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Ministry of Energy, Mines and
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Geological Survey Branch

GEOLOGICAL FIELDWORK 1987

A summary of Field Activities and Current Research

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FOREWORD

The 1987 edition of *Geological Fieldwork: A Summary of Field Activities and Current Research* is the thirteenth in this publication series. It covers a year during which the Geological Survey Branch continued its expansion of mapping and research activity to improve the mineral exploration database in British Columbia.

The most significant event for the branch was the allocation of an additional $2 million to the base budget. This, coupled with $1.67 million in funding from the Canada/British Columbia Mineral Development Agreement, allowed delivery of a significantly expanded field program in 1987. The following deserve special mention:

- Eight 1:50 000 regional mapping projects, covering some 6500 square kilometres, were undertaken in the Kootenay District, Vancouver Island, the central Interior and north and northwestern British Columbia.
- Reconnaissance regional geochemical surveys were completed over four 1:250 000 map sheets in northwestern British Columbia, covering the Stewart, Iskut and Muddy Lake gold belts.
- Seven metallogenic projects, focusing on precious metal deposits, were undertaken in active mining camps. In the Hedley gold-skarn camp, a metallogenic zonation has been outlined that indicates that tungsten skarns in the Cordillera may also have potential for significant gold mineralization. A new project to assess the mineral potential Alaskan-type ultramafic rocks has been initiated.

The Geological Survey Branch also increased its commitment in the priority fields of coal resource evaluation, industrial minerals, land-use evaluation and the development of computerized databases. The growing interest in the province's industrial minerals potential is reflected by strong sales of publications in this field. Preliminary results from the first year of a two-year evaluation of the mineral resource potential of the Kokanee Glacier Provincial Park are reported in this edition of *Fieldwork*. 1987 saw the first release from the improved mineral inventory database, MINFILE. The file operates on both mainframe and personal computers; a user-friendly IBMpc-based search system is available from the branch and described in this volume.

The Geoscience Research Grant Program to universities was reinstated in 1987 to assist original research on the geology and mineral deposits of the province. Twenty-six grants were awarded to ten institutions and the preliminary results of this program are reported in this publication. Topics include district-scale geological mapping, mineral deposit studies, lead isotope research, conodont biostratigraphy and various studies in applied geochemistry. The publication of a listing of recently completed theses on the geology of British Columbia and related topics, begun last year, is continued in this volume.

Publications stemming from this increased activity appeared in record number during the year and included 22 Open File maps and reports. The number of papers contributed to this edition of *Fieldwork* shows an increase of 25 per cent over last year. This volume was edited and compiled by John Newell and Rosalyn Moir. The time available between completion of fieldwork and going to press is very short; their efforts, together with those of Jacqui Patenaude and Debbie Bulinckx, who input and updated most of the manuscripts and assisted with many other tasks, are gratefully acknowledged.

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PREFACE
1987 PROJECTS OF THE GEOLOGICAL SURVEY BRANCH

By W. J. McMillan

INTRODUCTION

Field projects undertaken by the Geological Survey Branch expanded again in 1987. The base budget continues to be augmented; the Canada/British Columbia Mineral Development Agreement and supplemental funds from the province allowed us to add three more 1:50 000-scale mapping projects, accelerate mineral deposit and industrial mineral studies and cover more area under the Regional Geochemical Survey program.

In the south (Figure 1), mapping continued near Duncan and was completed in the Hedley area. New projects were begun on the mineral potential of the Rossland volcanics and rocks in the Kokanee Park. In central British Columbia, work continued in the Bridge River area and adjacent areas to the north, and near Quesnel; a new project was initiated near Manson Creek. In the north, crews continued work near Whitesail Lake, in the Babine Range, and north of Cassiar; a new project was started in the Tutshi Lake area.

SOUTHERN BRITISH COLUMBIA

On Vancouver Island, Nick Massey and Steve Friday extended mapping begun last year, completing the Cowichan and most of the Duncan sheets. The project is resolving stratigraphic and structural problems in the Cowichan uplift. The uplift is cored by rocks of the Paleozoic Sicker Group, which hosts volcanogenic massive sulphides such as the Lara and Mount Sicker (Lenora-Tyee) deposits. The older volcano-sedimentary rocks are overlain by Mesozoic volcanic and sedimentary rocks and cut by Mesozoic and Tertiary granitic bodies. The work has shown that Sicker rocks in the area cannot be directly correlated with the Buttle Lake uplift, which hosts the Westmin deposits, or other areas cored by Sicker Group rocks. Stratigraphic nomenclature in the uplift is being revised, and it appears that a major unconformity occurs within the Sicker in the Cowichan Lake area. Interpretation is complicated by lateral facies changes and thrust faults; locally the thrusting involved sedimentary rocks of the Cretaceous Nanaimo Group. The Sicker Group continues to offer exciting potential for polymetallic massive sulphide deposits, as well as auriferous jaspers and gold-bearing quartz-ankerite veins along shears, like those at the Debbie deposit. The area also has potential for industrial minerals, such as limestone and rhodonite. In rocks of the Bonanza Group, there is potential for porphyry copper mineralization, and possibly massive sulphides in marine lower Bonanza rocks. Skarn mineralization may occur in limy rocks adjacent to Jurassic Island Intrusions.

Fieldwork was completed near Hedley, the site of British Columbia's newest gold producer – the Nickel Plate mine. The focus of this study by Gerry Ray and Garnet Dawson is skarn-related gold mineralization. This season the work was extended northeastward to the Oka property, west of Peachland, where a roof pendant of Nicola Group metasedimentary rocks and younger dioritic intrusions hosts gold-bearing skarn mineralization. Near Hedley, the structurally and stratigraphically controlled skarn mineralization is related to diorite intrusions that are localized at the edge of the Nicola sedimentary basin. Tungsten-skarn mineralization on Mount Riordan and mixed gold-tungsten skarns at the French and Goodhope mines suggest zoning in the Hedley Camp from gold-rich to tungsten-rich skarns. This interpretation suggests that areas peripheral to other tungsten skarns hosted by island arc volcanic and sedimentary rocks should be prospected for gold mineralization. The Hedley area may also have potential for mesothermal gold quartz veins and porphyry copper-gold deposits of the Copper Mountain type.

A new project initiated in the Nelson area by Trygve Höy and Kathryn Andrew will study the structural and stratigraphic controls of gold and silver mineralization in rocks of the Jurassic Rossland Group. The first phase of the project mapped a section through the Ymir and Elise formations into the overlying Hall Formation; the work successfully determined internal stratigraphy within the largely volcanic Elise Formation. Recently, roof pendants of Rossland volcanics have been recognized within the Nelson batholith. At Tillicum Mountain a skarn hosts gold mineralization and, near Silverton, a breccia pipe hosts the Willa copper-gold deposit and quartz veins carry gold mineralization. Zircon ages show that dacite porphyry at Willa is Early Jurassic, the same age as the Rossland volcanics. Other deposit types include molybdenum-tungsten in porphyritic quartz monzonites intrusive into Rossland volcanics, stratabound gold-copper mineralization in altered andesitic pyroclastics, and vein copper-gold mineralization similar to that mined in the old Rossland Camp. Other targets could include volcanogenic massive sulphides and perhaps platinum in potassic, mafic Coryell intrusions.

Geological mapping of Kokanee Glacier Provincial Park was undertaken to evaluate its mineral potential. The 2-year study, undertaken by Derek Brown and Jim Logan, represents the Geological Survey Branch's contribution to the Kokanee Park master plan. The park area is underlain predominantly by the Middle Jurassic, potash-feldspar megacrystic Nelson batholith, which hosts narrow, high-grade silver-lead-zinc quartz veins, some of which carry gold. Within the park, there is potential only for mesothermal quartz veins. Past production was from low-tonnage, high-grade mesothermal veins (less than 10 000 tonnes). West of the park, a roof pendant of early Jurassic Rossland volcanics hosts the Willa gold-copper-silver breccia pipe deposit. In the park, roof pendants consist of pelitic and psammitic rocks that are probably correlative with the Slocan Group.

