient (Nurkowski, 1984), or a higher geothermal gradient existed in the southern part of the basin.

Seam rank gradient in the Comox sub-basin follows Hilt's Law, in that rank increases regularly with depth. This is evidenced in the Trent River section (Figure 4-2-5). Proximate analysis data from old mines in this area, on file with the Ministry of Energy, Mines and Petroleum Resources in Victoria, indicate constant rank values in the same seam. Pretectonic coalification causes a seam to maintain constant rank, given that other factors have not affected the coal (Bustin *et al.*, 1983). Some scatter is present which could be attributed to analytical or sample variability or to the difference of heat flow characteristics of rock types (Grieve, 1987). The latter may explain the abrupt increase in rank at the base of the section.

The regional pattern of coalification in the Comox sub-basin is overprinted by thermal aureoles associated with regional plutonism. Intrusions may affect coal by hydrothermal activity or contact metamorphism. A good example of the latter is provided by the Browns River section (Figure 4-2-5) where coal rank increases within the thermal aureole surrounding a porphyritic dacite sill.

There is a fairly broad area of hydrothermal activity associated with plutons (Stach and Mackowsky, 1975). Samples taken close to Tertiary intrusions have anomalous reflectance values due to the affects of circulating hot water (Figure 4-2-2b).

The shapes of reflectance-indicating surfaces are influenced by time, temperature and tectonism (Kilby, 1986). If the surface is not uniaxial (–), the assumption can be made that post-tectonic coalification occurred. Data obtained from the Comox sub-basin support this assumption.

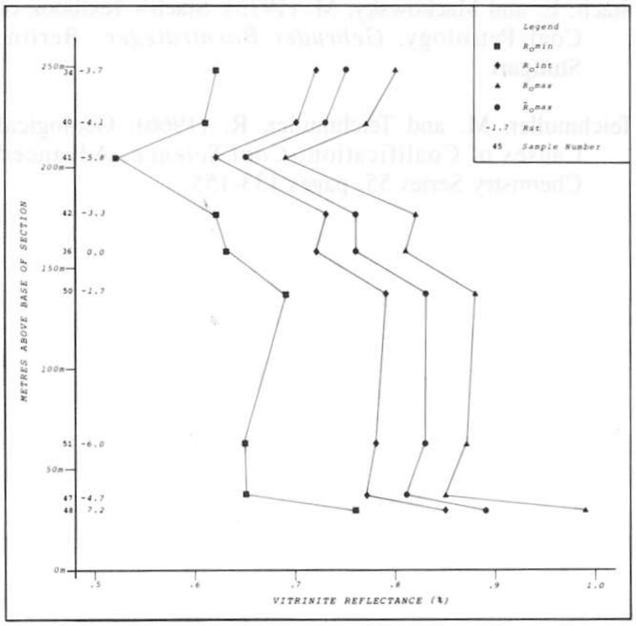


Figure 4-2-7. Reflectance-depth profile of measured section of the Trent River Comox Formation. Refer to Figure 4-2-6.

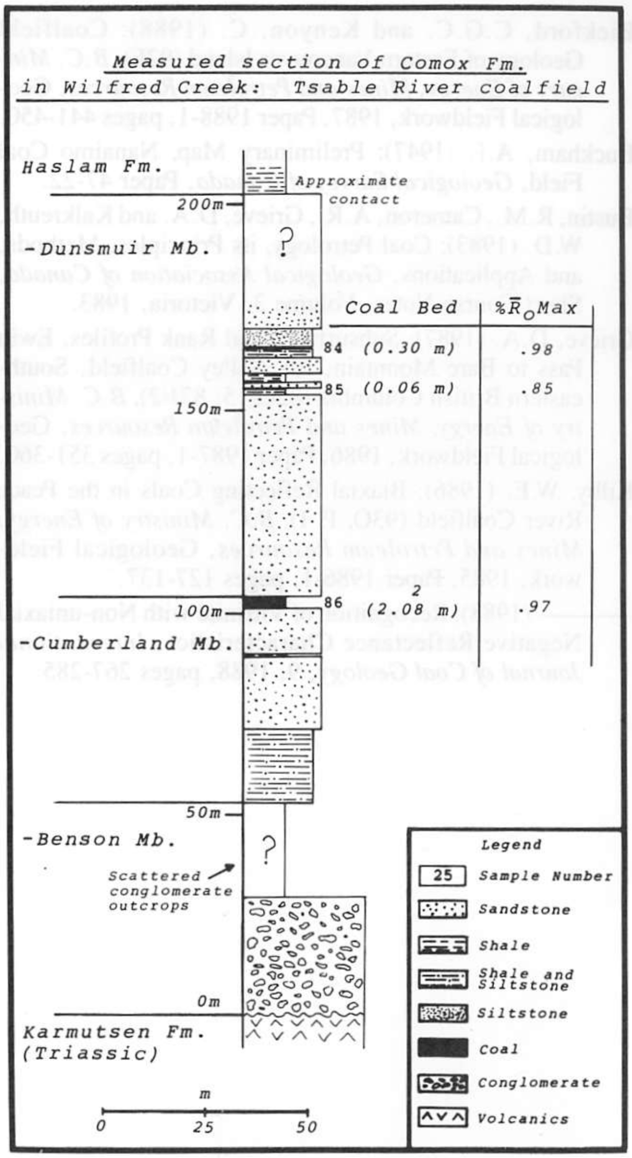


Figure 4-2-8. R_o max values from coal samples along Wilfred Creek. Refer to Section C-C′ in Figure 4-2-2c (modified from Atchinson, 1968).

FURTHER WORK

Investigations of vitrinite reflectance for rank determination are continuing in both sub-basins. Detailed section measurement of the Comox Formation will be completed in the northern part of the Comox sub-basin, for seam correlation purposes. An attempt will be made to sample along major faults in the Nanaimo sub-basin to further demonstrate the relationship between anomalous rank and hydrothermal circulation. Further reflectance-indicating-surface studies will lead to a better understanding of the stresses in effect during coalification. The information determined from the biaxial reflecting coals will help in the interpretation of the structural and thermal history of the coal deposits of Vancouver Island.

ACKNOWLEDGMENTS

The authors would like to thank Sharon Chapman for her excellent field assistance and sample preparation and V.A. Preto who assisted in the sampling program. Ward Kilby, David Grieve and Alex Matheson helped collect the tonstein sample at Quinsam. Joanne Schwemler carried out reflectance measurements. Special thanks are due to Steve Gardner and Dorothy Wilson of Quinsam Coal Ltd. for their assistance.

REFERENCES

Atchinson, M. (1968): Stratigraphy and Depositional Environments of the Comox Formation (Upper Cretaceous), Vancouver Island, British Columbia, Unpublished Ph.D. Thesis, *Northwestern University*, Evanston, Illinois, 139 pages.

Bickford C.G.C., Hoffman G. and Kenyon, C. (1989): Coal Measures Geology of the Quinsam Area (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, This Volume.

Bickford, C.G.C. and Kenyon, C. (1988): Coalfield Geology of Eastern Vancouver Island (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 441-450.

Buckham, A.F. (1947): Preliminary Map, Nanaimo Coal Field, *Geological Survey of Canada*, Paper 47-22.

Bustin, R.M., Cameron, A.R., Grieve, D.A. and Kalkreuth, W.D. (1983): Coal Petrology, its Principles, Methods, and Applications, *Geological Association of Canada*, Short Course Notes, Volume 3, Victoria, 1983.

Grieve, D.A. (1987): Subsurface Coal Rank Profiles, Ewin Pass to Bare Mountain, Elk Valley Coalfield, Southeastern British Columbia (82G/15, 82J/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 351-360.

Kilby, W.E. (1986): Biaxial Reflecting Coals in the Peace River Coalfield (93O, P, I), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 127-137.

——— (1988): Recognition of Vitrinite with Non-uniaxial Negative Reflectance Characteristics, *International Journal of Coal Geology*, 9, 1988, pages 267-285.

McCartney, J.T. and Teichmuller, M. (1972): Classification of Coals According to Degree of Coalification by Reflectance of the Vitrinite Component, *Fuel*, Volume 51, pages 64-68.

Muller, J.E. and Jeletsky, J.A. (1970): Geology of the Upper Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia, *Geological Survey of Canada*, Paper 69-25.

Nurkowski, J. (1984): Coal Quality, Coal Rank Variation and its Relation to Reconstructed Overburden, Upper Cretaceous and Tertiary Plains Coals, Alberta, Canada, *American Association of Petroleum Geologists*, Volume 68, Number 3, pages 285-295.

Stach, E. and Mackowsky, M. (1975): Stach's Textbook of Coal Petrology, *Gebruder Borntraieger*, Berlin, Stuttgart.

Teichmuller, M. and Teichmuller, R. (1966): Geological Causes of Coalification, *Coal Science*, Advanced Chemistry Series 55, pages 133-155.

GEOLOGY, MINING CONDITIONS AND RESOURCE POTENTIAL OF THE WELLINGTON COAL BED, GEORGIA BASIN* (92F/1; 92G/4)

By Corilane G.C. Bickford
The University of British Columbia

KEYWORDS: Coal geology, Nanaimo coalfield, stratigraphy, sedimentology, mining hazards, coal resource potential, coal bed splits, Wellington, Millstream member, Northfield member, Extension Formation.

INTRODUCTION

This report presents initial results of a geological study of the Wellington coal bed and its bounding strata, based on surface and underground mapping, and examination of mine plans and borehole records. It documents the stratigraphy and sedimentology of the Wellington coal, with the intent of identifying and ultimately reducing mining hazards. This project is being done under the auspices of the Ministry of Energy, Mines and Petroleum Geoscience Research Grant program, and forms part of a broader study of the coal resources of eastern Vancouver Island, which is being undertaken by officers and contract staff of the Ministry.

The Wellington coal bed has been extensively worked in the western portion of the Nanaimo coalfield, commencing with its discovery at Harewood in 1864 and continuing for over 120 years, culminating in the opening of a modern colliery at Wolf Mountain in 1984. While mining of the Wellington coal is presently suspended awaiting an improvement in coal markets, ongoing geological studies have outlined several prospective sites for new mines.

EXTENT OF AVAILABLE DATA

Summaries of the geology of the Nanaimo coalfield have been published by the federal and provincial geological surveys (Clapp, 1914; Buckham, 1947a and b; Muller and Atchison, 1971; Bickford and Kenyon, 1988). More detailed reports on specific properties are contained in the coal assessment report files of the Ministry, and in the collections of the Provincial Archives of British Columbia.

Geological records of 158 old boreholes are held by the Provincial Archives. Most of these holes were drilled with primitive diamond-coring tools, resulting in poor core recovery by modern standards. The very earliest boreholes were drilled with churn drills or cable-tool equipment and have relatively more complete records, perhaps as a result of their slower rate of penetration. Between 1980 and 1982, an additional 15 air-rotary boreholes were drilled by oil and mining companies during a brief resurgence of exploration activity. Two wildcat gas tests were drilled by BP Canada Inc. in 1986 (Harmac c-36-F and Yellow Point d-84-C, both in 92G/4).

These wells penetrated the horizon of the Wellington seam but did not encounter coal, demonstrating the coal bed does not extend uniformly into the deeper areas of Georgia Basin. Most of the holes drilled since 1980 have downhole geophysical logs, which are useful for stratigraphic correlation.

Abandonment plans of the larger collieries are preserved in the files of the Inspection and Engineering Branch of the Ministry of Energy, Mines and Petroleum Resources. These plans are of value as they often contain spot measurements of the worked sections. The most detailed and recent mapping has been at Wolf Mountain colliery, where over 200 sections were measured by the author within a 7-hectare area (Bickford, 1987).

Surface geological mapping is less rewarding, owing to the scarcity of coal outcrops. Most of the natural exposures reported by Clapp (1914) have since been obliterated either by mining or by housing development. The roof and floor of the coal are more frequently exposed however, allowing the position and structural configuration of the coal bed to be fairly closely established.

GEOLOGICAL SETTING

The Wellington coal bed crops out along the northwestern erosional margin of the Nanaimo sub-basin of Georgia Basin, near the city of Nanaimo. It lies near the base of the Extension Formation, which is of early Campanian age based on ammonite and molluscan faunal zonation. A geological sketch map is presented as Figure 4-3-1 which depicts the extent of thrusting and folding of the coal bed, which is presumed to be the result of convergent plate motions along the Pacific margin of North America.

STRATIGRAPHIC FRAMEWORK

The stratigraphy of the coal-bearing portions of the Nanaimo Group has recently been revised (Bickford and Kenyon, 1988), taking into account the concentration of coals in comparatively thin units within the sedimentary pile. The Extension Formation, as first proposed by Clapp (1912), has been subdivided into two members: the upper and dominantly conglomeratic Millstream member and the lower, fine-grained Northfield member. Figures 4-3-2 and 4-3-3 depict the relationships between the two members and their bounding strata in the northern and central portions of the Nanaimo coalfield.

The Millstream member consists mainly of quartz-chert-volcanic conglomerate which coarsens from small pebbles in the north at Departure Bay, to cobbles in the south along the Nanaimo River. Millstream conglomerates contain minor

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

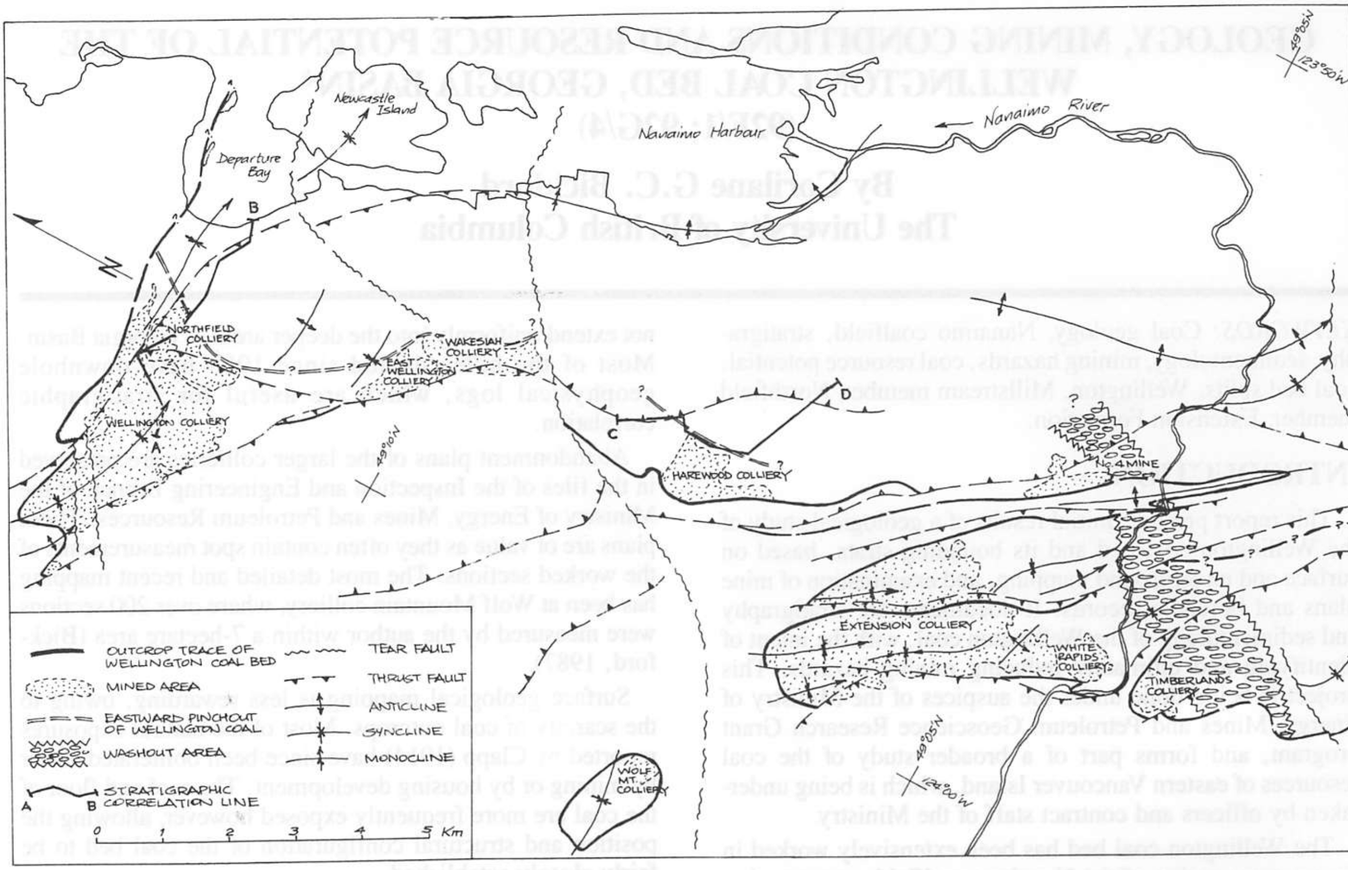


Figure 4-3-1. Geological sketch map of the Wellington coal bed, Nanaimo coalfield.

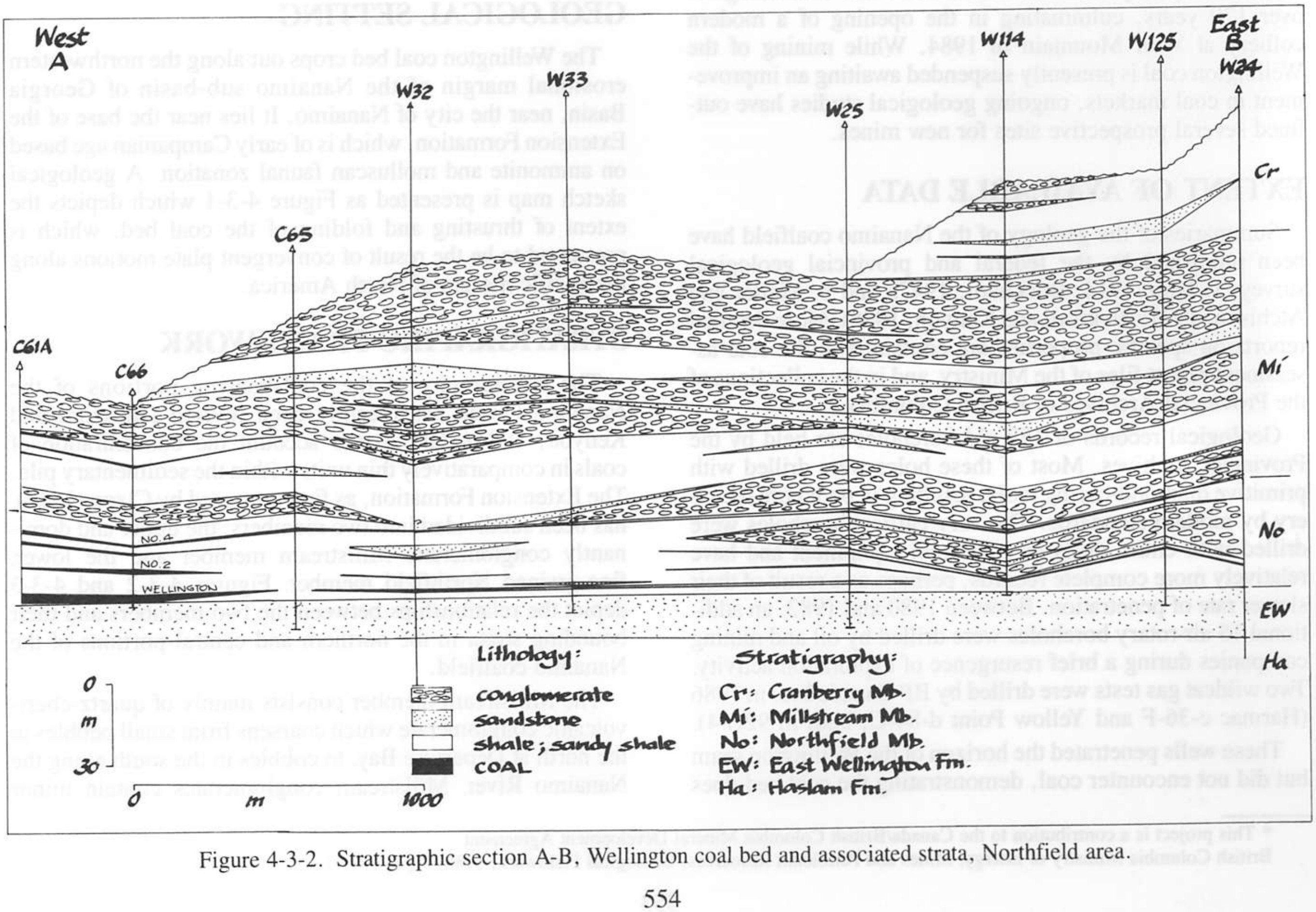


Figure 4-3-2. Stratigraphic section A-B, Wellington coal bed and associated strata, Northfield area.

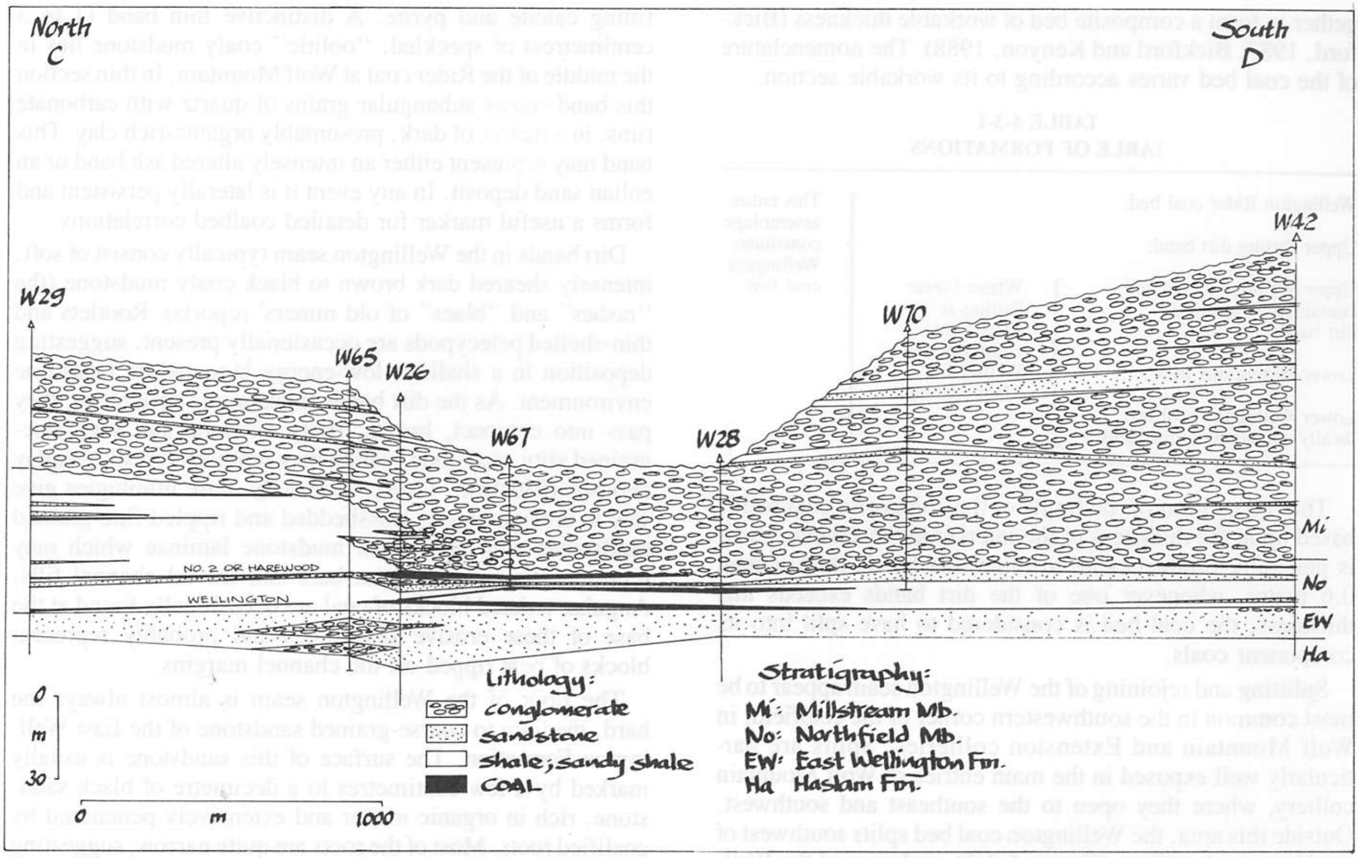


Figure 4-3-3. Stratigraphic section C-D, Wellington coal bed and associated strata, Northfield area.

amounts of a distinctive red hematitic chert or jasper (Clapp, 1914), which appears to have been derived from the Paleozoic rocks of the Sicker Group. Lenses of cherty sandstone and greenish grey siltstone are locally present. The Millstream member is 120 to 150 metres thick along its western outcrop. Isolated deep boreholes show this unit thins eastward into Georgia Basin.

In the southwestern part of the coalfield, near Extension and Wolf Mountain collieries, the Millstream conglomerates are in erosional contact with the underlying Northfield coal measures. In most cases, this contact is expressed merely as a scour surface with minimal vertical relief, but to the south of Extension and Timberlands collieries, the contact takes the form of a washout which has substantially or completely replaced the Northfield member. This washout effectively forms the southeastern limit of known mineable Wellington coal. The onset of the washout is rapid; in Timberlands colliery it cuts down 3 metres in a distance of 30 metres and thus completely takes out the Wellington seam together with its immediate siltstone roof. Beyond the washout, isolated occurrences of coal of potentially mineable thickness have been found in adits and boreholes, but their correlation with the Wellington coal bed has not been conclusively demonstrated.

At least three thin coal beds have been encountered locally by boreholes through the Millstream member. Other than at Wolf Mountain, these coals do not consistently attain a mineable thickness and they cannot be readily mapped (Clapp, 1914). At Wolf Mountain, the Millstream coals have been found to contain numerous partings of black, coaly mudstone, resulting in very high raw ash contents. They are therefore not regarded as mineable (Perry, 1982).

The Northfield member consists mainly of brown and grey mudstone and siltstone (the "sandy shale" of old drilling records). In the northeastern part of the coalfield, near Departure Bay, an eastward-thickening tongue of conglomerate up to 25 metres thick occurs in the middle of the member. The thickness of the Northfield member ranges from 10 metres in the south to 45 metres at Wellington colliery; some of the thickness variation is due to scouring by the overlying Millstream conglomerates, while an abrupt thickening near Harewood colliery (as shown on Figure 4-3-2) appears to be due to lateral intertonguing of the Millstream and Northfield members.

Several coals are present within the Northfield member, of which the thickest is the Wellington coal bed, which lies at the base of the member. Thinner coals overlie the Wellington seam, as shown on Figures 4-3-2 and 4-3-3. Closely spaced underground boreholes in Northfield colliery have disclosed these upper coals are not splits off the Wellington bed; on the contrary they maintain a fairly consistent stratigraphic separation both from the Wellington bed and from each other.

SEAM SPLITS

Contrary to the notion expressed by Hacquebard *et al.* (1967) that the Wellington coal bed shows no sign of splitting and rejoining, on closer examination splits appear to be fairly common. The Wellington coal bed itself is made up of three thinner but closely adjacent coals, which locally come together to form a composite bed of workable thickness (Bickford, 1987; Bickford and Kenyon, 1988). The nomenclature of the coal bed varies according to its workable section:

TABLE 4-3-1
TABLE OF FORMATIONS

Wellington Rider coal bed;		This entire assemblage constitutes Wellington coal bed.
Upper Parting dirt band;		
Upper Wellington coal bed, containing several thin dirt bands;	Where Lower Parting is absent, this comprises the Wellington Main coal bed.	
Lower Parting dirt band;		
Lower Wellington coal bed, locally containing a dirt band.		

The recognition of the limits of the composite coal bed is based upon the thickness of the intervening dirt bands. As it is generally impracticable to mine dirt bands thicker than 0.6 metre, whenever one of the dirt bands exceeds this thickness, the coal bed is considered to have split into its component coals.

Splitting and rejoining of the Wellington seam appear to be most common in the southwestern corner of the coalfield, in Wolf Mountain and Extension collieries. Splits are particularly well exposed in the main entries of Wolf Mountain colliery, where they open to the southeast and southwest. Outside this area, the Wellington coal bed splits southwest of the Harewood colliery (Figure 4-3-3), and west of the Wellington colliery. In general, the Wellington coal bed appears to split more frequently in a westward direction, while to the east it tends to pinch out and ultimately disappear.

SEDIMENTOLOGY

Nanaimo Group sediments, including the Wellington coal bed, were deposited on a surface of high relief (Clapp, 1914; Muller and Atchison, 1971). Basement knobs and ridges projected above the general level of sedimentation and exerted a profound influence on the thickness and character of the basin-filling sediments. Geological mapping along the basin margins, and boreholes within the basin, indicate that some of the basement ridges, for example the prominent ridge of volcanic rocks north of Departure Bay, were emergent features at the time of deposition of the Wellington bed. Another isolated basement knob was encountered by boreholes and mine workings at Wakesiah colliery, west of Nanaimo.

Immediately adjacent to these basement hills, the Wellington seam tends to be thin and high in ash, grading locally into black coaly mudstone. At greater distances from the basement hills, the coal attains its normal thickness; in some cases the basement hills appear to have sheltered the coal-forming swamps from the influx of sediments, resulting in the accumulation of unusually thick coal bodies in their lee (Buckham, 1947a).

Away from basement hills, the Wellington coal is characteristically bright banded and very hard. Its inherent ash content ranges from 6 to 10 per cent, and appears to be highest in the Rider coal, which is often marked by cleat-filling calcite and pyrite. A distinctive thin band (1 to 3 centimetres) of speckled, "oolitic" coaly mudstone lies in the middle of the Rider coal at Wolf Mountain. In thin section this band shows subangular grains of quartz with carbonate rims, in a matrix of dark, presumably organic-rich clay. This band may represent either an intensely altered ash band or an eolian sand deposit. In any event it is laterally persistent and forms a useful marker for detailed coalbed correlations.

Dirt bands in the Wellington seam typically consist of soft, intensely sheared dark brown to black coaly mudstone (the "rashes" and "blaes" of old miners' reports). Rootlets and thin-shelled pelecypods are occasionally present, suggesting deposition in a shallow, low-energy lagoonal or lacustrine environment. As the dirt bands thicken into split areas, they pass into compact, brown, rooty siltstone and very fine-grained silty sandstone, which may represent crevasse-splay deposits (Bickford, 1988). Ultimately these lithologies give way to erosive-based, crossbedded and rippled fine-grained sandstones with occasional mudstone laminae which may represent clay-draped point bars and fluvial channel fills. Angular, twisted blocks of coal are occasionally found at the base of these erosive sandstones and probably represent blocks of peat ripped off the channel margins.

The floor of the Wellington seam is almost always the hard, medium to coarse-grained sandstone of the East Wellington Formation. The surface of this sandstone is usually marked by a few centimetres to a decimetre of black sandstone, rich in organic matter and extensively penetrated by coalified roots. Most of the roots are quite narrow, suggesting they supported the growth of sedges rather than large shrubs or trees. The contact of the Wellington coal with its floor is abrupt except in the extreme northwestern corner of the coalfield, west of Wellington colliery. In this area the basal few decimetres of the seam often contain lenses and stringers of coaly sandstone and sandy coal, suggestive of post depositional disturbance, perhaps by waves acting to partially lift the coal-forming peat.

Stone rolls are a common feature of the floor surface. At Wolf Mountain colliery it is possible to examine them in detail. Here they are of two types: linear rolls striking to the northwest with a steep face down to the southwest, and sinuous rolls with no preferred orientation. The linear rolls may represent relict beach ridges, as described by Bunnell *et al.* (1984). The sinuous rolls probably represent the margins of meandering streams or tidal channels incised into the floor prior to peat deposition.

The lateral persistence of its component coal plies, the presence of extensive rooting in its floor, the occurrence of coalified stumps in its partings and its immediate roof suggest that the Wellington coal is not of detrital origin. Coal-forming peat may have accumulated in a forested coastal swamp, which in most places was sheltered from direct attack by waves except during major storms.

MINING HAZARDS

While mining conditions are generally good in the Wellington coal bed, the potential for major accidents remains. This is amply demonstrated by the historic record of explosions and inundations of mine workings, commencing with the 1888 explosion and fire at Wellington colliery, in which 77 miners were killed.

The major source of accidents, as opposed to fatalities, is falls of roof or top coal. The immediate roof of the Wellington coal bed is generally a laminated siltstone or silty mudstone, which although relatively strong, will readily undergo bed separation if not adequately supported soon after exposure by mining. Prior to the availability of rockbolts, this sort of material was difficult to support by means of timber alone, and accounted for many accidents owing to its tendency to fail without warning.

The presence of thin rider coals above the worked section, particularly at White Rapids and Wolf Mountain, is a contributory factor to bed separation and subsequent roof falls. The presence of a rider coal is particularly hazardous in that it may lie at such a height above the worked section that rockbolts may be anchored below the rider, resulting in the potential for massive failure of the strata underlying the rider. Where rider coals lie closer to the worked section, intervening strata may be unusually friable due to pedogenic slickensiding.

Compared with the other coals of the Nanaimo coalfield, the Wellington bed is not particularly gassy. Despite its low gas yield, gas may accumulate in poorly ventilated cavities and ignite on contact with naked lights (as happened at Wellington colliery), or by means of frictional sparking during roof falls (which may have happened at Extension colliery in 1909).

The hard, vitrinite-rich Wellington coal makes a large amount of dust during mining, and the fine dust is carried for long distances by ventilating currents, ultimately accumulating along mine roadways. Coal dust may have been involved in, and increased the violence of, some of the larger explosions. Systematic stone-dusting of mine workings has largely reduced this hazard, but a possibility of dust ignitions still exists due to incendive sparking at the coal face. Sparks may be generated when powered coal-cutters contact the hard, quartz-bearing sandstone floor of the Wellington seam.

Areas of oxidised coal along the outcrop of the Wellington bed are prone to spontaneous combustion, following mining-induced caving and crushing of the strata. The northern end of Extension colliery has been on fire since the late 1930s, hampering efforts to recover remnant pillars of coal. Besides the possibility of encountering an active fire, the smouldering coal generates carbon monoxide, which may migrate through subsidence cracks either into adjoining workings or to the surface. Spontaneous combustion thus represents a hazard both to continued mining operations and to the use of the overlying lands for residential development.

Oxidation of coal and timber in old workings results in the formation of carbon dioxide, which being heavier than air can accumulate in low points within the workings. Carbon dioxide poisoning has caused at least two fatalities to children who had crawled into old workings at Harewood colliery.

Several inrushes of groundwater and water-bearing sediment have occurred within collieries working the Wellington seam. While very few fatalities have resulted, this has been more the result of fortuitous timing of the inrushes, rather than precautions taken against their occurrence. The No. 4 mine at Extension broke through into water-bearing sand, gravel and peat underlying a lake; it was abandoned in 1917 following the failure of dams which had been built underground in an effort to contain these materials. In 1936, miners in Northfield colliery broke through into the flooded workings of Wellington colliery, owing to these older workings extending beyond the points shown on their abandonment plan. A similar inrush occurred at Beban colliery in 1937, resulting in three fatalities. In this case, flanking drillholes failed to detect the old flooded workings, perhaps due to them being at a different horizon within the thick coal bed being worked (Robert Bone, Senior Inspector of Mines, personal communication, 1988).

Because most of the workable remnants of the Wellington coal bed lie adjacent to old workings, their development will probably require dewatering of old workings by means of boreholes, preferably from surface so as to intersect the full thickness of the coal bed in which flooded workings may be present. Disposal of mine water should not be a major problem, as its quality is adequate for irrigation use, as already practiced at one golf course west of Departure Bay.

Residential or industrial development above shallow mine-workings may require costly stabilisation of the old workings in order to assure an adequate foundation for building construction. While most subsidence problems in the Nanaimo coalfield are related to the presence of old workings in the Douglas and Newcastle seams underlying the city centre, mining-induced subsidence over the Wellington coal bed has caused geotechnical problems in residential areas above the Wellington and East Wellington collieries (Douglas Pelly, consulting geotechnical engineer, personal communication, 1986).

One of the major difficulties inherent in development over areas of old workings is the lack of accurate mine plans. In response to this problem, a compilation plan has been prepared by Island Geotechnical Services Ltd. (Pelly, 1979). Copies of this plan may be obtained through the Nanaimo City Engineer's office.

POTENTIAL FOR FURTHER EXPLORATION AND DEVELOPMENT

Despite a long history of exploration and mining, the mineable extent of the Wellington coal bed has not yet been completely outlined. In some areas, for example to the west of Wellington colliery, the early disposition of coal rights was such that effective exploration was not carried out owing to parts of the prospective area being unavailable for drilling. These areas are now unavailable for further exploration as they have been built over by suburban housing tracts. In other areas, particularly at Harewood, boreholes did not always reach the Wellington coal bed, owing to erroneous correlations of the intersected strata.

In the northern part of the Nanaimo coalfield, the eastward extent of mineable Wellington coal is defined by a gradual pinchout of the seam, from its optimal thickness of about 2 metres, to a practical workable limit of about 0.8 metre. These thin sections were most extensively worked in the 1940s at Northfield colliery, with the assistance of then-modern technology such as longwall-face conveyors. Given modern economic conditions, it is doubtful coal this thin could be worked at a profit. Present practice, by way of comparison, is to consider the minimum workable thickness to range from 1.5 to 1.8 metres, depending upon available equipment.

The pinchout has been established by closely spaced drilling in the vicinity of Northfield and Departure Bay. It appears to extend generally southward under the city of Nanaimo, passing just to the east of Malaspina College, where it was established by workings in the old Wakesiah colliery. The southward prolongation of the mineable limit is not yet known beyond Harewood colliery, owing to lack of effective drill control.

Within the prospective area of the Wellington coal bed, much of the easily accessible coal has already been mined or rendered unworkable by proximity to flooded old workings. Proven reserves lie west of Wolf Mountain colliery and can be reached through existing workings. Remnants of Wellington coal may be present to the southeast of Wellington colliery, to the southeast of Harewood colliery, and to the east of the washout area which bounds Timberlands colliery. With the exception of Wolf Mountain, all of these areas would require drilling or underground development in order to establish mineable reserves. A modest additional potential exists for salvage mining, by open-cast excavation of outcrop pillars, along the margins of the old collieries.

FURTHER WORK TO BE DONE

During the 1989 field season, paleocurrent indicators such as framework imbrication, cross-stratification and channel scours will be mapped in the Extension Formation. The aim of this work will be to more clearly establish the directions of sediment transport in strata associated with the Wellington coal bed. Petrographic examinations will be completed on pillar samples taken from the Wellington coal bed at Wolf Mountain colliery, in order to estabish the relationship between the macroscopic appearance of the coal and its maceral composition. This work should lead to a better understanding of the coal bed accumulation conditions.

ACKNOWLEDGMENTS

This project could not have been undertaken without the willing cooperation of the companies holding an interest in the Nanaimo coalfield, who supported the basic research into the extent of the Wellington coal bed. Thanks are due to Smoky River Coal Ltd., Toyomenka Canada Ltd., Mid-Island Coal Company, and to the Wolf Mountain Coal Limited Partnership and Netherlands Pacific Mining, who allowed access to the active workings of Wolf Mountain colliery. BP Canada Inc. provided aerial photographs of the coalfield. Craig Roberts and Bill Smith assisted with underground mapping of Wolf Mountain and Timberlands collieries; Georgia Hoffman and Esther Lobb assisted with underground mapping of White Rapids and Extension collieries. Dr. R.M. Bustin provided helpful and patient supervision of this project, which will eventually lead to a Master's thesis in geology at The University of British Columbia. Finally, thanks to Anwylydd Fraser Westwater for her sage counsel.

REFERENCES

Bickford, C.G.C. (1987): Mining Geology of Wolf Mountain Colliery, Nanaimo Coalfield, Vancouver Island, British Columbia, Unpublished Report, *Mid-Island Coal Company*.

——— (1988): Sedimentological Patterns and Associated Mining Hazards of the Complexly-split Wellington Coal Bed, Vancouver Island, British Columbia, *Geological Society of America*, Abstracts with Programs.

Bickford, C.G.C. and Kenyon, C. (1988): Coalfield Geology of Eastern Vancouver Island (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 441-450.

Buckham, A.F. (1947a): The Nanaimo Coal Field, *Canadian Institute of Mining and Metallurgy*, Transactions, Volume 50, pages 460-472.

——— (1947b): Preliminary Map, Nanaimo Coal Field, *Geological Survey of Canada*, Paper 47-22.

Bunnell, M.D., Kravits, C., and Reese, J. (1984): Marine Sandstone "Rolls" in a Coal Mine in Northern Wasatch Plateau, Utah, *American Association of Petroleum Geologists*, Bulletin, Volume 68, No.7, pages 933-934.

Clapp, C.H. (1912): Geology of Nanaimo Sheet, Nanaimo Coal Field, Vancouver Island, British Columbia, *Geological Survey of Canada*, Summary Report, 1911, pages 91-105.

Clapp, C.H. (1914): Geology of the Nanaimo Map Area, *Geological Survey of Canada*, Memoir 51.

Hacquebard, P.A., Birmingham, T.F. and Donaldson, I.R. (1967): Petrography of Canadian Coals in Relation to Environment of Deposition, *Symposium on the Science and Technology of Coal*, Ottawa, 1967, pages 84-97.

Muller, J.E. and Atchison, M.E. (1971): Geology, History and Potential of Vancouver Island Coal Deposits, *Geological Survey of Canada*, Paper 70-53.

Pelly, D. (1979): Coal Workings–Nanaimo Field, Composite Plan, *Island Geotechnical Services Ltd.*, project for City of Nanaimo.

Perry, J.H. (1982): Geological Data Summary of the Wolf Mountain Coal Property, Unpublished Report, *Netherlands Pacific Mining*.

COAL MEASURES GEOLOGY OF THE QUINSAM AREA (92F)

By Corilane G.C. Bickford and Georgia Hoffman
Bickford Consulting Ltd.
and
Candace Kenyon

KEYWORDS: Coal geology, stratigraphy, Vancouver Island, Comox sub-basin, Comox Formation, Dunsmuir member, Cumberland member, Benson member.

INTRODUCTION

This report is part of an ongoing project begun in 1987 to update critical geological relationships in the Vancouver Island coal deposits. Objectives of this study are to establish the lateral extent of coal-bearing strata and ascertain the structural style of the coal measures in the Quinsam area (Figure 4-4-1).

Coal was first discovered in the area near Middle Quinsam Lake by W. Sutton in 1908. Further mapping was done by J.D. Mackenzie, H.A. Rose and T.B. Williams in 1923 and by A.F. Buckham in 1946. Buckham's work convinced Canadian Collieries Limited to drill three widely spaced holes which indicated potential coal reserves. Development drilling was done from 1974 to 1985 by Weldwood of Canada Limited, Luscar Limited and Brinco Mining Limited. In total, more than 500 holes were drilled in the area. An open-pit mine has since been opened by Quinsam Coal Limited (Figure 4-4-1) and a deposit along Chute Creek was discovered by Can Del Oil Limited in 1981. Subsequent drilling, trenching and mapping was done by Can Del, Sulpetro Oil Limited and Nuspar Resources Limited in the Chute Creek area.

LOCATION

The study area covers approximately 220 square kilometres in the eastern foothills of the Vancouver Island Ranges, southwest of the town of Campbell River (Figure 4-4-1). The area is accessible by Highway 28 from Campbell River, and by a network of private forestry roads controlled by British Columbia Forest Products Limited, Crown Forest Industries Limited and MacMillan Bloedel Limited. Conditions of these roads vary with logging activity and many are overgrown and accessible only on foot.

Topography is fairly gentle with plateaus and rolling hills separated by narrow valleys aligned in a northeasterly direction. Three major rivers, flowing to the Strait of Georgia, drain the area; Campbell River in the north, Quinsam River in the central area and Oyster River in the south. Isolated lakes are scattered throughout the area.

Most of the study area is covered by till, obscuring bedrock geology, particularly in the low country along the southern shore of Campbell Lake. Exposures are generally limited to rivers, creeks and roadcuts, but a few outcrops occur on steep hillsides which project above the unconsolidated drift. The highwall of the Quinsam coal mine provides an excellent exposure.

Most of the area is covered by dense vegetation, primarily thick second-growth stands of conifers. Older stands of forest have thick underbrush particularly along river and stream banks. The climate is mild and humid but snowfall is heavy at higher elevations.

FIELDWORK

Geological mapping was done using 1:20 000-scale aerial photographs to plot data which were later transferred to 1:20 000 base maps. Detailed sections were measured where coal beds are exposed. Samples of coal and associated sandstone were taken for petrographic analysis. Geological and geophysical logs of exploratory boreholes, on file with the Ministry of Energy, Mines and Petroleum Resources in Victoria, were examined to establish geological relationships under drift-covered areas. Paleocurrent data were collected to establish the local shoreline configuration during the Late Cretaceous.

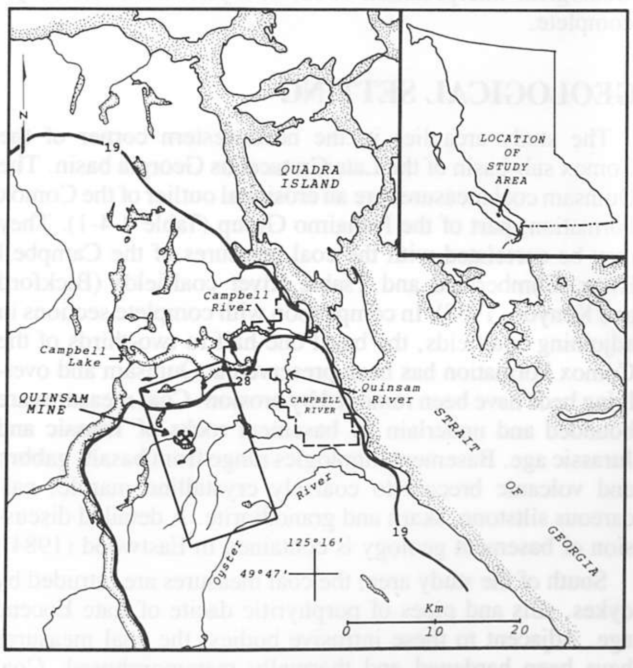


Figure 4-4-1. Location map, Quinsam area.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

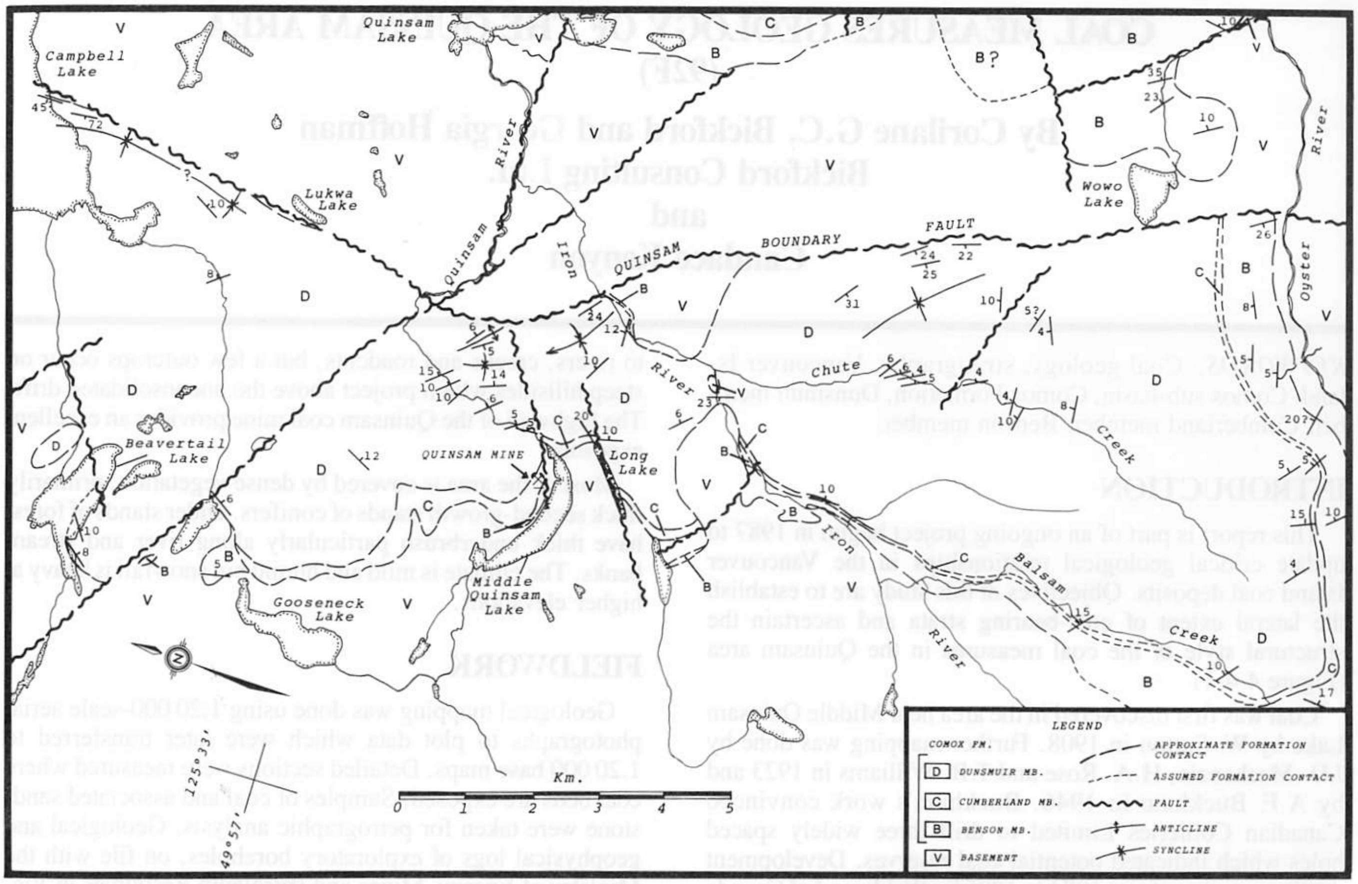


Figure 4-4-2. Geology of the Quinsam area.

A preliminary geological map of the area between Oyster River and Campbell Lake is presented as Figure 4-4-2. Geological interpretation south of Oyster River is not yet complete.

GEOLOGICAL SETTING

The study area lies in the northwestern corner of the Comox sub-basin of the Late Cretaceous Georgia basin. The Quinsam coal measures are an erosional outlier of the Comox Formation, part of the Nanaimo Group (Table 4-4-1). They may be correlated with the coal measures of the Campbell River, Cumberland and Tsable River coalfields (Bickford and Kenyon, 1988). In comparison with complete sections in adjoining coalfields, the basal one-half to two-thirds of the Comox Formation has been preserved at Quinsam and overlying beds have been removed by erosion. Coal measures are bounded and underlain by basement rocks of Triassic and Jurassic age. Basement lithologies range from basalt, gabbro and volcanic breccia to coarsely crystalline marble, calcareous siltstone, skarn and granodiorite. A detailed discussion of basement geology is contained in Eastwood (1984).

South of the study area, the coal measures are intruded by dykes, sills and pipes of porphyritic dacite of Late Eocene age. Adjacent to these intrusive bodies, the coal measures have been hardened and thermally metamorphosed. Coal rank increases markedly in the altered areas (Kenyon and Bickford, 1989, this volume). While basement rocks have locally undergone intense folding and faulting, the coal measures are usually only gently deformed by block-faulting and tilting along their western erosional margin. On the eastern margin of the basin, the coal measures are locally deformed and dip moderately to steeply westward at the eastern Quinsam boundary fault along which basement has been uplifted (Figure 4-4-2). This fault dips steeply east, and appears to be part of a more extensive stike-slip system. Vertical displacement across the boundary fault is in the order of hundreds of metres. The strike-slip displacement is not yet established but is probably a few kilometres, with dextral movement.

COAL-MEASURE STRATIGRAPHY

The three members of the Comox Formation, first recognized in the Cumberland coalfield (Bickford and Kenyon, 1988), are readily distinguished in the Quinsam area. The Benson member, which occurs at the base of the section, is conformably overlain by and locally interfingers with the Cumberland member, which is overlain by the Dunsmuir member. The contact of the Dunsmuir member with the underlying sediments is abrupt and locally erosional.

BENSON MEMBER

This unit consists mostly of dark green and brown conglomerate, with lesser amounts of greenish grey pebbly sandstone and red sandy siltstone. Most of the framework clasts in the conglomerate are volcanic, mainly basalt and andesite

TABLE 4-4-1
STRATIGRAPHIC UNITS OF THE NANAIMO GROUP

Maastrichtian	Spray Fm.	Dark shale: COAL
Late	(Boundary within	Classic turbidites, mostly shales
Campanian	Spray Fm.)	
	Geoffrey Fm.	Conglomerate and sandstone
	Northumberland Fm.	Classic turbidites, mostly shales
	De Courcy Fm.	Sandstone and conglomerate
	Cedar District Fm.	Classic turbidites, mostly shales
Early	Protection Fm.	(Subdivided in Nanaimo coalfield)
Campanian	McMillan Mbr.	Sandstone and siltstone
	Reserve Mbr.	Siltstone and sandstone: COAL
	Cassidy Mbr.	Sandstone and conglomerate
	Pender Fm.	(Subdivided in Nanaimo coalfield)
	Newcastle Mbr.	Shale and conglomerate: COAL
	Cranberry Mbr.	Sandstone and siltstone
	Extension Fm.	(Subdivided in Nanaimo coalfield)
	Millstream Mbr.	Conglomerate: COAL
	Northfield Mbr.	Siltstone and sandstone: COAL
	East Wellington Fm.	Sandstone (Nanaimo sub-basin only)
	Haslam Fm.	Classic turbidites, mostly shales
	Comox Fm.	(Subdivided in Comox sub-basin)
	Dunsmuir Mbr.	Sandstone: COAL
	Cumberland Mbr.	Siltstone and sandstone: COAL
	Benson Mbr.	Conglomerate and red beds
	UNCONFORMITY	
	Older basement rocks, chiefly volcanics	

with minor gabbro. Occasional plutonic clasts are present; they are mostly granodiorite but some true granite clasts are found in the Benson conglomerates south of Oyster River. Volcanic clasts predominate in Benson conglomerates, even where the underlying basement is granitic. This feature, first reported in the Tsable River coalfield by Atchinson (1968), may be due to the relative resistance to disintegration of volcanic compared to plutonic rocks. The granitic clasts are often decomposed and soft, due to the alteration of feldspars to clay minerals.

The conglomerates are thick bedded to massive, with large-scale low-angle cut-and-fill structures. Low-angle planar cross-stratification is occasionally present. Framework sorting tends to be fair to good and the conglomerate is usually framework supported with a sparse matrix of medium to coarse-grained sand. Abundant white calcite cement is present in some conglomerates, occasionally comprising up to 20 per cent of rock volume. Imbrication of framework clasts is often well developed, indicating paleoflow to the west and southwest.

The Benson member appears to have been deposited in incised, west to southwest-trending fluvial channels which were locally flanked by fault scarps and alluvial fans. Between major channels the member exists as isolated patches and ribbons, locally up to 10 metres thick; within major channels, as along the north bank of the Oyster River, it may be as thick as 270 metres.

CUMBERLAND MEMBER

This unit consists of grey sandy siltstone, dark grey mudstone and medium-grained greenish grey sandstone with coal beds which locally attain mineable thicknesses.

Major coals are the Quinsam No. 1 and No. 2 beds which are well exposed in the Quinsam mine highwall (Figure

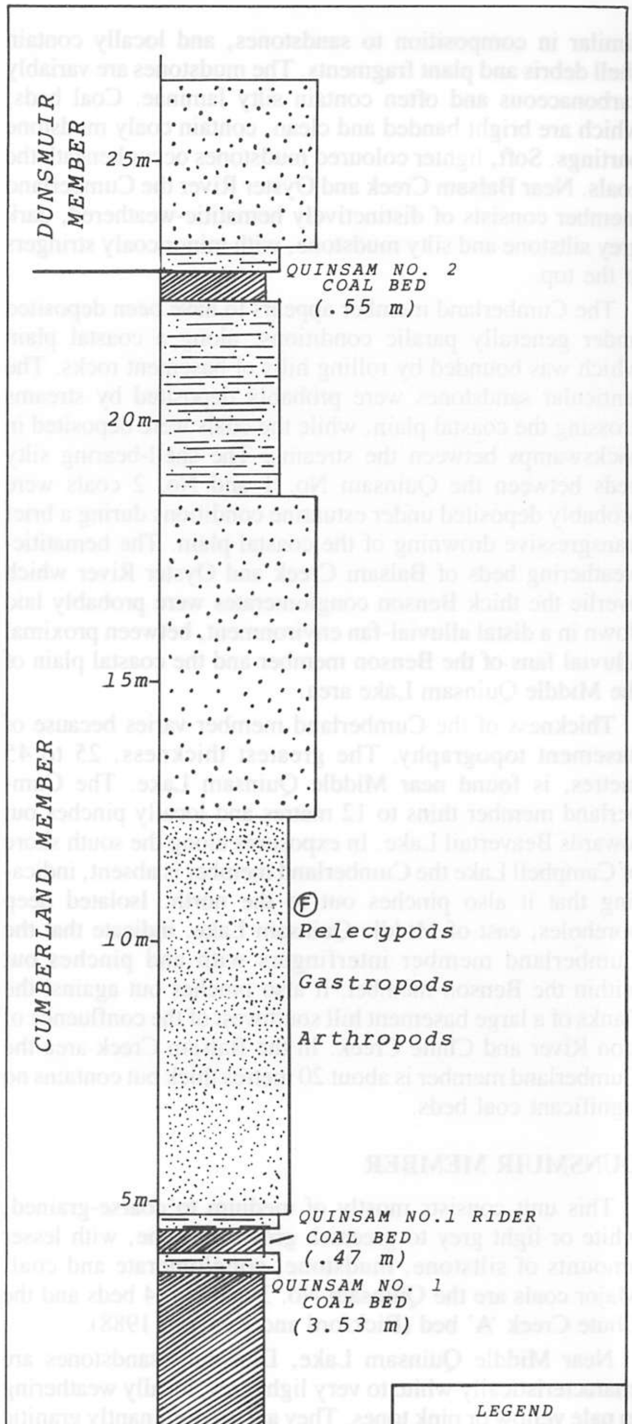


Figure 4-4-3. Measured section of highwall at Quinsam mine.

4-4-3). In the Quinsam area, sandstones of the Cumberland member consist of subequal amounts of volcanic rock fragments, plutonic quartz and kaolinized feldspar. They are lenticular in form, silty and poorly sorted. Siltstones are similar in composition to sandstones, and locally contain shell debris and plant fragments. The mudstones are variably carbonaceous and often contain silty laminae. Coal beds, which are bright banded and clean, contain coaly mudstone partings. Soft, lighter coloured mudstones occur beneath the coals. Near Balsam Creek and Oyster River the Cumberland member consists of distinctively hematitic-weathered, dark grey siltstone and silty mudstone, with minor coaly stringers at the top.

The Cumberland member appears to have been deposited under generally paralic conditions, along a coastal plain which was bounded by rolling hills of basement rocks. The lenticular sandstones were probably deposited by streams crossing the coastal plain, while the coals were deposited in backswamps between the streams. The shell-bearing silty beds between the Quinsam No. 1 and No. 2 coals were probably deposited under estuarine conditions during a brief transgressive drowning of the coastal plain. The hematitic-weathering beds of Balsam Creek and Oyster River which overlie the thick Benson conglomerates were probably laid down in a distal alluvial-fan environment, between proximal alluvial fans of the Benson member and the coastal plain of the Middle Quinsam Lake area.

Thickness of the Cumberland member varies because of basement topography. The greatest thickness, 25 to 45 metres, is found near Middle Quinsam Lake. The Cumberland member thins to 12 metres and locally pinches out towards Beavertail Lake. In exposures along the south shore of Campbell Lake the Cumberland member is absent, indicating that it also pinches out to the north. Isolated deep boreholes, east of Middle Quinsam Lake, indicate that the Cumberland member interfingers with and pinches out within the Benson member. It also pinches out against the flanks of a large basement hill southwest of the confluence of Iron River and Chute Creek. In the Balsam Creek area the Cumberland member is about 20 metres thick but contains no significant coal beds.

DUNSMUIR MEMBER

This unit consists mostly of medium to coarse-grained, white or light grey to greenish grey sandstone, with lesser amounts of siltstone, mudstone, conglomerate and coal. Major coals are the Quinsam No. 3 and No. 4 beds and the Chute Creek 'A' bed (Bickford and Kenyon, 1988).

Near Middle Quinsam Lake, Dunsmuir sandstones are characteristically white to very light grey, locally weathering to pale yellow or pink tones. They are predominantly granitic in composition, consisting of subequal amounts of plutonic quartz and plagioclase feldspar, with accessory dark minerals such as hornblende and magnetite. Volcanic rock fragments are a minor constituent of these sandstones. Along the ridgeline north of Oyster River, the Dunsmuir sandstones are more volcanic in composition, with quartz and feldspar comprising about 30 per cent of the framework grains. These volcanic-rich sandstones are greenish grey to olive-drab.

In the Quinsam River canyon, northeast of the Quinsam mine, a thin band of heavy-mineral sandstone is exposed. This sandstone contains about 50 per cent magnetite across a thickness of 5 centimetres. It lies within a thicker unit (1.6 metres) of granitic sandstone with about 10 per cent magnetite concentrated within many thin laminae. Similar iron-bearing sandstones have been encountered in boreholes situated to the northwest and southeast of the canyon.

Dunsmuir sandstones contain an abundant trace-fossil assemblage including *Thalassinoides*, *Ophiomorpha* and *Teredolites*, and *Pelecypodichnus*. Body fossils are comparatively rare, but include trigoniid bivalves (Eastwood, 1984), and *Inoceramus*.

Conglomerates within the Dunsmuir member occur as thin bands and stringers. A persistent conglomeratic horizon is found at the base of the member in the roof of the Quinsam No. 2 coal bed. Several thin conglomerate bands occur both above and below the Chute Creek 'A' coal bed, which is higher in the member. Dunsmuir conglomerates are distinguished from Benson conglomerates by an abundance of granitic clasts.

Mudstones and siltstones within the Dunsmuir member resemble but are much less abundant than those of the Cumberland member. Dunsmuir coals are somewhat dirtier than those in the Cumberland.

It appears that the Dunsmuir member was deposited in dominantly marine conditions, along a shallow sandy shelf bordered by a complex of beaches, spits and bars. Isolated hills of basement rocks remained exposed during at least the early stages of deposition. Most of the shelf sandstone was deposited below fairweather wave base but still within range of reworking by storm waves. The iron-rich sandstone likely represents an ancient beach placer. The coals and associated mudstones were probably formed in back-barrier lagoons sheltered from most clastic sedimentation but occasionally subjected to storm surges, resulting in partings of sediment within the coal-forming peats.

The upper part of the Dunsmuir member has been eroded throughout the study area. Its maximum preserved thickness, as indicated by boreholes, ranges from about 150 metres between Middle Quinsam Lake and Iron River, to about 230 metres west of Lukwa Lake.

ECONOMIC ASPECTS

Quinsam Coal Limited is mining Coal Bed No. 1 north of Middle Quinsam Lake (Figure 4-4-2). Thickness of the coal ranges from 3.3 to 4.2 metres. Local markets include Island pulp and paper mills as well as cement companies on the mainland. Over an 8-month period, February 1988 to September 1988, three trial shipments totalling 88 000 tonnes were sent to Japan. Quinsam Coal Limited forecasts production of 150 000 tonnes in 1988, 250 000 tonnes in 1989 and 500 000 tonnes in 1991. The company is permitted to produce up to 1 million tonnes per year.

The Quinsam area has been intensively prospected for coal by means of closely spaced boreholes followed by test pits. Most of the work done to date has focused on delineation of near-surface coal beds which would be amenable to open-pit mining. Considerable scope exists for both the extension of open-pit mining along strike from the existing site and for underground mining, at depths of 90 to 150 metres, to the north of the open-pit area (Barnstable, 1980). Additional drilling will probably be required to establish the full extent of underground reserves.

In the Chute Creek area, an adit was driven by Nuspar Resources Limited in 1986, in order to obtain unweathered coal for quality studies. Reserves of coal have not been reported by the owners, although they have disclosed the deposit may be suitable for either open-pit or shallow underground mining.

FURTHER WORK

Geology of the Quinsam area, extending from Oyster River to the south, will be completed. Work is currently being done to produce a deposit model of the Quinsam coal reserves. Vitrinite-reflectance data from samples collected this year will be determined as well as further study of rocks associated with the coal seams.

ACKNOWLEDGMENTS

The authors would like to thank Sharon Chapman and Michael Seifert for their field assistance. David Shaw of Crown Forest Industries provided detailed topographic maps of the Mount Washington area. MacMillan Bloedel provided access to the Chute Creek area. Joanne Schwemler is doing reflectance measurements on the coals and Dick Player is making thin sections of the sandstones. Special thanks are due to Stephen Gardner and Dorothy Wilson of Quinsam Coal Limited for their help, and to Becky Arnet for assistance in the office.

REFERENCES

Atchinson, M. (1968): Stratigraphy and Depositional Environments of the Comox Formation (Upper Cretaceous), Vancouver Island, British Columbia, Unpublished Ph.D. Thesis, *Northwestern University*, Evanston, Illinois, 139 pages.

Barnstable, D.R. (1980): The Quinsam Coal Project, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 73, Number 816, pages 89-97.

Bickford, C.G.C. and Kenyon, C. (1988): Coalfield Geology of Eastern Vancouver Island (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 441-450.

Eastwood, G.E.P. (1984): Geology of the Quinsam Lake Area, Vancouver Island, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1984-3.

Kenyon, C. and Bickford, C.G.C. (1989): Vitrinite Reflectance Study of Nanaimo Group Coals of Vancouver Island (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, This Volume.

NOTES

TECTONICALLY ALTERED COAL RANK, BOULDER CREEK FORMATION, NORTHEASTERN BRITISH COLUMBIA (93P/3)

By W.E. Kilby

KEYWORDS: Coal geology, vitrinite reflectance, tectonic heating, reflectance anisotropy, microscope automation.

INTRODUCTION

Fieldwork during the 1988 season involved investigation of the thermal affects of tectonic movement on vitrinite reflectance near the Quintette Coal Limited mining operation in northeastern British Columbia. Two samples, collected in 1987, from the same seam on either side of a fault, suggested a significant rank increase associated with the structure. These sites were revisited and sampled together with additional sites, to gain a better understanding of the process. Rank variations within the seam at one site proved greater than between the original pair of samples. Significant reflectance anisotropy was found, which is due to distillation of coal, and confirmed heating greater than coalification. The samples were also the test-set for a new reflectance data collection and analysis procedure which increases precision and provides a measure of the error associated with each reflectance reading. This article describes the procedures used and results obtained.

GEOLOGY

The study area is located immediately east and south of the Mesa pit of the Quintette Coal Limited mining operation near Tumbler Ridge (Figure 4-5-1). The seams investigated are located in the lower portion of the Lower Cretaceous Boulder Creek Formation of the Fort Saint John Group. The Boulder Creek Formation is overlain by the marine Hasler Formation and underlain by the marine Hulcross Formation, which separates it from the economically important coal measures of the Gates Formation.

Within the study area the Boulder Creek Formation is repeated by a folded thrust fault. Bedding-to-fault angles of about 30 degrees are associated with the fault which dips steeply east. The bedding is vertical to overturned (Figure 4-5-2). A shear zone, 8 centimetres wide, is located in the lower seam of the footwall beds. The sequence is cut by the mine access road providing excellent exposure of the coal seams and fault. Two samples collected from the lower seam and analyzed previously, 87-37 and 87-40, (Kilby and Johnston, 1988) suggested that the coal in the hangingwall of the thrust had experienced greater coalification than the equivalent seam in the footwall. More detailed sampling confirmed the earlier values but determined that there is an even greater variation in vitrinite reflectance (rank) within a single seam close to a thin shear zone.

More detailed mapping during the 1988 study has resulted in some modest adjustments to the interpretation presented earlier. The major change is that the fault appears to remain in the Boulder Creek Formation for a greater distance to the east. This interpretation increases the displacement associated with the thrust. Orientation of the fault above the access road remains the same (Figure 4-5-2). It is now felt that the fault is parallel to the massive conglomerates of the Boulder Creek Formation for a distance of about 200 metres below the road exposure where it then cuts upsection through the competent lower portion of the formation before becoming subparallel to bedding in the upper Boulder Creek Formation.

Table 4-5-1 presents the results of the new samples together with the two samples reported in Kilby and Johnston (1988). Measures $\bar{R}_M$, R_{MAX}, R_{INT}, R_{MIN}, R_{ST} and R_{EV} are developed and described in Kilby (1988). Note the error in the original reporting of the value of sample 87-40. The revised value, though lessening the difference between the two samples, is still a significant variation and does not alter the previous conclusions. A total of 14 samples were collected during the 1988 study but two of these proved too severely weathered for analysis. The sample sites are located on a cross-section illustrating the structural geology of the outcrop (Figure 4-5-2).

METHOD

Samples were prepared and examined using standard techniques. The interpretation of the raw data was based on Kilby (1988). Reflectance crossplots provide the means to obtain a significantly greater description of the reflectance characteristics of a coal than the traditional measures of $\bar{R}_{oMAX}$ and $\bar{R}_M$. $\bar{R}_M$ remains a valid description of the overall sample coalification but is not unique. $\bar{R}_{oMAX}$ is theoretically invalid when the reflectance indicating surace (RIS) is not uniaxial negative, Kilby (1988) showed that only about 25 per cent of the samples from the Rocky Mountains and Foothills meet this criterion. Samples from this study cover the spectrum of possible RIS-shapes from uniaxial negative to uniaxial positive (Figure 4-5-3).

Refinements have been made to the standard methodology of recording and evaluating vitrinite reflectance values. Traditionally reflectance readings are obtained from individual vitrinite particles by measuring the amount of polarized light reflected during a single revolution of the microscope stage. Generally the reflectance values form an ellipse when plotted against the respective stage angles. Until recently the majority of researchers collected only the apparent maximum values during stage rotation (R'_{MAX}). Kilby (1986) illustrated the value of also collecting the apparent minimum reflectance obtained for each vitrinite particle (R'_{MIN}). Development of a new analysis technique, the reflectance

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

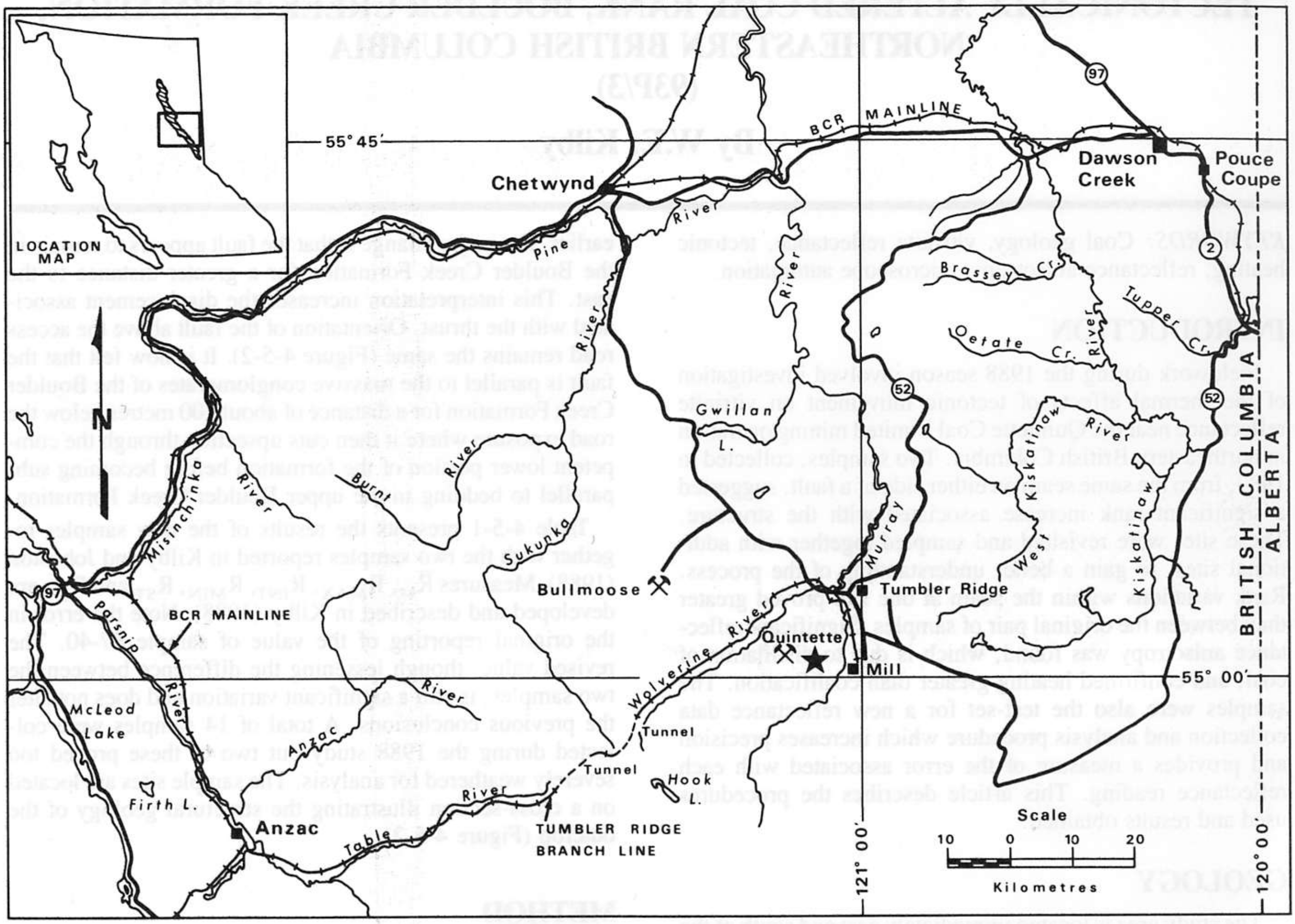


Figure 4-5-1. Location map showing study area (star), referenced to the province and the infrastructure of northeastern British Columbia.

crossplot Kilby (1986, 1988), provides the means to determine true maximum, intermediate and minimum reflectance axes for the RIS of a coal (R_{MAX}, R_{INT} and R_{MIN}). In addition reflectance crossplots can be used to identify particles from differing RIS within one sample (Figure 4-5-3a).

The initial version of the reflectance crossplot was explained in Kilby (1986); subsequent work (Kilby, 1988) developed measurement values associated with it. A computer-enhanced interpretation program has been developed which allows interactive on-screen interpretation of reflectance values and calculation of various reflectance measures (Figure 4-5-3). Increased use of R'_{MIN} values in this methodology identified susceptibility of this measurement to technical problems resulting in anomalously low values. Several conditions may cause invalid low readings;

(1) foreign material in immersion oil (dust or air bubbles),

(2) poor polish on pellet surface, or

(3) electrical problems.

R'_{MAX} values are also susceptible to anomalously high readings, primarily due to electrical problems. As a result it became essential to be able to determine the best-fit ellipse for datasets and use this average ellipse to determine R'_{MAX} and R'_{MIN} values for each particle. The first step in this correction process was automation of data collection and stage rotation.

AUTOMATION

Automation of data collection and microscope stage control has been designed and largely constructed in-house. All

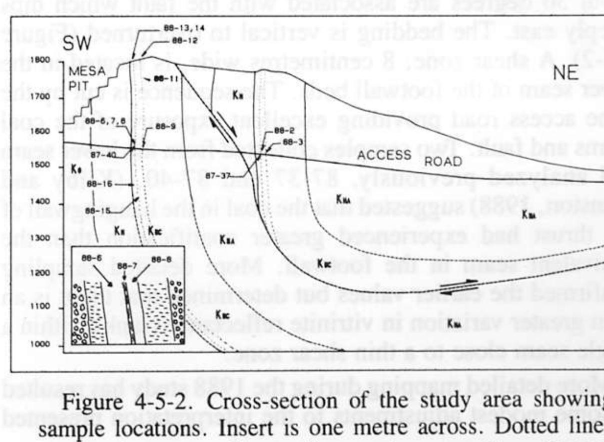


Figure 4-5-2. Cross-section of the study area showing sample locations. Insert is one metre across. Dotted lines are coal seams. Formation codes are; K_G = Gates, K_H = Hulcross, K_{BC} = Boulder Creek and K_{HA} = Hasler.

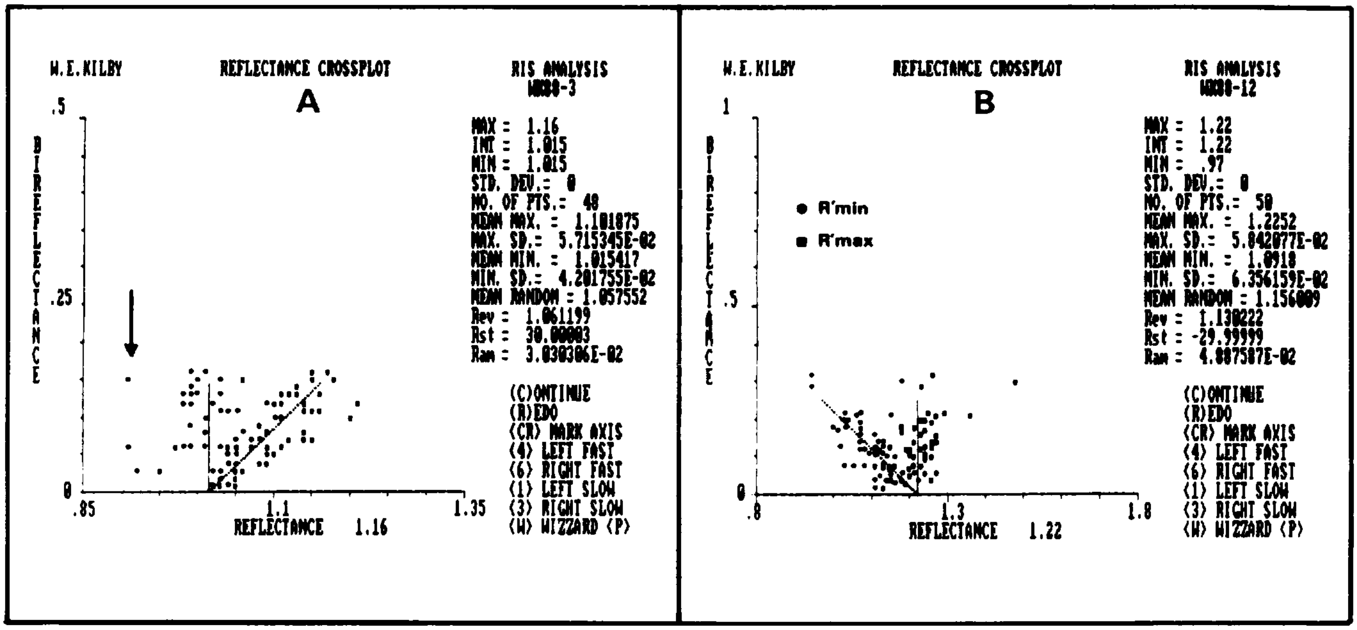


Figure 4-5-3. Reflectance crossplots of samples 88-3 and 88-12 showing the two possible end-members of RIS-shapes. Plots are screen dumps from microcomputer. Note the second minor RIS population in sample 88-3 (arrow).

controlling software was written by the author. An Octagon Systems SYS-2A microcontroller forms the heart of the system. Communication with the controller is through standard serial interface protocol with any computer. Twelve bit analog to digital conversion is used to sample a 0 to -5 VDC current representing the reflectance values from the microscope. Two of the eight available digital output lines from the controller are used to drive a KEM 802-12 (Kaientai Electronics Merchants Ltd.) stepper motor driver. A stepping motor with a stepping angle of 1.8° was mounted centrally under the microscope stage. With the one-half step capabilities of the motor driver 0.9° stage steps are realized.