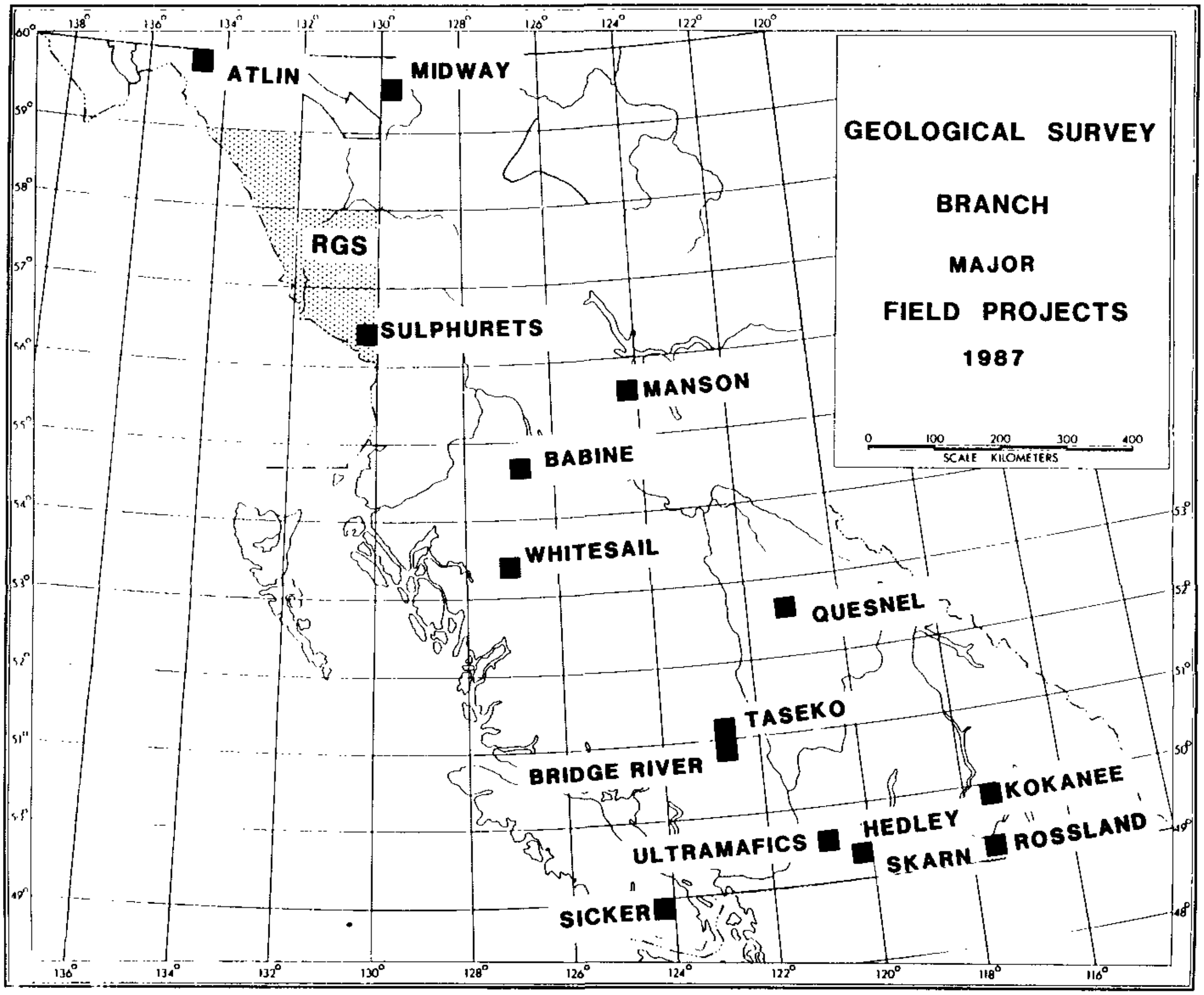


Figure 1. Location map for major field projects.

In the Bridge River camp, Neil Church and Bob Gaba finished mapping the east half of the Bralorne sheet (92J/15) and extended coverage to the north and south from last year's work. The study will re-evaluate the geology and controls of gold mineralization in the old but very productive Bridge River camp. Bralorne-type gabbro diorite intrusions were apparently emplaced along old deep-seated faults. The faults also acted as conduits for ultramafic bodies and hydrothermal fluids that produced the Bralorne and Pioneer orebodies as well as other prospects throughout the camp. Other ore controls are relatively young subsidiary fractures feathering off large northerly trending faults, as on the Reliance claim. The area has potential for other gold deposits of the Bralorne-Pioneer type, gold-antimony veins and tungsten, molybdenum and mercury deposits. The Shulaps and President ultramafic bodies have potential for magnesite, jade, talc, and certain gold targets, like the Elizabeth-Yalakom prospect.

A project is also in progress nearby in the Taseko – Bridge River area. Regional mapping by Keith Glover and Paul Schiarizza continued eastward from the Warner Pass sheet (92O/03), east of Taseko Lakes, onto the Noaxe Creek sheet (92O/02). The area includes Lower Cretaceous sediments and Tertiary volcanic rocks northeast of the Yalakom fault, the area of the Poison Mountain porphyry copper deposit, and Triassic to Upper Cretaceous sedimentary and volcanic rocks southwest of the fault. This work has established relationships between the Taylor Creek and Kingsvale groups that will require redefinition of the Cretaceous stratigraphy of the area. Local areas of carbonate-altered serpentinite that have potential for gold mineralization occur along the trace of the Yalakom fault. This and other northwest-trending strike-slip faults offset the Mesozoic rocks and are locally truncated by or are the locus of Tertiary granitic intrusions of probable Tertiary age. These intrusive rocks are hydrothermally altered in places and host epithermal to mesothermal gold mineralization.

In the Quesnel area, Andre Panteleyev, Mary Anne Bloodgood, Lu Jun and Dave Bailey continued 1:20 000-scale mapping as part of a study of precious metal deposits in the

Quesnel trough. This project has two elements. The first is a study of the controls of lode gold mineralization in the basal Triassic black phyllites, such as those at the Frasergold prospect near Eureka Peak, and higher in the section at the CPW prospect on Spanish Mountain, where mineralization is in mixed sedimentary and volcanic rocks. The second considers the distribution and controls of copper-gold deposits in the central volcanic belt, which hosts deposits like QR, where mineralization occurs in propylitically altered volcanic rocks adjacent to subvolcanic alkalic dioritic intrusions, and Cariboo Bell which is a porphyry copper-gold deposit. The mappers noted some low- temperature alteration patterns indicative of large-scale geothermal flow systems; one silicified fault zone contains significant concentrations of silver, arsenic and antimony.

In the new Manson Lake project, Filippo Ferri and David Melville mapped a complex area with metamorphic rocks of the Wolverine complex of the Omineca Belt on the northeast, and mafic to intermediate volcanics, cherts and related sediments of the Slide Mountain Group of the Intermontane Belt on the southwest. The metamorphic rocks are cut by coarse granitic rocks and pegmatites, the volcanic rocks by granitic rocks of the Germansen batholith. The area has potential for hydrothermal gold deposits in Slide Mountain rocks, porphyry copper-molybdenum deposits related to the Germansen batholith, and rare earths in carbonatites in the Wolverine complex. Talc-altered volcanic and ultramafic rocks along the southwest extension of the Manson fault zone along Manson Lakes valley are being prospected for precious metal mineralization.