Prior to stage automation the stage was rotated manually while the reflectance signal was sampled 100 times over a 6-second time period. The maximum and minimum values of the one hundred readings were saved as the R'_{MAX} and R'_{MIN} of the vitrinite particle. This procedure, though mimicking the completely manual method, is susceptible to erratically high or low readings, as is the manual method. To examine and overcome this problem readings are now taken every 9° of stage rotation. The stage is rotated 9°, then five reflectance readings are taken. The largest of these five readings is recorded. A complete stage rotation of 360° will result in 40 values. If these 40 readings are plotted using polar coordinates, an ellipse (reflectance ellipse) will be formed. Examination of this ellipse will reveal conformity to a theoretically perfect ellipse and highlight erratic values. Figure 4-5-4 shows representative reflectance ellipses from vitrinite particles taken from some of the samples in this study.

A variety of problems are apparent with the reflectance ellipses in Figure 4-5-4. The left ellipse is severely deformed. This shape is probably due to some foreign material interfering with reflecting light transmission. R'_{MAX} and R'_{MIN} values from either the raw data or fitted ellipse would be erroneous. The centre ellipse illustrates the case where a very good elliptical shape was formed by the raw data and closely approximates the fitted ellipse. The right ellipse is an example where several anomalously low readings are obtained, which could result from some floating material in the immersion oil. In this study standard deviations greater than 0.05 per cent resulted in the particle being discarded. Methods of patching ellipses with greater than half the values being valid are being tested. If they prove useful, then particles which are now discarded could be used in the analysis of the coal.

During this study two methods of fitting an ellipse to the raw sample data were tested. A regression analysis and an eigen-vector technique gave virtually identical results. The eigen-vector technique proved to be much faster in obtaining the solution to the data, and was adopted. Eigen vectors and

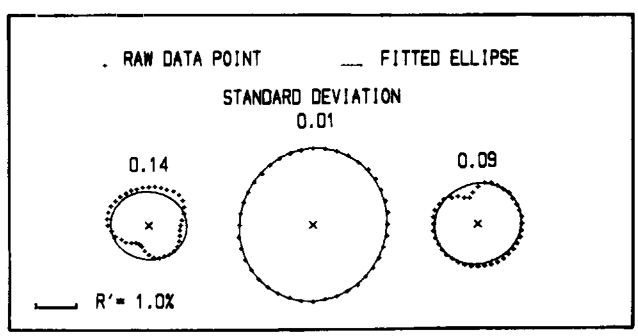


Figure 4-5-4. Examples of reflectance ellipses taken from several samples. The left ellipse illustrates the affect of anomalously low readings, the centre ellipse is an example of a very good dataset and the right ellipse is an example of extremely poor raw reflectance data.

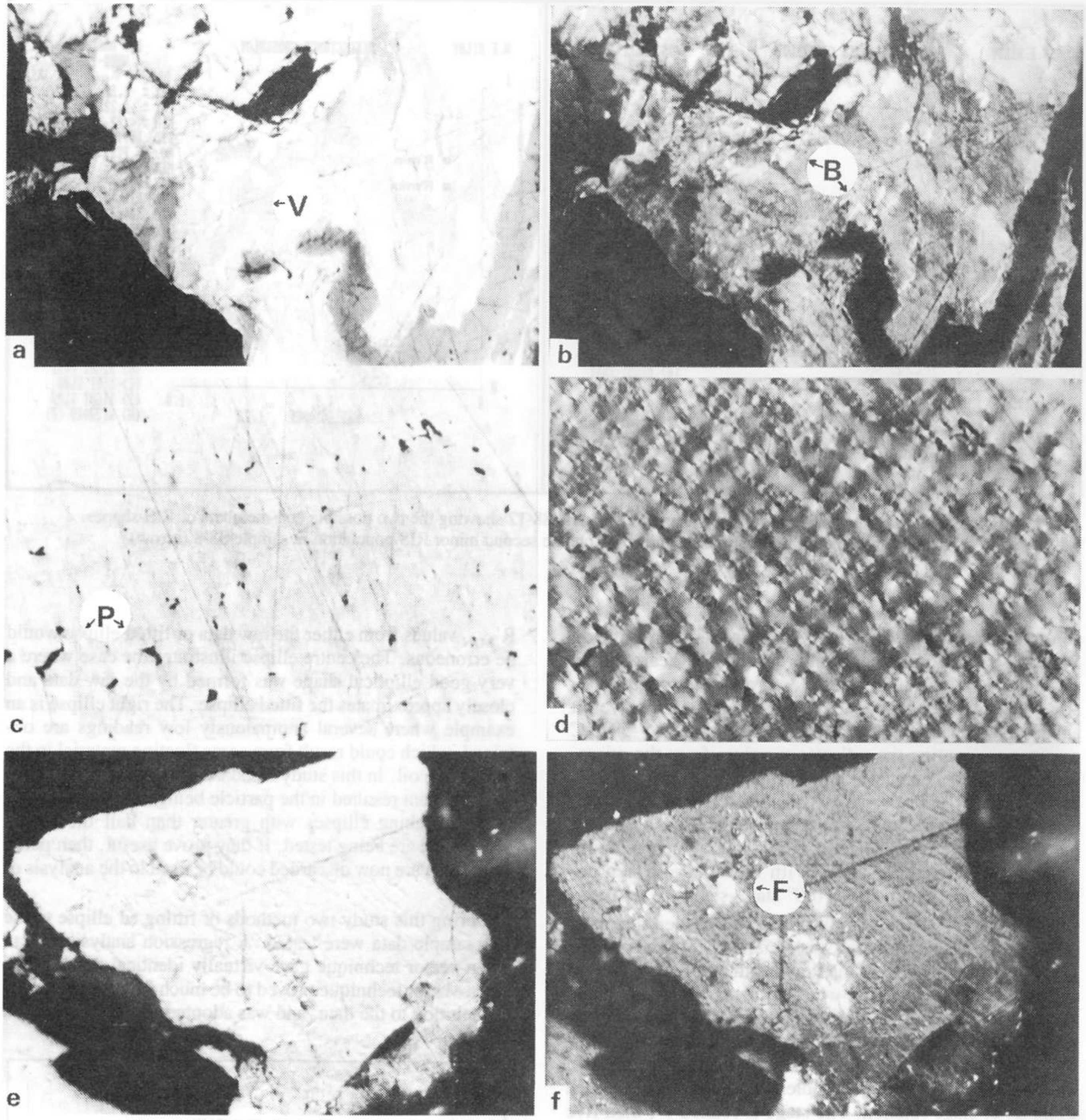


Plate 4-5-1. Sample 88-6 (a,b) shows fine-grained mosaic anisotropic texture in vitrinite (V). (1b) same view as (1a) but with partially crossed polars. Note mottled anisotropy in vitrinite and strong anisotropy in inert maceral (B). (1c), sample 88-6, contains a large vitrinite grain showing mottled texture under plain polarized light. Pore opening likely caused by devolatilization of coal (P). (1d), sample 88-6, under crossed polars shows strong cross-hatched anisotropy. (1e), sample 88-7, under plane polarized light, showing large vitrinoid grain with relic cell structure and pyrolitic carbon. (1f), sample 88-7, viewed under partially crossed polars showing extreme anisotropy of pyrolitic carbon (F).

eigen values were obtained from a 2-by-2 matrix whose elements are weighted two-dimensional direction cosines of the stage angles at which readings were taken. The weighting factor is the reflectance value obtained at each reading stage angle. The eigen-vector method was modified after Charlesworth *et al.*, (1976). Input to either method of analysis must be based on an unbiased sample distribution of the reflectance ellipse circumference. Sample distributions based on equal angular increments are biased towards the minimum apparent reflectance axis value. To overcome this bias, a new set of reflectance data were calculated, based on equal spacing along the ellipse circumference. This modi-

TABLE 4-5-1
RESULTS OF SAMPLE ANALYSIS

Sample	$\bar{R}_M$	$\bar{R}_{MAX}$	R_{MAX}	R_{INT}	R_{MIN}	R_{ST}	R_{EV}	Biref	Anisotropy
87-37	1.21	1.29	1.37	1.25	1.05	−3.4	1.20	(.24)	Mod
87-40	0.87	0.96	1.06	0.90	0.72	−9.2	0.88	(.24)	High
88-2	1.19	1.25	—	—	—	—	—	.21	Low
88-3	1.06	1.10	1.17	1.01	1.01	30.0	1.06	.16	Low
88-6	0.95	1.00	—	—	—	—	—	.14	High
88-7	1.04	1.10	—	—	—	—	—	.27	Mod-High
88-8	1.74	1.84	1.92	1.77	1.57	−4.7	1.75	.30	Mod-High
88-9	1.12	1.17	—	—	—	—	—	.17	Mod
88-11	0.95	0.99	—	—	—	—	—	.15	Mod-High
88-12	1.16	1.23	1.22	1.22	0.97	−30	1.13	.30	Mod
88-13	1.02	1.08	1.16	1.02	0.91	4.0	1.02	.20	Mod-High
88-14	1.07	1.12	1.17	1.03	1.03	30.0	1.07	.17	Mod
88-15	1.14	1.18	1.23	1.15	1.06	−1.0	1.14	.19	Low
88-16	1.03	1.09	—	—	—	—	—	.19	Mod-High

Missing values are due to uninterpretable reflectance crossplots. 1987 sample results not interpreted using eigen-vector method.

fication provided excellent fits to the raw data (Figure 4-5-4b). In addition to the R'_{MAX} and R'_{MIN} values, the orientation of the R'_{MAX} axis and the standard deviation of the raw data about the mean ellipse are reported. The standard deviation provides a measure of the validity of fitting an ellipse to the data.

ANISOTROPY

Reflectance anisotropy was identified in samples 87-37 and 87-40 by Goodarzi (personal communication, 1988). Cross-polarized reflected light was used to examine all samples in this study for this phenomenon. Development of reflectance anisotropy within single maceral grains is due to heating higher than that associated with normal coalification and is a standard feature of coked coals. Natural causes of this anomalous heating are: coal-seam fires, igneous intrusions, coal-swamp fires, tectonic heating and detrital high-rank coals (Goodarzi and Murchison, 1985 and 1986).

Coal-seam fires and igneous intrusions may be discounted within the study area as there is no evidence of either and exposure is excellent along the road cut. Coal-swamp fires and detrital high-rank coals can also be discounted as the anisotropic particles are ubiquitous rather than minor components of the samples. The remaining cause of anomalous heat is tectonic friction; the proximity of a large folded thrust fault and an obvious shear zone within the coal seam is ample evidence of tectonic activity. Analysis of anisotropy was made on the basis of type and intensity present (Table 4-5-1). Examples of some common reflectance anisotropic features are shown in Plate 4-5-1.

Different types and intensity of reflectance anisotropy are recognized in the sample set. The weakest form is fine-grained mosaic anisotropy which may occur throughout the vitrinite maceral or only as patches or streaks within the particle (Plate 4-5-1a, 1b). Granular mosaics are thought to form at temperatures of greater than 450°C and involve the active decomposition of coal substance and the onset of plasticity (fluidity) (Goodarzi and Murchison, 1972). A cross-hatched pattern of anisotropy often forms the background to a particle with ubiquitous fine-grained mosaic anisotropy. Occasionally an intense cross-hatched pattern may be present without any fine-grained mosaic texture, but this may be due to complete overprinting (Plate 4-5-1c, 1d). Wavy anisotropy then appears to develop in vitrinites and, at about this stage, inert macerals begin to display anisotropy. Coarse-grained mosaic anisotropy, though rare in these samples, tends to develop after the fine-grained mosaic anisotropy. Pyrolitic carbon forms during thermal cracking of carbonaceous material (500 to 1100°C). Plate 4-5-1e and 4-5-1f illustrate pyrolitic carbon which has formed in a vitrinoid maceral. The intensity (brightness) of the anisotropy also increases as the patterns become more developed. Eventually flow structures become visible as a result of the coal melting during carbonization (this feature, though not seen in this study, is common in coke ovens and high-grade metamorphism). Devolatilization voids form at various stages of heating to become a major component of a coked swelling coal.

The validity of typical reflectanee measures, including those obtained from a reflectance crossplot, are questionable under high anisotropic conditions where the whole sample is not described by a single RIS. Multiple RIS-shapes on a single-reflectance crossplot will result in a uninterpretable plot where the R'_{MIN} and R'_{MAX} datafields overlap and have increased standard deviations. Large standard deviations were noted by Bustin (1983) from samples taken near faults and these may be due to similar features. In the case of mosaic anisotropy, more than one RIS could easily fall within the analysis field (5 to 10 micrometres). The results from such a situation would be valid only if the two RIS were parallel to each other and of equal value, otherwise the result would be based on a composite RIS and therefore invalid. Several of the samples in this study have uninterpretable reflectance crossplots which are largely due to this feature.

DISCUSSION

Tectonism has increased the rank of coals within the study outcrop. Frictional heating associated with the major thrust fault may be responsible for the increaseding $\bar{R}_M$ values of coals near the thrust by 0.2 per cent reflectance. The separation between these increased rank coals and the fault is about 20 metres, which is significantly larger than the 5-centimetre heating zone of influence found by Bustin (1983). There is not a large increase in reflectance anisotropy associated with this rank increase.

The largest variation in reflectance is associated with intra-seam faulting. An $\bar{R}_M$ increase of 0.75 per cent was noted across a 10-centimetre shear zone within a single seam. The elevated reflectance value is located above the shear. The sample site was more than a 100 metres from the major fault, and the rank increase is not attributed to it, but rather to heating along the shear zone formed as a result of flexural slip between the competent conglomerate units being concentrated within the coal seam. Reflectance anisotropy at this sample location is strong and suggests temperatures in excess of 450°C.

Techniques and equipment were developed to evaluate reflectance data obtained from discrete angular increments for each measured vitrinite particle in a sample. The procedure reduces the problem of noisy data and provides a measure of error associated with each reflectance measurement.

Reflectance crossplots provide better analysis parameters than traditional techniques. In this study they provided the means to identify the full spectrum of reflectance indicating surface shapes from uniaxial negative to uniaxial positive. Multiple RIS populations can be identified in reflectance crossplots. Uninterpretable reflectance crossplots (mixtures of several populations) may prove to be a method of predicting reflectance anisotropy. If this anisotropy is due to shearing of the coal, this tool would have application in predicting disturbed seams in mining situations.

A semiquantitative measure of reflectance anisotropy correlates well with visible shearing, increased vitrinite reflectance and multiple RIS populations. Identification of reflectance anisotropy in complicated reflectance profiles, often present in the Peace River coalfield, may provide an explanation based on tectonic structures.

ACKNOWLEDGMENTS

The author would like to acknowledge the contribution to this study of Joanne Schwemler in preparing and obtaining the vitrinite reflectance values. In particular her patience in contending with prototype equipment and many procedural changes is greatly appreciated. Dr. R.M. Bustin assisted with a program to fit an ellipse to the raw reflectance data using regression techniques. The author is grateful to Quintette Coal Ltd. for access and assistance in sampling during this study. In particular discussions and interest shown by D. Johnson are greatly appreciated.

REFERENCES

Bustin, R.M., (1983): Heating During Thrust Faulting in the Rocky Mountains: Friction or Fiction?, *Tectonophysics*, Volume 95, pages 309-328.

Charlesworth, H.A.K., Langenberg, C.W. and Ramsden, J., (1976): Determining Axes, Axial Planes, and Sections of Macroscopic Folds Using Computer-based Methods, *Canadian Journal of Earth Sciences*, Volume 13, pages 54-65.

Goodarzi, F. and Murchison, D.G., (1972): Optical Properties of Carbonized Macerals, *Fuel*, Volume 51, pages 322-328.

——— (1985): Optically Anisotropic Fragments in a Western Canadian Subbituminous Coal, *Fuel*, Volume 64, pages 1294-1300.

——— (1986): Anisotropic Fragments in Strongly Folded and Faulted Coals from the Rocky Mountain Area of Southeast British Columbia, *Canadian Journal of Earth Sciences*, Volume 23, Number 2, pages 254-258.

Kilby, W.E., (1986): Biaxial Reflecting Coals in the Peace River Coalfield (93 O, P, I), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 126-137.

——— (1988): Recognition of Vitrinite with Non-uniaxial Reflectance Characteristics, *International Journal of Coal Geology*, Volume 9, pages 267-285.

Kilby, W.E. and Johnston, S.T., (1988): Kinuseo Mapping and Compilation Project (93I/14, 15; 93P/3), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 463-470.

PETROLOGY, SEDIMENTOLOGY AND GEOCHEMISTRY OF GATES FORMATION COALS, NORTHEASTERN B.C.: PRELIMINARY RESULTS (93P/3, 4; 93I/13, 14)

By M. N. Lamberson and R. M. Bustin
The University of British Columbia

KEYWORDS: Coal geology, Gates Formation, lithotypes, Quintette mine, Bullmoose mine.

INTRODUCTION

In northeastern British Columbia, economic coal deposits are found within the lower Albian Gates Formation; the coals are currently being mined at the Bullmoose (Teck Corporation) and Quintette (Quintette Coal Ltd.) operations. The preliminary results of a petrological, sedimentological and geochemical study of coal samples collected from the two mines, as well as outcrop and Deep Basin drill core are described in this report.

The study was undertaken in order to: (1) document the lateral and stratigraphic variation in the organic (maceral, microlithotype and lithotype) and inorganic (trace and minor elements) facies of the coals and associated strata in the Foothills of northeastern British Columbia; and (2) to determine the factors which control the variation. The sample base consists of coal and associated strata collected from outcrop, road and mine cuts, petroleum and coal exploration drill cores and well cuttings. The primary purpose of this study is to develop a methodology for predicting variations in coal quality within a mine more accurately. Fieldwork, including sample collection and analysis, began during the summer of 1988.

SITE LOCATION AND GEOLOGY

The study area is in northeastern British Columbia in the Rocky Mountain Foothills and Great Plains between 54°45′ and 55°30′ north latitude, and 120°15′ and 121°30′ west longitude (Figure 4-6-1). The regional geology was described by Stott (1968, 1982). Leckie (1983) and Carmichael (1983) studied the regional sedimentology of the Gates Formation. Lower Cretaeeous strata consist of a series of transgressive-regressive clastic wedges deposited in response to periodic uplift of the Cordillera (Smith *et al.*, 1984). The Moosebar (marine) and Gates (nonmarine and nearshore marine) formations and their subsurface equivalents, the Wilrich, Falher and Notikewin members of the Spirit River Formation (Figure 4-6-1), form one of the transgressive-regressive sedimentary packages. Moosebar sediments were deposited as the Boreal sea advanced southward to the vicinity of Elbow River, Alberta (McLean, 1982). Renewed uplift and erosion in the Cordillera supplied the Gates Formation sediment which prograded northward over the Moosebar sediments. The progradation was not uniform; Leckie (1986) recorded seven individual coarsening-upward regressive cycles within the Moosebar-Gates interval.

The Gates Formation outcrops in the Foothills from north of the study area at the "Gates" of the Peace River near Hudson Hope, British Columbia, southeastward across the Alberta border in the vicinity of Grande Cache (Stott, 1982). The northern limit of economic coal deposits in the Gates Formation is in the vicinity of the Bullmoose mine leases. North of the Bullmoose mine, the sediments consist primarily of marine shelf sediments (Stott, 1982; Leckie and Walker, 1982) while within the study area there is extensive intertonguing of marine and nonmarine facies.

No formal subdivision of the Gates Formation has been widely accepted. Informally three major subdivisions (Figure 4-6-2) are made (Rance, 1985; Leckie, 1986; Carmichael, 1988): Torrens member, middle Gates and upper Gates. Carmichael (1988), correlated the Torrens member with the Falher cycle "F", the middle Gates with Falher cycles "E" through "A" and the upper Gates with the Notikewin member of the Spirit River Formation (subsurface terminology). The coal seams currently being mined at Bullmoose and Quintette are found within the middle Gates. Thinner (noneconomic) seams are found within the upper Gates.

No correlation of the seams between Bullmoose and Quintette has been published. Nine coal seams are recognized on the Quintette property (Rance, 1985); from youngest to oldest, the seams are referred to as A, B, C, D, E, F, G/I, J and K. Seams A, B and C are found within the upper Gates. Five seams of economic thickness are present at Bullmoose (Drozd, 1985); the seams are designated, from oldest to youngest, A, B, C, D and E. Upper Gates coals are present at Bullmoose, but are not named. Details of the pit geology and mining methods, as well as gross chemical and compositional characteristics of the seams at both mines may be found in Rance (1985) and Drozd (1985).

COAL DEPOSITIONAL ENVIRONMENTS

The Gates Formation is inferred to represent a wave and tide-dominated linear clastic shoreline (Leckie and Walker, 1982). The Lower Cretaceous coastlines in this area are believed to have been characterized by arcuate wave-dominated deltas and associated strandplains (Kalkreuth and Leckie, in preparation). Thick, laterally extensive peat (coal) deposits accumulated on a delta plain shoreward of thick (15 to 35 metres), regionally extensive sheets of shoreface sand and gravel (traceable along strike for about 230 kilometres).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

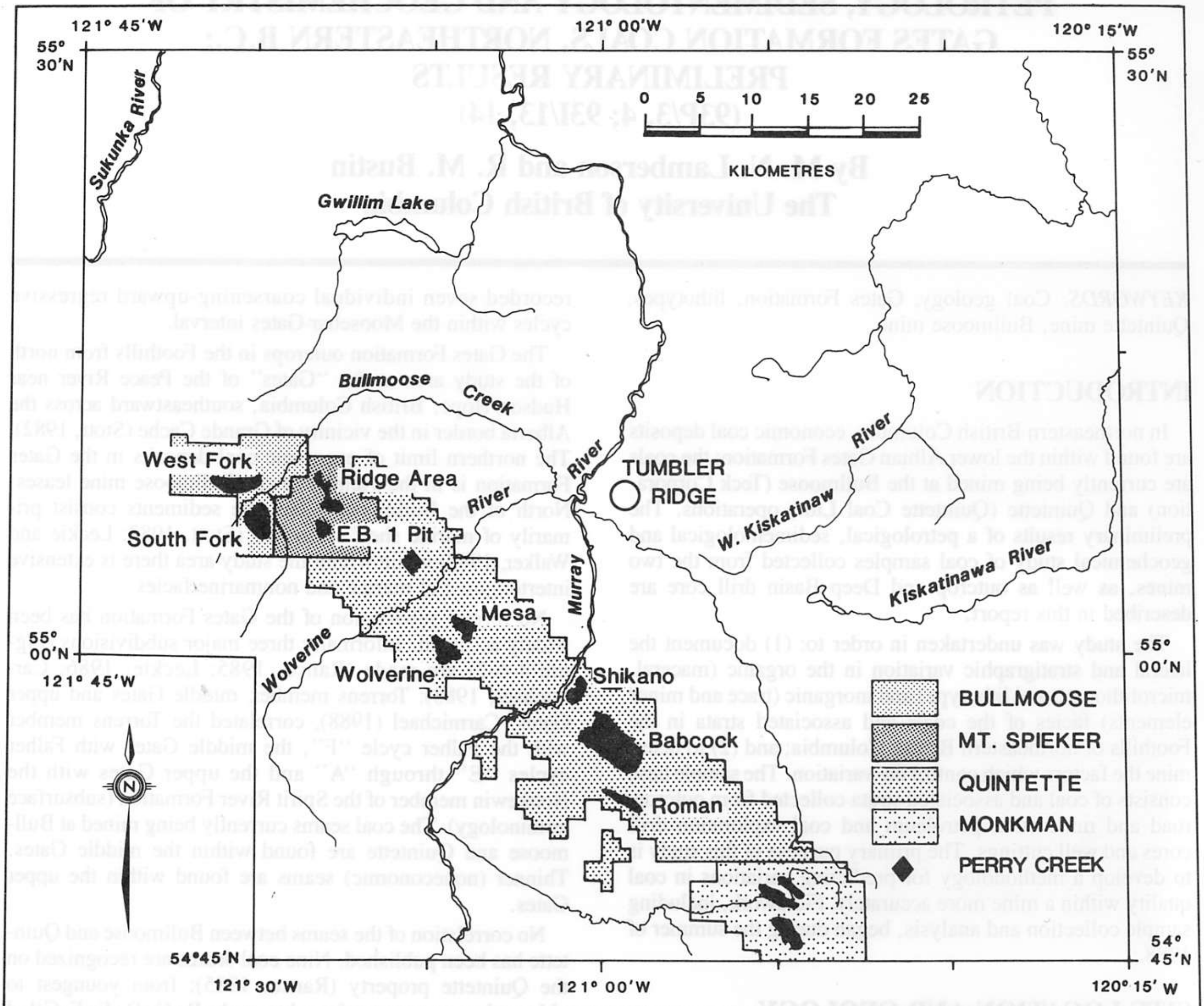


Figure 4-6-1. Location map of study area. Shaded areas indicate major coal leases. Diamond indicates location of outcrop sample of J seam on Perry Creek road. Named areas are current production sites or areas of proposed development. Modified from Matheson (1986).

METHODS

During June, July and August of 1988, 16 whole-seam samples, 50 coal grab samples (from core) and representative coal and carbonaceous rock fragments in the cuttings of 20 Deep Basin petroleum wells were collected. Approximately 1300 samples of strata associated with the coal were taken from outcrop and core. In addition, a number of plant fossils were collected in order to assess plant assemblages present in the original wetland environments during Gates time.

Fresh samples of coal were extracted from the Bullmoose and Quintette (Wolverine and Shikano pits) mines. An attempt was made to collect whole-seam bench samples from within the mine pits. However, where the seam was either too sheared or too fractured to collect blocks, the seams were described using the lithotype terminology explained below and whole-seam channel samples were taken. Bench samples of seams A1 (two sites), A2, C, D, and E at Bullmoose, and the E2 and E3 seams at Quintette (Wolverine pit) were collected. Lithotypes were described and channel samples were taken of seams K2, E1, E2, E3, D, C, B and A from Quintette (Shikano pit) in conjunction with W. Kalkreuth of the Geological Survey of Canada. A channel sample of the Quintette J seam was collected from an outcrop on the Perry Creek road between Mount Spieker and the Wolverine River.

Coal lithotypes (layers of different brightness or texture within the coal seam) were described using a modified version of the Australian classification scheme (Diessel, 1965; Marchioni, 1980). Seven lithotypes were distinguished: bright, banded bright, banded coal, banded dull, dull, fibrous and sheared (Table 4-6-1). A minimum band thickness of 1 centimetre was used in defining lithotypes. Mineral partings in the seam were noted. The seven lithotypes are illustrated in Plate 4-6-1.

TABLE 4-6-1
LITHOTYPE CLASSIFICATION SCHEME
(modified from Diessel, 1965 and Marchioni, 1980)

BRIGHT	subvitreous to vitreous lustre, conchoidal fracture, less than 10% dull coal laminae
BANDED BRIGHT	predominately bright coal with 10-40% dull laminae
BANDED COAL	interbedded dull and bright coal in approximately equal proportions
BANDED DULL	dull coal with approximately 10-40% bright laminae
DULL	matte lustre, uneven fracture, less than 10% bright coal laminae, hard
FIBROUS	satin lustre, very friable, sooty to touch
SHEARED COAL	variable lustre, disturbed bedding, numerous slip/ slickenside surfaces, very brittle

RESULTS

Lithotype descriptions of Bullmoose seams A1 (two locations), C, D and E are graphically illustrated in Figure 4-6-3. Other bench samples are currently being analyzed. Banded lithotypes predominate in the seams studied; no fibrous coal was noted in any of the seams. Fibrous material (fusain in Stopes-Heerlan terminology) is present however, as scattered fragments and very thin laminae. There is no consistent pattern of repetition of the lithotypes and additional analysis and sample collection is necessary before any conclusions concerning depositional environment or compositional variation can be drawn.

FUTURE RESEARCH

Currently, the bench and spot coal samples are being processed for further analysis. The bench samples will be split. Half of the sample will be kept intact, polished and microlithotypes described. The other half will be analyzed by lithotype for petrographic composition. In addition, the samples will be analyzed by Rock-Eval pyrolysis. The spot samples will be analyzed for petrographic composition, as well as Rock-Eval pyrolysis.

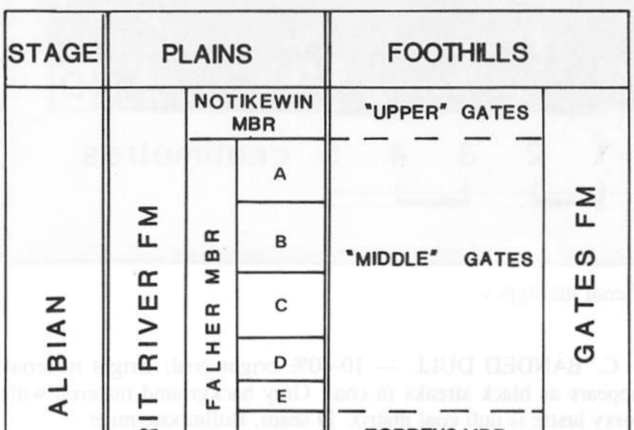


Figure 4-6-2. Stratigraphic chart of Lower Cretaceous formations in northeastern British Columbia. Modified from Leckie (1986) and Carmichael (1988).

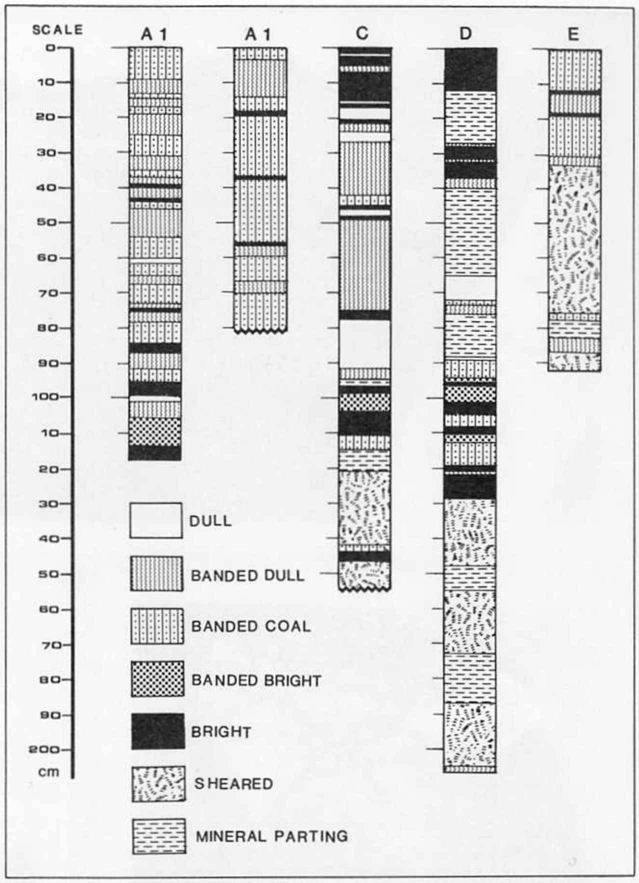


Figure 4-6-3. Lithotype columns for selected bench seam samples collected during 1988 from Bullmoose mine. Seam designation at top of column.

In order to properly evaluate compositional variation in terms of organic depositional environment, it will be necessary to collect additional bench samples. Future fieldwork will concentrate on obtaining at least two more bench samples of each of the coal seams at Bullmoose mine which are less tectonically deformed than those at Quintette.

Laboratory research will focus on characterizing the coal lithotypes in terms of maceral composition and major and trace element geochemistry. The variation in type and quantity of organic matter in the lithofacies associated with the coals will be investigated. The rock samples will be analyzed in terms of the same parameters as the coal samples and organic facies delineated. In order to further aid in understanding the depositional environments, fossil plant assemblages will be determined.

ACKNOWLEDGMENTS

The authors would like to thank Mr. David Johnson and the staff at the Charlie Lake core-storage facility for their assistance with petroleum and coal drill core. We would also like to thank the exploration and production geological staff at Quintette and Bullmoose for their help with sample collec-

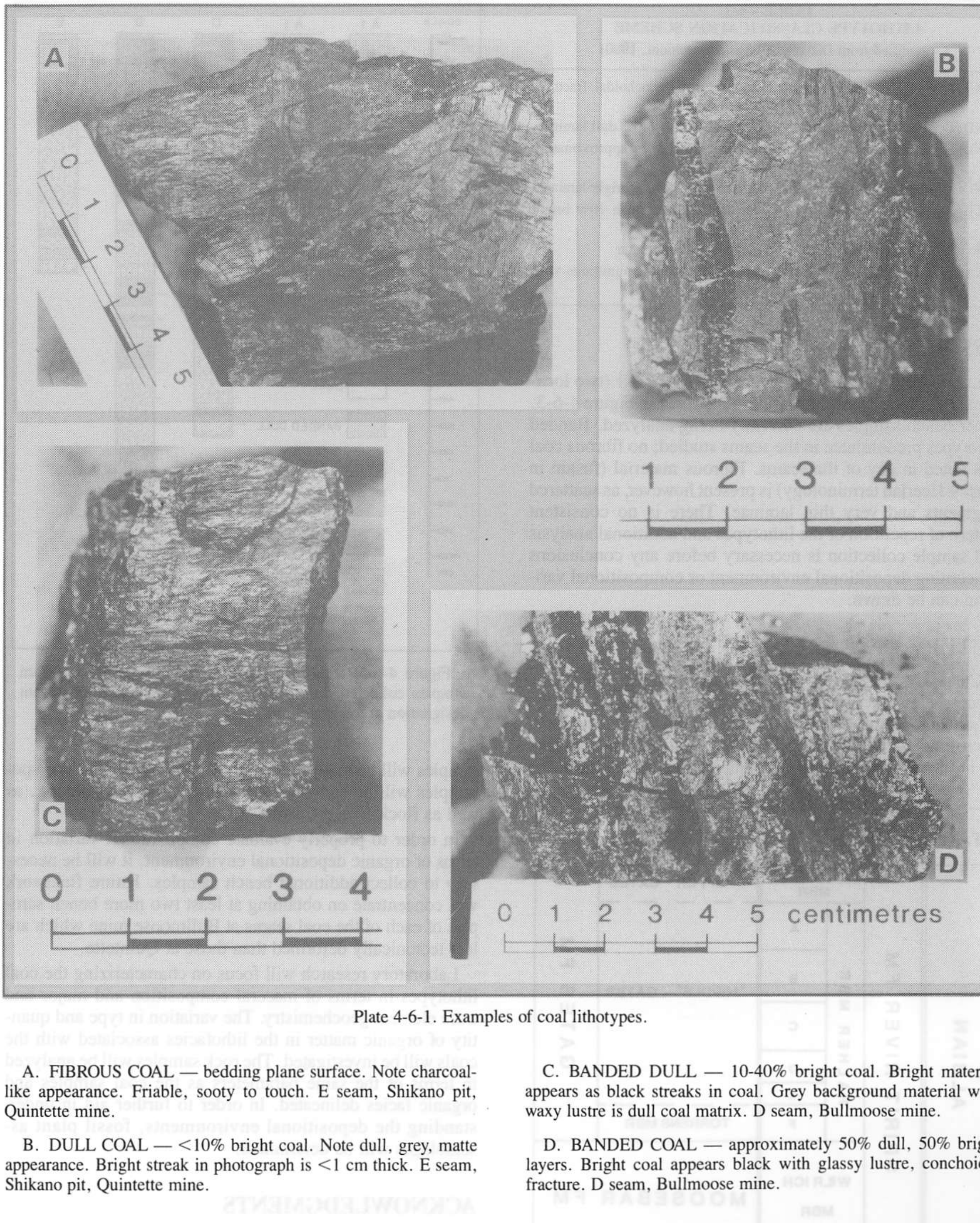


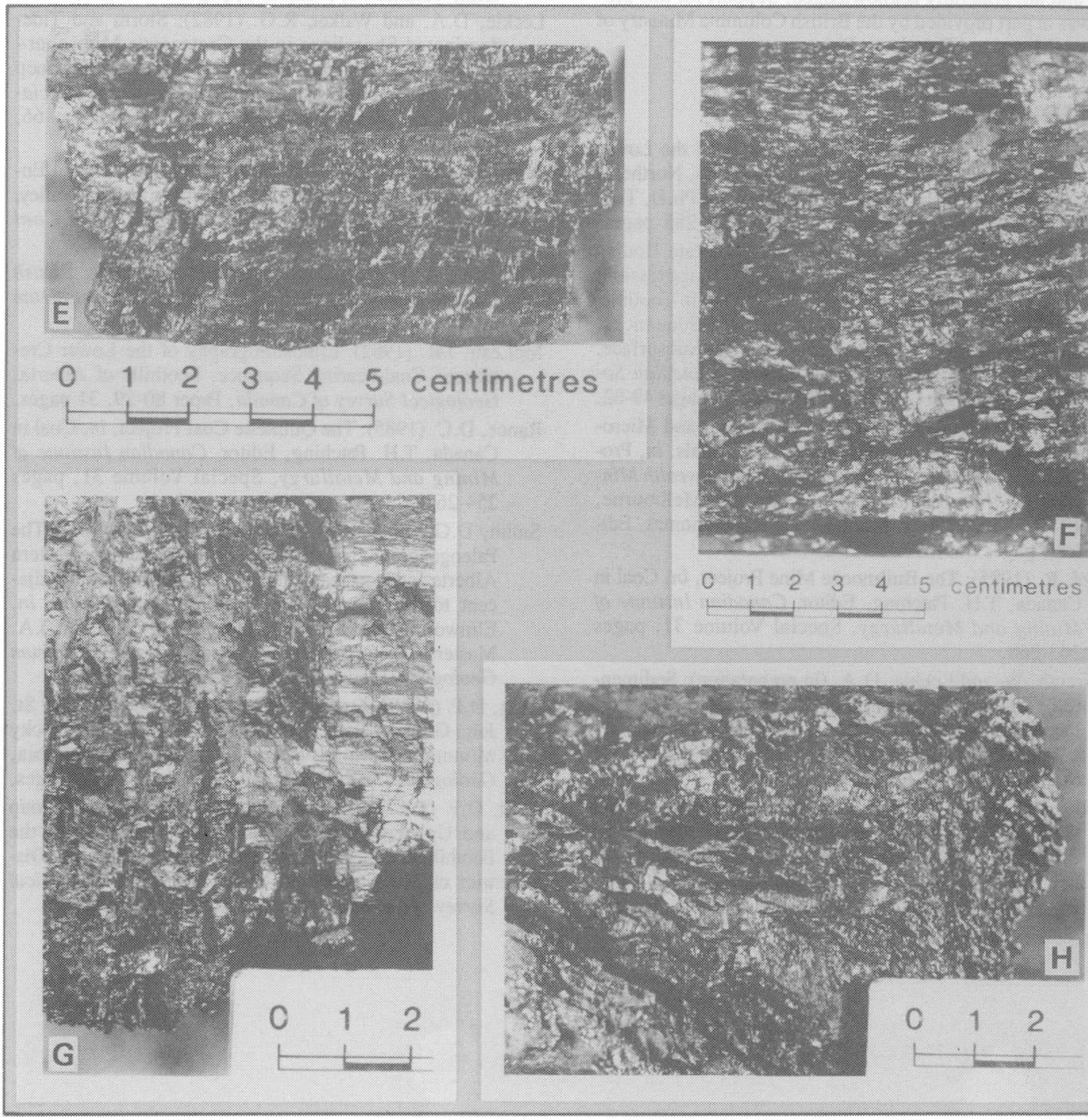
Plate 4-6-1. Examples of coal lithotypes.

A. FIBROUS COAL — bedding plane surface. Note charcoal-like appearance. Friable, sooty to touch. E seam, Shikano pit, Quintette mine.

B. DULL COAL — <10% bright coal. Note dull, grey, matte appearance. Bright streak in photograph is <1 cm thick. E seam, Shikano pit, Quintette mine.

C. BANDED DULL — 10-40% bright coal. Bright material appears as black streaks in coal. Grey background material with waxy lustre is dull coal matrix. D seam, Bullmoose mine.

D. BANDED COAL — approximately 50% dull, 50% bright layers. Bright coal appears black with glassy lustre, conchoidal fracture. D seam, Bullmoose mine.



E. BRIGHT COAL — 10-40% dull coal. Thick bright layers with thin streaks of dull coal. E seam, Shikano Pit, Quintette mine.

F. BRIGHT COAL — <10% dull coal. Note glassy lustre, black color, conchoidal fracture. Material is quite brittle. D seam, Bullmoose mine.

G,H. SHEARED COAL — Two examples of sheared coal. Note random orientation of layers, slickenside surfaces. Material is quite friable, falls apart easily to touch. D seam, Bullmoose mine.

tion and access to areas within the mines. Mr. Murray Gant and Mr. John Whittles provided excellent assistance in the field and are gratefully acknowledged. Support for this project was in part provided by the British Columbia Ministry of Energy, Mines and Petroleum Resources.