Mapping by Larry Diakow and Victor Koyanagi in the Whitesail Lake area covered parts of two 1:50 000 map sheets, 93E/06 and 93E/10. The area is underlain mainly by Jurassic island arc calcalkaline flows and tuffs that are overlain by a Cretaceous succession of subaerial flows, tuffs and epiclastic rocks. The Jurassic volcanic succession is locally separated by a marine tongue of the Smithers Formation into two nearly identical packages of largely maroon volcanics. To the north, the lower Telkwa Formation volcanics have rhyolitic flows that host auriferous base metal-bearing quartz veins at the New Moon property. The fault that thrust a panel of metavolcanic and metaplutonic rocks over Skeena Formation near Lindquist Lake hosts auriferous pyritic quartz veins at the Deer Horn deposit and base metal veins to the west; it is a regional target for mineralizaton.

In the Babine Range, Don MacIntyre and Patrick Desjardins completed 1:20 000-scale mapping in the south half of sheet 93L/15. The mapping focused on the north part of the range where a thick pile of folded and thrust-faulted, Late Cretaceous to Tertiary volcanic and sedimentary rocks underlies Mount Hyland and Mount Cronin. These rocks are interpreted to be remnants of a Late Cretaceous volcanic centre. The work also documents a complex Tertiary tectonic event that was accompanied by extensive hydrothermal activity. Shear zones with numerous gossans and veins cut the Late Cretaceous volcanics; these were sampled during the mapping program. Known occurrences, such as the Cronin mine, were also visited and sampled.

Dani Alldrick and Jim Britton began a project in the bustling Sulphurets area this summer and Dave Lefebure mapped south of the Iskut River in the Johnny Mountain area. In the Sulphurets area about 500 square kilometres centred on Brucejack Lake were mapped. The work revised old mapping, discovered previously unmapped intrusions, and established stratigraphic continuity with the Stewart area to the south. The main targets are high-grade gold-silver veins, but copper, lead, zinc, molybdenum, nickel and barite occurrences are also known.

South of the Midway area, JoAnne Nelson and John Bradford mapped sheet 104P/12 as part of the Midway/Cassiar project. The Sylvester allochthon, which underlies much of the area, consists of three major units, two of which show linkages with ancestral North America. Dating of samples collected in 1986 reveals Middle and Late Cretaceous episodes of mineralization; Midway is Late Cretaceous. Mineralization has been found in association with northwest-trending wrench fault systems, particularly within quartz and carbonate breccias in carbonate host rocks. These are interesting targets for precious metals.

In the Tutshi Lake area, Mitch Mihalynuk and Jonathan Rouse mapped sheet 104M/15, concentrating on a northwest-trending belt that hosts most of the area's known mineral occurrences. The map area is underlain dominantly by rocks of the Lower Jurassic Laberge Group that are cut by Late Cretaceous granitic bodies. The mapping showed that Upper Triassic Stuhini volcanics are much less abundant than previous work indicated. There is a significant package of previously unrecognized Middle to Late Jurassic volcanics. The Mesozoic rocks lie unconformably over pre-Permian metamorphic rocks and locally a basal conglomerate is developed. Potential exploration targets are precious metal vein deposits, gold-quartz veins like those at the Engineer mine, gold-stibnite veins, auriferous quartz-carbonate zones and gold-rich skarns.

Activity in Industrial Minerals Subsection increased in 1987. Gary White carried out assessments of dimension stone, olivine and feldspar/nepheline syenite resources in the province. Peter Read continued an evaluation of Tertiary basins. The study considers clay, zeolites, pozzolanic rocks, diatomite, germanium, bentonite and other deposits. Stephen Butrenchuk extended his phosphate resource evaluation into northeastern British Columbia. Jennifer Pell began an evaluation of garnet, kyanite, sillimanite and andalusite resources, which mainly occur in the Omineca and Coast crystalline belts. Office-based compilations of talc, magnetite, sulphur, barite, chromite and peat resource potential will be released as Open File reports in early 1988.

In the southeast, David Grieve completed 1:10 000-scale mapping of the north half of the Elk Valley coalfield. In the northeast, Andrew Legun continued work to evaluate the coal potential of the Gething Formation, and Ward Kilby completed 1:50 000-scale compilation and field checks in the Kinuseo area (93I/14 and 15). On Vacouver Island, Candace Kenyon compiled geological data and carried out field checks in the Nanaimo and Comox coal basins.

The Geological Survey Branch also aided 21 post-graduate thesis projects with potential applications to mineral exploration. Progress reports are presented in this volume. The projects range from mineral deposit studies, to mapping, to the origin of ultramafic rocks and include stable isotope and geochemical research projects.

SPECIAL PROJECTS

A special project to examine auriferous skarns throughout the province was begun this summer by Art Ettlinger in cooperation with Gerry Ray. Art studied deposits in the Zebellos, Atlin and Hedley areas, and on Texada and Banks islands. Petrologic, isotopic, whole-rock geochemical and microprobe analyses are planned to try to relate mineral compositions with skarn types and hence mineralization.

Another special project, under Graham Nixon, will study platinum group element abundances and potential in ultramafic rocks in the Cordillera. Detailed work this year was on the Alaskan-type Tulameen complex, located near Princeton, where placer miners have recovered platinum from their operations. Platinum occurrences to the east, in the Franklin Camp, were also examined. Extensive lithogeochemical, geochronological, petrological and mineralogical analyses are planned.

APPLIED GEOCHEMISTRY PROGRAM

The Applied Geochemistry Subsection was involved in a number of baseline geochemical surveys, orientation surveys and research projects in 1987. Paul Matysek and Stephen Day conducted orientation studies in a variety of geological and physiographic environments to determine the characteristics of stream sediment anomalies associated with five typical modes of mineralization on northern Vancouver Island. The 1987 Regional Geochemical Survey (RGS) under the direction of Paul Matysek and John Gravel sampled 35 000 square kilometres of rugged and remote terrain in northwestern British Columbia (104B, F, G, and K). In total, 2726 sites were sampled at a density of one sample per 12 square kilometres. All stream sediments will be analysed for gold and the routine RGS 19-element suite; stream waters will be analysed for uranium, fluorine and pH.

The subsection also provided advice on sampling methods to regional mapping crews, and in cooperation with Dr. W.K. Fletcher of The University of British Columbia, is undertaking a study of the dispersion of platinum and palladium in stream sediments and soils from four geologically distinct platinum occurrences (Tulameen, Giant Nickel, Franklin Camp and Scottie Creek).

SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES

Drift-covered area .... (LEFT BLANK)

Glacial striae (direction of ice movement known, unknown) (Numbers indicate relative age, 1 being the oldest.) 1 2

End moraine ....

Minor moraines, rib moraines, washboard moraines, 'annual' moraines, till ridges transverse to ice flow (irregular, straight) ....

Drumlins, drumlinoid ridges (direction of ice movement known, unknown) ....

Crag and tail hills and ramps ....

Glacial linear feature ....

Esker (direction of flow known, unknown) ....

Esker (continuous, discontinuous) ....

Raised beaches ....

Limit of marine or lacustrine submergence (well marked, assumed) ....

Dunes ....

Area of sand dunes ....

Landslide scar ....

Escarpment, cirque ....

~~Rock outcrop~~, area of outcrop, [redacted] ....

Geological boundary (defined, approximate, assumed, gradational, dip indicated) 50

Intrusive contact with younger unit indicated ....

Unconformity (defined, assumed) ....

Limit of geological mapping ....

Bedding, tops known (horizontal, inclined, vertical, overturned) 90

Bedding, top unknown (horizontal, inclined, vertical, dip unknown) ....

Bedding, general trend (dip unknown, top unknown; dip and top known; dip known, top unknown) ....

Bedding, estimated dip (gentle, moderate, steep) .... g, m, s

Igneous flow banding (inclined, vertical) ....

Primary igneous layering, tops known (horizontal, inclined, vertical, overturned) ....

Primary igneous layering, tops unknown (horizontal, inclined, vertical) ....

Strike and dip of pillows, tops known (horizontal, inclined, vertical, overturned) ....

Strike and dip of pillows, tops unknown (horizontal, inclined, vertical) ....

Volcano ....

Flow contact ....

Roof pendant (unit number indicated; too small to map separately) ....

Schistosity, cleavage, foliation; used where ages of foliation are indicated on the map (horizontal, inclined, vertical):

- Schistosity of unknown age ....
- S_1 ....
- S_2 ....

SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES—*Continued*

Schistosity, gneissosity, cleavage, foliation, general trend

Gneissosity, foliation or banding (horizontal, inclined, vertical, dip unknown)

Shearing and dip

Axial plane of minor fold (inclined, vertical, dip unknown)

Axes of minor folds (horizontal, inclined, vertical) 0 30 90

Lineation of unknown age (horizontal, inclined, inclined but plunge unknown, vertical) 0 30 90

Type of lineation denoted by letter:

- Mineral lineation M
- S intersections S
- Microcrenulations C
- Boudin axes B
- Deformed clasts D
- Igneous inclusions I
- Rodding, mullion structure R
- Metamorphic aggregates A
- Deformed pillows P

Age of lineation and of minor fold axes:

- L_1
- L_2

Mineral isograd

Other alternatives when more than one mineral isograd

Sense of vergence of minor structures (used with minor fold axis symbol or lineation S intersection symbol; read looking along the arrow)

Box anticline, box syncline

Fold

Structural trend (from aerial photographs)

Anticline (defined, approximate, assumed)

Antiform

Syncline (defined, approximate, assumed)

Synform

Anticline and syncline (overturned)

Antiform or synform

Lineament (from aerial photographs)

Fault (defined, approximate, assumed)

Fault (inclined, vertical)

Fault (solid circle indicates downthrown side, arrows indicate relative movement)

Thrust fault (teeth in direction of dip; defined, approximate, assumed) (teeth indicate upthrust side)

Zone of numerous imbricate thrust faults

Fault zone, shear zone (width indicated)

Tectonic slide

Vein fault (defined, assumed)

SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES—*Continued*

Mineralized bed or seam (hematite) .... hem hem

Dyke, vein or stockwork (defined, approximate, assumed; dip indicated) 30

Joint (horizontal, inclined, vertical) ....

Sheeted dykes (horizontal, inclined, vertical) ....

Fossil locality .... Ⓕ

Locality where age has been determined, in millions of years .... Ⓐ 1400

Location of measured section ....

Gravel pit or quarry (active, abandoned) ....

Borrow pit (active, abandoned) ....

Open-pit mine or quarry ....

Rock dump or tailings ....

Rock quarry (active, abandoned) ....

Mine (lead, zinc) .... Pb Zn

Mine (lead, zinc; abandoned) .... Pb Zn

Mineral prospect; mineral occurrence (manganese) .... X 3 X Mn

Placer deposit (gold) .... Au

Show of oil and gas (abandoned) ....

Show of gas (abandoned) ....

?

~~Gas producer~~ ....

gas

~~Oil~~ producer ....

Oil ~~and gas~~ producer ....

oil + gas

Dry (abandoned) ....

Location of drilling .... o

Trace of coal seam ....

Shaft, raise, winze ....

Shaft (abandoned) ....

Trench ....

Opencut ....

Adit or tunnel portal ....

Adit or tunnel (caved) ....

Borehole .... ● BH ● BH2

Diamond-drill hole .... ● DDH

Sinkhole .... o SH

Gossan, limonite capping .... G G G

Regional and District Mapping

PRELIMINARY GEOLOGY AND GEOCHEMISTRY OF THE ELISE FORMATION, ROSSLAND GROUP, BETWEEN NELSON AND YMIR, SOUTHEASTERN BRITISH COLUMBIA (82F/06)

By Trygve Höy and Kathryn Andrew

KEYWORDS: Regional geology, Rossland Group, Elise Formation, Nelson batholith, Ymir Group, Archibald Formation, Hall Formation, gold-bearing veins, volcanic centres.

INTRODUCTION

The Rossland project was initiated in 1987 in order to develop a better understanding of the structural and stratigraphic controls of gold and silver vein mineralization in Rossland Group rocks. The Rossland Group has been a major producer of precious metals, with over 84 000 kilograms of gold and 105 000 kilograms of silver recovered from the Rossland camp, ranking it second in the province in gold production (Panteleyev and Schroeter, 1986). Exploration continues to be active in the camp and throughout the length of exposures of Rossland Group rocks, particularly with the recent discovery of significant gold mineralization at the Willa property in a roof pendant within the Nelson batholith.

The 1987 field project included regional mapping, at a scale of 1:20 000, on an area centred on Highway 6A approximately 10 kilometres south of the town of Nelson (Figure 1-1-1). The mapping focused on the Elise Formation, the central volcanic part of the Rossland Group, and subdivided the formation into a number of distinct and mappable units. Work planned for the 1988 season will extend the mapping to include all exposures of Rossland Group rocks south to Salmo and west to the Nelson batholith. The area is within the Selkirk Mountains, with relief varying from 900 metres in the valley floors to greater than 3500 metres on the higher ridges. Exposure is variable, from 10 to 20 per cent on the heavily wooded lower slopes to almost 100 per cent on the ridges.

The results of the 1987 mapping will be released as an open file map early in 1988. Work begun this winter includes trace and major element geochemistry of volcanic rocks of the Elise Formation, uranium-lead and potassium-argon isotope geochronology of both intrusive and extrusive rocks, fluid inclusion studies of vein occurrences, and lead-lead isotope analyses of vein galena.

REGIONAL GEOLOGY

The Rossland Group is exposed in a broad arcuate belt in southeastern British Columbia, bounded to the east, north and west by granitic rocks of the lower Cretaceous Nelson batholith, and in fault contact with lower Paleozoic rocks of the Kootenay arc on the south (Figure 1-1-1). It is intruded by numerous small, irregular stocks, probably correlative with the Nelson batholith (Little, 1964), by apophyses of the Nelson batholith and, in the south near the town of Rossland, by Coryell alkalic intrusions of Eocene age.

The Rossland Group is subdivided into a lower, generally highly deformed sequence of predominantly fine-grained clastic rocks of the Ymir Group and Archibald Formation, a thick accumulation of pyroclastic and epiclastic volcanic rocks of the Elise Formation, and overlying, generally less intensely deformed clastic rocks of the Hall Formation (Table 1-1-1). The age of the Elise Formation is bracketed by Sinemurian macrofossils in the Archibald Formation and Toarcian fossils in the overlying Hall Formation; no fossils have been found in the Ymir Group.

A variety of gold, silver, copper, lead and zinc vein deposits as well as molybdenite deposits occurs within the Rossland Group or in intrusions cutting these rocks. These deposits are concentrated in the more northern exposures southwest of Nelson (Mulligan, 1952; Little, 1982), east and northeast of Ymir (Cockfield, 1936; McAllister, 1951), and in the Rossland camp itself (Fyles, 1984).

STRUCTURE

The map area is at the southwestern extension of the Kootenay arc, tectonically emplaced on highly deformed lower and middle Paleozoic rocks to the south and east, and intruded by granitic rocks of the Nelson batholith on the west. The northern part of the belt of Rossland Group rocks has been folded into broad north-trending and east-verging folds that repeat formations. The Ymir Group is exposed along the eastern margin of the belt and is correlative with the Archibald Formation in an anticline on the west, and the Elise Formation is repeated on both limbs of an intervening syncline cored by the Hall Formation.