REFERENCES

Carmichael, S.M.M. (1983): Sedimentology of the Lower Cretaceous Gates and Moosebar Formations, Northeast Coalfields, British Columbia, Unpublished Ph.D. Thesis, *The University of British Columbia*, 285 pages.

——— (1988): Linear Estuarine Conglomerate Bodies Formed during a Mid-Albian Marine Transgression; "Upper Gates" Formation, Rocky Mountain Foothills of Northeastern British Columbia, *in*, Sequences, Stratigraphy, Sedimentology: Surface and Subsurface, D.P. James and D.A. Leckie, Editors, *Canadian Society of Petroleum Geologists*, Memoir 15, pages 49-62.

Diessel, C.F.K. (1965): Correlation of Macro- and Micropetrography of Some New South Wales coals, *in*, Proceedings-General, Volume 6, *8th Commonwealth Mineralogical and Metallurgical Congress*, Melbourne, J.T. Woodcock, R.T. Madigan and R.G. Thomas, Editors, pages 669-677.

Drozd, R. (1985): The Bullmoose Mine Project, *in*, Coal in Canada, T.H. Patching, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 31, pages 263-268.

Kalkreuth, W. and Leckie, D.A. (in preparation): Sedimentological and Petrographical Characteristics of Cretaceous Strandplain Coals: A Model for Coal Accumulation from the North American Western Interior Seaway.

Leckie, D.A. (1983): Sedimentology of the Moosebar and Gates Formations (Lower Cretaceous), Unpublished Ph.D. Thesis, *McMaster University*, 515 pages.

——— (1986): Rates, Controls, and Sand-body Geometries of Transgressive-regressive Cycles: Cretaceous Moosebar and Gates Formations, British Columbia, *American Association of Petroleum Geologists*, Bulletin, Volume 70, Number 5, pages 516-535.

Leckie, D.A. and Walker, R.G. (1982): Storm and Tide-dominated Shorelines in the Cretaceous Moosebar–Lower Gates Interval–Outcrop Equivalents of Deep Basin Gas Trap in Western Canada, *American Association of Petroleum Geologists*, Bulletin, Volume 66, Number 2, pages 138-157.

Marchioni, D.L. (1980): Petrography and Depositional Environment of the Liddell Seam, Upper Hunter Valley, New South Wales, *International Journal of Coal Geology*, Volume 1, Number 1, pages 35-61.

Matheson, A. (1986): Coal in British Columbia, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 1986-3, 170 pages.

McLean, J.R. (1982): Lithostratigraphy of the Lower Cretaceous Coal-bearing Sequence, Foothills of Alberta, *Geological Survey of Canada*, Paper 80-29, 31 pages.

Rance, D.C. (1985): The Quintette Coal Project, *in*, Coal in Canada, T.H. Patching, Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 31, pages 254-262.

Smith, D.G., Sneider, R.M. and Zorn, C.E. (1984): The Paleogeography of the Lower Cretaceous of Western Alberta and Northeastern British Columbia in and Adjacent to the Deep Basin of the Elmworth Area, *in*, Elmworth–Case Study of a Deep Basin Gas Field, J.A. Masters, Editor, *American Association of Petroleum Geologists*, Memoir 38, pages 79-114.

Stott, D.F. (1968): Lower Cretaceous Bullhead and Fort St. John Groups between Smoky and Peace Rivers, Rocky Mountain Foothills, Northeastern British Columbia, *Geological Survey of Canada*, Bulletin 152, 279 pages.

Stott, D.F. (1982): Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the Foothills and Plains of Alberta, British Columbia, District of MacKenzie and Yukon Territory, *Geological Survey of Canada*, Bulletin 328, 124 pages.

Applied Geochemistry

APPLIED GEOCHEMISTRY SUBSECTION: HIGHLIGHTS OF 1988 ACTIVITIES

By Paul F. Matysek, Stephen J. Day and John L. Gravel

KEYWORDS: British Columbia, applied geochemistry, Regional Geochemical Surveys, orientation surveys, sampling procedures, data analysis.

INTRODUCTION

The Applied Geochemistry Subsection of the British Columbia Geological Survey Branch was formed in 1986 to manage and provide Regional Geochemical Surveys (RGS), complimentary research and orientation surveys designed to promote the effective use of exploration geochemistry by industry. This paper highlights some of the subsection's 1988 investigations.

REGIONAL GEOCHEMICAL SURVEY PROGRAM (RGS)

To date, almost half of British Columbia (approximately 420 000 square kilometres) has been sampled at an average density of one sample every 12.5 square kilometres (33 500 samples). Results from these surveys are available in both open file and floppy diskette format. Complete reconnaissance coverage of the province is anticipated by 1997 at current sampling rates. Further details of the RGS program are described by Matysek (1987).

1988 RGS RELEASE — NORTHWESTERN BRITISH COLUMBIA

Data from the joint federal-provincial reconnaissance Regional Geochemical Survey completed in the summer of 1987 were simultaneously released on July 27 and July 29, 1988, in Stewart, Dease Lake and Vancouver (Figure 5-1-1). As expected, the release was well attended, benefiting from the high level of exploration activity in the survey area. The addition of the 1:100 000 sample-location maps and highly visible RGS aluminum site-identification tags proved helpful in claim staking. The availability of data on diskette enabled at least one company to process the data on site at the release and thus effect a rapid interpretation and target selection. A total of 205 Open File datasets and 47 floppy diskettes have been sold to November 15, 1988.

Survey results clearly outlined areas of known mineralization and identified several new regions of elevated precious and base metal concentrations, especially in the Sumdum map area (104°F). Simple sorting of the data on the basis of the age of underlying lithologies at the sample site indicates that 40 per cent (N = 85) of gold values greater than 50 ppb are associated with Triassic rocks. Similarily, close to 41 per cent (N = 48) of gold values greater than 100 ppb were collected from sites with a high volcanic component in the bedrock geology.

1988 RGS ENHANCEMENTS

In an ongoing effort to improve the quality of the RGS program, the Applied Geochemistry Subsection routinely conducts orientation surveys in areas selected for future surveys. These studies aid in the optimization of RGS parameters such as sample medium, sampling pattern, analytical procedures, interpretation and data presentation so that genuine regional geochemical and geological features and trends can be identified. As a result of the 1987 orientation studies (Matysek and Day, 1988), a number of new enhancements in sample collection procedures and data evaluation techniques were established.

NEW SAMPLE MEDIUM ON VANCOUVER ISLAND: MOSS-MAT SEDIMENTS

Scarcity of easily collected conventional stream sediment (fine sands to silts) is a common problem in drainage sediment surveys on Vancouver Island. In response to this predicament, orientation studies were conducted (Matysek and Day, 1988) focusing on the applicability of fines-rich moss-mat sediments as an alternative sample medium. Assessment of field and analytical data obtained from detailed stream and moss-mat sediment sampling of 30 drainage basins on northern Vancouver Island indicated that moss mats are ubiquitous, easily sampled and yield up to 50 per cent more −80 mesh (fine sands, silts) material than stream sediments. In addition:

- Determinations of several elements are similar for both stream and moss-mat sediment samples.
- Elements dispersed as heavy minerals are concentrated up to 100-fold in moss mats.
- Background to anomaly contrast for gold is up to an order of magnitude greater in moss-mat sediments.

Based on these data, collection of moss-mat sediments on Vancouver Island was initiated for the 1988 RGS program. Details on results of this year's program are described in Gravel and Matysek (1989, this volume).

NEW RGS FIELD-DATA CARD

During collection of drainage sediments for Regional Geochemical Surveys, it has become customary to record categorical observations of characteristics of the drainage catchment (for example, drainage pattern), sample site (for example, site contamination) and sediment sample (for example, sediment colour). Despite their subjective character, categorical field observations can be related to significant variations in metal content of drainage sediments associated with a single rock unit (Matysek, 1985). New field-data cards were designed for the 1988 RGS program to improve data

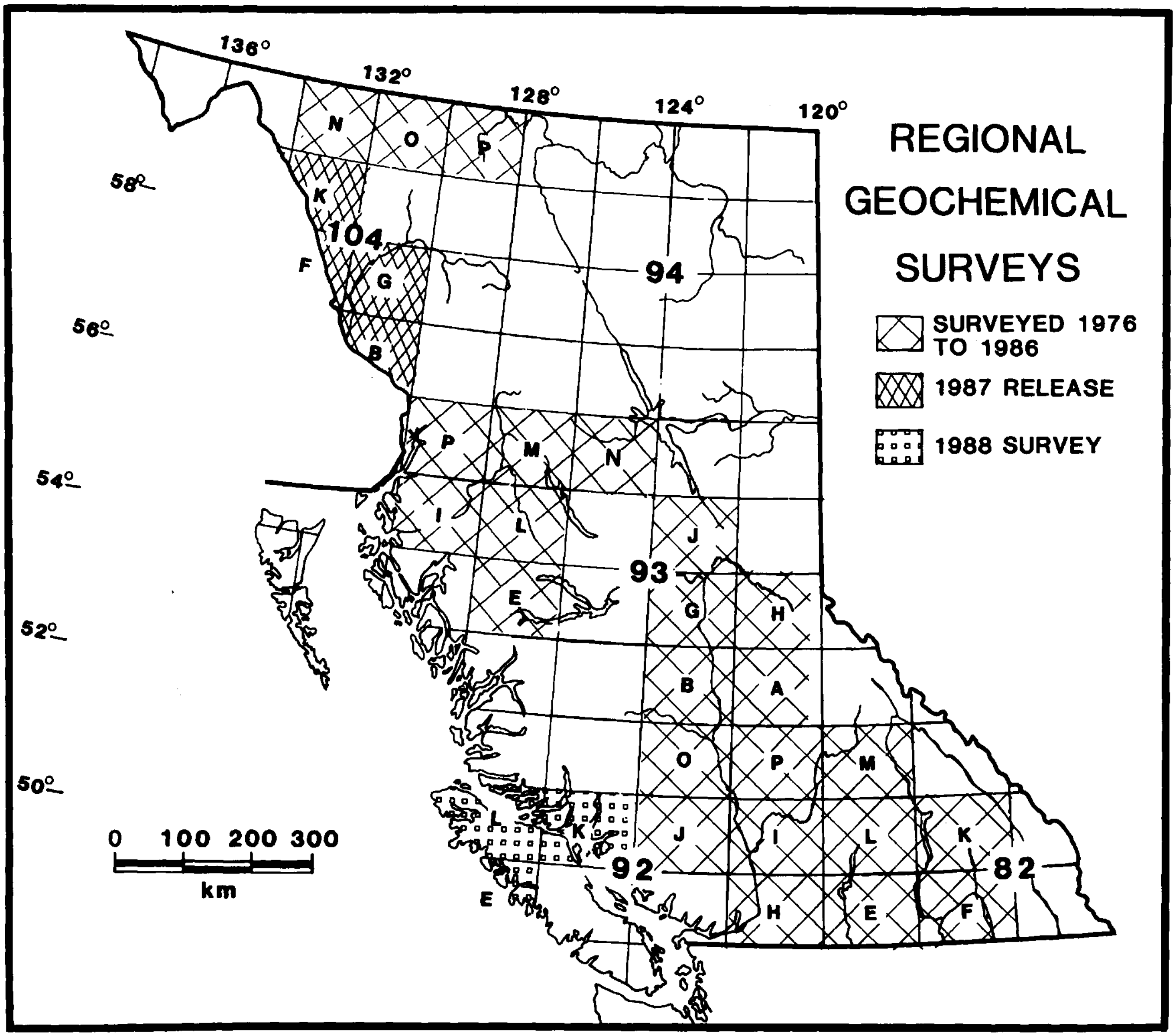


Figure 5-1-1 Areal distribution of Regional Geochemical Surveys.

capture and quality control on sampling and sample processing. Improvements included:

- Eliminating redundant field observations.
- Alphabetical recording of categorical field observations.
- Recording of field observations that aid in the interpretation of moss-mat sediment data.

DATA EVALUATION

The ability to discriminate real trends related to geological and geochemical causes from those that result from spurious factors such as sampling and analytical errors is of paramount importance in the success of geochemical interpretation. In the case of the RGS, analytical duplicates and control reference samples are randomly inserted in every batch of 20 samples in order to control and monitor short and long-term precision as well as accuracy (Matysek, 1985). To ensure strict adherence to national standard accuracy, tolerance and precision guidelines, the Applied Geochemistry Subsection has developed a microcomputer quality control program – CONTROL. Features include rapid identification of bad analytical batches, recognition of temporal drift, and estimation of detection limits and precision levels using Thompson and Howarth (1978) plots. The program provides:

- Summary statistics of control reference standards.
- Identification of unacceptable analytical batches (usually defined as 2.5 standard deviations of the control reference mean and/or analytical duplicates that exceed user-defined tolerances).
- Graphical representation of analytical drift from batch to batch.
- Thompson and Howarth plots with precision estimates and calculated detection limits.

The CONTROL program is designed for use with the Regional Geochemical Survey data, but is easily applied to other large-scale geochemical sampling programs. Copies of the software are available to interested parties on request.

ORIENTATION SURVEYS

In 1988, several stream sediment orientation surveys were conducted in areas of proposed future RGS projects on southern Vancouver Island (92B, C, F), Lower Mainland (92G) and the Bowser Basin (104A). In addition, samples were collected to prepare for a land-use study in the Purcell Mountains. An open-file compilation of the results of the 1987 and 1988 orientation studies is planned.

SOUTHERN VANCOUVER ISLAND AND LOWER MAINLAND

Stream sediment orientation sampling on Vancouver Island focused on deposits hosted by the Sicker Group and associated with Tertiary intrusions in the Nanaimo Group (Table 5-1-1). On the mainland, veins and stratiform deposits are hosted by pendants of Gambier Group in the Coast plutonic complex.

The sampling design used in the northern Vancouver Island orientation project proved to be highly effective and was used again with some minor modifications [*compare* Matysek and Day (1988) and Table 5-1-2].

TABLE 5-1-1
STREAMS SAMPLED FOR THE SOUTHERN VANCOUVER ISLAND AND LOWER MAINLAND ORIENTATION SURVEY

Stream	Deposit Name and Type	Number of Samples[1] S	M	B	Z	H	Length of Traverse (km)
McKay Creek (92F/14)	Mount Washington Copper Tertiary intrusion in Nanaimo Group	11	11	6	1	1	5.2
Murex Creek (92F/14)	Murex deposit Tertiary intrusion in Nanaimo Group	12	12	7	1	1	5.7
Franklin River (92F/02)	Thistle mine Cu-Au-quartz vein in Sicker Group volcanics	9	13	6	1	1	7.6
Cous Creek (92F/02)	Rex showing Disseminated molybdenite in Karmutsen Basalt	10	11	5	1	1	5.4
Salmonberry Creek (92F/04)	Epic-Mowgli showings Epithermal shear zone mineralization, associated with Eocene intrusion	10	10	5	1	1	4.9
Silver/Solly Creeks (92B/13)	Lara deposit Stratiform polymetallic massive sulphide in Sicker Group sediments	10	9	5	1	1	4.1
Stawamus River (92G/11)	War Eagle prospect Shear zone sulphides (Cu-Pb-Zn) in Gambier Group pendant	12	12	6	1	1	7.1
Background (un-mineralised)		14	17	12	12	12	

[1] S = Stream sediment samples, M = Moss-mat samples, B = 10-kilogram fine sediment samples, Z = large moss-mat samples, H = sieved-gravel sample.

PRELIMINARY RESULTS: McKAY CREEK, MOUNT WASHINGTON

The Mount Washington copper-gold-silver deposit is hosted by a Tertiary quartz diorite stock which intrudes an outlier of Comox Formation (Nanaimo Group) uncomformably overlying Karmutsen Formation mafic lows (Wilton, 1987).

McKay Creek, which drains the area of the deposit, falls approximately 1000 metres over a distance of 6 kilometres. Banks and bed vary from bedrock (Karmutsen Formation) in the steeper sections, to till and alluvium in the lower reaches. Sediment samples were collected from ten stations. Samples were also collected from two streams draining unmineralized parts of Mount Washington, to provide geochemical background information.

Dispersion patterns for arsenic, copper, molybdenum, and to a lesser extent, antimony, silver, lead and zinc in stream sediments and moss-mat sediments show the familiar exponential anomaly decay downstream of a spatially re-

TABLE 5-1-2
ORIENTATION SURVEYS SAMPLING DESIGN

Sample Type	Stream: Drains mineralization	Stream: No mineralization
Collection[1]		
1-kg moss	Every 500 m	One station
2-kg sand	Every 500 m	One station
10-kg sand	Every 1000 m	One station
2-kg moss	Up to two stations	One station
10-kg sieved gravel (18 mesh)	One station	One station
Preparation		
1-kg moss	Dry, sieve to 80-mesh, discard organics	
2-kg sand	Dry, sieve to 80-mesh	
10-kg sand	Dry, sieve to −45+80, −80+170, −170	
2-kg moss	Dry, sieve to −45+80, −80+170, −170	
10-kg gravel	Dry, sieve to −45+80, −80+170, −170 prepare heavy-mineral concentrate with tetrabromoethane (TBE, S.G. = 2.9)	
Analysis		
All fractions except concentrates	Aqua regia digestion on 0.5 g followed by: 30-element by ICP-ES As,Sb,Bi,Te,Ge,Se by hydride - ICP-ES Hg by flameless AAS Aqua regia digestion on 10 g followed by Au by MIBK pre-concentration	
Concentrates	Non-destructive instrumental NAA Au and 30 other elements	

[1] At least 10% of all samples are duplicates.

stricted source (Figure 5-1-2). Anomaly contrast is greater than 10 for most elements at the station nearest the source and the anomaly is detected at the lowest station where concentrations are typically five times regional background levels. The trend for gold in moss-mat sediments is unusual but shows that anomaly contrast is greater than 50 at the lowest station compared to 3 for stream sediments. High gold concentrations in the finest fraction analyzed (–170 mesh, very fine sand and finer) show that the high contrast for moss-mat sediments is due to entrapment of fine sediment in the mats.

PURCELL MOUNTAINS

A limited orientation survey was conducted in the Purcell Mountains in preparation for a land-use study. The survey sought to define the appropriate sampling medium, sampling density and sample preparation and analysis scheme to enable an evaluation of the area's mineral potential. Samples were collected from two streams draining mineralization typical of the area (Springs Creek, tributary to Toby Creek (82K/8), base metal veins; Victoria Creek (82G/11), Kootenay King stratiform base metal deposit). Samples were also collected from seven streams which are not apparently draining mineralization.

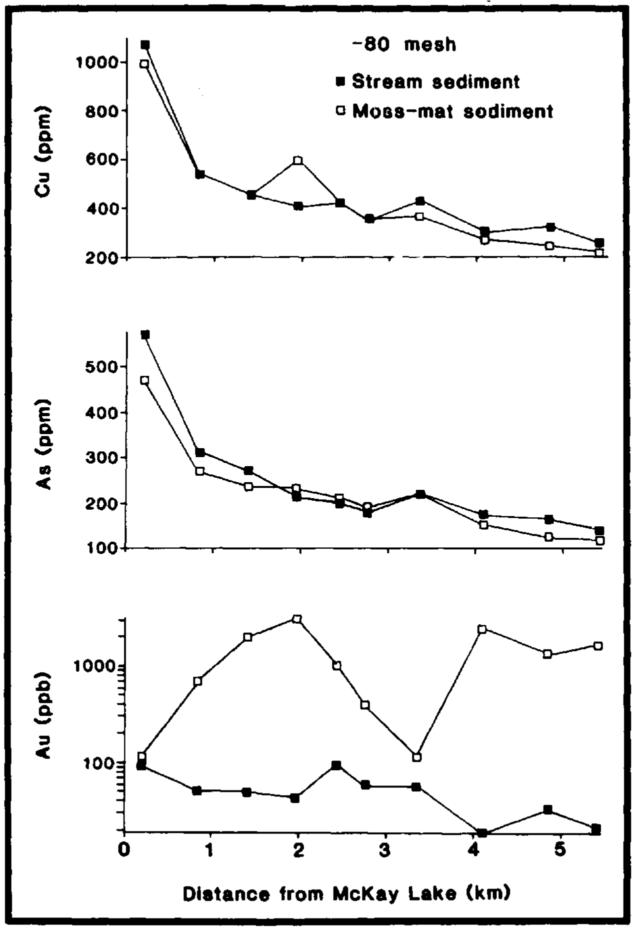


Figure 5-1-2 Stream sediment and moss-mat sediment dispersion patterns in McKay Creek, Mount Washington. Estimated background levels for copper, arsenic and gold are 50 ppm, 20 ppm and 7 ppb respectively in stream sediments and 50 ppm, 24 ppm and 13 ppb respectively in moss-mat sediments.

In addition to the standard sampling design (Table 5-1-2), all fractions were analysed for total tin content (ammonium iodide fusion with atomic absorption spectroscopy finish).

SUMMARY OF RESULTS

Moss mats proved to be the most readily available sampling medium. Fine stream sediments were extremely difficult to locate in the steep streams and sieving of gravels for heavy mineral analysis was time-consuming. Moss-mat sediments revealed very similar elemental dispersion patterns to fine stream sediments. Concentrations in moss-mat sediments tended to be greater than in paired sediment samples, reflecting greater concentrations in the finest fraction (–170 mesh). This effect was especially useful for increasing tin concentrations which are typically at the detection limit (1 ppm) in stream sediments. In moss-mat sediments tin concentrations are above the detection limit (up to 14 ppm) downstream from mineralization and average 3 to 4 ppm in streams not draining mineralization.

BOWSER BASIN

Historically, the sedimentary rocks in the Bowser Basin have been regarded as poor hosts for economic metal deposits, although in the Hazelton area, vein and porphyry deposits are associated with Cretaceous granitic stocks intruding the sediments. A Regional Geochemical Survey is planned in 104A which is largely underlain by poorly mapped and explored Bowser Lake Group rocks. This survey will compliment the regional mapping program of the Geological Survey of Canada (Evenchick, 1988).

Orientation was carried out on four streams in 103P, 103I and 93M (Table 5-1-3) and the logistics of sampling in 104A were investigated. Complete chemical results have yet to be received.

MOSS-MAT SEDIMENT INVESTIGATIONS

In addition to the orientation surveys which involve comparison of several sampling media, two programs have been initiated to further increase understanding of sediment accumulation in moss mats.

SPATIAL VARIATION

Detailed within-station sampling was carried out in March, 1988 at Gold Valley Creek (92L/2) near Zeballos, and Red Dog Creek, which drains the Red Dog copper-molybdenum deposit (92L/12), near Holberg (Matysek and Day, 1988). At each of eight stations, six large moss-mat samples were collected to investigate how the height above the stream bed affects the type of sediment trapped in the mat. As well as the usual suite of elements, magnetite was removed from all samples. Preliminary results from Gold Valley Creek show that magnetite concentrations are strongly correlated with gold concentrations, confirming that gold is trapped in mosses due to its high density.

TABLE 5-1-3
STREAMS SAMPLED FOR THE BOWSER BASIN ORIENTATION SURVEY

Stream	Deposit Name and Type	Number of Samples[1] S	M	B	Z	H	Length of Traverse (km)
Wesach/Hall creeks (103I/15)	Bear, Gold Cap Motherlode Pb-Zn-Cu-Au vein	7	5	3	2	1	3.1
Flint Creek (103I/16)	Seven Sisters Au-Ag-Cu vein	9	9	5	1	1	4.0
Stirrit Creek (93M/12)	Bear Cu-Mo porphyry	9	8	4	3	1	2.5
Kit Creek (103P/08)	Kit Mo-quartz vein stock-work hosted by grano-diorite	6	6	3	0	1	2.0
Background (un-mineralized)		12	10	11	6	11	

[1] S = Stream sediment samples, M = Moss-mat samples, B = 10-kilogram fine sediment samples, Z = large moss-mat samples, H = sieved-gravel sample.

SEASONAL VARIATION

A study of the seasonal variation of elemental concentrations in moss-mat sediments and sandy sediments was begun in November 1988 at McKay and Murex creeks (Mount Washington, 92F/14). Samples will be collected approximately every month from a bar on each stream. Both bars were divided into four or five 10 to 20-square-metre cells and two sediment and moss samples will be collected from each cell at each visit. Although it is impossible to resample exactly the same location at each visit, the study will indicate if seasonal variability is apparent when compared to spatial variation.

PENDING STUDIES

ANALYSIS OF ARCHIVED RGS SAMPLES

To encourage mineral exploration in previously sampled RGS areas, the Geological Survey Branch is planning to add a number of new elements (gold, arsenic, antimony, tungsten, chromium, rare earths) to the existing RGS database. Analyses of archived pulps will be performed through non-destructive neutron activation analysis. After consultation with staff and industry advisory committees, map sheets 92H, I, J, O and P have been selected for analysis (Figure 5-1-1). These map sheets cover an area of over 78 000 square kilometres and take in over 4300 RGS sample sites. To avoid, "data overload" on the majority of non-computer-oriented users of the RGS releases, simplified data-display formats will be developed to assist in disseminating results.

EXPLORATION IN GLACIATED TERRAINS

Plateau areas which account for over 20 per cent of the province's landmass are characterized by complex glacial deposits. Selection of exploration techniques in these areas is dependant on the type and thickness of the surficial deposits. The mineral exploration industry has avoided these areas because British Columbia's surficial geology database is poor (less than 15 per cent coverage). A program of systematic mapping of surficial geology as well as development of appropriate exploration techniques has been proposed for next year. Results of the surficial surveys will be integrated with the Ministry's bedrock mapping and geochemical surveys to guide and stimulate more effective exploration.

GEOCHEMICAL RESPONSES AROUND MINERAL DEPOSITS

A project will be initiated to assemble data on the geochemical response in soils and sediments around selected mineral deposits. The study will compile information on deposits and their geological and geochemical environments; a list of elements that are enriched or depleted, and the dimension of the halos for each anomalous element; and a record of elements that do not respond. These data will be published together with an interpretative summary on the controls of dispersion of indicator elements within the secondary environment. It is hoped that this catalogue will provide detailed geochemical guidelines for exploration in a systematic format; it will also be useful in assessing the mineral potential of a region.

ACKNOWLEDGMENT

Wayne Jackaman provided excellent assistance in field and office projects.

REFERENCES

Evenchick C. (1988): In the Field, Bowser Basin, *Mining Review*, September/October 1988, pages 32-37.

Gravel, J.L. and Matysek, P.F. (1989): 1988 Regional Geochemical Survey, Northern Vancouver Island and Adjacent Mainland, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, Paper 1989-1, This volume.

Matysek, P.F. (1985): An Evaluation of Regional Stream Sediment Data by Advanced Statistical Procedures, Unpublished M.Sc. Thesis, *The University of British Columbia*, 95 pages.

——— (1987): A New Look for the Regional Geochemical Survey Data, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 385-394.

Matysek, P.F. and Day, S.J. (1988): Geochemical Orientation Surveys: Northern Vancouver Island, Fieldwork and Preliminary Results, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 493-502.

Thompson, M. and Howarth, R.J. (1978): A New Approach to the Estimation of Analytical Precision, *Journal of Geochemical Exploration*, Volume 9, pages 23-30.

Wilton, H.P. (1987): Mount Washington (Domineer, Murex), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Exploration in British Columbia, 1986, pages B29-B32.

NOTES

1988 REGIONAL GEOCHEMICAL SURVEY, NORTHERN VANCOUVER ISLAND AND ADJACENT MAINLAND* (92E, 92K, 92L, 102I)

By John L. Gravel and Paul F. Matysek

KEYWORDS: Regional geochemical surveys, moss-mat, stream sediments, stream waters, multi-element analyses, mineral potential, Nootka Sound, Bute Inlet, Alert Bay, Cape Scott.

INTRODUCTION

The Geological Survey Branch conducted three regional geochemical surveys (RGS) on northern Vancouver Island and the adjacent mainland during the 1988 field season. In June and August a reconnaissance stream water and sediment sampling program covered an area of 30 000 square kilometres in the Nootka Sound (92E), Bute Inlet (92K), Alert Bay (92L) and Cape Scott (102I) map sheets (Figure 5-2-1). This report describes the sampling program and reviews the mineral potential of the area.

HIGHLIGHTS

There has been very little sustained and systematic exploration within the survey area in recent years, despite the relative ease of access and the occurrence of nearly 20 past or currently producing mines. Regional geochemical surveys were conducted in order to stimulate exploration in this neglected but high-potential area. A number of technical modifications were adopted based on earlier field, laboratory and research studies to optimize the applicability of these surveys to northern Vancouver Island and the adjacent mainland. These include:

- Systematic sampling of moss-mat sediments on Vancouver Island.
- Addition of precious metal pathfinder elements, bismuth and chromium, to the analytical suite.

Results from the 1988 survey will be released in early June as an Open File map series and on floppy diskettes.

RGS SURVEY AREA FEATURES

PHYSIOGRAPHY AND GEOLOGY

Three physiographic terrains dominate the 1988 RGS area (Figure 5-2-2). The Coastal Trough represented by the Queen Charlotte Strait and the Nahwitti and Hecate lowlands divides the Insular Mountains of Vancouver Island from the Coastal Mountains on the mainland. The Coastal Trough also marks the divide between two major geological provinces. The Insular Belt, comprising Paleozoic to Mesozoic volcanic and sedimentary rocks intruded by Jurassic to Tertiary felsic plutons, underlies most of Vancouver Island. The Coast Complex, consisting predominantly of granodioritic to quartz dioritic plutons and batholiths of Jurassic to Eocene age, with highly elongate pendants of Proterozoic to Cretaceous metasediments and volcanics, forms the adjacent mainland. Table 5-2-1 is an abridged description of the physiography (Holland, 1976; Howes, 1981) and the geology (Muller 1977; Muller *et al.*, 1974, 1981; Roddick, 1977).

MINERALIZATION AND EXPLORATION POTENTIAL

Mineral deposits on northern Vancouver Island and the adjacent mainland can be divided into four main types, namely; (1) iron, copper or lead-zinc skarn, (3) massive sulphide, (3) stockwork, and (4) gold-quartz veins. Deposit categories are based on work by Muller and Carson, (1969) and Muller *et al.* (1974). Stockwork subcategories have been combined for clarity as have epithermal and mesothermal gold occurences. Salient geological and mineralogical features of these deposit types are listed in Table 5-2-2. The distribution of representative examples on northern Vancouver Island is illustrated in Figure 5-2-3.

Nine producing and potentially producing mines are located within the survey area (Preliminary Map 65, 1987). On northern Vancouver Island, the Island Copper porphyry copper deposit has proven reserves of 45 million tonnes of 0.52 per cent copper, 0.017 per cent molybdenum and 0.24 gram per tonne gold. In the Zeballos camp, the Privateer and Spud Valley mesothermal gold-quartz vein deposits, have reported proven and probable reserves of 123 000 tonnes of 9.15

Figure 5-2-1. Present status of the British Columbia Regional Geochemical Survey.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

TABLE 5-2-1
ABRIDGED DESCRIPTION OF PHYSIOGRAPHY AND GEOLOGY OF 1988 RGS PROJECT AREA

PHYSIOGRAPHY

AREA	UNIT	SUBUNIT	LOCATION	QUATERNARY GEOLOGY	DESCRIPTION
VANCOUVER ISLAND	Coastal Trough	Nahwitti Lowland	Northern tip of Vancouver Island	Thin mantle of colluvium and till on hills, thick (glacio-) fluvial sediments and till in lowlands	Low relief, rounded hills, narrow valleys, broad lowlands and valleys
		Suquash Basin	Eastern margin of Nahwitti Lowland	As Nahwitti Plateau	Rolling to level topography below 300 m a.s.l. scattered rounded hillocks and uplands
		Nanaimo Lowland	Eastern coast of Vancouver Island south of Sayward	Thin mantle of colluvium and till on hills, thick (glacio-)fluvial sediments and tills in lowlands and along coast	Rolling hills below 600 m a.s.l., ridges separated by narrow valleys, box-like canyons of deeply incised overburden along coast
	Vancouver Island Mountains	Estevan Coastal Plain	3 kilometre strip along west coast	Mantle of bedrock-derived colluvium, (glacio-)fluvial sediments, till and marine sediments along coast	Flat, featureless, rock cliffs and platforms, pocket beaches
		Fiord-land	Peninsulas and islands along west coast	Colluvial materials on steep valley walls and summits; till on lower valley slopes	Land rises abruptly to 600 to 900 m a.s.l.; rounded, timbered hill-tops
		Vancouver Island Range Mountains	NW/SE oriented ranges, north oentral Island	Very similar to fiord-land; fluvial and glacio-fluvial deposits in valleys	Very rugged; U-shaped valleys, dissected Tertiary surface
		Nimpkish River Valley	Central portion of Island	Dominantly till mantling bedrock on valley sides and bottoms,	Broad, U-shaped valleys; valley floor broken by a few peaks
MAINLAND	Coastal Trough	Hecate Lowland	West coast of mainland, 15-40 kilometre strip	Thin mantle of colluvium and till on hills and slopes, fluvial deposits in valleys	Tertiary erosion surface rising towards Coast Mtns with increasing dissection, dividing line is 600 m elevation, broad valleys
	Coast Mountains	Pacific Ranges	Adjacent to Hecate Lowland, 125-160 kilometre-wide strip	Tertiary erosion surface, upper to mid-slopes covered by colluvium and till, thick fluvial and glacio-fluvial deposits in valleys	Tertiary surface rises, becoming more dissected towards east untill old surface is completely eroded, jagged peaks, broad U-shaped valleys

TABLE 5-2-1 CONT'D
GEOLOGY

VANCOUVER ISLAND

Stratified Rocks

NAME	AGE	DESCRIPTION
Queen Charlotte Island Group	Cretaceous	Conglomerate, greywacke, siltstone, shale, coal
Westcoast gneiss complex	Jurassic	Gneiss, metaquartzite, marble, agmatite, amphibolite
Bonanza Group	Lower Jurassic	Andesitic to rhyolitic lava, tuff breccia
Vancouver Group		
Parsons Bay Formation	Upper Triassic	Calcareous siltstone, shale, limestone, greywacke, conglomerate, breccias
Quatsino Formation	Upper Triassic	Limestone, marble
Karmutsen Formation	Upper Triassic	Basaltic pillow lava, breccia, minor limestone
Sicker Group	Pennsylvanian	Lower basaltic to rhyolitic volcanic package, upper sediment and limestone units

Plutonic Rocks

NAME	AGE	DESCRIPTION
Intrusives	Eocene	Quartz diorite (e.g. Zeballos stock)
Island Intrusives	Jurrassic	Quartz diorite, granodiorite, quartz monzenite, quartz feldspar porphyry

MAINLAND

Stratified Rocks

NAME	AGE	DESCRIPTION
Gambier Group	Upper Cretaceous	Greenstone, volcanic breccia, argillite, minor conglomerate, limestone and schist
Vancouver Group		
Karmutsen Formation	Upper Triassic	Basaltic pillow lava, breccia and minor limestone
Metamorphics	Paleozoic to Lower Triassic	Amphibolite, schist, quartzite minor crystalline limestone, greenstone

Plutonic Rocks

NAME	AGE	DESCRIPTION
West Coast Complex	Cretaceous to early Tertiary	Quartz monzonite, granodiorite, quartz diorite, diorite, gabbro

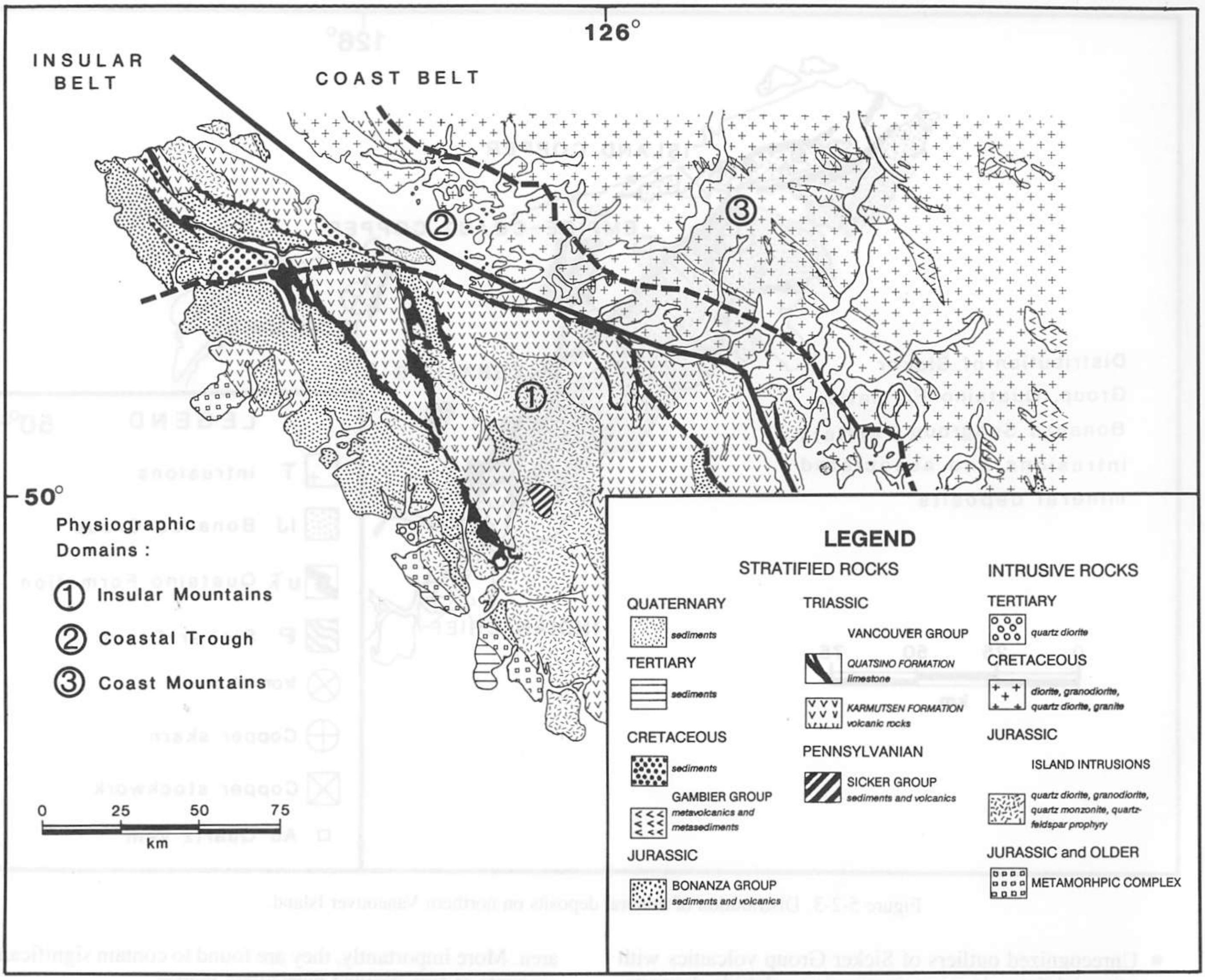


Figure 5-2-2. Physiography and Geology of the 1988 RGS program area.

grams per tonne gold and 224 000 tonnes of 14.1 grams per tonne gold, respectively. On the mainland, the Lucky Jim skarn deposit has reported reserves of 12 700 tonnes of 2 per cent copper, 11 grams per tonne silver and 17 grams per tonne gold.

The level of exploration activity in the project area as indicated by assessment report filings, is summarized in Table 5-2-3. A cursory scan of the table shows that despite the proven mineral potential of the survey area, the general level of activity is low. The following observations can be made:

- During the peak period from 1982 to 1984, only 30 assessment reports were filed per year.
- While most of British Columbia was experiencing a sharp increase in exploration activity from 1985 onwards, due largely to flow-through share financing, northern Vancouver Island saw a general drop in activity.
- Exploration of the Bute Inlet area (92K) has been largely neglected since 1983.
- The Cape Scott area remains essentially unexplored.
- Iron skarns, which accounted for up to a third of the activity in the early eighties, were generally ignored later in the decade.
- Exploration efforts from 1982 onwards focused on copper-molybdenum stockwork and gold-bearing sulphide vein deposits, and can be mainly attributed to grassroots level programs by two major companies.