The structure of the area is not complex. Numerous top indicators and bedding-cleavage intersections indicate that the Elise and Hall Formations form a right-way-up structural panel on the east limb of the syncline. A prominent mineral foliation trends north to northwesterly and dips to the west, parallel to the axial plane of the syncline. Mineral lineations are variable, but generally plunge south at 10 to 20 degrees.

Structures within the underlying Ymir Group are, however, considerably more complex. Reversals of top indicators and fold vergence indicate that, locally, tight to isoclinal intrafolial folds occur in these less competent rocks. These folds and related shears repeat parts of the Ymir Group. In general, the Ymir Group faces west with the oldest rocks exposed in more eastern outcrops.

STRATIGRAPHY

YMIR GROUP

The Ymir Group is a sequence of fine-grained clastic and carbonate rocks at least 1500 metres thick. The base of the Ymir has been cut off by Nelson intrusions and is not exposed in the map area.

A Ymir section was examined in detail from exposures on the Apex Creek road (Figure 1-1-2). Although structural repetitions are recognized in this section, it nevertheless represents an approximate stratigraphic sequence through the upper part of the Ymir Group. The structural base is dominated by over 300 metres of massive to impure limestone beds interlayered with grits, siltstone and argillite. It is overlain by a fining-upward succession of grits, siltstone and argillite and finally interbedded argillite and chert at least 500 metres thick. The top of the Ymir Group is characterized by finely laminated argillite interbedded with feldspathic wacke and minor limy siltstone beds.

ELISE FORMATION

The Elise Formation is differentiated into units on the basis of the following criteria: (1) textures, either massive or fragmental; (2) per cent pyroclastic, epiclastic and autoclastic fragments; (3) average clast size; and (4) phenocryst assemblage, size and abundance. Facies changes are distinguished by separating units of the same composition into massive and fragmental components. Original textures and primary phenocryst assemblages are used to describe units regardless of the degree of metamorphism or alteration.

A basal augite porphyry succession (Units 1, 2, and minor 3 and 4) lies with apparent conformity on sedimentary rocks

TABLE 1-1-1
REGIONAL CORRELATION OF THE ROSSLAND GROUP, SOUTHEASTERN BRITISH COLUMBIA

AGE			ROSSLAND AREA		NELSON AREA		SLOCAN AREA	
PERIOD	EPOCH	AGE	GROUP	FORMATION	GROUP	FORMATION	GROUP	FORMATION
JURASSIC	L		? NELSON INTRUSIONS		? NELSON INTRUSIONS			
	M		?	?	?	?		
	E	TOARCIAN		HALL		HALL		
		PLIENSBACHIAN						
		SINEMURIAN	ROSSLAND	ELISE	ROSSLAND	ELISE		
		HETTANGIAN		ARCHIBALD		YMIR		
TRIASSIC	L		?	?	?	?	SLOCAN	
	M							
	E							
PERMIAN							KASLO	
CARBONIFEROUS							MILFORD	
DEVONIAN							LARDEAU	
CAMBRIAN								BADSHOT
								MOHICAN
								HAMILL

of the Ymir Group; argillite beds persist through the lower part of the Elise Formation. The upper Elise section is characterized by mafic to intermediate volcanic and volcaniclastic rocks (Units 3 to 10). Feldspar porphyry intrusions, including the Silver King porphyry, are interpreted to be coeval with the Elise Formation and hence are also described in this section. The principal lithologic units are shown in Figures 1-1-2 and 1-1-3, outlined in Table 1-1-2, and described in detail following.

Basal Section

The lower part of the Elise Formation (predominantly Units 1 and 2) is a sequence of dominantly mafic flows and

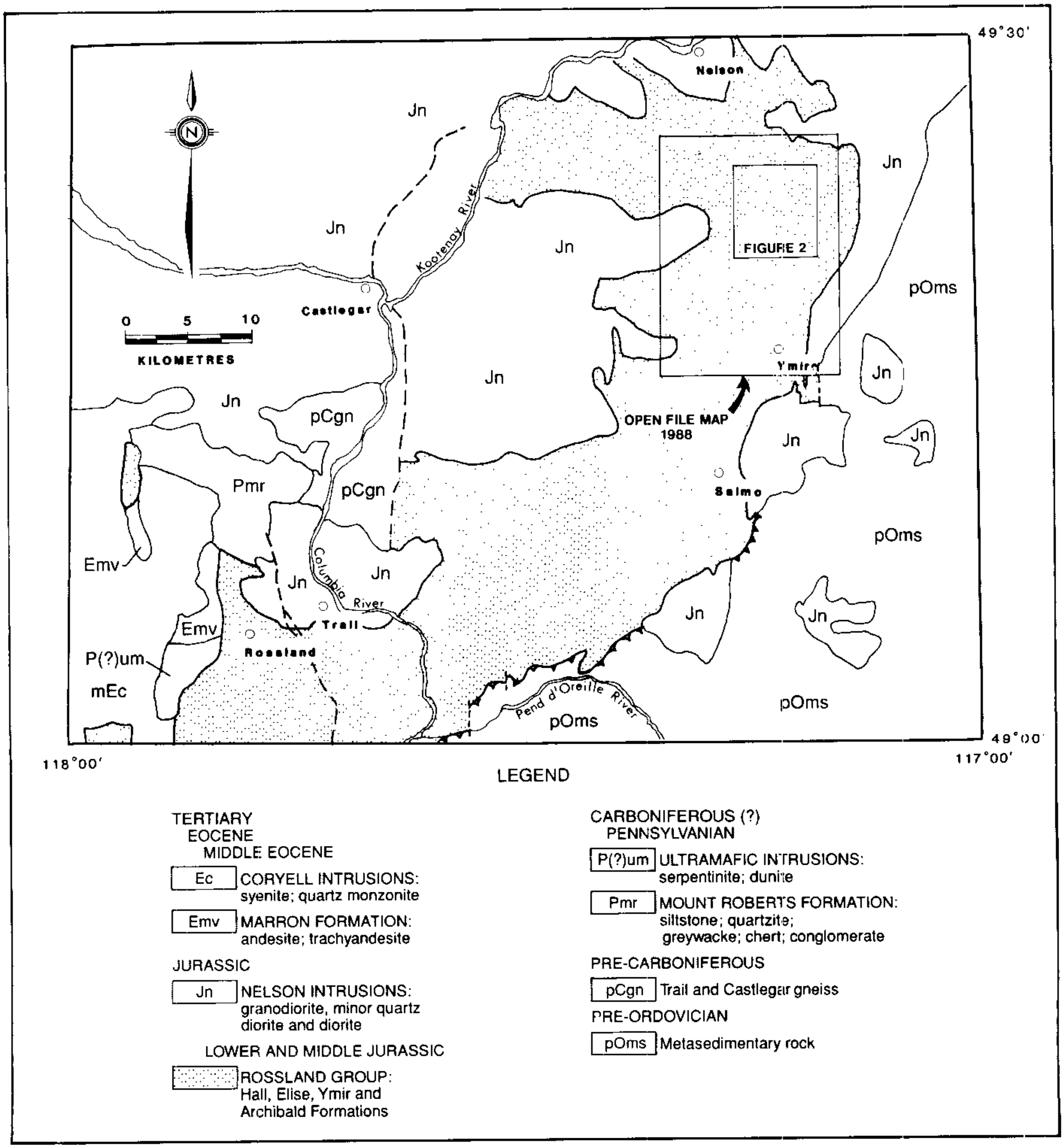


Figure 1-1-1. Map showing distribution of Rossland Group in southeastern British Columbia and location of Figure 1-1-2 and Open File map. Regional geology after Little (1960, 1964, 1982), Fyles (1984), Simony (1979), Corbett and Simony (1984), and Parrish (1984).