More than 80 per cent of assessment work filings represent the grassroots or intermediate stages of exploration, suggesting that most properties have received only a cursory examination. A few of the potential targets that could be highlighted by the results of the 1988 RGS survey are:

- Jurassic Island intrusions reclassified as Tertiary intrusions with the possibility of epithermal gold (Mount Washington) and porphyry copper (Catface) potential.
- The recognition of mineralogically favourable S-type versus unfavourable I-type granites in the Island intrusions and the Coast plutonic complex.

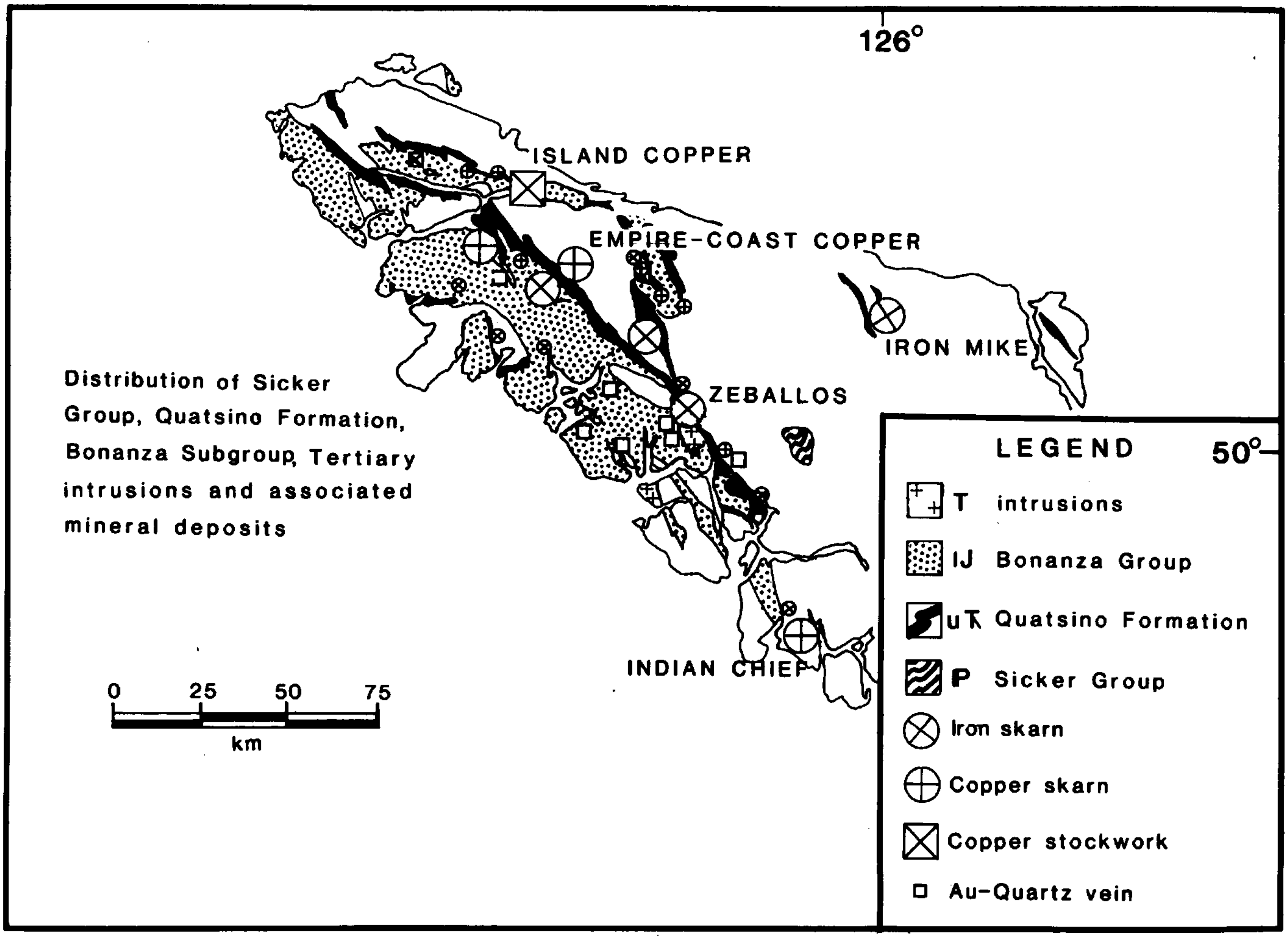


Figure 5-2-3. Distribution of mineral deposits on northern Vancouver Island.

- Unrecognized outliers of Sicker Group volcanics with potential for volcanogenic massive sulphide deposits.
- Massive sulphide, skarn and mesothermal gold deposits associated with the roof pendants in the scantily explored Coast plutonic complex.

1988 SAMPLING PROGRAM

BACKGROUND

Orientation studies (Matysek and Day, 1988) were conducted within the survey area prior to the 1988 RGS sampling program for the purpose of establishing the optimum sampling medium; recognizing new region-specific field observations to be recorded by the samplers; and defining elemental dispersion patterns from mineral occurrences typical of the area.

Results indicated that collection of conventional 1 to 2-kilogram stream-sediment samples (fine sands to silts) is difficult in regions of heavy annual rainfall, such as northern Vancouver Island. Sediment deposited by these highly active streams is often flushed clean of all material finer than medium sand, which includes the fraction used for analytical determinations. Collection of moss-mat samples was initiated to circumvent this problem; they can be quickly and easily sampled and are relatively ubiquitous in the survey area. More importantly, they are found to contain significant amounts of fine-grained particulate matter.

Analytical results for 100 paired moss-mat and stream-sediment samples within the survey area indicated no significant differences for molybdenum, copper, lead, cobalt, iron, arsenic, boron, mercury and selenium (Matysek and Day, 1988). More importantly, elements dispersed as heavy minerals appear to be concentrated by the mats. As a result, analytical reproducibility is improved, anomalous dispersion trains are longer, and the background-to-anomaly contrast for gold is up to an order of magnitude greater than in stream sediments.

The subsequent Regional Geochemical Surveys on Vancouver Island are based on moss-mat sediment samples. For comparative purposes, one stream-sediment check sample was collected for every 20 moss-mat samples. Conventional stream-sediment samples were taken on the mainland because the availability of moss mats was unknown and most of the streams are glacier fed and would have a high proportion of dilutant rock flour in the moss-mat sediments.

SAMPLE COLLECTION

The highly varied terrains, ranging from marshy coastal lowlands to glacier-covered mountain ranges, required an

TABLE 5-2-2
Deposit Types and Mode of Occurrance in the 1988 RGS Project Area (Muller et al. 1974)

DEPOSIT CLASS	DEPOSIT SUBCLASS	TYPE DEPOSIT	COMMODITIES	HOST ROCK	INTRUSIONS
Gold-quartz veins	Gold-qtz veins	Zeballos Au Camp	Au, As, (Pb, Zn, Cu, As)	Sicker Group, Vancouver Group Nanaimo Group, intrusive rocks	Tertiary quartz diorite intrusions
	Gold-qtz shears	Alexandria	Au, Ag, Cu (Zn, Pb)	Shear zones in Coast intrusions in pendants and along sheared intrusion/pendant contacts	Mid-Jurrassic Coast complex quartz diorites and granodiorites
	Gold-sulphide veins	Sin	Au, Ag, (Cu, Fe)	Parsons Bay Formation occassionly seen as Fe-sulfide skarn	Jurassic Island intrusions
Iron ± copper ± lead-zinc skarns	Iron skarn	Empire	Fe, (Cu)	Quatsino Formation and/or surrounding skarnified volcanic and intrusive rocks	Jurassic Island intrusions
	Copper skarn	Coast Copper	Cu, (Au, Ag, Fe)	Quatsino-Karmutsen contact, limestone units in Quatsino, Karmutsen or Sicker, skarnified volcanic and sedimentary rocks	Same as above
	Lead-zinc skarn	H.P.H.	Pb, Zn, (Cu, Au, Ag)	Limestone of Sicker Group, upper Quatsino and Karmutsen Formations	Same as above
Stock-work	Porphyry copper	Island Copper	Cu, (Mo)	Bonanza pyroclastics of basic to intermediate composition	High-level Jurassic Island intrusions
	Porphyry Cu-Mo	Don	Cu, Mo	Quartz-feldspar porphyry in composite porphyritic biotite granite stock	Early Tertiary Coast intrusions
	Stockwork copper	Quatsino King	Cu, (Mo, Ag, Au, Zn)	Sicker Group, Karmutsen Fm., Bonanza volcanics, granitic rocks	Basic to felsic and porphyritic Island intrusions
Massive sulphide	-	Buttle Lake	Zn, Cu, Pb (Ag, Au, Ba)	Upper volcanic sequence in lower formation of Sicker Group	None

innovative approach to designing the sampling program. McElhanney Engineering Services Limited of Surrey, B.C., was awarded the sampling contract based on both its design and competitive bid.

A multiphase sampling program was employed with truck and boat-supported crews making an initial pass through the area, followed by a helicopter crew to sample remote sites. The senior author was on site during the program to provide crew training, to answer questions and to maintain quality control.

Sediment and water sampling were restricted to primary and secondary streams having drainage-basin areas less than 10 square kilometres. On average, 49 sites were sampled per day between June 11 and August 5, for a total of 2746 sites. Of the total sites, 1657 were sampled for moss-mats, and 1089 for stream sediment (Table 5-2-4). The average sampling density was 1 site every 10.9 square kilometres. In general the samplers found moss mats were abundant in all drainage basins on Vancouver Island and easier to locate than suitable low-energy sites bearing sufficient fine stream sediment.

FIELD PREPARATION (MOSS-MAT SEDIMENT SAMPLES)

The collection of moss-mat samples presented several new problems, in particular for field preparation of samples. Unless the samples are dried soon after collection, the mats will rot, making sample disaggregation nearly impossible.

Once a sample had been thoroughly dried, it was placed in a large Pyrex bowl and gently pounded with a wooden mallet. The pounding helped to disaggregate the fine sediment from the moss fronds without breaking the plant fibres. Sieving of the sample through a 1-millimetre (18 mesh ASTM) screen recovered the sediment finer than coarse sand while removing nearly all undecomposed plant material. Sieving each moss-mat and stream-sediment sample vastly reduced sample bulk and subsequently shipping costs, while allowing a qualitative assessment of the amount of fine sediment. The –1-millimetre fraction was returned to the original sample bag and set aside for later inspection by the senior author. Routine sieving to –177 microns (–80 mesh ASTM) of at least one sample in each block of twenty, or those appearing deficient in fines, ensured that such samples

TABLE 5-2-3
EXPLORATION ACTIVITY COMPILED FROM FILED ASSESSMENT REPORTS

NTS MAP SHEET	1981 DT	1981 I	1981 II	1981 III	1981 IV	1982 DT	1982 I	1982 II	1982 III	1982 IV	1983 DT	1983 I	1983 II	1983 III	1983 IV
92E	5I 1G 1S	1	3 1 1		1	2I	2				3I 1G	1 1	1	1	
92K	3G 1M 1S	2 1	1 1			3G 3I 2M 2S	1 2 2	2 1	 2		3I 3G 1S	 1	3 1 1		 1
92L	3G 3I	2	 2	1 1		11G 4I 2S	9 2	1	1 2 2		7G 6I 5S	 3 1	4 1 3	3 2 2	
102I						1I	1								
Total	18	6	9	2	1	30	19	4	7		29	6	14	8	1

NTS MAP SHEET	1984 DT	1984 I	1984 II	1984 III	1984 IV	1985 DT	1985 I	1985 II	1985 III	1985 IV	1986 DT	1986 I	1986 II	1986 III	1986 IV	1987 DT	1987 I	1987 II	1987 III	1987 IV
92E	2I 1M 1S	2 1		 1		1G	1				2I 2G 1M 1S	1	1 2 1	 1		1I 1G	1		 1	
92K	2G 2M 1I	2 1 1	 1			2M	1	1			2G 1S	1	 1		1	3G 1I 1S	1	1 1 1	1	
92L	7G 7S 5I 1M	4 3 3	3 2 2 1	 2		5G 5I 1S	4 2	 2	1 1 1		6G 6S 2I	3 1	3 4 1	 2		6G 5S 2I	3 2	 4	3 1	
102I	1I	1																		
Total	30	18	9	3		14	8	3	3		21	6	12	3	1	20	7	7	6	

LEGEND

Deposit Type (DT)

G = Gold + Quartz Veins
I = Iron ± copper ± lead-zinc Skarn
M = Massive sulphide
S = Copper ± Molybdenum Stockwork

Exploration Activity

I = Grassroots: prospecting, minor geochemical sampling
II = Intermediate: mapping, moderate-scale geophysical and geochemical surveys
III = Advanced: drilling, trenching, extensive ground surveys
IV = Development: underground development, i.e. drifting, drilling

Example:

	1981 DT	1981 I	1981 II	1981 III	1981 IV
92E	5I	1	3		1

Interpretation: During 1981, on map sheet 92E, (5) five assessment reports were filed on properties hosting (I) iron ± copper ± lead-zinc skarn type deposits. Of the five, one was at the grassroots stage of exploration, three were at the intermediate stage, and one was at the development stage.

had the requisite minimum of 40 grams of fines for subsequent chemical analyses. Only four sites were resampled due to insufficient fine sediment in the original sample.

LABORATORY PREPARATION

Within a month of completion of the sampling program, all water and sediment samples were sent to Kamloops Research and Assay Laboratory. In cooperation with the Ministry, a routine was designed that would minimize sample contamination while optimizing efficiency. Sample preparation comprises the following steps:

(1) checking for samples missing or destroyed during transit,
(2) drying and sieving to −177 microns (−80 mesh ASTM),
(3) weighing the coarse and fine fractions of each sample, and
(4) inserting analytical duplicates and control reference material into the sample sequences.

Critical to the success of the program is the ability to distinguish anomalous and background elemental concentrations. Determination of background can only be accomplished by assessing the sources of variation, these being the geology (including mineralization), characteristics of the sample site, subsampling problems, and analytical techniques.

Each group of twenty RGS samples includes a field duplicate (to test sample site variability), a blind duplicate (to test laboratory subsampling variability) and a control reference (to test analytical variability). The positions of these samples are unknown to the analytical laboratory, thereby removing any potential bias.

ANALYTICAL DETERMINATIONS

Following sample preparation, all samples are sent to an analytical contractor chosen by a competitive bid. Over the 13-year history of the RGS program, the list of elements analysed has grown steadily. Currently, sediment samples are analyzed for antimony, arsenic, barium, cadmium, cobalt, copper, fluorine, gold, iron, lead, manganese, mercury, molybdenum, nickel, silver, tin, tungsten, uranium, zinc and organic matter by loss on ignition (LOI). Determinations for bismuth and chromium will also be included this year. Stream-water samples are analyzed for uranium, fluoride ions and pH.

The analytical methodology for each element is based on standards set by the Geological Survey of Canada National Reconnaissance Program. The techniques were established to optimize extraction of each element at its lowest detection limit while providing nation-wide consistency between surveys. The quality of the analytical results is evaluated using the determinations from the inserted analytical duplicate and

TABLE 5-2-4 SAMPLE DISTRIBUTION IN 1988 RGS PROGRAM AREA

92E - NOOTKA SOUND					
MAP SHEET	MOSS MAT	STREAM SEDS	TOTAL SITES	AREA KM^2	DENSITY SITES/KM^2
08	55	0	55	570	10.4
09	85	0	85	930	10.9
10	35	0	35	425	12.1
14	22	0	22	225	10.2
15	97	0	97	840	8.7
16	92	0	92	985	10.7
TOTAL	386	0	386	4042	10.5

92K - BUTE INLET[a]					
MAP SHEET	MOSS MAT	STREAM SEDS	TOTAL SITES	AREA KM^2	DENSITY SITES/KM^2
01	78	0	78	920	11.8
02	42	24	66	700	10.6
03	0	50	50	660	13.2
04	0	104	104	985	9.5
05	18	54	72	810	11.3
06	23	39	62	690	11.1
07	63	13	76	785	10.3
08	77	0	77	960	12.5
09	85	0	85	995	11.7
10	91	0	91	865	9.5
11	84	0	84	950	11.3
12	89	0	89	850	9.6
13	86	0	86	860	10.0
14	79	0	79	975	12.3
15	65	0	65	890	13.7
16	52	0	52	980	18.8
TOTAL	932	284[b]	1216	13,875	11.4

92L - ALERT BAY[a]					
MAP SHEET	MOSS MAT	STREAM SEDS	TOTAL SITES	AREA KM^2	DENSITY SITES/KM^2
01	97	0	97	985	10.2
02	97	0	97	980	10.1
03	94	0	94	800	8.5
04	41	0	41	320	7.8
05	75	0	75	770	10.3
06	96	0	96	950	9.9
07	84	0	84	955	11.4
08	90	2	92	900	9.8
09	41	38	79	730	9.2
10	9	0	9	120	13.3
11	33	0	33	640	19.4
12	91	0	91	890	9.8
13	39	0	39	400	10.3
14	0	12	12	365	30.4
15	18	52	70	610	8.7
16	9	53	62	800	12.9
TOTAL	914	157[b]	1071	11,215	10.5

102I - CAPE SCOTT					
MAP SHEET	MOSS MAT	STREAM SEDS	TOTAL SITES	AREA KM^2	DENSITY SITES/KM^2
09	47	0	47	550	11.7
16	26	0	26	240	9.2
TOTAL	73	0	73	790	10.8

[a] Stream sediments collected from Mainland only
[b] Does not include check samples

control reference samples to ensure strict adherence to national standards.

RELEASE INFORMATION

Results will be distributed in three Open File map packages (RGS 21 – 92E, Nootka Sound; RGS 22 – 92K, Bute Inlet; RGS 23 – 92L, Alert Bay and 102I, Cape Scott) and floppy diskettes. Individual packages will consist of both 1:100 000 and 1:250 000-scale sample-location maps, geochemical maps (1:250 000 scale) for each analysed element, detailed listings of field and analytical results, brief statistical analysis and updated 1:250 000 Mineral Inventory maps. Complete listings of analytical and field data will also be available on standard MS-DOS 5¼ inch double-sided, double-density floppy diskettes.

Release of data is tentatively planned for early June. Final details on costs, distribution centres and dates will be made available at a later date.

ACKNOWLEDGMENTS

The authors wish to thank Stephen Day for his critical review of this paper, also Shaun Pattenden and Wayne Jackaman for drafting the diagrams.

REFERENCES

Holland, S.S. (1964): Landforms of British Columbia, a Physiographic Outline, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 48.

Howes, D.E., (1981): Terrain Inventory and Geological Hazards: Nothern Vancouver Island, *B.C. Ministry of Environment*, APD Bulletin 5.

Matysek, P.F. and Day, S.J. (1988): Geochemical Orientation Surveys: Northern Vancouver Island, Fieldwork and Preliminary Results, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 88-1, pages 493-502.

Muller, J.E. (1977): Geology of Vancouver Island, *Geological Survey of Canada*, Open File 463.

Muller, J.E. and Carson, J.T. (1969): Geology and Mineral Possibilities of Vancouver Island, Proceedings, *Prospectors and Developers Association*, Annual Meeting, Toronto.

Muller, J.E., Northcote, K.E. and Carlisle, D. (1974): Geology and Mineral Deposits of Alert – Cape Scott Map Areas, British Columbia, *Geological Survey of Canada*, Paper 74-8.

Muller, J.E., Cameron, B.E.B. and Northcote, K.E. (1981): Geology and Mineral Deposits of Nootka Sound Map-area, Vancouver Island, British Columbia, *Geological Survey of Canada*, Paper 80-16.

Roddick , J.A. (1977): Notes on the Stratified Rocks of Bute Inlet Map-area, *Geological Survey of Canada*, Open File 480.

NOTES

USING THE REGIONAL GEOCHEMICAL SURVEY DATABASE: EXAMPLES FROM THE 1988 RELEASE* (104B, F, G, K)

By Stephen J. Day and Paul F. Matysek

KEYWORDS: Applied geochemistry, regional geochemical survey, Iskut River, data analysis, anomaly definition, geochemical associations.

INTRODUCTION

Regional geochemical survey (RGS) results for the Iskut River (104B), Telegraph Creek (104G) and Tulsequah (104K) areas were released in July 1988. The release consists of chemical and physical data for sediment and water samples collected from more than 2700 streams over an area of 35 000 square kilometres underlain by 50 different rock units. For each sample over 40 variables were recorded in the field or determined later in a laboratory. The resulting product is complex and demands a thoroughly systematic approach to analysis if the full value of the survey is to be realised. This paper presents a simple but rigorous method for using the data which relies on the recognition of geochemical subsets appropriate to the scope of the project.

All database manipulations and statistical calculations described can be carried out on a microcomputer using commercially available software. Raw regional geochemical survey data for the entire province are available on floppy diskettes from the Applied Geochemistry Subsection, Ministry of Energy, Mines and Petroleum Resources.

PROJECT SCALE AND SUB-DATASETS

The RGS data are used in private sector, government and academic studies (*see* Matysek, 1987, for a bibliography) at a variety of scales ranging from comparison of tectonic terranes (McMillan *et al.*, 1988) to selection of exploration targets. Regardless of scale, these investigations demand definition of a baseline model to identify anomalies. The ability to detect significant anomalies is increased by defining a simple model that reflects the scale of the study. In this paper, working models are defined by dividing the data into logical subsets:

- Large scale analytical subsets. The province-wide database has been developed over a 12-year period by several private contractors.
- Environmental units. Major variations in surficial geology, climate, vegetation and topography result in significant differences in the dispersion characteristics of elements in drainage sediments.
- Tectonic terranes. The Cordillera has been divided into tectonic terranes, each with distinctive lithogeochemical characteristics which are reflected in stream sediments (McMillan *et al.*, 1988).
- Geological units. Rock units of different lithologies and ages show well-established variation of elements reflecting their mineralogical composition (Matysek *et al.*, 1982; Johnson, 1984).

Thus, sub-datasets are defined such that anomalies are readily identifiable and can be attributed to a limited number of sources, each of which can be rejected or accepted by examining a relatively small number of physical and chemical variables.

SOURCES OF GEOCHEMICAL ANOMALIES

Anomalies are defined as departures from a model. In the search for new mineral deposits it is tempting to ascribe all anomalies to the presence of unrecognized mineralization. However, lithological and environmental factors are equally likely to produce high values for elements frequently associated with mineralization. Samples high in organic carbon or iron and manganese oxides may yield high values for base metals (Rose *et al.*, 1979). Likewise, an unmapped mafic intrusion in terrain characterized by felsic intrusions may yield anomalously high values for siderophile elements such as nickel, cobalt and iron. In addition, anomalies may be generated by man-made contamination such as mining or logging activity.

THE 1988 RELEASE

A description of the area covered by the three RGS Open Files released in 1988 (BC RGS 18, 19 and 20) is provided by Gravel and Matysek (1988). Complete sampling and analytical details are presented in the Open File data booklets and the document files provided with the floppy diskette version of the release (Matysek *et al.*, 1988).

The survey area straddles over 300 kilometres of the boundary between the Intermontane Belt and the Coast plutonic complex. The geology of the region is complex with ultramafic to syenitic intrusions and gneissic complexes varying in age from Mississippian to early Tertiary. Intermontane volcanic and sedimentary rocks include the Triassic Stuhini Group, Jurassic Laberge and Hazelton groups and Jurassic to Cretaceous Bowser Lake Group. Locally, Tertiary and Quaternary volcanism has produced extensive cones and flows.

Much of the region is mountainous, especially adjacent to the Alaskan border. Here, icefields and bare rock are extensive with tills covering the lower valley sides. Areas of extensive thick glacial drift are uncommon in the region though the larger valleys (Iskut, Stikine, Taku) are filled with fluvioglacial deposits. Predominant glacial directions during

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

the final (Wisconsin) glaciation vary from southwestward down the Iskut valley, to eastward away from the Coast Mountains towards the Interior Plateau and northwards parallel to Atlin and Teslin lakes (Holland, 1976).

DATA ANALYSIS

SOFTWARE AND HARDWARE

Readily available database management and statistical packages were used throughout the study. dBase III Plus (Ashton-Tate) was used to create data subsets and perform simple statistical calculations. PROBPLOT (Stanley, 1988; distributed by the Association of Exploration Geochemists) was used to produce probability plots. Conventional symbol maps and scatter plots were produced using in-house plotting packages, but similar programs are available commercially.

A microcomputer equipped with a hard disk is essential due to the large databases involved.

METHODOLOGY

Data analysis methodology is similar to that described by Sinclair and Fletcher (1980). Their method was based on subdivision of data by predominant rock type followed by evaluation of probability plots and multiple regression studies. The importance of other variables such as stream-water pH as a control on concentrations of elements in stream sediments was also considered.

In the current study, initial subdivision of data is on the basis of sampling medium and whether the same laboratory analysed all the samples using the same analytical method (Figure 5-3-1). The data are then subdivided by map sheet and stratigraphic formation in the sediment-sample provenance area. Regional-scale variables such as physiography and stream types are considered so that data from low-lying areas potentially characterised by low-mechanical/high-chemical weathering rates are not mixed with mountainous regions where the opposite conditions prevail. At the same time, important variables characterising the chemical environment in the waters (pH) and sediments (sediment colour, sediment composition, loss-on-ignition, manganese, iron) are investigated for regional variability. The importance of these variables has been demonstrated statistically by Matysek *et al.*(1981).

For the most part, this initial data sorting can be done using the topographic maps and surficial geology maps provided in the release package, combined with the field observations. The four measured chemical indicators (iron, manganese, loss-on-ignition, pH) can be evaluated using probability plots. Screening of regional environmental variability potentially yields a dataset which is as homogeneous as can be expected and is ready for studies of geochemical variations which reflect bedrock geology.

In the second pass, probability plots are used on the assumption that geochemical data distributions can be modeled with mixtures of Gaussian normal or lognormal populations. The plots can be used to determine background and anomalous mean values and a value or range of values that discriminates background and anomalous samples. The selection of a single value as a threshold for an element largely depends on the particular needs of the geochemical program.

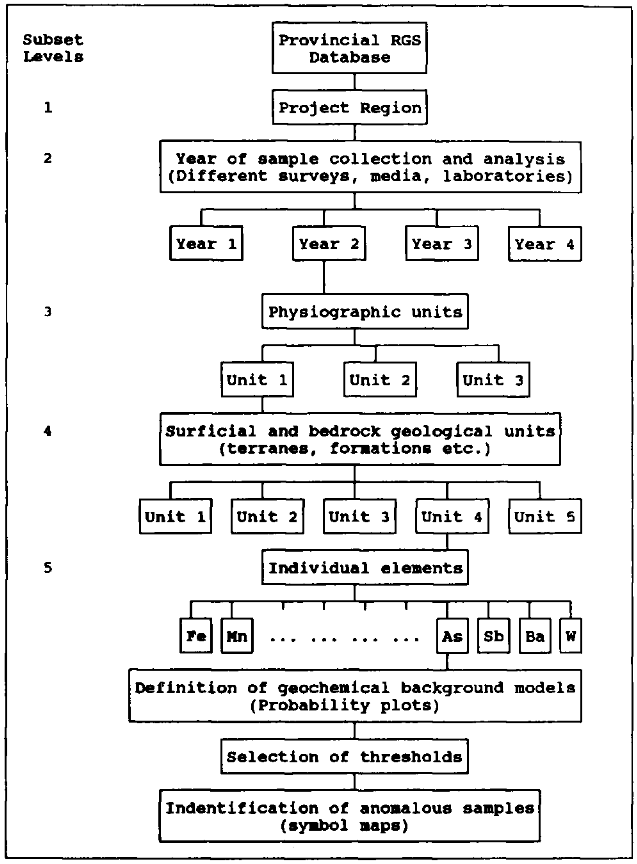


Figure 5-3-1. Flow diagram for data analysis.

Thresholds selected from probability plots were used to prepare simple elemental symbol maps, typically with three concentration intervals, namely background, overlap between background and anomalous, and anomalous. Symbol maps are preferred to contoured maps because elemental concentrations determined at a sediment sampling site are not representative of the site but are a composite of material eroded from the entire drainage basin.

Symbol plots are overlayed on the drainage pattern base map so that clusters of anomalous concentrations can be related to the direction of drainage and size of drainage basin.

LABORATORY DETAILS

Analytical responsibilities for the 1988 RGS were shared between the British Columbia Geological Survey Branch (104B, 104F, 104K) and the Geological Survey of Canada (104G). As a result, samples were prepared and analysed at two different locations. Identical methods were used for the determination of all elements except gold; in this case fire assay was used with different finishing methods.

Laboratories using the same analytical method may disagree on the absolute concentration of an element in a sample, even though their precision levels are identical and satisfactory. This arises from minor differences in digestion procedures and the model and age of the machine used for the final determination. Analytical results from the two laboratories must be compared, otherwise anomalies determined at a later stage of the data analysis may prove to be analytical artifacts. In the RGS, control reference samples are routinely inserted in each batch of twenty samples to permit a direct comparison of concentrations determined for the same standard material at the two laboratories. Three standards are used which provide a wide range of concentrations for most elements.

Results (x_j) for each element can be presented on one diagram (Figure 5-3-2) by calculating the mean (x_j) and standard deviation (s_j) for each of three control references and determining a standardised concentration (z_i) for each of the control samples:

$$z_i = (x_{i,j} - x_j)/s_j.$$

The resulting diagram for each element shows deviations from the standardized mean of each control reference. Ideally, results from the two laboratories should be scattered about the $z=0$ line as shown by the results for uranium (Figure 5-3-2b). However, for most elements the laboratories consistently produce different results (for example manganese, Figure 5-3-2a). These visual conclusions were quantified with Students t-test to compare two means which shows that only copper, silver, uranium and antimony have indistinguishable results (95 per cent confidence). Although the absolute differences between concentrations determined for the standards might be considered small relative to the range of concentrations encountered in stream sediments, the difference is recognizable and can be eliminated by not mixing results from two laboratories. This example illustrates the importance of monitoring control concentrations in large multi-year multi-laboratory projects of any kind (*see* Day *et al.*, 1988). If data from two surveys are to be considered together, the analysis must be done separately for each component survey. Different absolute geochemical

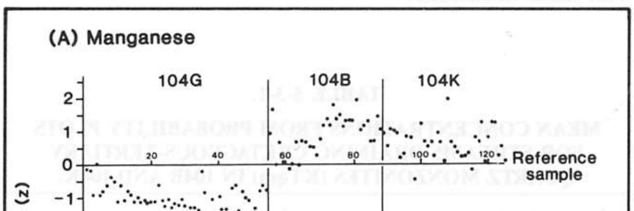


Figure 5-3-2. Standardised concentration (z_i) versus batch number for (a) manganese and (b) uranium. Calculation of z_i is described in the text.

thresholds will be produced permitting subtle anomalous trends between adjacent surveys to be recognized. Undivided data produced by different laboratories may allow recognition of gross trends but the potential for producing misleading false anomalies is increased.

EXAMPLES

USING THE RGS DATA IN TECTONIC AND METALLOGENIC STUDIES

Two tectonic terranes are represented in the survey area. The Coast plutonic complex in the westerly portion of the area is composed of intrusions ranging in age from Triassic to early Tertiary. In particular, large batholiths of quartz monzonite dated as Cretaceous to Tertiary (coded as "KTqm" in the database) are mapped throughout 104B, 104G and 104K (Figure 5-3-3; Souther, 1970, 1972; Souther *et al.*, 1974) and present an opportunity to study how the trace element composition of intrusions changes within the plutonic belt. Only samples in 104K and 104B were considered because intrusions in these areas are widely separated and the sediment samples were analysed at the same laboratory.

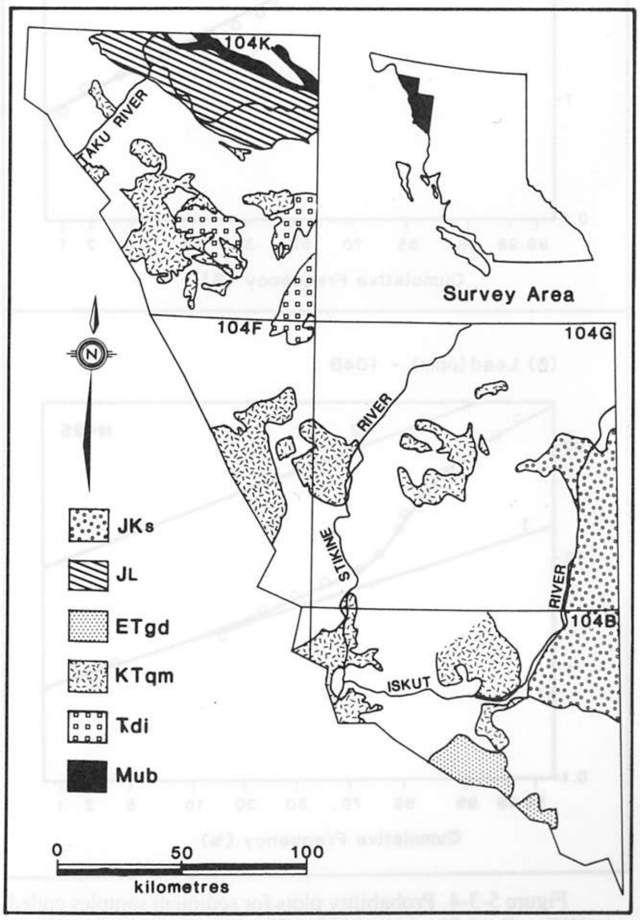


Figure 5-3-3. Distribution of geological units discussed in this paper. JKs = Bowser Lake Group; JL = Laberge Group; ETgd = Early Tertiary granodiorite; KTqm = Cretaceous-Tertiary quartz monzonite; Tdi = Triassic diorite; Mub = Mississippian ultrabasic rocks.

Probability plots for sediment samples, coded as "KTqm", were examined separately for 104B (95 samples) and 104K (145 samples). Usually logarithmic or arithmetic probability plots can be modelled with one normal population (Figure 5-3-4a) or a mixture of two populations that do not overlap (Figure 5-3-4b). In the latter case one population is large (more than 90 per cent of samples) with a lower mean concentration than the smaller population. A few elements cannot be modelled adequately, either because the majority of concentrations are below the detection limit (for example, tungsten, tin) or the plot is not readily interpreted in terms of normal distributions. The large low-concentration population presumably represents background values for the intrusions. Theoretical mean concentrations are summarized in Table 5-3-1.

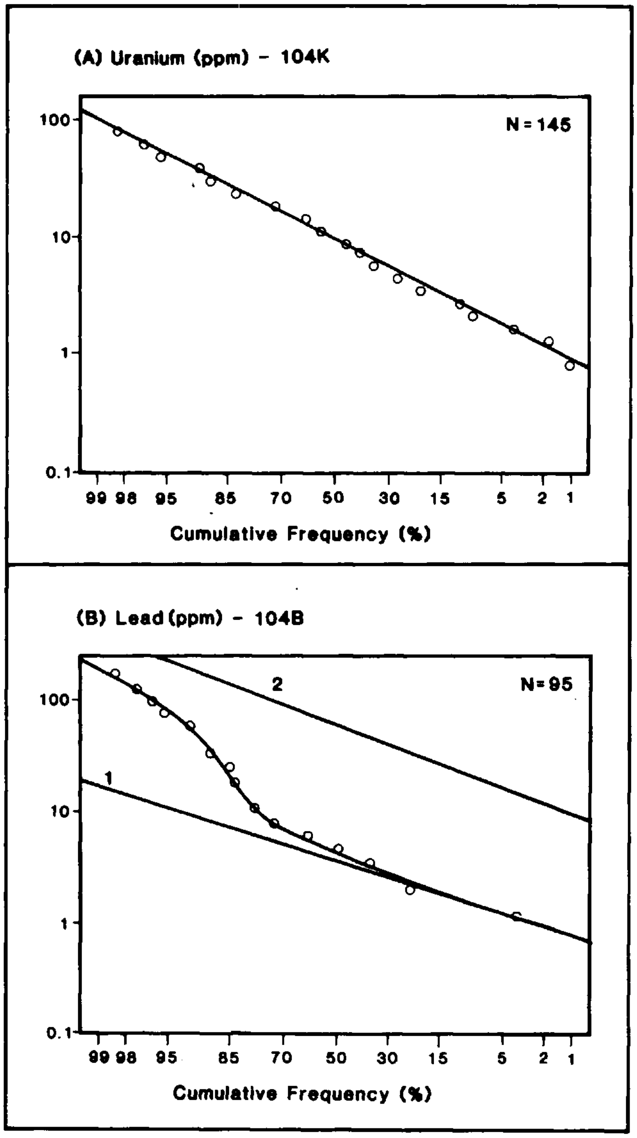


Figure 5-3-4. Probability plots for sediment samples coded as "KTqm". (a) Single population for uranium in 104K. Mean of ideal population is 9.2 ppm, coefficient of variation is 45.8%. (b) Two population fit for lead in 104B. Means of labelled ideal populations 1 and 2 are 3 ppm and 57 ppm, respectively. Coefficients of variation are 53.3% and 10.3%, respectively.

Elements showing similar patterns can be grouped by their associations. Siderophile elements (that is, elements associating with iron) show higher concentrations in samples draining Cretaceous and Tertiary quartz monzonite batholiths in 104B than 104K, though gold is not enriched, perhaps because it shows a stronger chalcophile association in this case. In contrast, the heavy lithophile elements, tungsten and uranium, and the volatile element fluorine, are consistently relatively enriched in the batholiths in 104K. Chalcophile elements show no tendency to be enriched in batholiths in either area.

Interpretation

Batholiths rising through the crust assimilate material which alters their bulk chemistry. Armstrong (1985), shows that the strontium isotope ratio ($^{87}Sr/^{86}Sr$) has a steep gradient in the survey area. In 104K, Mesozoic intrusions have values of 0.704 to 0.707 for the ratio, whereas further south in 104B, the ratio is 0.703 to 0.704. Likewise a similar relationship is observed for Cenozoic intrusions. Higher values of the ratio in 104K imply assimilation of highly evolved continental crust with its heavy isotopes and elements such as uranium and tungsten. On the other hand, low values imply assimilation of primitive oceanic crust with its high concentrations of lighter isotopes and siderophile elements. McMillan (personal communication, 1988) suggested that deeply buried Precambrian continental crustal rocks underlying 104K and the thick iron-rich volcanic sequences of the Intermontane Belt underlying 104B are responsible for the observed trends.

From a mineral exploration standpoint, "KTqm" batholiths in 104K are clearly better targets for the heavy elements. Tungsten and uranium are clearly enriched in these batholiths, and tin, although occurring in very low concentrations in stream sediments, is also likely to be enriched. Rare-earth elements are also more likely to be associated with these intrusions.

TABLE 5-3-1.

MEAN CONCENTRATIONS FROM PROBABILITY PLOTS FOR STREAMS DRAINING CRETACEOUS-TERTIARY QUARTZ MONZONITES (KTqm) IN 104B AND 104K.

Association/ Element/Unit		104B[1]	104K[2]	Association/ Element/Unit		104B[1]	104K[2]
Siderophile				Chalcophile			
Co	ppm	14	4	Cu	ppm	47	—
Ni	ppm	11	3	Pb	ppm	3	11
Fe	%	3.02	1.82	Zn	ppm	61	61
Mn	ppm	513	400	Ag	ppm	0.1	0.1
Au	ppb	5	5	Hg	ppb	10	4
				As	ppm	3	6
				Sb	ppm	0.4	0.3
Lithophile							
W	ppm	3[3]	3				
U	ppm	1.5	9.2				
F	ppm	345	424				
Ba	ppm	994	1031				

[1] N = 95 (in the original dataset)
[2] N = 145 (in the original dataset)
[3] P_{98} for W = 6 ppm for 104B and P_{98} = 22 ppm for 104K

Using the RGS Data to Determine Regional Background Values

Interpretation of the geochemistry of stream sediments derived from rocks of widely different ages and compositions must begin with the determination of geochemical background levels. As an extension of the previous example, background compositions of stream sediments eroded from early Tertiary granodiorites ("ETgd", i04B), Triassic diorites and gabbros ("Trdi", 104K) and Mississippian ultrabasic rocks ("Mub") (Figure 5-3-3) were determined (Table 5-3-2). Most probability plots for the granodiorites, diorites and gabbros were easily interpreted in terms of single or double normal, or logarithmic normal populations.

Interpretation of the data for samples coded as "Mub" requires further explanation. Two well-defined chemical groups are apparent which cannot be explained by environmental variables such as stream water acidity or organic content of the sediments. Fourteen of the samples are relatively enriched in cobalt and nickel (Figure 5-3-5) whereas the remaining twelve are enriehed in copper, lead, zinc, arsenic, antimony and mercury. Spatially the latter group are closer to a northeasterly dipping thrust fault which truncates the rocks to the south. Although one or two of these samples may contain a high proportion of sediments eroded from the Jurassic Laberge group to the south, the smaller group of samples is presumed to represent samples altered by solutions in the fault zone. Thus, Table 5-3-2 reflects the laiger sample group which appears to represent relatively unaltered ultrabasic rocks.

Table 5-3-2 shows a sharp contrast between the relatively felsic rocks and the ultrabasic rocks. In particular, concentrations of cobalt, nickel and iron are high in the ultrahasic rocks due to the high proportion of ferromagnesian minerals. The higher content of such minerals as zircon, potassium feldspars and apatite in felsic and intermediate rocks is reflected by the much higher concentrations of uranium, barium and fluorine in the sediments. Although it would normally be expected that lead would show greater concentrations in the more felsic rocks (reflecting the mica and potassium feldspar content), concentrations are very low, preventing determination of reliable background mean concentrations.

TABLE 5-3-2

MEAN CONCENTRATIONS FROM PROBABILITY PLOTS FOR SELECTED ELEMENTS IN STREAM SEDIMENTS ERODED FROM PLUTONIC ROCKS IN 104B AND 104K

Element/Unit		ETgd (N=45)[1]	Trdi (N=71)[1]	Mub (N=26)[1]
Cu	ppm	7	62	22
Pb	ppm	3?	5?	3?
Zn	ppm	43	63	50
Sb	ppm	<0.3	0.4	0.1
Hg	ppb	<20	14	17
U	ppm	1.4	2.7	0.8
F	ppm	386	439	81
Co	ppm	8	9	65
Ni	ppm	11	4	1356
V	ppm	58	50	46
Ba	ppm	1119	899	70
Fe	%	1.78	2.24	4.17
LOI	%	1.2	2.2	—

[1] N is the number of samples in the original dataset.

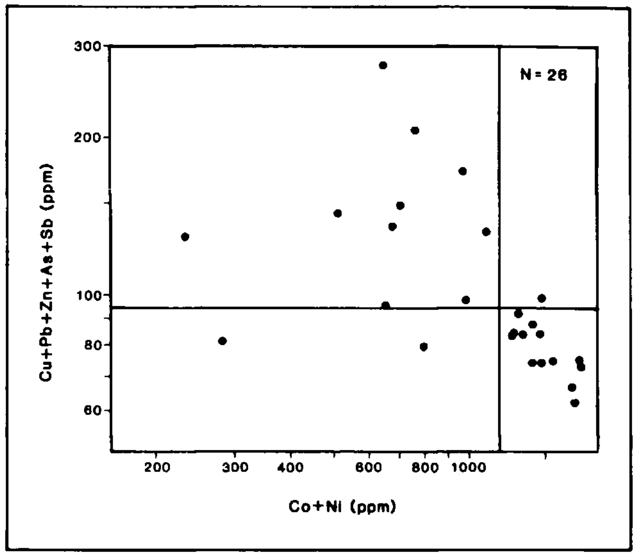


Figure 5-3-5. Co+Ni (siderophile affinity) verses Cu+Pb+Zn+As+Sb (chalcophile affinity) for samples coded as "Mub" in 104K. Dividing lines are thresholds from probability plots.

Evaluating Geochemical Anomalies in the RGS Data

The previous two examples have emphasized the need to subset geochemical data to evaluate background concentration levels. The adequately defined background model with its mean and variance can be used to identify concentrations above or below which samples are labelled anomalous. The following cases show examples of the types of anomalies encountered in the survey area.

Jurassic Laberge Group ("JL") – Effect of Glaciation(?)

The Laberge Group (Figure 5-3-3), consisting of greywackes and conglomerates, underlies part of the northeastern quadrant of 104K, a dissected upland with moderate relief (1000 metres). Very few intrusions, outliers and inliers are mapped, thus stream sediment geochemistry should be fairly simple, reflecting the relatively homogeneous geology.

Two kinds of elemental distributions are evident on the 1:250 000 maps. Three elements (cobalt, nickel, iron; Figure 5-3-6) show absolute concentrations decreasing toward the southwest, whereas concentrations of other elements appear to vary in a nonsystematic fashion. The three siderophile elements have probability plots that can be modelled with two populations. The proportion of the high concentration population varies from 25 per cent for nickel to 12 per cent for iron. Other elements have a small high-concentration population (proportions less than 6 per cent).

The regional geology map shows that the Laberge Group is bounded to the northeast by Mississippian ultrabasic rocks

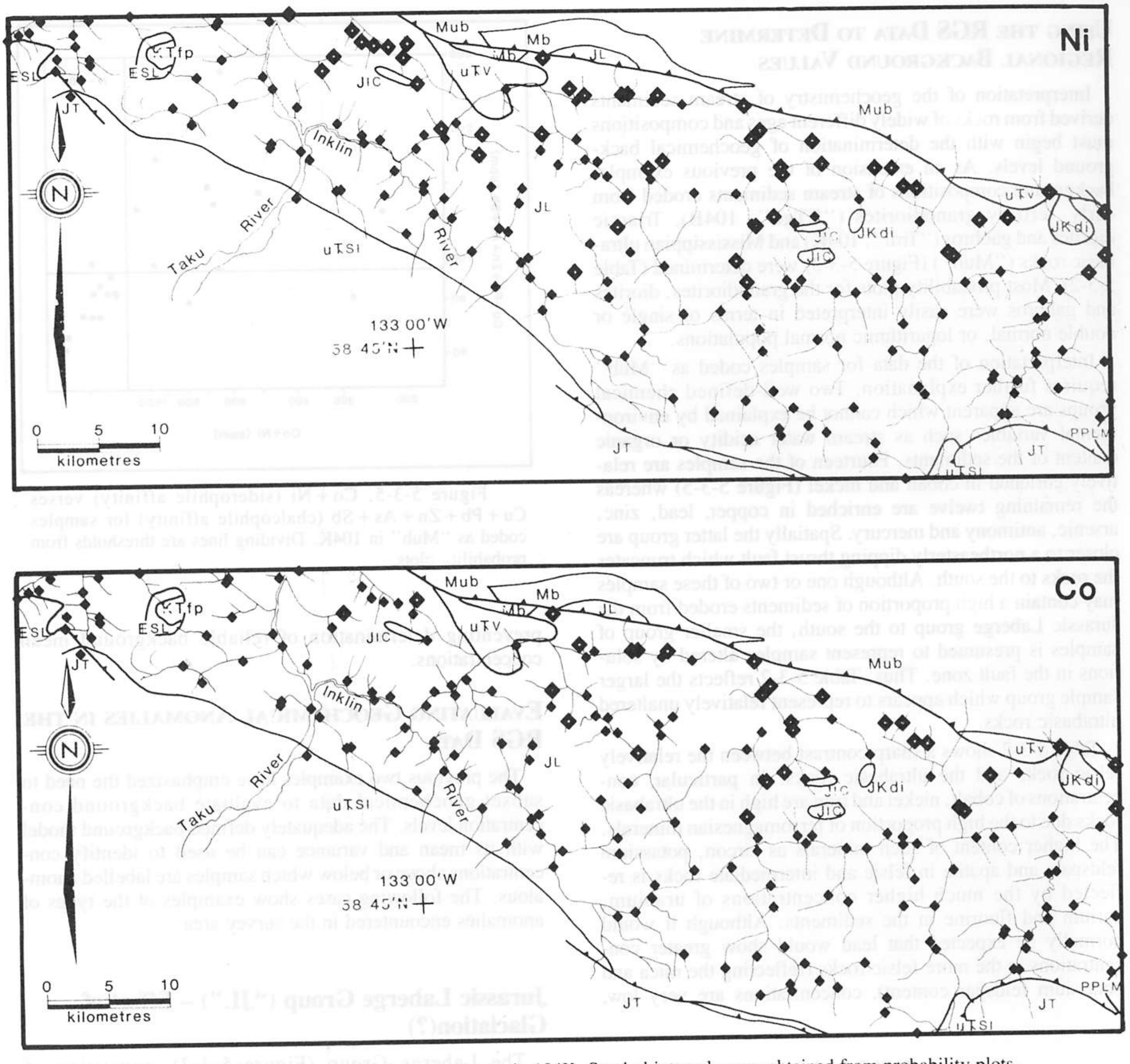


Figure 5-3-6. Element maps for Laberge Group in 104K. Symbol intervals were obtained from probability plots.

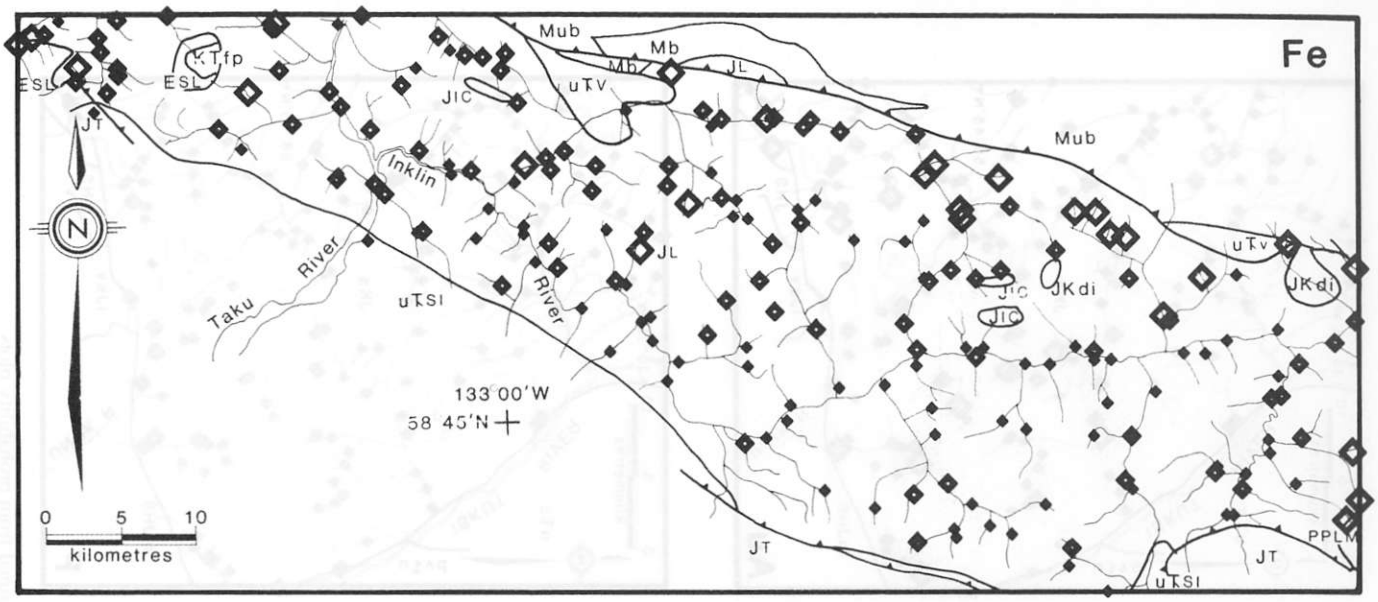


Figure 5-3-6 — *Continued.*

LEGEND

ELEMENTS	◆ (small)	◆	◇
Ni (ppm)	1 - 111	>111	
Co (ppm)	1 - 27	>27	
Fe (%)	0.01 - 2.31	2.32 - 2.47	>2.48

STRATIFIED ROCKS

PPLM	Pliocene-Pleistocene: basalt
ESL	Eocene: rhyolite, trachyte, andesite, basalt
JL	Jurassic Laberge Group: greywacke, conglomerate
JIC	Jurassic: limestone
JT	Jurassic: limestone
uTSI	upper Triassic: limestone
uTv	upper Triassic: andesite, basalt

PLUTONIC ROCKS

KTfp	Cretaceous-Tertiary: felsite, feldspar porphyry
JKdi	Jurassic-Cretaceous: diorite
Mb	Mississippian: gabbro, diorite
Mub	Mississippian: peridotite, serpentinite

(Mub). As shown in Table 5-3-2, these rocks have high background concentrations of nickel, cobalt and iron. The presence of southerly decreasing values for these elements in the area underlain by the Laberge Group implies southerly transport of sediments derived from the ultrabasic rocks. Although this effect may occur if a stream is coded as "JL" but erodes ultrabasic rocks in its headwaters, the regional scale of the effect suggests southerly glacial transport of sediments. Unfortunately, glaciation directions in this region have not been mapped.

Further analysis of data for the Laberge Group requires that the region be split into two parts. A more southerly area representing minimal "contamination" by sediments eroded from the ultrabasic rocks should be considered separately. Because nickel gives the best indication of the extent of contamination, a threshold value selected from the nickel probability plot shows the geographical dividing line between the two areas.

Cretaceous-Jurassic Bowser Lake Group ("JKs")

Bowser Lake Group (siltstone, greywacke, conglomerate, shale) crops out in the northeast corner of map sheet 104B over an area of approximately 1200 square kilometres. Relief is moderate (1000 metres), with small areas of alpine glaciation (southwest) and locally chaotic drainage indicated by abundant small lakes (northwest) (Figure 5-3-7). Mineral occurrences have not been reported in this area which is historically considered to have low mineral potential.

Probability plots are relatively simple and provide meaningful threshold values for most elements. As in the previous examples, nickel values may indicate areas where streams are eroding material other than Bowser Lake Group. A small number of samples returned above (nickel greater than 136 ppm) or below (nickel less than 69 ppm) average values. The low values are due to headwater erosion of felsic intrusions at the southern contact of the Bowser Lake Group (Figure 5-3-7). High values occur in a well-defined group in the southeast corner of the area. This may represent lithological variations such as siltstone to shale. Cobalt values are not elevated in this area, precluding the presence of unmapped mafic volcanic rocks.

An association of elevated uranium, fluorine, lead, zinc, barium and antimony concentrations occurs in the southwest corner of the area (Figure 5-3-7). In particular, the association of uranium and fluorine suggests that a felsic stock underlies the fairly extensive cirque glaciers drained by the streams sampled.

Several elements show definable trends and associations but only those for gold will be mentioned here. Despite the notoriety of gold analyses on stream sediments, overlapping thresholds could be selected from a probability plot of the square root of gold concentrations (Hoyle, 1973). The thresholds are very low (4.6 to 6.4 ppb) but the symbol plot defines several coherent areas of anomalous gold concentrations.

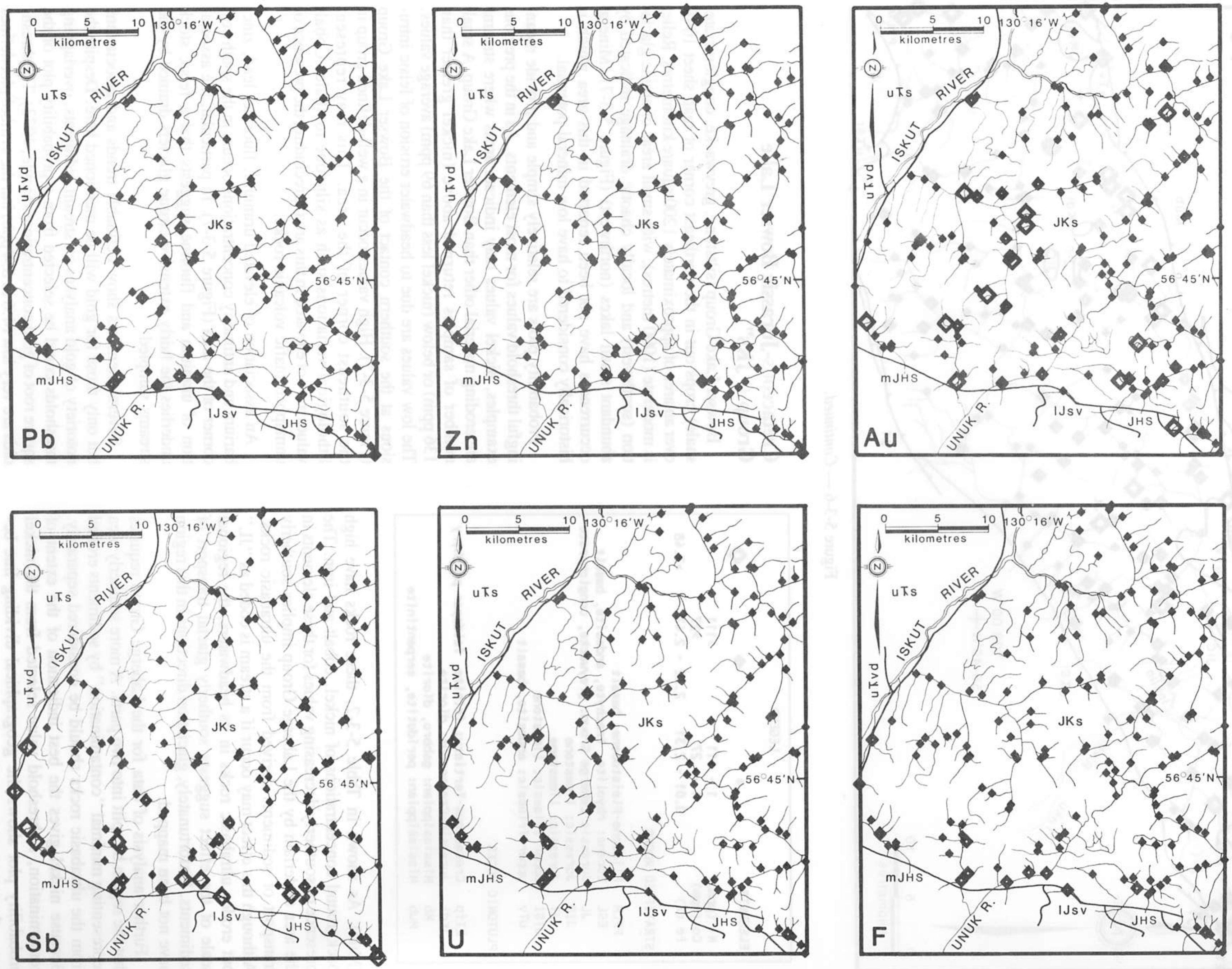


Figure 5-3-7. Element maps for the Bowser Lake Group in 104B. Symbol intervals were obtained from probability plots.

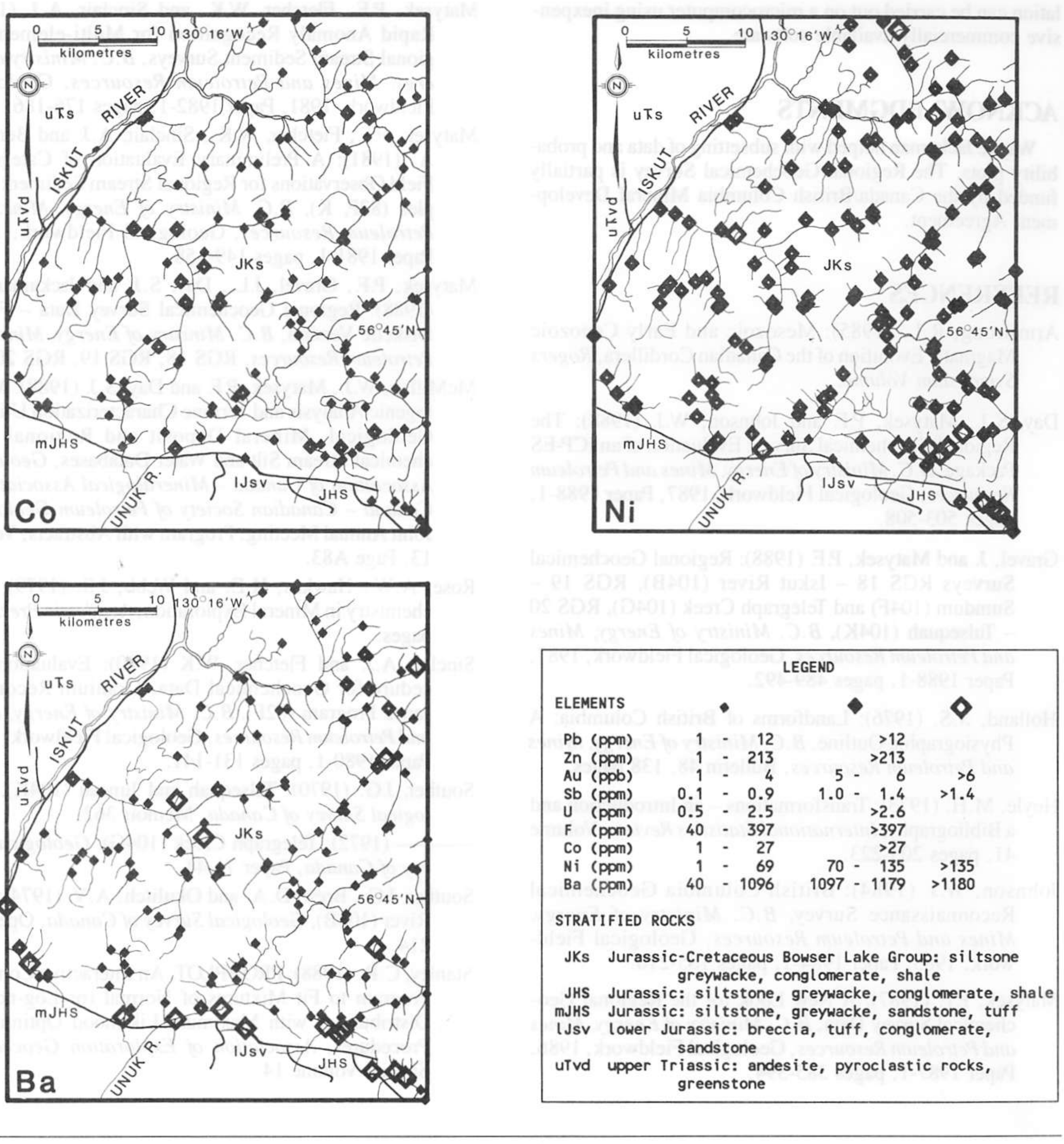


Figure 5-3-7 — *Continued.*

CONCLUSIONS

The provincial RGS database consists of chemical and physical data for nearly 30 000 stream sediment samples collected since 1976. It provides an excellent tool for private sector, government and academic projects provided that geochemical models are defined which take into account the target and scale of the project.

The method presented here follows the following steps:

(1) Recognition of large-scale subsets such as mapsheets sampled in different years, or elements determined by different analytical methods.

(2) Recognition of smaller scale subsets such as geological terranes, environmental units or stratigraphic units.

(3) Definition of background geochemistry models using probability plots.

(4) Identification of samples that do not fit the background model (anomalies).

The method can be applied to the identification of geochemical variations within a terrane, definition of geochemical background levels for different geological units, recognition of lithological variation within a geological unit and identification of local-scale anomalies. All data manipulation can be carried out on a microcomputer using inexpensive commercially available software.

ACKNOWLEDGMENTS

Wayne Jackaman helped with subsetting of data and probability plots. The Regional Geochemical Survey is partially funded by the Canada/British Columbia Mineral Development Agreement.

REFERENCES

Armstrong, R.L. (1985): Mesozoic and Early Cenozoic Magmatic Evolution of the Canadian Cordillera, *Rogers Symposium Volume.*

Day, S.J., Matysek, P.F. and Johnson, W.J. (1988): The Regional Geochemical Survey: Evaluation of an ICP-ES Package, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 503-508.

Gravel, J. and Matysek, P.F. (1988): Regional Geochemical Surveys RGS 18 – Iskut River (104B), RGS 19 – Sumdum (104F) and Telegraph Creek (104G), RGS 20 – Tulsequah (104K), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 489-492.

Holland, S.S. (1976): Landforms of British Columbia: A Physiographic Outline, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 48, 138 pages.

Hoyle, M.H. (1973): Transformations – an Introduction and a Bibliography, *International Statistics Review*, Volume 41, pages 203-223.

Johnson, W.J. (1984): British Columbia Geochemical Reconnaissance Survey, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 185-210.

Matysek, P.F. (1987): A New Look for the Regional Geochemical Survey Data, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 385-394.

Matysek, P.F., Fletcher, W.K. and Sinclair, A.J. (1982): Rapid Anomaly Recognition for Multi-element Regional Stream Sediment Surveys, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1981, Paper 1982-1, pages 176-186.

Matysek, P.F., Fletcher, W.K., Sinclair, A.J. and Bentzen, A. (1981): A Preliminary Evaluation of Categorical Field Observations for Regional Stream Sediment Samples (82F, K), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1980, Paper 1981-1, pages 149-158.

Matysek, P.F., Gravel, J.L., Day, S.J. and Jackaman, W. (1988): Regional Geochemical Survey Data – Floppy Diskette Version, *B.C. Ministry of Energy, Mines and Petroleum Resources*, RGS 18, RGS 19, RGS 20.

McMillan, W.J., Matysek, P.F. and Day, S.J. (1988): Metallogenic Analysis and Terrane Characterization Utilizing Geological, Mineral Deposit and Regional Geochemical Stream Silt and Water Databases, *Geological Association of Canada – Mineralogical Association of Canada – Canadian Society of Petroleum Geologists*, Joint Annual Meeting, Program with Abstracts, Volume 13, Page A83.

Rose, A.W., Hawkes, H.E. and Webb, J.S. (1979): Geochemistry in Mineral Exploration, *Academic Press*, 657 pages.

Sinclair A.J. and Fletcher, W.K (1980): Evaluation Procedure for Geochemical Data, Uranium Reconnaissance Program (82F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1979, Paper 1980-1, pages 131-141.

Souther, J.G. (1970): Tulsequah and Juneau (104K), *Geological Survey of Canada*, Memoir 362.

——— (1972): Telegraph Creek (104G), *Geological Survey of Canada*, Paper 71-44.

Souther, J.G., Brew, D.A. and Okulitch, A.V. (1974): Iskut River (104B), *Geological Survey of Canada*, Open File 214.

Stanley, C.R. (1988): PROBPLOT, An Interactive Computer Program to Fit Mixtures of Normal (or Log-normal) Distributions with Maximum Liklihood Optimization Procedures, *Association of Exploration Geochemists* Special Volume 14.

SIZE DISTRIBUTION OF GOLD IN DRAINAGE SEDIMENTS: MOUNT WASHINGTON, VANCOUVER ISLAND*
(92F/14)

By W.K. Fletcher
The University of British Columbia
and
Zhang Wenqin
Qinghai Geochemical Exploration Brigade,
Xining City, Qinghai, PRC

KEYWORDS: Applied geochemistry, heavy minerals, placer gold, stream sediments, size distribution, Mount Washington.

INTRODUCTION

Information on the size distribution of gold in stream sediments is useful in deciding where to sample, how large a sample to colleet and what size fraction to analyse in stream sediment and heavy mineral surveys for gold (Day and Fletcher, 1986, and *in press;* Fletcher and Day, 1988). Previous publications provided this information for several streams draining gold mineralization in southern British Columbia. Similar data are now presented for streams draining Mount Washington, Vancouver Island.

DESCRIPTION OF THE STUDY AREA

Mount Washington (elevation 1590 metres) is 22 kilometres northwest of Courtenay on Vancouver Island (Figure 5-4-1). Logging roads provide good access to sampling sites on tributaries of the Tsolum and Oyster rivers (Figure 5-4-2).

Bedrock geology consists largely of basaltic flows of the Karmutsen Formation (Upper Triassic). These flows are locally unconformably overlain by sandstones and basal conglomerates of the Upper Cretaceous Comox Formation and intruded by Tertiary porphyritic quartz diorites (Muller, 1968). Near the summit of Mount Washington, gold-silver-copper mineralization, with pyrite and arsenopyrite, is associated with breccia zones. Extensive gold-arsenic soil geochemical anomalies in the headwaters of McKay and Murex creeks (Better Resources Limited, 1987; J.W. Bristow, personal communication) are related to this mineralization. Gold mineralization is also found in the headwaters of Piggott Creek and in the east of the study area near Constitution Hill (H.P. Wilton, personal communication, 1988).

The entire area has been glaciated by ice moving in an easterly arc around the northern flanks of Mount Washington and over the summit in a northeasterly direction (Fyles, 1959). Bedrock and talus slopes occur at higher elevations but glacial till is widespread and forms an important component of the material eroded by streams. Ground moraine, together with fluvioglacial and marine sediments, mantles the lower slopes of Mount Washington along the Tsolum River valley (Figure 5-4-2).

METHODS

At each sampling location 10 and 50-kilogram sediment samples were collected from a high-energy site by wet sieving gravels through a 10-mesh (2 millimetre) screen. In the laboratory both samples were wet sieved to give, respectively, a –70-mesh (ASTM) fraction and eight size fractions finer than 2 millimetres. After drying and weighing, heavy mineral concentrates were prepared for the –70+100, –100+140, –140+200 and –200+270-mesh fractions of the 50-kilogram sample using methylene iodide (SG 3.3). All fractions were weighed before pulverizing in a hardened-steel ring mill.

Samples were submitted to a commercial laboratory for determination of gold by fire assay and atomic absorption

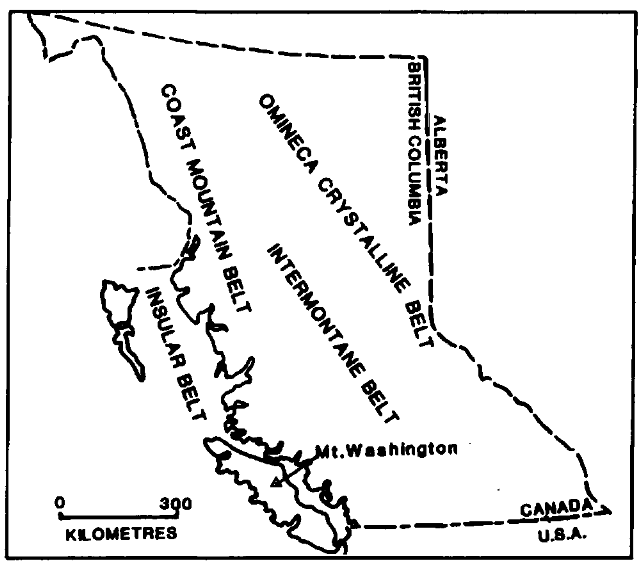


Figure 5-4-1. Location map.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

Table 5-4-1
Results of duplicate gold analyses of pulverized −70 mesh samples

Sample	Gold (ppb) Set 1	Set 2
1	7465	7065
2	20	25
3	1135	735
4	<5	10
5	40	60
6	<5	15
7	<5	10

Table 5-4-2
Weight percentage of size fractions finer than 10 mesh

Site	Size fraction (ASTM mesh) −10 +18	−18 +40	−40 +70	−70+ 100	−100 +140	−140 +200	−200 +270	−270
1	48.0	35.2	12.8	1.84	0.65	0.42	0.14	1.03
2	58.0	30.3	9.0	1.12	0.49	0.37	0.10	0.66
3	58.7	30.9	7.6	1.36	0.56	0.23	0.10	0.60
4	46.4	30.8	13.5	3.54	2.06	0.75	0.46	2.43
5	46.0	43.1	9.1	0.99	0.27	0.20	0.09	0.35
6	60.6	26.9	8.3	1.64	0.87	0.37	0.17	1.14
7	54.0	29.0	11.0	2.46	1.30	0.52	0.30	1.45

Table 5-4-3
Gold contents (ppb) of different size and density fractions of stream sediments

Site	Size fraction (ASTM mesh) −70	−70 +100	−100 +140	−140 +200	−200 +270	−270
A. Heavy mineral fractions except −70 and −270 mesh whole sediment						
1	7465	800	3215	2745	1640	330
2	20	10 440	10 225	8730	15 000	910
3	1135	6755	15 505	19 330	14 440	1000
4	<5	6700	4455	1545	2035	50
5	40	5	705	25	<55	50
6	<5	4135	6665	<75	<145	200
7	<5	155	3835	<45	1540	60
B. Light mineral fractions						
1		<5	20	20	10	
2		15	35	20	90	
3		25	15	20	35	
4		5	5	<5	5	
5		5	5	<5	<5	
6		<5	15	15	10	
7		5	5	15	5	

spectroscopy. The entire heavy mineral concentrate was analysed. For all other fractions, a 30-gram subsample of the pulverized material was taken with a riffle splitter. Results of duplicate analyses of −70-mesh samples are summarized in Table 5-4-1.

RESULTS AND DISCUSSION

The weight percentages of each size fraction finer than 2 millimetres and the gold content of the light and heavy mineral fractions are summarized in Tables 5-4-2 and 5-4-3.

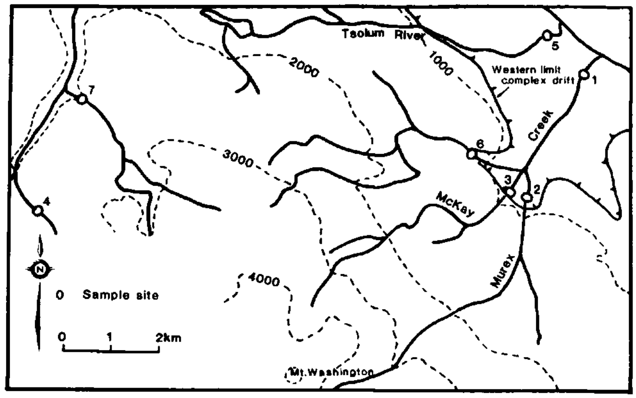


Figure 5-4-2. Drainage basins and sample locations, Mount Washington. Western limit of complex drift from Fyles (1959). Elevations in feet.

The latter shows that although gold occurs almost exclusively in the heavy mineral concentrates there is considerable variability in their gold content between both different sites and size fractions. The latter could result from either differences in size distribution of gold in the source material (that is, the eroding banks and perhaps ultimately the bedrock source of the gold) or differential sorting of different size fractions by the action of the stream.

Insufficient data are available to estimate background concentrations of gold. Nevertheless, the relatively high concentrations in all size fractions of heavy mineral concentrates from McKay, Murex and Piggott creeks suggest that the gold potential of Mount Washington could be clearly recognized by a low-density, heavy mineral survey. Choice of a size fraction does not seem to be too critical. However, as discussed by Day and Fletcher (1986), 20 particles of free gold are required to give a sampling reproducibility (RSD) of 22 per cent. Estimates of the number of gold particles in each fraction (Table 5-4-4) suggest that this could be most conveniently achieved by analysis of the −100-mesh heavy mineral concentrate obtained from approximately 50 kilograms of −10-mesh material. Reducing the sample size to about 2 kilograms of −10-mesh sediment (given one particle of free gold in the heavy mineral concentrate) would theoretically result in an almost 40 per cent chance of missing an anomalous site.

Direct analysis of a sediment sample is an alternative to preparation of a heavy mineral concentrate. Concentrations

Table 5-4-4
Estimated number of particles of free gold in heavy mineral fractions

Site	Size fraction (ASTM mesh) −70 +100	−100 +140	−140 +200	−200 +270
1	0.9	4.2	6.7	4.0
2	4.2	5.8	9.8	8.9
3	4.7	12.5	14.8	14.0
4	3.6	6.8	3.0	6.9
5	—	0.5	—	0.1
6	0.8	1.5	—	0.1
7	0.1	2.2	—	1.1

Table 5-4-5
Estimated gold content (ppb) of combined size fractions

Site	Size fraction (ASTM mesh)				
	−70	−100	−140	−200	−270
1	163	261	277	305	330
2	507	604	678	847	910
3	580	815	883	940	1000
4	83	74	52	53	50
5	20	37	30	41	50
6	115	133	141	176	200
7	39	60	46	55	60

Table 5-4-6
Percentage contribution of −270-mesh fraction to total gold content of −70-mesh fraction

Site	Gold content[1] −70 fraction (ppb)	Per cent contributed by −270 fraction
1	163	51
2	507	44
3	580	36
4	83	16
5	20	45
6	115	48
7	39	36

[1] Based on the contribution of the weighted gold content of the −270-mesh fraction to the estimated gold content of the −70-mesh fraction (from Table 5-4-5).

of gold in different size fractions of the original sediment have therefore been calculated (Table 5-4-5). Once again, although gold concentrations tend to increase with decreasing grain size, all analysed size fractions of sediments from the McKay-Murex drainage have relatively high gold contents. In Piggott Creek, however, low gold values in the -270-mesh fraction mask the anomalous gold content contributed by the heavy mineral fractions. This is corroborated by a gold content of less than 5 ppm in the -70-mesh fraction of the 10-kilogram sample from the same site (Table 5-4-2).

Regarding the amount of sediment collected and analysed it is important to note that the gold content of the -270-mesh fraction is a major component of the total gold content of a sediment (Table 5-4-6). Thus, where anomalous gold concentrations are present in this fraction, as at Sites 1 and 2 on McKay and Murex creeks, relatively small samples should suffice. This is consistent with the detection of anomalous gold concentrations in -70-mesh sediment at Sites 1 and 2 on McKay Creek using 30-gram fire assay samples. At most sites on Mount Washington this amount of -70-mesh sediment can be obtained from less than 1 kilogram of -10-mesh sediment. However, as noted above, analysis of this fraction does not indicate the presence of anomalous gold values at the site on Piggott Creek.

CONCLUSIONS

The gold potential of Mount Washington could be recognized in low-density surveys with -100-mesh heavy mineral (SG greater than 3.3) concentrates obtained from about 50 kilograms of gravels at high-energy sites. Use of -70-mesh sediment samples also indicates the presence of anomalous concentrations of gold in McKay and Murex creeks but not in Piggott Creek. The latter has the advantage of requiring a much smaller (1 kilogram) field sample than that needed to prepare a representative heavy mineral concentrate.

ACKNOWLEDGMENTS

This study was funded through the Canada/British Columbia Mineral Development Agreement. S. Chase and H. Yuen assisted with sampling. Information provided by J.F. Bristow (Better Resources Limited) and H.P. Wilton (British Columbia Ministry of Energy, Mines and Petroleum Resources) is gratefully acknowledged.

REFERENCES

Better Resources Limited (1987): Mount Washington Precious Metal Project, Vancouver Island, British Columbia, Company Release, January 1987, 8 pages.

Day, S. and Fletcher, K. (1986): Particle Size and Abundance of Gold in Selected Stream Sediments, Southern British Columbia, Canada, *Journal of Geochemical Exploration*, Volume 26, 203-214 pages.

_______ (in press): Effects of Valley and Local Channel Morphology on the Distribution of Gold in Stream Sediments, *Journal of Geochemical Exploration*.

Fletcher, K. and Day, S. (1988): Behaviour of Gold and other Heavy Minerals in Drainage Sediments: some Implications for Geochemical Surveys, *in* Prospecting Areas of Glaciated Terrain, D.R. McDonald and K.A. Mills, Editors, *Canadian Institute of Mining and Metallurgy*, Halifax, 1988, pages 171-183.

Fyles, J.G. (1959): Surficial Geology, Oyster River, Comox, Nanaimo and Sayward Districts, *Geological Survey of Canada*, Map 49-1959.

Muller, J.E. (1968): Geology of Alberni, British Columbia, *Geological Survey of Canada*, Map 17-1968.

NOTES

PRELIMINARY INVESTIGATION OF PLATINUM CONTENT OF SOILS AND SEDIMENTS, SOUTHERN BRITISH COLUMBIA (82E/9, 92H/7, 10, 92I/14)

By W.K. Fletcher
The University of British Columbia

KEYWORDS: Applied geochemistry, platinum, palladium, heavy minerals, soils, stream sediments, Tulameen, Scottie Creek, Franklin Camp.

INTRODUCTION

An almost complete lack of information on the distribution of platinum in soils and sediments is limiting application of exploration geochemical methods to the search for platinum deposits in British Columbia. As part of an ongoing study, this paper reports results of preliminary investigations of the platinum and palladium content of soils and sediments from the Franklin mining district (82E/9) near Grand Forks, from the Tulameen ultramafic complex (92H/7 and 92H/10) and from Scottie Creek, north of Cache Creek (92I/14).

DESCRIPTION OF STUDY AREAS AND SAMPLE LOCATIONS

Study area locations are shown in Figure 5-5-1.