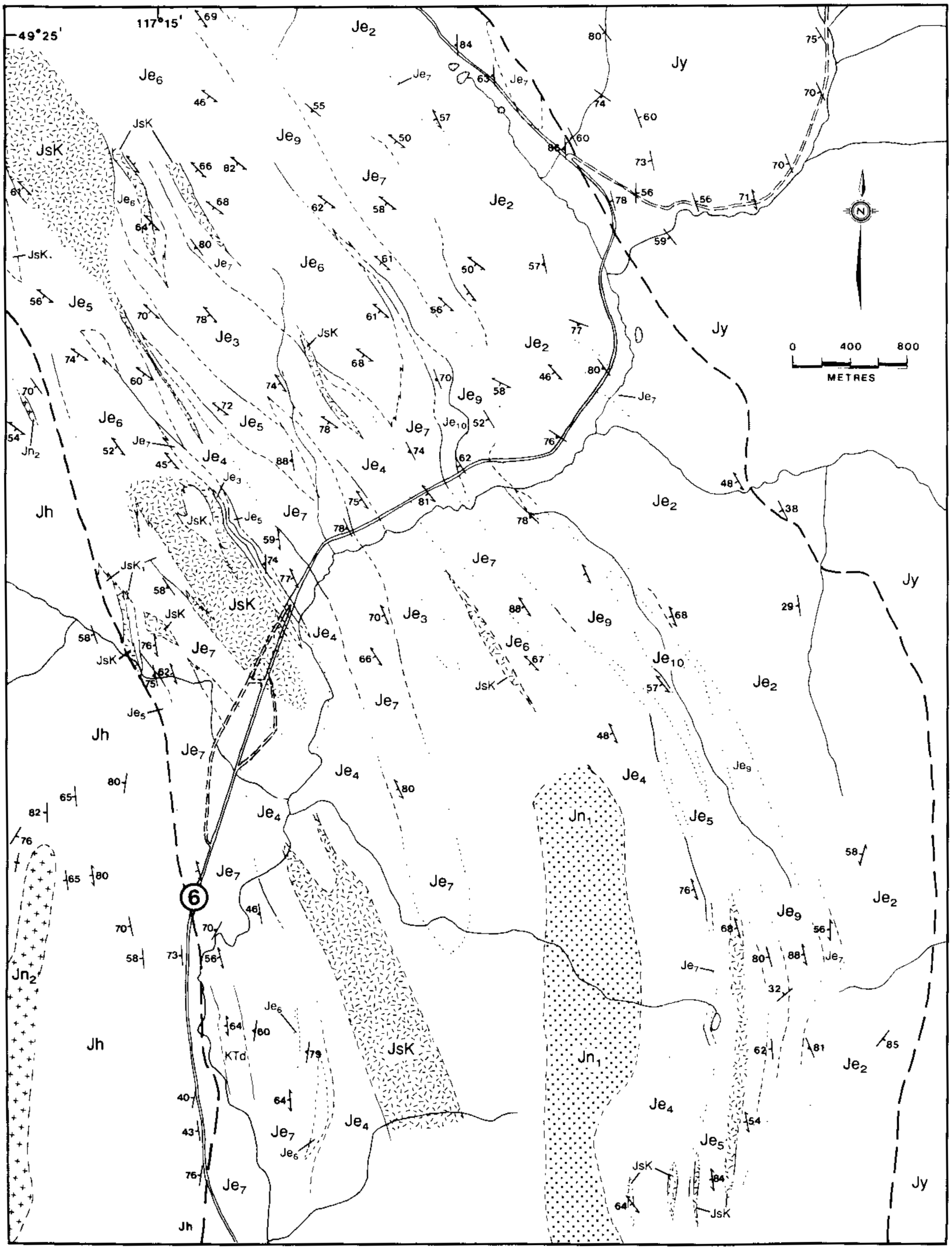


Figure 1-1-2. Geological map of the Hall Creek--Apex Creek area south of Nelson; *see* Figure 1-1-3 for legend.

TABLE 1-1-2
UNITS OF THE ELISE FORMATION

Unit No.	Unit Name	Texture	Fragments	Phenocrysts
Je_1	Coarse-grained augite porphyry flows	Massive	—	Augite, 20-40% (10 mm)
Je_2	Coarse-grained augite porphyry flow breccias	Fragmental	Autoclastic	Augite, 20-40% (10 mm)
Je_3	Medium-grained augite porphyry flows	Massive	—	Augite, 20-30%m (5 mm)
Je_4	Medium-grained augite porphyry flow breccias	Fragmental	Autoclastic, 20-30% (2-5 cm)	Augite, 20-30% (5 mm)
Je_5	Mafic ash tuff	Fragmental	Pyroclastic, 20-80% (<1 mm)	Augite, <5% (2-5 mm) Biotite, 10-15% (1-4 mm)
Je_6	Plagioclase augite crystal tuff	Massive	Pyroclastic, 20-80% (2-64 mm)	Augite, <5% (2-5 mm) Plagioclase, 10-20% (1-2 mm)
Je_7	Plagioclase lapilli tuff	Fragmental	Pyroclastic, 5-20% (2 mm-10 mm)	Augite, <5% (2-5 mm) Augite, <5% (2-5 mm)
Je_8	Plagioclase-porphyritic flows	Massive	—	Augite, <2% (<2 mm) Plagioclase, 15-30% (<3 mm)
Je_9	Tuffaceous siltstone	Fragmental	Epiclastic 90% (<2 mm)	—
Je_{10}	Tuffaceous conglomerate	Fragmental	Epiclastic 15-30% (2 mm-10 mm)	—
Je_{11}	Plagioclase porphyry	Porphyritic	—	Plagioclase, 20-30% (10 mm)

Plate 1-1-1. Massive and brecciated flows of Unit Je_1, Highway 6, 2 kilometres west of Apex Creek. Note thin mud selvages between flows.

flow breccias, minor lahars and tuffs, up to 1 kilometre thick. Near its base it is interbedded with argillite of the Ymir Group. Autoclastic fragments, including broken amygdaloidal pillows, characterize the section and are incorporated in flows 0.5 to 1 metre thick. Such textures are indicative of fragmentation by mechanical friction or gaseous explosion during lava flow movement, or gravity crumbling of spines and domes.

Despite regional greenschist facies metamorphism, primary euhedral augite phenocrysts are occasionally preserved. They are partially altered to an assemblage of actinolite, biotite, epidote and chlorite. More commonly, the augite phenocrysts are totally replaced. Plagioclase phenocrysts are less common in the basal units and are generally partially saussuritized. The phenocrysts are set in a fine-grained matrix of secondary plagioclase, biotite, chlorite, epidote and carbonate.

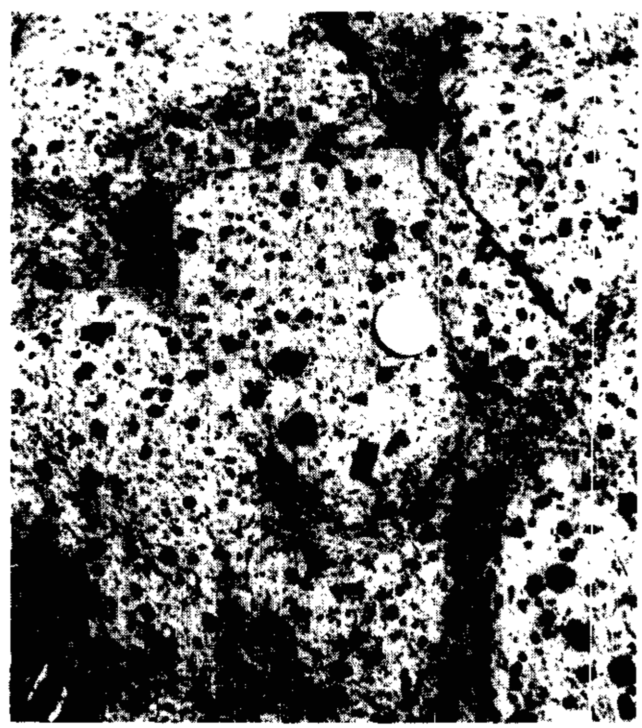
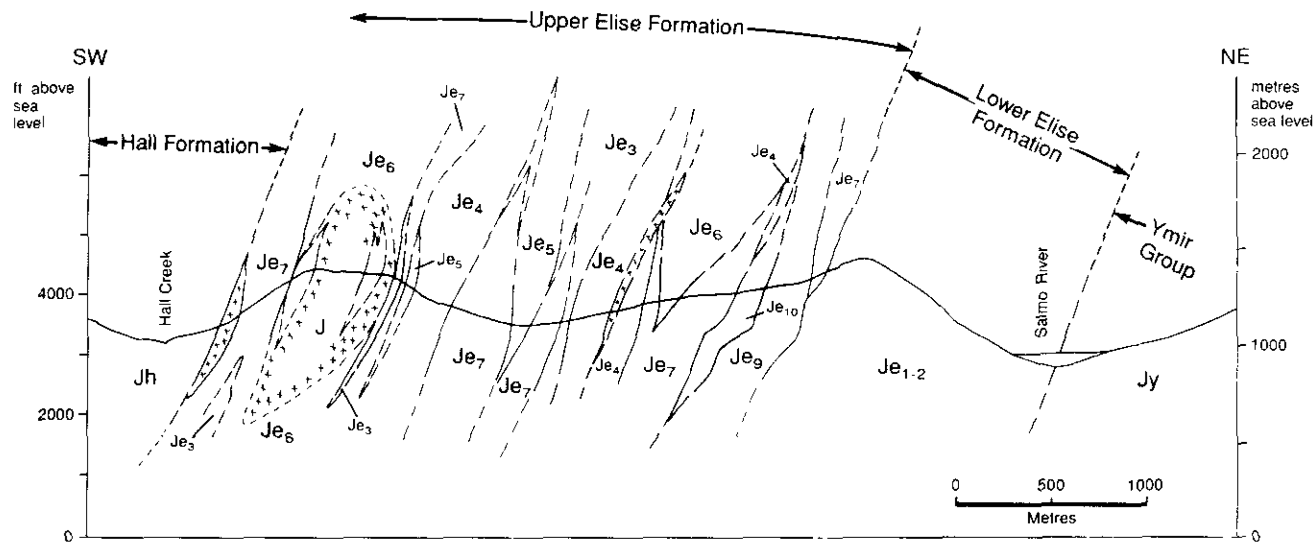


Plate 1-1-2. Coarse-grained augite porphyry flow breccia of Unit Je_2; note large augite phenocrysts in both matrix and fragments.

Coarse-grained Augite Porphyry Flows (Je_1)

Dark green, massive, compound flows (0.5 to 1 metre thick) typify this unit. The flows are characterized by 20 to 40 per cent augite phenocrysts commonly up to 1 centimetre in diameter and virtually no plagioclase phenocrysts. Truly massive flows are subordinate to those with autoclastic fragments and are not differentiated at this map scale.



LEGEND

CRETACEOUS AND/OR TERTIARY

KTd	Diorite dykes

JURASSIC

Jn	Nelson intrusions

LOWER AND MIDDLE JURASSIC

Jh	Hall Formation
	Grit, sandstone, conglomerate, argillite
Je	Elise Formation
Je_1	Coarse-grained augite-porphyry flows
Je_2	Coarse-grained augite-porphyry flow breccias
Je_3	Medium-grained augite-porphyry flows
Je_4	Medium-grained augite-porphyry flow breccias
Je_5	Mafic ash tuff
Je_6	Plagioclase augite crystal tuff
Je_7	Plagioclase augite lapilli tuff
Je_8	Plagioclase-porphyritic flows
Je_9	Tuffaceous siltstone
Je_{10}	Tuffaceous conglomerate
Je_{11}	Plagioclase porphyry intrusion
Jy	Ymir Group
	Argillite, limey siltstone; minor wacke, limestone

Figure 1-1-3. Vertical cross-section through the Hall Creek–Apex Creek area; *see* Figure 1-1-2 for location of section.

Way-up structures include amygdaloidal pillows and flowtop breccia. Thin (1 to 5 centimetres) mud selvages, often seen between flows, mark short periods of quiescence (Plate 1-1-1).

Coarse-grained Augite Porphyry Flow Breccia (Je_2)

This autoclastic unit is volumetrically more extensive than Unit Je_1 and is its fragmental counterpart. Monolithic fragments of the same composition as Je_1 are broken or quenched *in situ* (Plate 1-1-2). As a result, the size, shape and abundance of clasts are widely variable. Most often, flow breccias are matrix supported with subrounded clasts ranging from 2 to 10 centimetres in diameter.

Due to the similarity in fragment and matrix composition, the autoclastic nature of Unit Je_2 is often difficult to confirm. Generally, fragments are finer grained, are more felsic, and tend to have more augite phenocrysts and calcite amygdules from broken pillows. In places fragments are cemented by an impure brown carbonate.

Upper Section

The upper Elise Formation (Units 3 through 10) is a sequence of mafic to intermediate flows, tuffs and subvolcanic intrusions with minor epiclastic deposits. This section is up to 2.5 kilometres thick in the map area. Pyroclastic and epiclastic deposits are distinguished on the basis of their pyroclastic fragment content (Fisher and Schminke, 1984).

Medium-grained Augite-Porphyry Flows (Je_3)

These massive medium-grained flows outcrop throughout the upper section but are subordinate to coarser grained units in the basal section (Je_1 and Je_2) and thus not differentiated there at this scale of mapping. The unit is characterized by 20 to 30 per cent augite phenocrysts, generally less than 0.5 centimetre in diameter and virtually no plagioclase phenocrysts. Microphenocrysts of titaniferous magnetite (Beddoe-Stephens and Lambert, 1980) have also been identified in thin section.

Individual flows range in thickness from 1 to 4 metres and are typically massive and rarely pillowed. Compound flows are unusual. In outcrop, pillows (up to 1 metre in diameter) are amygdaloidal with glassy rinds (Plate 1-1-3).

Medium-grained Augite Porphyry Flow Breccia (Je_4)

Unit Je_4 is compositionally similar to Unit Je_3, but is its fragmental counterpart. This relationship is parallel to that between Units Je_2 and Je_1. Flow breccias of this unit are intimately associated with rocks of Unit Je_3 in outcrop but distinguished from them by their fragmental nature. The unit is characterized by mafic, angular, monolithic fragments (2 to 5 centimetres in diameter) hosted in a matrix of similar composition.

Plate 1-1-3. Stretched amygdaloidal pillows of Unit 3, station R33-13, on Highway 6, north of Ymir (*see* section, Figure 1-1-7).

Ash Tuff (Je_5)

This unit occurs as dark green fine-grained lenses (less than 100 metres thick) closely associated with medium-grained augite porphyry units (Je_3 and Je_4). Several per cent broken, commonly saussuritized plagioclase phenocrysts (An_{55-65}) less than 1 millimetre in diameter, and rare quartz crystals (0.5 millimetre in diameter) are the only primary textures preserved in the tuff.

A conspicuous biotite mineral foliation imparts a slabby parting in outcrop. The elongate biotite (up to 4 millimetres in diameter) comprises 15 per cent of the rock and is its most distinguishing feature. In thin section, the groundmass is seen to be metamorphosed to predominantly epidote, secondary plagioclase and minor calcite.