FRANKLIN CAMP (82E/9)

The Franklin camp lies between Franklin and Gloucester creeks approximately 70 kilometres north of Grand Forks. Platinum is associated with pyroxenite bodies in the alkaline Averill plutonic complex (Keep and Russell, 1988). Thomlinson, quoted in Rublee (1986), reported platinum grades between 1.37 and 15.4 grams per tonne in pyroxenite samples carrying pyrite and chalcopyrite. Sperrylite is the major platinum mineral.

Bulk sediment samples were collected from Franklin and Gloucester creeks approximately 0.5 and 2 kilometres above their confluences with Burrell Creek. Soils were sampled in three pits on the Platinum Blonde property. All three sites were on steep slopes where overburden either contained abundant pyroxenite float or consisted of a disintegrated pyroxenite sand. Platinum values ranging from 10 to 45 ppb had been reported from the area in an earlier soil geochemical survey (Placer Dome Inc., personal communication).

TULAMEEN ULTRAMAFIC COMPLEX (92H/7, 92H/10)

The Tulameen ultramafic complex, approximately 25 kilometres west of Princeton, has recently been remapped and its geological history reinterpreted by Nixon and Rublee (1988). Principal ultramafic/mafic units are dunite, olivine and hornblende clinopyroxenites, and gabbroic rocks. The dunite, which forms a core to the northern part of the complex between Olivine and Grasshopper mountains, is deeply dissected by the valley of the Tulameen River. Platinum (and the other platinum group metals except palladium) occur in platinum-iron alloys associated with chromitite pods and schlieren in the dunite (St. Louis *et al.*, 1986; Bohme, 1987, 1988).

The area has been glaciated from the north and till is widely distributed except near the summits of Olivine and Grasshopper mountains and on steep talus-covered slopes. Till and ultramafic colluvium are often mixed in overburden profiles. Fluvioglacial sediments have been deposited along the lower slopes of the Tulameen River valley.

Soil samples were taken from disintegrating dunite colluvium near the summit of Olivine Mountain and from mixed till and dunite colluvium on Grasshopper Mountain. Profile 6 on Grasshopper Mountain is immediately downslope from a platinum-rich chromite showing in the dunite. Sediment samples were collected near the months of Britton and Olivine creeks.

SCOTTIE CREEK (92I/14)

The Scottie Creek chromite showings, approximately 20 kilometres north of Cache Creek and 5 kilometres east of

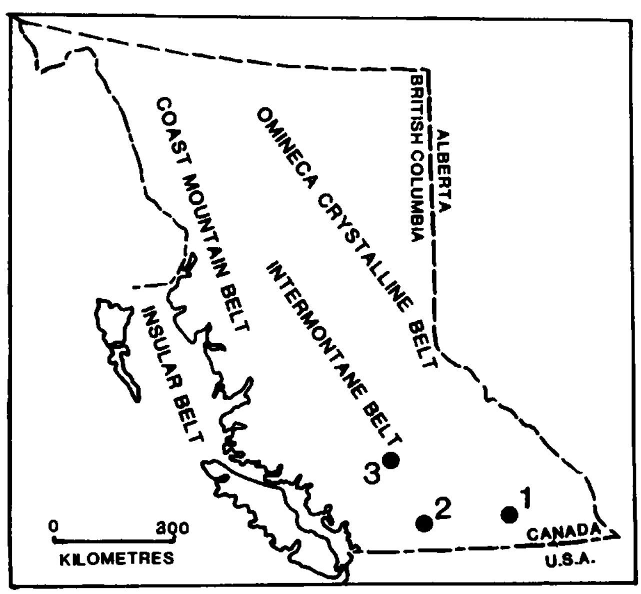


Figure 5-5-1. Location of study areas: 1 – Franklin mining district; 2 – Tulameen ultramafic complex; 3 – Scottie Creek.

Highway 97, are associated with serpentinized peridotites and dunites in Chrome Creek above its junction with Scottie Creek. Thomlinson (quoted in Rublee, 1986) reported values of 1.37 to 4.8 grams per tonne platinum in panned samples from the creek.

Except on the steeper slopes, bedrock is generally concealed beneath thick deposits of glacial till and fluvioglacial sediments. However, the soil profiles sampled were developed on ultamafic colluvium and talus at the base of two knobs of serpentinized ultramafite. A bulk sediment sample was collected from Scottie Creek approximately 1 kilometre below its confluence with Chrome Creek.

METHODS

FIELD SAMPLING

Soil sampling sites were selected, either by resampling sites previously reported to give high platinum values or because of their proximity to known platinum mineralization; this was done to increase the chance of having abnormally high platinum contents. During site selection it was noted that tills and fluvioglacial deposits are important components of the geochemical landscape in all three study areas and that platinum-rich sites usually occur on steeper slopes where locally derived ultramafic colluvium is abundant. At each of the selected sites a soil pit was dug and bulk samples (approximately 10 kilograms) taken of each of the principal soil horizons.

Sediment samples were collected from streams draining platiniferous areas by wet sieving sufficient gravel from a high-energy site to obtain 50 kilograms of 10 mesh material. More comprehensive suites of sediments were collected from the Franklin Camp and Tulameen ultramafic complex by Matysek (1988).

SAMPLE PREPARATION

Wet sieving was used to prepare three soil size-fractions (−10+40, −40+70 and −70 mesh) and seven sediment fractions (−10+40, −40+70, −70+100, −100+140, −140+200, −200+270 and −270 mesh). Sediment fractions between 70 and 270 mesh were then separated into light and heavy mineral density fractions using methylene iodide (SG 3.3). All fractions were dried, weighed, pulverized in a ring mill and split with a Jones riffle to obtain subsamples for analysis.

On the basis of preliminary analytical results and availability of material, heavy mineral concentrates from selected soils were further separated into magnetic and nonmagnetic fractions using a hand-held piston magnet.

ANALYSIS

Samples were submitted to a commercial laboratory for determination of platinum and palladium on 10-gram subsamples using a lead fire assay in conjunction with an inductively coupled plasma mass spectrograph (ICP-MS) finish. Results of replicate determinations are summarized in Table 5-5-1. It is not known to what extent the variability observed reflects analytical variability or lack of homogeneity among 10-gram splits. The latter, however, is likely to be a major source of variation if platinum is present as very rare platinum-rich particles.

TABLE 5-5-1
REPLICATE DETERMINATIONS OF Pt AND Pd: REPLICATES ARE ON SPLITS OF SAMPLES PULVERIZED IN A RING MILL.

Sample No.	Pt (ppb)	Pd (ppb)
87-KF-46	72	228
	74	372
	91	356
	71	243
87-KF-54	143	5
	157	56
	179	38
	235	11
	145	11
UBC-Pt-5	385	4
	389	4
	270	5
	572	4
	435	3
	431	3
	530	4
	231	2

TABLE 5-5-2
Pt AND Pd CONCENTRATIONS (ppb) IN SOILS, FRANKLIN CAMP, SOUTHERN BRITISH COLUMBIA.

Depth (cm)	Horizon	−40+70		−70	
		Pt	Pd	Pt	Pd
Profile 1					
0–20	A	6	9	11	7
20–55	B	7	15	6	14
55–85	C	7	15	22	22
Profile 2					
0–15	A	33	27	21	32
15–75	B/C	11	25	8	4
Profile 3					
0–20	A	31	60	34	88
20–80	B/C	24	128	67	181

RESULTS

FRANKLIN CAMP

Concentrations of platinum and palladium in soils range from 6 to 67 ppb and 4 to 181 ppb, respectively (Table 5-5-2). There is no strong partitioning of either element between the −40+70 and the −70 mesh fractions or between the poorly developed soil horizons. There is, however, a rough relationship between platinum and palladium contents and the abundance of pyroxenite float, with the highest concentrations of both elements in Profile 3 on the edge of a talus slope. This profile consists of about 70 per cent friable, decomposing pyroxenite float. In contrast, the lowest values are in Profile 1 that contains about 10 per cent pyroxenite float.

Platinum and palladium concentrations in all size fractions of light minerals from Franklin and Gloucester creeks are 3 ppb or lower. Concentrations in the heavy mineral fractions are only slightly higher, with a maximum value of 10 ppb (Table 5-5-3). It is interesting to note that O'Neil and Gunning (quoted in Rublee, 1986) reported 1.03 grams per tonne platinum in a panned concentrate taken near the mouth of Franklin Creek, although such a value may easily be influenced by site selection or sample size.

TABLE 5-5-3
Pt AND Pd CONCENTRATIONS (ppb) IN STREAM SEDIMENTS, FRANKLIN CAMP, SOUTHERN BRITISH COLUMBIA.

Size fraction (ASTM)	Lights Pt	Lights Pd	Heavies Pt	Heavies Pd
Franklin Creek				
−70+100	2	3	7	6
−100+140	2	2	3	10
−140+200	2	2	4	9
−200+270	2	2	2	8
−270*			2	3
Gloucester Creek				
−70+100	2	2	3	5
−100+140	2	2	3	6
−140+200	2	2	2	2
−200+270	2	2	3	nd
−270*			2	3

* Lights + heavies.

TABLE 5-5-4
Pt AND Pd CONCENTRATIONS (ppb) IN SOILS, TULAMEEN ULTRAMAFIC COMPLEX SOUTHERN BRITISH COLUMBIA.

Depth (cm)	Horizon	−40+70 Pt	−40+70 Pd	−70 Pt	−70 Pd
OLIVINE MOUNTAIN					
Profile 4					
0–20	A/C	155	3	54	2
Profile 5					
0–25	A	115	3	61	2
25–50	B/C	69	3	26	2
GRASSHOPPER MOUNTAIN					
Profile 6					
0–10	A	27	7	28	2
10–28	B/C	48	6	38	4
28–70	C	22	6	30	6
Profile 7					
0–20	A/C	17	42	15	5

TULAMEEN ULTRAMAFIC COMPLEX

With one exception, palladium values in soils are less than 10 ppb (Table 5-5-4). Associated platinum concentrations range from 15 to 155 ppb with the highest values in residual soils derived from disintegrating dunite near the summit of Olivine Mountain. Heavy minerals from these soils contain up to almost 500 ppb platinum (Table 5-5-5).

In Profile 6, immediately downslope from platinum-rich chromite showings on Grasshopper Mountain, soils on mixed till and dunite colluvium contain 22 to 48 ppb platinum. More detailed studies of the C-horizon of this profile indicate that most of the platinum is in a magnetic heavy mineral fraction that contains from 138 to 210 ppb platinum depending on the size fraction (Table 5-5-5).

Platinum content of stream sediments shows a very clean partitioning between the light and heavy mineral fractions with the latter containing up to 522 ppb platinum (Table 5-5-6). However, distribution of platinum between the different size fractions is erratic and shows no obvious trends.

TABLE 5-5-5
Pt AND Pd CONCENTRATIONS (ppb) IN HEAVY MINERALS (SG>3.3) FROM SELECTED SOIL SAMPLES

Size fraction (ASTM)	Magnetic Pt	Magnetic Pd	Non magnetic Pt	Non magnetic Pd	Combined Mag. & Non mag. Pt	Combined Mag. & Non mag. Pd
Olivine Mtn. (Profile 4, Table 5-5-4)						
−40+70	NO DATA		NO DATA		446	5
−70+100					140	2
−100+140					159	2
−140+200					489	30
−200+270					319	9
Grasshopper Mtn. (Profile 6, Table 5-5-4)						
−40+70	138	6	19	7	NO DATA	
−70+100	202	9	27	37		
−100+140	159	6	16	18		
−140+200	210	7	84	19		
−200+270	204	5	101	27		

TABLE 5-5-6
Pt AND Pd CONCENTRATIONS (ppb) IN STREAM SEDIMENTS, TULAMEEN ULTRAMAFIC COMPLEX, SOUTHERN BRITISH COLUMBIA.

Size fraction (ASTM)	Lights Pt	Lights Pd	Heavies Pt	Heavies Pd
Britton Creek				
−70+100	2	3	336	8
−100+140	2	2	41	6
−140+200	2	2	46	3
−200+270	2	2	522	4
−270*			7	2
Olivine Creek				
−70+100	2	3	25	12
−100+140	3	4	25	1
−140+200	3	5	204	17
−200+270	6	3	329	19
−270*			29	8

* Lights + heavies.

TABLE 5-5-7
Pt AND Pd CONCENTRATIONS (ppb) IN SOILS, SCOTTIE CREEK, SOUTHERN BRITISH COLUMBIA.

Depth (cm)	Horizon	−40+70 Pt	−40+70 Pd	−70 Pt	−70 Pd
Profile 8					
0–45	A/C	2	2	2	4
45–100	C	2	3	3	4
Profile 9					
0–20	A	6	4	8	8
20–60	B	8	5	10	16
60–100	C	10	8	10	31

SCOTTIE CREEK

Platinum and palladium concentrations in soils developed on ultramafic colluvium range from 2 to 10 ppb and 4 to 31 ppb, respectively (Table 5-5-7). Concentrations in both light and heavy mineral fractions of a sediment sample from Scottie Creek are similarly low (Table 5-5-8).

TABLE 5-5-8
Pt AND Pd CONCENTRATIONS (ppb) IN STREAM SEDIMENTS, SCOTTIE CREEK, SOUTHERN BRITISH COLUMBIA.

Size fraction (ASTM)	Lights Pt	Lights Pd	Heavies Pt	Heavies Pd
−70+100	2	3	2	4
−100+140	2	2	2	5
−140+200	2	2	3	3
−200+270	2	2	2	11
−270*			2	2

* Lights + heavies.

DISCUSSION

Although the results are of a very preliminary nature, several aspects of the data may be of general significance:

- As might be expected, concentrations of platinum in soils appear to be crudely related to the amount of ultramafic float present in the soil profile. For example, soils formed from weathered dunite on Olivine Mountain have much higher platinum values than soils from Grasshopper Mountain where till and local dunite colluvium are mixed. Soil geochemical maps for platinum will therefore tend to reflect the extent to which materials derived from different sources have been mixed. It follows that it will be difficult to interpret soil geochemical data unless it is accompanied by information on the distribution of glacially derived material and ultramafic float.
- Partly as a result of dilution by till, platinum concentrations in soils near known platinum mineralization are often below 50 ppb. More reliable results should be obtainable by determining the mode of occurrence of platinum in the soils as a basis for preconcentrating it into a suitable density or mineralogical fraction prior to analysis. Preliminary data from Grasshopper Mountain indicate concentration of platinum into the magnetic, heavy mineral fraction. This, however, requires verification and may not be the case in other areas.
- In the poorly differentiated soils examined in this study, platinum does not show any particular redistribution or trend between either soil horizons or size fractions.
- Where relatively high concentrations of platinum are present in drainage sediments (for example, Britton and Olivine creeks, Tulameen district), there is a very clean partitioning of the platinum into the heavy mineral fraction. The forms of platinum present in the heavy mineral fraction have still to be established.

On the basis of these results, more detailed studies of the distribution and behaviour of platinum and associated elements in the surficial environment are now underway on Grasshopper Mountain in the Tulameen district.

CONCLUSIONS

Platinum concentrations in soils tend to reflect the amount of ultramafic float in the profile. However, as a result of dilution by till, concentrations close to known bedrock occurrences are often less than 50 ppb. In poorly developed soil profiles there is no obvious redistribution of platinum between soil horizons or size fractions. In drainage sediments platinum is very cleanly partitioned into the heavy mineral fraction.

ACKNOWLEDGMENTS

The assistance and cooperation of P. Matysek, British Columbia Ministry of Energy, Mines and Petroleum Resources; D.M. Bohme, Newmont Exploration of Canada Limited; and Placer Dome Inc. is gratefully acknowledged. The study was supported by the Geoscience Research Grant Program through the B.C. Ministry of Energy, Mines and Petroleum Resources.

REFERENCES

Bohme, D.M. (1987): Geological, Geochemical and Geophysical Report on the Grasshopper Claims, Similkameen Mining Division, British Columbia, (92H/10W), *Newmont Exploration of Canada, Limited,* 47 pages.

——— (1988): Report on the 1987 Exploration Program, UM Project on the Grasshopper Claims, Similkameen Mining Division, British Columbia, (92H/10W), *Newmont Exploration of Canada, Limited,* 29 pages.

Keep, M. and Russell, J.K. (1988): Geology of the Averill Plutonic Complex, Franklin Mining Camp (82E/9), *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork, 1987, Paper 1988-1, pages 49-53.

Matysek, P.E. (1988): Applied Geochemistry Subsection, Overview of the First Two Years, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork, 1987, Paper 1988-1, pages 481-487.

Nixon, G.T. and Rublee, V.J. (1988): Alaskan-type Ultramafic Rocks in British Columbia: New Concepts of the Structure of the Tulameen Complex, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork, 1987, Paper 1988-1, pages 281-294.

Rublee, V.J. (1986): Occurrence and Distribution of Platinum-group Elements in British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1986-7, 94 pages.

St. Louis, R.M., Nesbitt, B.E. and Morton, R.D. (1986): Geochemistry of Platinum Group Elements in the Tulameen Ultramafic Complex, Southern British Columbia, *Economic Geology,* Volume 81, pages 961-973.

Data
Systems

THE SEARCH-AND-REPORT POWER OF MINFILE/pc©*

By L.D. Jones

KEYWORDS: MINFILE, mineral inventory, MINFILE/pc, search program, mineral deposit, commodity, MINGRAPH, Tulsequah, Golden Bear, terrane, query, computer database.

INTRODUCTION

MINFILE/pc, Version 2.0, is a search-and-report program that operates on a set of files containing locational, mineralogical, geological, reserve and production information, all related to a unique mineral occurrence. There are over 10 000 documented occurrences within British Columbia, ranging from small showings to large producing deposits. The complete mineral occurrence file is collectively known as MINFILE.

MINFILE/pc is one of the tools used to interrogate the MINFILE database and may be used to compile information on known mineral occurrences in the province. The program provides answers on the relationships between economic and geologic features of an area, thus providing a basis for further investigation.

MINFILE is a compilation of historic and current exploration data and is thus sometimes limited by incomplete or inaccurate reporting. It is, at the same time, one of the most extensive mineral occurrence databases available. Users of the MINFILE system should understand how the data are collected and stored before attempting to "navigate" and query the database.

The purpose of this article is to describe the MINFILE/pc system, the type of information available, how it may be used, and how the results of a search may be expressed quantitatively and qualitatively. Its usefulness as a searching tool will be demonstrated using examples from a selected area.

THE MINFILE/pc SYSTEM

MINFILE/pc is a stand-alone, menu-driven program, operating in the MS-DOS environment of personal computers. The program requires at least 512 kilobytes of RAM, a 5¼ inch floppy-disk drive, and a hard-disk drive with sufficient space to accommodate the set of distributed data files and their subsequent configuration. A 1000-occurrence subset of ASCII data requires about 4 megabytes of disk space, the configured dataset requires another 4 megabytes of disk space, and the MINFILE/pc system program requires 0.35 megabytes, for a total of 8.35 megabytes. The 10 000-occurrence ASCII dataset for the province of British Columbia is presently about 20 megabytes and contains updated data for only 50 per cent of the known occurrences. The province-wide database, when completed, is expected to reside on a hard drive of at least 40 megabytes, or preferably a 70-megabyte drive, to allow for supporting software.

MINFILE/pc has the ability to interrogate the provincial mineral database as a series of manageable subsets. The locational subset includes data such as latitude and longitude, UTM coordinates, NTS map number, mining division, tectonic belt, physiographic region or terrane. Subsequent search criteria could include: commodity, status, deposit name, mineralogy, host rock/mineral age, deposit character and classification, lithology, formal/informal host names, deposits with production, and deposits with reserves. On most of the screens, search parameters are presented to the program using Boolean algebra (AND, OR, NOT) expressions.

Several fields in the MINFILE database are ranked; these include the occurrence status, commodity, mineral, and lithology fields. The status, or stage of development, of the occurrence is ranked as showing, prospect, developed prospect, producer or past producer.

Commodities are ranked in decreasing order of importance, based on perceived economic significance and amount of significant minerals. Ranking is sometimes biased, commodity listings for a deposit tend to use such conventions as gold-silver and lead-zinc rather than silver-gold and/or zinc-lead regardless of the relative abundance or value of the metals. Such paired commodities may be better dealt with by combining them in a search. Commodities recorded in the database may be present in any amount and do not have to be economically recoverable.

The variety of deposit models and classifications presents difficulties in attempting to describe deposit types. Occurrences in MINFILE are categorized according to "deposit character", which is derived from field observations, and "deposit classification", which is an interpretation of the genesis of an occurrence. More than one character and classification of an occurrence may be listed in the database.

An appreciation of the way MINFILE data are recorded permits the user to draw meaningful conclusions regarding the significance of the occurrence and the recorded data.

Reports resulting from a MINFILE/pc search may include standard data format files, tabular reports, capsule geology and bibliography reports and a master report. A standard data format (SDF file) is used in a plotting program known as MINGRAPH. The SDF file includes the MINFILE number, occurrence name, commodities, status, latitude/longitude, UTM coordinates and NTS map number. The tabular reports may be sorted by commodity, name, NTS map sheet and MINFILE number. A capsule geology and bibliography report presents summary information on the occurrence and the master report provides the complete data on the occurrence. These reports are generated using a runtime module of R&R Relational Report Writer.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

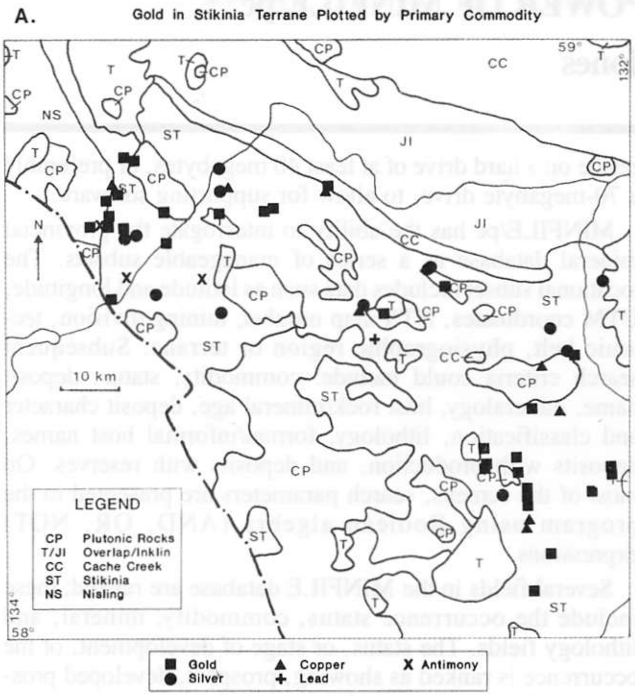
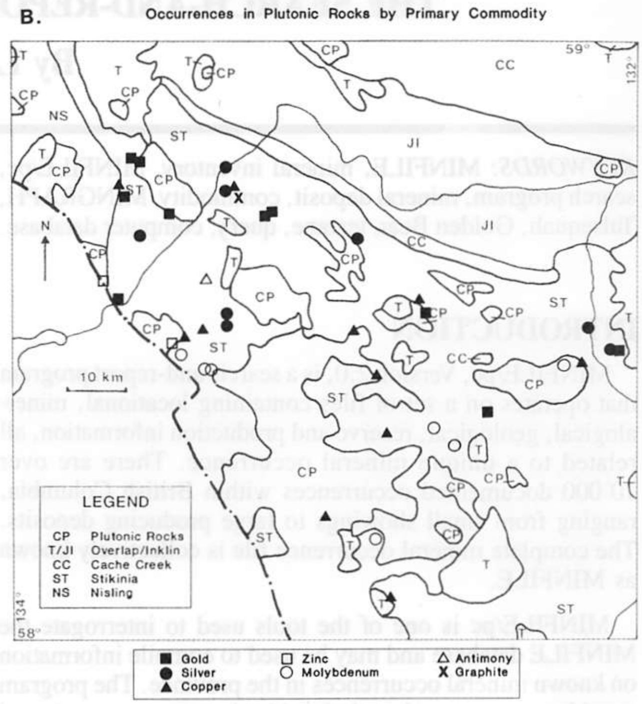
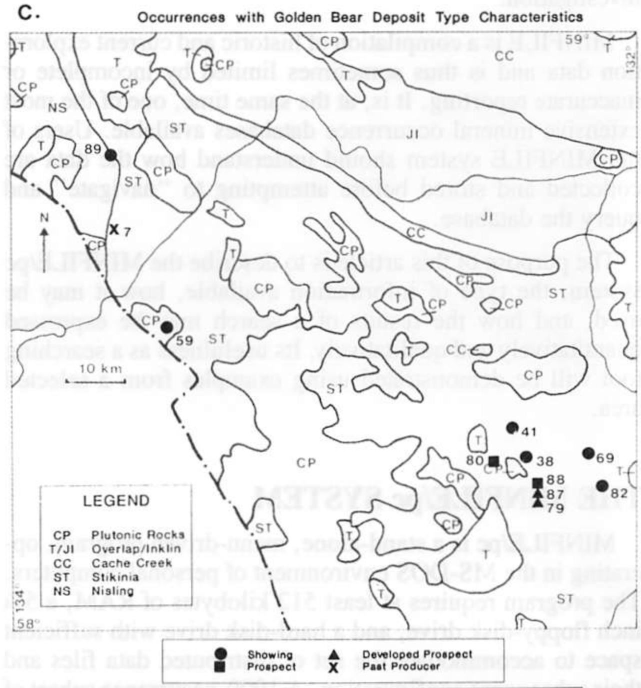


Figure 6-1-1. Plots generated by MINGRAPH on terrane base map of 104K.





MINFILE NO	NAME	COMMODITIES
104K 007	BANKER	Ag,Au,Pb,Zn,Cu
104K 038	TATSAMENIE L	Ab,Tc
104K 041	TATSAMENIE LAKE WEST	Cu
104K 059	WRIGHT GLACIER	Cu,Ag,Mo
104K 069	TATSAMENIE LIMESTONE	Ls
104K 079	MUDDY LAKE	Au,Ag
104K 080	TUT	Au,Ag,Sb,Pb,Cu,Zn,As
104K 082	SLAM	Au,Ag,Sb,As,Hg
104K 087	FLEECE BOWL	Au,Ag
104K 088	TOTEM SILICA	Au,Ag
104K 089	ONO	Au,Ag,Pb,Zn,Cu,Ar,Su

HOW MINFILE/pc CAN BE USED

Statistical graphs and plots of the search, such as histograms, bar and pie charts, and tables may be displayed using a presentation graphics package. In this case Harvard Graphics was used. The companion graphics program, MINGRAPH, generates MINFILE occurrence location plots based on the results of a MINFILE/pc search. These plots, referred to as commodity maps, thematic maps, dot density, or even scatter plots, illustrate mineral distribution patterns and their relationships to regional geology. The maps may show single, multiple, or dominant commodities and can be displayed at a variety of scales, using a variety of symbols and labels.

Presently MINGRAPH is used to plot mineral inventory maps at a 1:250 000-scale, with 1:50 000-scale inserts when required. These will be available on a geological base map. Geochemical distribution maps are also available at the same scale. Representation of the data as histograms, statistical charts, tabular reports and maps, provides a quantitative and qualitative analysis of the frequency and distribution of mineral occurrences and ranking of information.

These MINFILE tools are an invaluable aid in developing exploration strategies, evaluating resource potential, land-use planning and carrying out metallogenic studies.

TEST CASE — THE TULSEQUAH MAP SHEET (104K)

The Tulsequah map sheet (104K) is used here as an example to show the power of MINFILE/pc. Questions were asked to illustrate the frequency and distribution of known commodities and deposit types within the different terranes of the area. Also some specific queries are listed with examples of MINFILE/pc reports. The 116-occurrence dataset available for this map sheet limits the scope of the analysis; a larger dataset would allow a more meaningful interpretation. Histograms and maps are presented to document the results of the searches.

The 104K map area covers parts of the Coast and Intermontane belts. The east half of the area is underlain by intensely folded and regionally metamorphosed Permian, Triassic and older strata of the Stikine terrane. These rocks host epigenetic gold deposits, such as the Golden Bear. The west half of the map sheet covers the Tulsequah Chief and Big Bull volcanogenic massive sulphide deposits. These occur within Upper Triassic volcanics of the Stikine terrane, in a wedge between the Cache Creek terrane and Coast plutonic complex.

Lithotectonic terranes are areas with rock assemblages distinct from their neighbours. They are generally bounded by major faults, although these may be interrupted by overlap assemblages or intrusions. The Nisling, Stikine, and Cache Creek terranes are represented in the 104K map area. Although the overlap assemblages and intrusive bodies do not constitute a terrane in the normal definition, they are treated as such in MINFILE. Gold, silver, copper, lead, zinc, molybdenum and antimony were searched and the frequency and distribution of occurrences charted and plotted by terrane (Figures 6-1-1A and 1B, and 6-1-2). The distribution of anomalous stream sediments determined by the Regional Geochemistry Survey (RGS) were also noted within each terrane.

The deposit character and classification fields were searched to derive the number and distribution of deposit types associated with each terrane (Figure 6-1-2B). The deposit-type search included vein, skarn, porphyry and stratabound/stratiform, including volcanogenic. A search of occurrences by terrane will often produce duplication as many lie near terrane boundaries. Isolating these duplicates will highlight occurrences associated with this geological setting.

The Nisling terrane is a metamorphosed Proterozoic to lower Paleozoic passive continental margin assemblage, with carbonaceous and siliceous offshelf sediments. This terrane, which underlies only a small area in the northwest quadrant of the 104K map area, contains three documented mineral occurrences; all are veins containing gold, with some containing silver, copper and antimony.

The Stikine terrane consists of Devonian to Permian arc volcanics and platform carbonates, overlain by Triassic and Lower Jurassic arc volcanics, volcaniclastics and chert, and intruded by comagmatic plutonic rocks. Over 80 per cent of the known occurrences in 104K lie within this terrane which underlies about half the map area. The ordered frequency of commodities is silver, gold, copper, lead, zinc, antimony and molybdenum. However, a search of the dominant or primary commodity reveals a ranking order of gold, silver, copper, molybdenum, antimony, zinc and lead. The distribution map (Figure 6-1-1A) shows that the Stikine terrane apparently hosts primarily polymetallic mineralization in the western part of the map area and dominantly gold, silver, and copper mineralization in the east. Stream sediments reflect a distribution of anomalous lead in the Tulsequah area, copper in the east part of the Stikine terrane, and gold, silver and arsenic scattered throughout this terrane.

The Stikine terrane also displays the greatest variety of deposit types. The ranked order is vein, stratabound, and a roughly equal number of skarn, porphyry and volcanogenic occurrences.

The Cache Creek terrane consists of Mississippian to Upper Triassic oceanic volcanics and sediments, including radiolarian chert, argillite and basalt, shallow-water carbonate and alpine ultramafics. It underlies approximately 10 per cent of the map area in its northeast corner and contains about 13 per cent of the known mineral occurrences. Ranked commodities are silver, gold, equal lead, antimony and zinc, and equal nickel and copper. None of the commodities are dominant except nickel, which is also concentrated within stream sediments in the Cache Creek terrane and its overlap assemblage (Inklin). Known deposits in this terrane are mainly vein and stratabound types and a skarn deposit.

Post-terrane-accretion overlap assemblages include the Jurassic Inklin on the Cache Creek terrane and other undifferentiated Jurassic to Tertiary assemblages, which occur largely on the Stikine terrane. The commodities present are mainly copper and silver, with minor lead and gold. In the

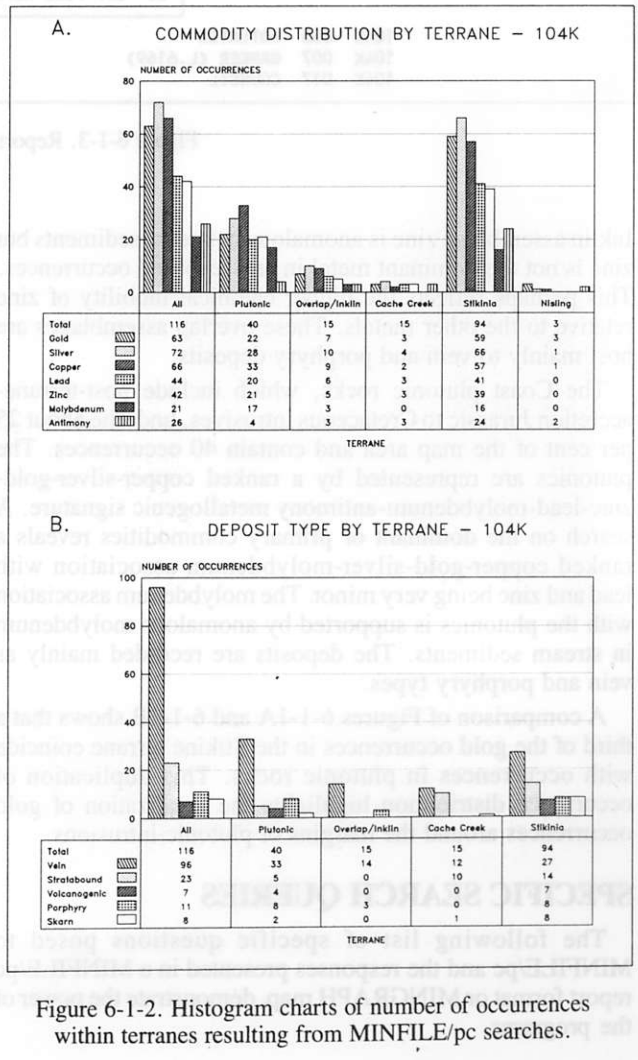


Figure 6-1-2. Histogram charts of number of occurrences within terranes resulting from MINFILE/pc searches.

A. NTS MAP NUMBER-INDEX REPORT FROM QUERY NUMBER 1

NAME	MINFILE NO	NTS	COMMODITIES	LATITUDE	LONGITUDE	UTM	NORTH	EAST	R	P
BIG BULL	104K 008	104K12E	AG AU CU ZN PB BA	58 40 08	133 32 48	08	6503900	584300	Y	Y
ERIKSEN-ASHBY	104K 009	104K11W	AG PB ZN AU	58 39 30	133 28 23	08	6502800	588600	Y	
ERIKSEN-ASHBY ZONE 8	104K 021	104K11W	AG PB ZN RO	58 40 05	133 28 12	08	6503900	588750	Y	
TULSEQUAH CHIEF	104K 002	104K12E	AU AG ZN CU PB CD	58 44 10	133 35 57	08	6511300	581100	Y	Y
YELLOW BLUFF	104K 049	104K11U	AU PB ZN AG CU	58 42 26	133 27 50	08	6508250	589000		

B. COMMODITY-INDEX REPORT FROM QUERY NUMBER 2

NTS	MINFILE NO	NAME	COMMODITIES	LATITUDE	LONGITUDE	UTM	NORTH	EAST	R	P
OCCURRENCES CONTAINING COMMODITY -: AG Silver										
104K10W	104K 107	BARB	AU AS SB AG	58 45 01	132 53 42	08	6513950	621800	Y	
104K14W	104K 054	KING SALMON CREEK	PB AG	58 47 54	133 12 48	08	6518750	603250		
OCCURRENCES CONTAINING COMMODITY -: AS Arsenic										
104K10W	104K 107	BARB	AU AS SB AG	58 45 01	132 53 42	08	6513950	621800	Y	
OCCURRENCES CONTAINING COMMODITY -: AU Gold										
104K10W	104K 107	BARB	AU AS SB AG	58 45 01	132 53 42	08	6513950	621800	Y	
OCCURRENCES CONTAINING COMMODITY -: PB Lead										
104K14W	104K 054	KING SALMON CREEK	PB AG	58 47 54	133 12 48	08	6518750	603250		
OCCURRENCES CONTAINING COMMODITY -: SB Antimony										
104K10W	104K 107	BARB	AU AS SB AG	58 45 01	132 53 42	08	6513950	621800	Y	

C. SDF FILE REPORT FROM QUERY NUMBER 3

104K 006	POTLATCH	AUAGPBZNCU	SHOW0858200065045001 04K12E584013335
104K 007	BANKER (L.6169)	AGAUPBZNCU	PAPR08582600650390010 4K12E584013334
104K 017	COUNCIL	SBAUAGNI	SHOW085828006496000104K12E583513334

Figure 6-1-3. Reports generated by MINFILE/pc.

Inklin assemblage zinc is anomalous in stream sediments but zinc is not the dominant metal in any recorded occurrences. This perhaps reflects the higher chemical mobility of zinc relative to the other metals. These overlap assemblages are host mainly to vein and porphyry deposits.

The Coast plutonic rocks, which include post-terrane-accretion Jurassic to Cretaceous intrusives, underlie about 25 per cent of the map area and contain 40 occurrences. The plutonics are represented by a ranked copper-silver-gold-zinc-lead-molybdenum-antimony metallogenic signature. A search on the dominant or primary commodities reveals a ranked copper-gold-silver-molybdenum association with lead and zinc being very minor. The molybdenum association with the plutonics is supported by anomalous molybdenum in stream sediments. The deposits are recorded mainly as vein and porphyry types.

A comparison of Figures 6-1-1A and 6-1-1B shows that a third of the gold occurrences in the Stikine terrane coincide with occurrences in plutonic rocks. This duplication of occurrence distribution highlights the localization of gold occurrences around the margins of plutonic intrusions.

SPECIFIC SEARCH QUERIES

The following list of specific questions posed to MINFILE/pc and the responses presented in a MINFILE/pc report format or MINGRAPH map, demonstrate the power of the programs.

(1) **List the mineral occurrences representative of Kuroko-style stratiform, volcanogenic, massive sulphide deposits.**
Here deposit classification (volcanogenic) then character (stratiform) were searched, resulting in the five occurrences listed by NTS map number in Figure 6-1-3A. The "R" and "P" in the heading indicate that reserve and production data are in the database.

(2) **List the gold or silver occurrences reported to be associated with limestone of the Sinwa Formation of the Upper Triassic Stuhini Group.**
A search on the Sinwa Formation, followed by limestone, then gold or silver, produced two occurrences. These are listed in Figure 6-1-3B, which is an example of the commodity index report.

(3) **What gold occurrences are associated with mariposite?**
A gold commodity search, followed by a mineralogy search for mariposite produces the SDF file in Figure 6-1-3C, which may be used in MINGRAPH for plotting.

(4) **How many porphyry copper-molybdenum occurrences are associated with the boundary between the Coast and Intermontane belts?**

The parameters listed in the request may be obtained from MINFILE/pc, however, the relationship with the tectonic belt boundary is presently unavailable as the location search may be carried out only once with the entire database, not a subset of the data. However, an appreciation of the distribution of the occurrences can be obtained from viewing a plot on a map containing these belts. There are nine porphyry copper-molybdenum occurrences, five of which lie within 5 kilometres of the belt boundary.

(5) **The Golden Bear deposit, which is considered to be epithermal, is described in MINFILE as containing quartz, dolomite and pyrite as alteration minerals within tuff, limestone and breccia of Permian age. Are there similar occurrences in the map area?**

Here, 116 occurrences in 104K containing one or all of the alteration minerals are searched; 63 occurrences are reported. Then the rock types are searched, reducing the listing to 34 occurrences. Finally, the search is confined to rocks of Permian age to produce a list of 11 occurrences, all in the Stikine terrane. These are plotted on Figure 6-1-1C.

One is indeed the Golden Bear deposit and two others are nearby deposits, the "developed" Fleece Bowl and the "undeveloped" Totem Silica. Two silicified limestone showings with gold and silver, the Tut and Slam, may also have epithermal characteristics. Two of the results were polymetallic deposits, occurring to the northwest, and two were minor copper occurrences. The vein mineralization in these occurrences has a similar geological setting to the Golden Bear. An asbestos prospect and a limestone occurrence have a similar geological setting but contain no precious or base metals. These results illustrate how the MINFILE/pc search module can be used to identify known occurrences similar to the Golden Bear.

CONCLUSIONS

A quantitative study of the data resulting from MINFILE/pc searches reveals differences in the number of occurrences from one terrane to the next. These differences may be due to such variables as geology, intensity of exploration, outcrop density and area of the terrane.

The Stikine terrane has a polymetallic signature and hosts several types of deposits, small precious metal veins, skarn deposits, and large precious and base metal volcanogenic deposits. The plutonic rocks host similar commodities and deposit types, however, copper-molybdenum porphyry deposits are dominant.

An examination of the thematic maps reveals an uneven distribution of mineral occurrences within the terranes. However, clustering is observed in the Tulsequah area and a gold-vein mineral trend is seen along the north-northwest-trending fault in the Golden Bear area. Many occurrences are located along terrane margins and plutonic contacts.

Only three parameters, commodities, deposit types and terranes were used to provide this simple quantitative and qualitative analysis. The many searchable parameters of MINFILE/pc can provide a meaningful starting point in the evaluation of mineral resource potential in an area. The more explored, exposed and geologically understood areas may be used as models for the less known areas.

ACKNOWLEDGMENTS

I would like to acknowledge and thank the contributions to the MINFILE project by G. Lowe, B. Grant, A. Wilcox and the MINFILE team, consisting of C. Borsholm, E. Kneffel, G. Payie, L. Duffett, D. Jakobsen, W. Vanderpoll, S. Dumais, J. Rouse, G. McGee, and K. Aheirs.

REFERENCES

Grant, B. (1988): MINFILE Coding Manual, Version 3.2, *B.C. Ministry of Energy, Mines and Petroleum Resources*.

ESL Environmental Sciences Limited (1988): MINGRAPH/pc User's Guide.

Wilcox, A.F. (1988): New MINFILE – A Mainframe and Personal Computer Based Mineral Inventory Database, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1.

Sinclair, A.J., Wynne-Edwards, H.R. and Sutherland Brown, A. (1978): An Analysis of Distribution of Mineral Occurrences in British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 68.

Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W., and Woodsworth, G.J. (1988): Terrane Map of the Canadian Cordillera, *Geological Survey of Canada*, Open File 1894.

NOTES

LITHCHEM — GEOLOGICAL DATABASE SYSTEM: RECENT DEVELOPMENTS*

By Z.A. Radlowski and A.J. Sinclair
The University of British Columbia

KEYWORDS: Whole-rock chemistry, volcanic rocks, record format, system structure, search routines, graphics, LITHCHEM.

INTRODUCTION

LITHCHEM is a database system for storage, retrieval and graphic representation of whole-rock geochemical data. The first version of the LITHCHEM system was described by Harrop and Sinclair (1986). Since then, the system has been developed further. This paper briefly describes the structure and operational routines of the latest version, with emphasis on the recent achievements and developments. A detailed reference manual is available from the Department of Geological Sciences, The University of British Columbia. The system presently contains analyses of more than 2000 volcanic rock specimens from the Cordillera of British Columbia (Radlowski, 1988).

SYSTEM OBJECTIVE

LITHCHEM is designed for the following tasks: input and editing of lithogeochemical data, searching for individual records by various key data fields, plotting sets of records on a variety of petrogenetic, two-coordinate diagrams, and generating data subsets by selection based on graphical domains. These detailed procedures permit sequential selection of lithogeochemical data specifically to distinguish altered and unaltered samples in the existing compilation of chemical analyses of volcanic rocks in British Columbia.

HARDWARE/SOFTWARE REQUIREMENTS

The LITHCHEM system is written in Turbo Pascal and configurated for the IBM PC(XT) with 576k RAM, 10 megabytes (or more) hard disk storage, IBM CGA, running under MS/DOS 3.0 or later versions. In addition, an 8087 numerical coprocessor is highly recommended. Any dot matrix printer which can perform a graphics screen dump can be used for hardcopy output.

RECORD FORMAT

A primary element of the database is a record that represents information for a single sample. A new record is always entered at the end of the data file, hence a record number becomes an unique sample identifier.

A sample record consists of 24 fields that are either numerical or string type. The string fields contain geological names (assemblage, formation, rock name/occurrence, age) or they describe a sample location (NTS map sheet, details of stratigraphic unit). The numerical fields represent geochemical analyses (12 major oxides and volatiles) and specify a bibliographic reference (reference number and sample number). The record format can be modified or expanded with minor changes to the program.

SYSTEM STRUCTURE

The LITHCHEM system consists of two main programs, LITHED (Editor) and LITHP (Plotter), supported by a number of external subprograms and routines. The Editor and the Plotter comprise about 6000 lines each of source code, and the system requires approximately 120 kilobytes, plus 100 to 500 kilobytes for lithogeochemical data.

LITHCHEM is a menu-driven system with several options available from the Editor and/or the Plotter. The main menu commands relate to the following procedures:

- Editing and updating records
- Database file maintenance
- Compound search for records
- Graphic display
- Conversion of a LITHCHEM datafile to ASCII datafile and vice versa.

The LITHCHEM edit procedures have remained unchanged from those discussed by Harrop and Sinclair (1986). The file maintenance procedures are of marginal importance and are not discussed here. The most important achievement of the latest versions of the system is an extended development of the search and graphic procedures, and implementation of ASCII conversion routines.

SEARCH ROUTINES

LITHCHEM provides search routines to create, modify and maintain sets of data records. This procedure introduces two important concepts: source and target. The routines work with a general algorithm that searches in the source and processes in target. It is mandatory to specify explicitly which source is to be searched, and which target is to be processed; therefore, the system employs a flag concept. Each record has a 16-bit integer associated with it and 15 of these bits are used to signify a set membership. If the nth bit is ON, the corresponding record is a member of the set flagged with n-flag. The search source can be a whole database or an active flag, hence the source cannot be empty. The target might be an inactive flag unless the target and source are the same.

The search routines operate with the following sub-menu:

(1) Create set
(2) Remove set
(3) Join set
(4) Display set
(5) Rename set
(6) Clear set.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

When a search command is executed, the submenu is activated and the flag lists are displayed on the screen. The flags are labelled from 1 to 15 and these labels function as flag identifiers. All active flags are associated with names entered by the user or generated by the system. In other words, the flag labels without names are currently empty. Although the flag name is not a set identifier it is still a valid indicator of the set presence. The algorithm assumes that a set contains at least one record, and a zero-size set means a set absence.

GRAPHIC ROUTINES

LITHCHEM provides several graphic routines to plot the flagged set(s) and to generate subsets by plot domains. The plot routine involves a submenu with functions keyed from 0 to 8. The function "0" (zero) sets graphic characters for plotting and it should be executed first. The program allows the user to set up to eight graphic symbols that will identify sets (flags) on all diagrams unless "zero" option is rerun.

The selected sets are displayed on plot diagrams while executing the menu functions 1 to 8. The diagram appears with specific curves contouring domains of rock compositions. The program mostly deals with two boundary curves that divide a plot plan into three domains. Each sample of the set can then be identified by its location on the plot diagram and a domain membership. The system introduces a new search procedure that enables the user to split (subset) the set into domains. This routine is called from the selected diagram, and can be applied only to one set at a time.

The "subset" routine works with the following algorithm:

- Identify all samples above the upper curve (or right to the rightmost curve) and move them from the parent set to the first available flag; generate a name for the new set by adding a prefix predefined for the upper/right domain to the parent name.
- Search for all samples below the lower curve (or left to the leftmost curve), proceed as above, adding a prefix predefined for the lower/left domain to the parent name.
- Rename the remainder of the parent set by adding a prefix predefined for the central domain.

As a result, the "subset" procedure creates three smaller sets of which an arithmetic sum is equal to the parent set. These sets are recognized by all LITHCHEM procedures as independent sets, can be further processed with search or plot routines and can be subset again.

At present, the possible plots for graphic representation are: MgO vs. CaO, MgO vs. SiO_2, CaO vs. SiO_2, Na_2O vs. SiO_2, K_2O vs. SiO_2, alkaline vs. SiO_2, TiO_2 vs. FeO total, and MgO vs. FeO total. Others can be added easily, as required.

CONVERSION ROUTINES

LITHCHEM provides conversion routines to translate its database into ASCII, and vice versa. Any set of the LITHCHEM data, or a whole database, may be converted into a text file with records of a fixed format. An ASCII file can be converted to the LITHCHEM database if its records have the required structure and format. This means that the file should be checked as to record organization, and modified if necessary, prior to conversion to the LITHCHEM system.

The conversion routines are an important linkage between LITHCHEM and other systems, and allow an easy exchange of data.

CONCLUSIONS

LITHCHEM is a powerful tool for sorting, extracting, and grouping rock-chemistry records. Its search and plot routines can be applied repeatedly in different combinations, allowing one to select and display a very specific set of records.

The system is fully operational with a database of the whole-rock analyses of volcanic rocks of British Columbia compiled by A.F. de Rosen-Spence. The database has been used principally to define magmatic trends in various magmatic suites (de Rosen-Spence, 1985; de Rosen-Spence and Sinclair, 1987, 1988; Ray and de Rosen-Spence, 1986). It is presently being used to assist in the recognition of alteration in samples of volcanic rocks, and is being developed to further quantify alteration associated with mineralization in volcanic rocks, in cooperation with X. Cheng.

ACKNOWLEDGMENTS

This work has been supported by the Canada/British Columbia Mineral Development Agreement, The Science Council of British Columbia and the Natural Sciences and Engineering Research Council of Canada. The assistance of Dr. A.F. de Rosen-Spence is appreciated.

REFERENCES

de Rosen-Spence, A. (1985): Shoshonite and Associated Rocks of British Columbia. *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1984, Paper 1985-1, pages 426-442.

de Rosen-Spence, A., and Sinclair, A.J.(1987): Classification of the Cretaceous Volcanic Sequences of British Columbia and Yukon, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1986, Paper 1987-1, pages 419-427.

——— (1988): Lower Jurassic Volcanism of the Stikine Super-terrane, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1987, Paper 1988-1, pages 211-216.

Harrop, J.C., and Sinclair, A.J.(1986): Lithchem: An Integrated Geological Database for Microcomputers; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1985, Paper 1986-1, pages 285-287.

Radlowski, Z.A. (1988): Lithchem System: Reference Manual. Department. of Geological Sciences, *The University of British Columbia*.

Ray, G.E., and de Rosen-Spence, A. (1986): The Potassium-rich Volcanic Rocks at Tillicum Mountain–Their Geochemistry, Origin, and Regional Significance (82F/13, 82K/4). *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1985, Paper 1986-1, pages 45-49.

PTA SYSTEM: A SOFTWARE PACKAGE FOR MICROCOMPUTER CALCULATION AND DISPLAY OF ACTIVITY-TEMPERATURE-PRESSURE PHASE DIAGRAMS*

By Robert G. Berman, and Thomas H. Brown
The University of British Columbia
Ernest H. Perkins, Alberta Research Council

KEYWORDS: Computer software, PTA system, phase diagrams.

INTRODUCTION

In recent years, geologists have come to depend more and more on the use of phase diagrams to elucidate conditions of formation of a wide variety of rock types. Activity (A) diagrams are one type of phase diagram that has proved to be extremely valuable in providing a window to understanding processes involved in the genesis of economic mineral deposits. This report describes a recently completed IBM-compatible microcomputer program for the rapid calculation and display of a variety of such diagrams. With the development of accurate thermodynamic databases for minerals and aqueous species (see below), this program provides a powerful tool for understanding the physiochemical controls on formation of ore deposits. Copies of the program may be obtained by contacting the senior author.

GENERAL DESCRIPTION

Geo-Calc is a microcomputer software package consisting of programs for calculation of phase diagrams, thermodynamic databases for minerals and aqueous species, and auxiliary programs for viewing and printing of computed phase diagrams. The two main ingredients of the Geo-Calc package are the programs PTX-SYSTEM and PTA-SYSTEM. PTX-SYSTEM calculates complete pressure-temperature (P-T), temperature-composition (T-XH_2O-CO_2), and pressure-composition (P-XH_2O-CO_2) phase diagrams and has been previously described (Perkins *et al.*, 1986; Berman *et al.*, 1987; Brown *et al.*, 1988). PTA-SYSTEM, completed recently and described below, calculates activity-activity (A-A), temperature-activity (T-A) and pressure-activity (P-A) phase diagrams, where activity refers to the thermodynamic activity (or ratio and/or products of activities) of any mineral, gaseous or aqueous species.

The minimum hardware requirements for using the software are an IBM or compatible personal computer with 640K memory, and graphics card (CGA, EGA, or Hercules). Although a math coprocessor is not required, calculations with the PTA program proceed between six to ten times faster with a coprocessor installed. The PTA Version 2.0 release includes the programs described below.

SOFTWARE PROGRAMS

PTA: The PTA-SYSTEM program has been adapted for microcomputer use from mainframe programs that are available from E.H. Perkins. The major differences between the mainframe version and this implementation are that the three mainframe programs have been combined into one program, user input is simplified, several run-time options have been modified or removed, and the program generates and calculates each reaction separately rather than generating coefficients for all reactions before calculating any individual reaction. This last modification was necessary because of the limited memory available on most microcomputers for calculating and storing a large number of reaction coefficients.

Execution times are dependent on hardware, the most important component being the math coprocessor speed. In general, AT-compatibles run approximately 1.5 to 2 times faster than XT-compatibles and 386 machines run up to 10 times faster than XTs. Computation time is also affected by run-time options, increasing dramatically when calculations are carried out in the vicinity of the critical point of water. Activity-activity diagrams are calculated many times faster than temperature-activity and pressure-activity diagrams because the Gibbs free energy functions need to be calculated only once in a given run. Total execution time, with a math coprocessor installed, should be in the order of seconds for systems with less than a hundred possible reactions, minutes for systems with several thousand possible reactions, and hours for systems with more than several hundred thousand possible reactions.

The output of PTA-SYSTEM can be plotted for visual representation of phase relations or inspected from a table. The program evaluates all possible reactions in the user-specified PTA space. At the user's option, each point of every reaction is tested for stability with respect to all other phases in the system, and metastable extensions are eliminated. If a curve is completely outside the pressure-temperature-activity limits of the diagram, any remaining reactions containing the metastable assemblage are removed from further consideration. Finally, all curves written to the plot file are labelled with stable assemblages. Run-time options include setting the pressure-temperature-activity limits of the diagram, the selection of ideal or non-ideal H_2O-CO_2 (only for systems that do not involve aqueous species), and the specification of fixed phase or species activities. The user can also specify that only curves stable in the presence of a given

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

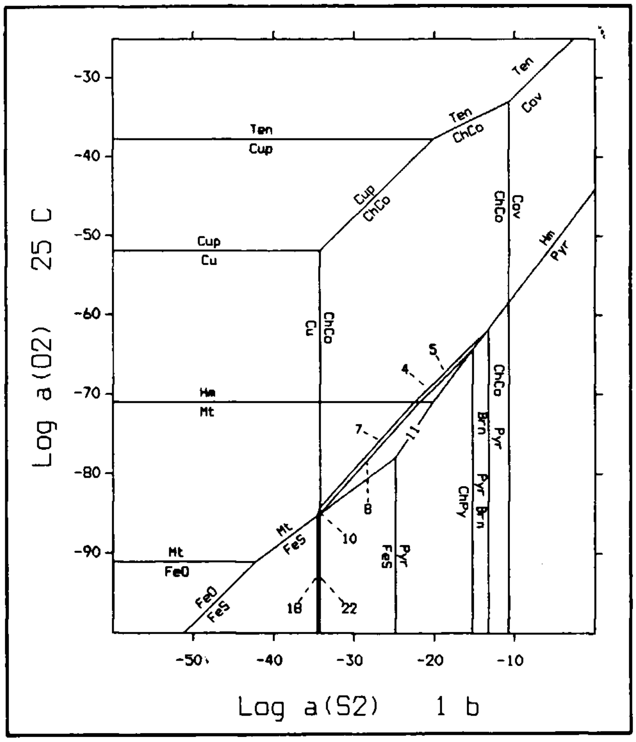


Figure 6-3-1. LASER plot of Log aS_2 vs. Log aO_2 diagram for the system Cu-Fe-S-O at 25°C and 1 bar. The unlabelled stability field in the lower centre of the diagram is that of bornite.

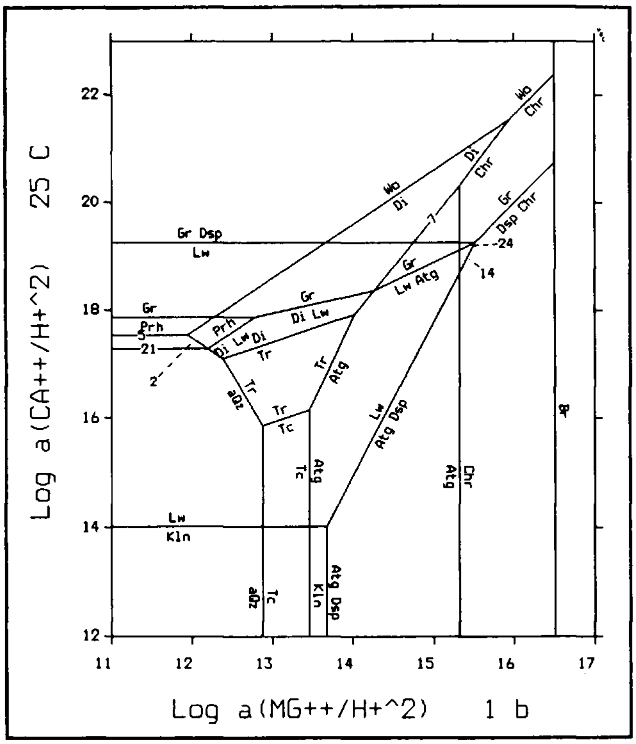


Figure 6-3-3. LASER plot of Log $aMg^{++}/(H^+)^2$ vs. Log $aCa^{++}/(H^+)^2$ diagram for the system CaO-MgO-Al_2O_3-SiO_2-H_2O at 25°C and 1 bar.

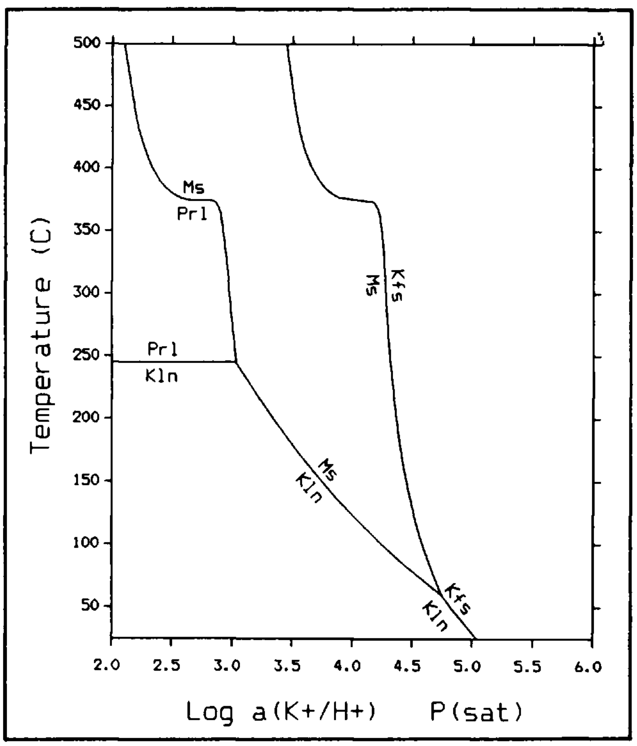


Figure 6-3-2. LASER plot of Temperature vs. Log aK^+/aH^+ diagram (projected from quartz) for the system K_2O-Al_2O_3-SiO_2-H_2O with pressure fixed by the boiling curve of water.

phase or assemblage be computed, so that the stability fields of particular phases or assemblages can be readily identified.

Progress of the calculation can be followed in graphics or text mode. In graphics mode, each reaction curve is plotted on the screen as it is calculated, allowing the user to follow the search strategies and to see the phase diagram take shape. In text mode, calculations are summarized on a text screen which shows the current reaction being examined, the number of reactions already calculated, and an estimate of the percentage of reactions remaining to be calculated.

PTA-system allows one to calculate any phase diagram using the variables P, T, or A (the activity of any phase or species), and faithfully calculates equilibrium curves defined by the equality of Gibbs free energy of reactants and products of each equilibrium. The user should always be aware that the accuracy of calculated phase diagrams is a direct function of the quality of thermodynamic input data. The data distributed with this software are those presented by Helgeson *et al.* (1981) for aqueous species and those derived by Berman (1988) for minerals in the system Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-TiO_2-H_2O-CO_2. Further details of the procedure used to derive this dataset are given by Berman *et al.* (1986).

Also included on the distribution discs is an alternate database for minerals derived by Berman *et al.* (1985). Although the 1988 database represents an update and improvement of this dataset, it is included in this package because several phases are present, notably zeolites, that are not present in the revised database. Note, however, that this database must be used in its entirety; phases from this dataset cannot be used meaningfully with phases from the revised dataset.

PLOTS: This program displays graphical output on video monitors using a Hercules card or an IBM or compatible colour-graphics adapter (CGA) or enhanced-graphics adapter (EGA). PLOTS offers a quick way to preview plots on the screen prior to making hard copies with the PRINTER or LASER programs (see below).

LASER: This program makes high-resolution hard copies of the graphical output on HP-LASERJET-II printers with at least 1.5 MB of memory. Figures 6-3-1, 2 and 3 show examples of phase diagrams printed on the laser printer. Provisions have been made to allow variable line types and widths.

PRINTER: This program makes high resolution hard copies of phase diagrams on EPSON or compatible dot-matrix printers. The hard copies produced by PRINTER look similar to Figures 6-3-1, 2 and 3 except the resolution is lower than that produced by LASER.

TABLE 6-3-1
MINERALS WHOSE THERMODYNAMIC PROPERTIES HAVE BEEN TAKEN FROM THE SUPCRIT COMPILATION OF HELGESON AND COWORKERS

Mineral	Formula
Acanthite	Ag_2S
Alabandite	MnS
Alunite	$KAl_3S_2O_{14}H_6$
Anglesite	$PbSO_4$
Anhydrite	$CaSO_4$
Azurite	$Cu_3C_2H_2O_8$
Barite	$BaSO_4$
Bornite	Cu_5FeS_4
Bunsenite	NiO
Celestite	$SrSO_4$
Cerrussite	$PbCO_3$
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Cinnabar	HgS
Covellite	CuS
Cuprite	Cu_2O
Ferrous oxide	FeO
Fluorite	CaF_2
Galena	PbS
Graphite	C
Halite	NaCl
Malachite	$Cu_2CH_2O_5$
Manganosite	MnO
Meta-cinnabar	HgS
Native copper	Cu
Native gold	Au
Native silver	Ag
Nickel	Ni
Pyrite	FeS_2
Pyrrhotite	FeS
Quicksilver	Hg
Rhodochrosite	$MnCO_3$
Siderite	$FeCO_3$
Smithsonite	$ZnCO_3$
Sphalerite	ZnS
Strontianite	$SrCO_3$
Sylvite	KCl
Tenorite	CuO
Witherite	$BaCO_3$
Wurtzite	ZnS

CLEAN: The graphical output of PTA-system is often difficult to read because reaction labels overlap one another in any reasonably complex phase diagram. The program CLEAN improves the appearance of complicated phase diagrams on which the reaction labels overwrite one another. It either moves the labels to new positions or replaces the conflicting reaction labels with numbers and writes a list of reactions that correspond to the numbers to a separate file. The CLEANed plot (for example Figures 6-3-1, 2 and 3) can be viewed on the screen with PLOTS or on hard copies made with PRINTER or LASER.

LIMITATIONS AND FUTURE DEVELOPMENTS

The principal limitation of the present software package is that imposed by incomplete description of the thermodynamic properties of ore minerals and the plethora of aqueous species relevant to their genesis. The latter problem is being addressed by a variety of workers and much progress has been made recently in improving and extending equations of state for aqueous species to 600°C and 500 megapascals (Tanger and Helgeson, 1988) and in calculating equation of state parameters for dissociated and associated species (Shock and Helgeson, 1988).

H.C. Helgeson and coworkers have compiled a database for their SUPCRIT program that includes many ore minerals. These data (Table 6-3-1) have been combined with the refined data of Berman (1988) for common rock-forming minerals, and included in this version of the PTA software package. The only inconsistency that this combination of data introduces occurs with iron-bearing minerals, because the thermodynamic properties of magnetite and hematite are slightly different in the two databases. Future work will remove this inconsistency, in addition to expanding the scope of the data for ore minerals and refining thermodynamic properties using phase equilibrium data.

Another shortcoming of the present software is that the means for calculating an equilibrium distribution of aqueous species is not provided. Future work will address this limitation.

ACKNOWLEDGMENTS

The authors gratefully acknowledge funding received through the Canada/British Columbia Mineral Development Agreement.

REFERENCES

Berman, R.G. (1988): Internally Consistent Thermodynamic Data for Stoichiometric Minerals in the System Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-TiO_2-H_2O-CO_2, *Journal of Petrology*, Volume 29, pages 445-522.

Berman, R.G., Brown, T.H. and Greenwood, H.J. (1985): A Thermodynamic Data Base for Minerals in the System Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-TiO_2-H_2O-CO_2, *Atomic Energy of Canada Ltd. Technical Report* 377, 70 pages, (available from Scientific Document Distribution Office, Atomic Energy of Canada Ltd., Chalk River, Ontario, K0J 1J0 Canada).

Berman, R.G., Brown, T.H. and Perkins, E.H. (1987): GE0-CALC: Software for Calculation and Display of P-T-X Phase Diagrams, *American Mineralogist*, Volume 72, pages 861-862.

Berman, R.G., Engi, M., Greenwood, H.J. and Brown, T.H. (1986): Derivation of Internally Consistent Thermodynamic Properties by the Technique of Mathematical Programming, Review with Application to the System MgO-SiO_2-H_2O, *Journal of Petrology*, Volume 27, pages 1331-1364.

Brown, T.H., Berman, R.G. and Perkins, E.H. (1988): GE0-CALC: Software Package for Calculation and Display of Pressure-temperature-composition Phase Diagrams using an IBM or Compatible Personal Computer, *Computers & Geosciences*, Volume 14, pages 279-290.

Helgeson, H.C., Kirkham, D.H. and Flowers, G.C. (1981): Theoretical Prediction of the Thermodynamic Behavior of Aqueous Electrolytes at High Pressures and Temperatures: IV. Calculation of Activity Coefficients, Osmotic Coefficients, and Apparent Molal and Standard and Relative Partial Molal Properties to 600°C and 5 kb, *American Journal of Science*, Volume 281, pages 1249-1516.

Perkins, E.H., Brown, T.H. and Berman, R.G. (1986): PT-system, TX-system, PX-system: Three Programs for Calculation of Pressure-temperature-composition Phase Diagrams, *Computers & Geosciences*, Volume 12, pages 749-755.

Shock, E.L. and Helgeson, H.C. (1988): Calculation of the Thermodynamic Properties of Aqueous Species at High Pressures and Temperatures: Correlation Algorithms for Ionic Species and Equation of State Predictions to 5 kb and 1000°C, *Geochimica et Cosmochimica Acta*, Volume 52, pages 2009-2036.

Tanger, J.C. and Helgeson, H.C. (1988): Calculation of the Thermodynamic and Transport Properties of Aqueous Species at High Pressures and Temperatures: Revised Equations of State for the Standard Partial Molal Properties of Ions and Electrolytes, *American Journal of Science*, Volume 288, 19-98.

University Research

UNIVERSITY RESEARCH IN BRITISH COLUMBIA

INTRODUCTION

This listing of recently completed theses on the geology and mineral deposits of British Columbia is now an annual feature in this publication. It is included to bring these important contributions to the attention of geoscientists, who otherwise may be unaware of them.

Earth Science Departments are encouraged to send a current listing to the Geological Editor, Geological Fieldwork and Current Research, no later than October 31 of each year.

THE UNIVERSITY OF BRITISH COLUMBIA

Anderson, W.S.; An Assessment of the CSIR and NGI Rock Mass Classification Systems. (B.A.Sc., 1988).

Arthur, A.J.; Mesozoic Stratigraphy and Paleontology of the West Side of Harrison Lake, Southwestern British Columbia. (M.Sc., 1987).

Ashford, P.G.; Geological Hazard Assessment of a Residential Development in West Vancouver, British Columbia. (B.A.Sc., 1988).

Atchison, D.; Evaluation of the Dilatometer Test to Compute Settlement. (B.A.Sc., 1988).

Broatch, J.C.; Palynologic Zonation and Correlation of the Peace River Coalfield, Northeastern British Columbia. (M.Sc., 1987).

Brooke, J.A.; Underground Cryogenic Storage of Liquefied Natural Gas in the Lower Mainland, British Columbia. (B.A.Sc., 1987).

Case, S.J.; On The Classification of Silts. (B.A.Sc., 1987).

Christian; J.; Settlement Under a Load Fill: Predictions and Observed Field Results. (B.A.Sc., 1988)

De Capitani, C.; The Computation of Chemical Equilibrium and the Distribution of Fe, Mn and Mg Among Sites and Phases in Olivines and Garnets. (Ph.D., 1987).

Forster, C.B.; Interaction and Groundwater Flow Systems and Thermal Regimes in Mountainous Terrain: A Numerical Study. (Ph.D., 1987).

Friedman, R.M.; Geology and Geochronometry of the Eocene Tatla Lake Metamorphic Core Complex, Western Edge of the Intermontane Belt, British Columbia. (Ph.D., 1988).

Garwin, S.L.; Structure and Metamorphism in the Niagara Peak Area, Western Cariboo Mountains, British Columbia. (Ph.D., 1987).

Holbek, P.M.; Geology and Mineralization of the Stikine Assemblage, Mess Creek Area, Northwestern British Columbia. (M.Sc., 1988).

Laidlaw, J.S.; Tomographic Techniques and Their Application to Geotechnical and Groundwater Flow Problems. (M.A.Sc., 1987).

Lewis, P.D.; Polyphase Deformation and Metamorphism in the Western Cariboo Mountains Near Ogden Peak, British Columbia. (M.Sc., 1987).

Luckman, N.B.; History, Geology, Stratigraphy and Operations at the Otter Creek Mine, Atlin Mining District, Northwestern British Columbia. (B.A.Sc., 1988).

Massmann, J.W.; Groundwater Contamination From Waste-management Sites: The Interaction Between Risk-based Engineering Design and Regulatory Policy. (Ph.D., 1987).

McFarlane, R.B.; Lower Jurassic Biostratigraphy of Central Graham Island, Queen Charlotte Islands, British Columbia: the Upper Sinemurian of the Sandilands Formation. (B.Sc., 1988).

McKenzie, K.R.; Slope Stability Analysis of Newman Slide. (B.A.Sc., 1988).

Meidal, K.M.; A Two-dimensional Stability Analysis of Dutchman's Ridge, Kinbasket Lake Reservoir, Mica Dam, B.C. (B.A.Sc., 1988).

Nachtigal, G.J.; A Proposal for a Tunnel Design at a Site on Highway 99, North of Britannia Beach, British Columbia. (B.A.Sc., 1988).

Naumann, C.M.; Determination of the Extent of Contaminant Mixing Within a Fracture Junction Using a Discrete Fracture Junction Computer Model. (B.A.Sc., 1988).

Pritchard, M.A.; The Bat Groundwater Monitoring System: An Evaluation and Correlations to Cone Penetration Tests. (B.A.Sc., 1987).

Sather, S.M.; Lineament Analysis of the Rockslide Area Southeast of Hope, British Columbia. (B.A.Sc., 1988).

Siebert, S.A.; A Case History of a Catastrophic Erosion in the Coquitlam Valley, British Columbia. (B.A.Sc., 1988).

Stanley, C.R.; Comparison of Data Classification and Procedures in Applied Geochemistry Using Monte Carlo Simulation. (Ph.D., 1988).

Stasiuk, M.V.; Steady State Heat Flow Modelling with Full-weighting Finite Difference. (B.Sc., 1988).

Stephen, J.D.; Sampling Stream Sediments for Gold in Mineral Exploration, Southern British Columbia. (M.Sc., 1988).

Szefer, G.A.; A Sensitivity Analysis of Two-phase Immiscible Flow Using the Waterloo (WSTIF) Computer Model. (B.A.Sc., 1987).

Tod, J.D.; A Preliminary Analysis of the Engineering Geology of the Muddy Lake Rock Avalanche, Northwestern British Columbia. (B.A.Sc., 1988).

Vellutini, D.; Organic Maturation and Source Rock Potential of Mesozoic and Tertiary Strata, Queen Charlotte Islands, British Columbia. (M.A.Sc., 1988).

Woodbury, A.D.; Simultaneous Inversion of Thermal and Hydrogeologic Data [*Available in Main Library only LE 3 B7 1987 A1 W662*]. (Ph.D., 1987).

Zavoral, D.Z.; Laboratory Testing Evaluation of Cone Penetration Test Correlations for Geotechnical Soil Parameters. (B.A.Sc., 1988).

UNIVERSITY OF ALBERTA

Crowe, A.S.; A Numerical Model for Simulating Mass Transport and Reactions During Diagenesis in Clastic Sedimentary Basins. (Ph.D., 1988).

Leslie, L.E.; Late Glacial History of the Finlay River Valley, British Columbia. (M.Sc., 1988).

Lu, Z.; Rock Avalanches on Mount Cayley, British Columbia. (M.Sc., 1988).

Metcalfe, P.; Petrogenesis of Quaternary Alkaline Lavas in Wells Grey Provincial Park, B.C., and Constraints on the Petrology of the Sub-Cordilleran Mantle. (Ph.D., 1987).

McClymont, G.L.; Expert Systems Applications in Hydrogeology. (M.Sc., 1988).

Rakhit, K.; Potentiometric Surface Anomalies Due to Flow Through Highly Permeable, Lenticular Glastic Rocks and Their Utilization in Petroleum Exploration. (M.Sc., 1987).

Reasoner, M.A.; Holocene Lacustrine Records from the Upper Cataract Brook Valley, Yoho National Park, British Columbia. (M.Sc., 1988).

Vivian, G.J.; The Geology of the Blackdome Epithermal Gold Deposit, British Columbia. (M.Sc., 1988).

Xue, X.; Geochemical and Isotopic Studies of Ultramafic Xenoliths Form West Kettle River, Southern British Columbia. (M.Sc., 1988).

BROCK UNIVERSITY

Webster, I.C.L.; Skarn and Ore Mineralogy at the Hedley Amalgamated Mine, Hedley, B.C. (B.Sc., 1988).

CARLETON UNIVERSITY

Beneteau, S.; Fluorine Content of Topaz in Relation to Geological Environment. (B.Sc., 1988).

Gagnier, G.; Mineralogy and Paragenetic Sequence of the North Zone at Equity Silver Mine, Houston, B.C. (B.Sc., 1988).

Harvey-Kelly, F.; Metallogeny of the Southwest Vent Field on Axial Seamount, Juan de Fuca Ridge. (B.Sc., 1987).

MacRobbie, P.A.; Stratigraphy, Structure and Volcanogenic Sulphides in Sicker Group Volcanic Rocks on Mt. Sicker, Vancouver Island, B.C. (M.Se., 1988).

UNIVERSITY OF NEW BRUNSWICK

Baird, D.; The Development of an Interactive System for the Two-dimensional Modelling of Gravity Data. (B.Sc., 1988).

UNIVERSITY OF OTTAWA

Muir, I.D.; Middle Devonian Hare Indian and Ramparts Formations, MacKenzie Mountains, NWT: Basin Fill Platform and Reef Development. (Ph.D., 1988).

UNIVERSITY OF TORONTO

McConachy, T.F.; Hydrothermal Plumes Over Spreading Ridges and Related Deposits in the Northeast Pacific Ocean: The East Pacific Rise Near 11° N and 21° N, Explorer Ridge and J. Tuzo Wilson Seamounts. (Ph.D., 1988).

THE UNIVERSITY OF WESTERN ONTARIO

McKinlay, F.T.; Geology and Control of Sulphide Deposition of the J and L Massive Sulphide Deposit, Southeast British Columbia. (M.Sc., 1988).

GEOLOGICAL SURVEY BRANCH, 1988

LEFT TO RIGHT and BACK TO FRONT

Cindy Borsholm, Tom Schroeter, Mike Fournier, Dave Melville, Dan Hora, John Drobe, Kirk Hancock, Andre Panteleyev, Victor Koyanagi, Wayne Jackaman, Bob Gaba, Dave Grieve.

Dave Lefebure, Paula Lezetec, James Pardy, Gary White, Dick Player, Bish Bhagwanani, Ward Kilby, Paul Ralph, Judy Rubingh, Paul Wilton, Derek Brown.

Bev Wendt, Lynn Byrnell, Cathy Colbourne, Mac Chaudhry, Joanne Schwemler, Kim Passmore, Talis Kalins, Alex Matheson, Ted Faulkner.

Barb Mouner, Trygve Höy, Pierino Chicorelli, Alan Wilcox, Steve Butrenchuk, Graeme McLaren, Gib McArthur, Jeanette Gogo, George Owsiacki, Jim Britton, Jim Logan, Chris Rees, Mike Gunning.

Mitch Mihalynuk, Kathryn Andrew, Cathy Lund, John Armitage, Graham Nixon, Jennifer Pell, Don McIntyre, Pat Desjardins, Larry Jones, Gary Payie.

Mary Anne Bloodgood, Rick Meyers, Beverly Brown, Vic Preto, Norma Chan, Paul Matysek, Geri Dickson, John Gravel, Shielagh Pfuetzenreuter, Ron Arksey, Bill McMillan, Jahak Koo.

Laura deGroot, Candace Kenyon, Janet Fontaine, Eleanor Kneffel, Claudia Sturko, Ron Smyth, Karen Ahiers, Gerri Magee, Dani Alldrick, Greg McKillop.

GSB ORGANIZATIONAL CHART

W.R. Smyth
Chief Geologist

N. Chan,
Secretary
Tel: 387-0688

MINERAL DEVELOPMENT AGREEMENT
*G. McKillop, Manager
Tel: 356-2854
*J. Gogo, Secretary
*B. Mouner, GSB Accounts

BRANCH COORDINATOR
***C. Sturko

CARTOGRAPHY
J. Armitage
P. Chiccorelli
M. Taylor

SCIENTIFIC REVIEW
B. Grant
*J. Newell
Tel: 356-1693
D. Fehr

VANCOUVER REGIONAL OFFICE
T. Schroeter
Senior Regional Geologist
Tel: 660-2812
**P. Carpenter, Secretary
**C. Lund, Research Assistant

MINERAL DEPOSITS AND REGIONAL MAPPING

W.J. McMillan
Manager
Tel: 356-2849
B. Mordaunt
Secretary

MINERAL DEPOSITS SUBSECTION

A. Panteleyev
N. Church
T. Hoy
G. Ray
D. Alldrick
M. Fournier
*G. Nixon

REGIONAL MAPPING SUBSECTION

D. MacIntyre
L. Diakow
N. Massey
M. Mihalynuk
*J. Nelson
*P. Schiarizza
**F. Ferri
**D. Brown
**J. Logan
**M.A. Bloodgood
**P. Desjardins

GEOCHEMISTRY SECTION

P. Matysek
**S. Day
*J. Gravel
*W. Jackaman

LAPIDARY

R. Player

ANALYTICAL SCIENCES

Vacant
Chief Analyst
Tel: 387-6249
L. Byrnell
Secretary

P. Ralph
B. Bhagwanani
M. Chaudry
V. Vilkos
*C. Colbourne

RESOURCE DATA & ANALYSIS

J.G. McArthur
Manager
Tel: 356-2839
B. Wendt
Secretary

B. Brown
Receptionist

MINERAL LAND USE SUBSECTION

G. McLaren
Vacant
J. Rubingh

MINERAL INVENTORY SUBSECTION

T. Kalnins
A. Wilcox
C. Borsholm
L. DeGroot
*L. Jones
*G. Payie
**G. Owsiacki
*L. Duffett, Vancouver

INDUSTRIAL MINERALS SUBSECTION

Z.D. Hora
G. White
**S. Butrenchuk
*J. Pell
*J. Fontaine

DISTRICT GEOLOGY AND COAL RESOURCES

V.A. Preto
Manager
Tel: 356-2833
G. Dickson
Secretary

DISTRICT GEOLOGY SUBSECTION

P. Wilton, Victoria
R.E. Meyers, Kamloops
A. Legun, Nelson
T. Faulkner, Prince George
D. Lefebure, Smithers
S. Ciampichini, Secretary

PROSPECTORS ASSISTANCE

**J. Pardy, Victoria
**P. Lezetc, Secretary

COAL RESOURCES SUBSECTION

W. Kilby

*B. Arnet
Secretary

J. Koo
C. Kenyon
A. Matheson
D. Grieve
**J. Schwemler

* MDA Contracts
** Contracts
*** Temporary Secondment

Queen's Printer for British Columbia ©
Victoria, 1989

NX