Plagioclase Augite Crystal Tuffs (Je_6)

Crystal tuffs of Unit Je_6 are characterized by a significant plagioclase component in the phenocryst assemblage and are interpreted to be of andesitic composition. Phenocrysts are dominantly 10 to 20 per cent euhedral plagioclase (An_{60-80}) laths (1 to 2 millimetres in diameter) and less than 5 per cent subhedral augite crystals (2 to 5 millimetres in diameter). Several per cent microphenocrysts of magnetite are evident in thin section.

Plagioclase Augite Lapilli Tuff (Je_7)

Unit Je_7 is typified by 5 to 20 per cent subrounded cognate pyroclasts ranging from 2 millimetres up to 6 centimetres in diameter. Fragments are the same composition as Je_6 and generally darker in colour than their matrix. This marked colour contrast is due to the preferential alteration of the fine-grained matrix to calcite, epidote and secondary plagioclase.

Plagioclase-Porphyritic Flows (Je_8)

The most distinguishing feature of these massive flows is the abundance of euhedral plagioclase laths. The flows are

Plate 1-1-4. Cross-bedded volcanic sandstone and minor siltstone of Unit Je_9. Note graded bed above siltstone layer.

typically 1 to 2 metres thick and occur in scattered outcrops of more mafic composition. Phenocrysts are mainly 15 to 30 per cent plagioclase (An_{50-70}) up to 3 millimetres in length, and minor augite up to 2 millimetres in diameter. The groundmass is a finely interwoven network of plagioclase microlites which have been altered to sericite, calcite and epidote.

Tuffaceous Siltstone (Je_9)

This unit is typified by mixed pyroclastic and epiclastic fragments with average clast size less than 1 millimetre. Pale green volcanic siltstone is interbedded with coarser tuffaceous plagioclase-rich beds that contain small lithic fragments. The siltstone is thinly (0.5 to 2 centimetres) bedded and finely laminated with well-defined graded beds, basal scours, crossbeds and channels (Plate 1-1-4). The tuffaceous and reworked material was probably emplaced in a high-energy shallow-marine environment.

Tuffaceous Conglomerate (Je_{10})

This unit is an interbedded sequence of conglomerate, grit, sandstone and siltstone of predominantly volcanic or subvolcanic provenance. It underlies Unit Je_9 and hence forms the basal part of a thick fining-upward succession. It comprises a series of fining-upward clastic cycles, generally, a few to several tens of metres thick, that are coarser near the base of the succession and finer at the top. Hence, cycles near the base grade from coarse conglomerates (Plate 1-1-5) to grits whereas those at the top typically grade upward from sandstone to siltstone. As in Unit Je_9, crossbeds, scours and channels are common throughout the unit.

The most abundant clasts are subrounded boulders and cobbles of feldspar porphyry that are similar in texture and composition to the Silver King porphyry (Plate 1-1-6). These clasts provide the most compelling evidence that the suite of Silver King porphyries are high-level subvolcanic intrusions. Other clasts include chert fragments, less commonly mafic volcanic fragments and rarely felsic volcanics with fiammé textures.

Units Je_9 and Je_{10} are epiclastic deposits formed by weathering of a more felsic volcanic centre and an exposed subvolcanic intrusion. Je_9 is overlain abruptly by coarse fragmentals of Unit Je_7.

Plagioclase Porphyry (Je_{11}) Including the Silver King Intrusions

This unit occurs as subvolcanic intrusions up to 400 metres thick that conform to stratigraphy. The porphyry is characterized by 20 to 30 per cent euhedral plagioclase phenocrysts (An_{56-60}), up to 1 centimetre across, and less than 5 per cent hornblende laths. Textural evidence for the subvolcanic origin of these plutons includes several per cent resorbed quartz phenocrysts. Highly sheared zones within and along the margins of the porphyries are evidence of considerable strain within the Elise Formation.

GEOCHEMISTRY

Considerable rock and mineral chemical analyses of Rossland volcanic rocks have been undertaken by Beddoe-Stephens and Lambert (1981). Whole-rock analyses of a few samples of various units of the Elise Formation, collected in 1986, are presented in Table 1-1-3.

Our analyses indicate that Elise volcanic rocks include dominantly undersaturated basic volcanics of mainly alkaline affinity (Figure 1-1-5). The volcanics are chemically classified as tephrite basanite, trachybasalt and basalt based on the total alkali-silica diagram of LeBas *et al.* (1986). Samples are neither sodic, $(Na_2O-4)>K_2O$, nor potassic, $Na_2O<K_2O$, and do not plot as shoshonites. The total alkali-silica diagram (TAS) is considered reliable despite low-grade metamorphism that has affected the Rossland Group; these samples plot in the "unaltered" field on an MgO-CaO plot from de Rosen-Spence (1976) (Figure 1-1-6).

Beddoe-Stephens and Lambert (1981) propose that Rossland volcanics have an alkalic, shoshonitic association based on the presence of ankaramitic rocks, amphibole-bearing basalts, and trace element abundances. However, they also show that tectonic discrimination diagrams indicate a calcalkaline affinity. They conclude that the Rossland volcanics are not typically calcalkaline in character but formed in the late stages of island arc development when tensional

Plate 1-1-5. Boulder conglomerate near the base of Unit Je_{10}.

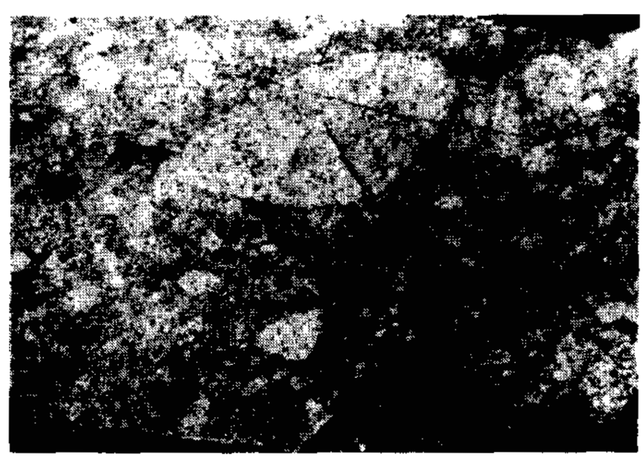


Plate 1-1-6. Boulder conglomerate containing abundant subrounded clasts of intrusive feldspar porphyry, Unit Je_{10}.

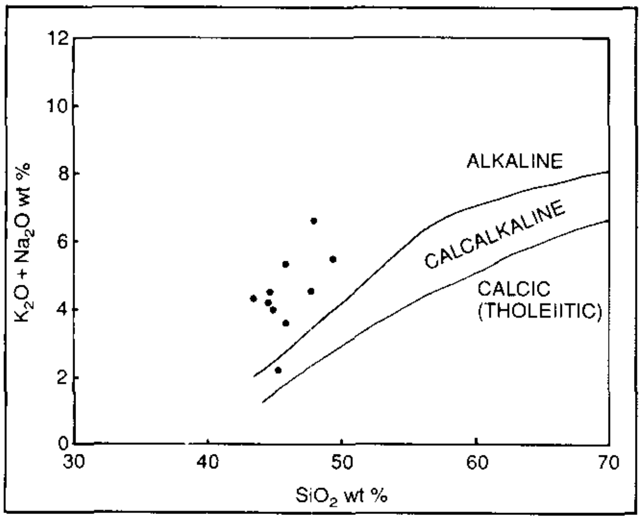


Figure 1-1-5. Alkali-silica plot of Elise Formation volcanic rocks; the field boundaries are modified from Kuno by Spence (1985).

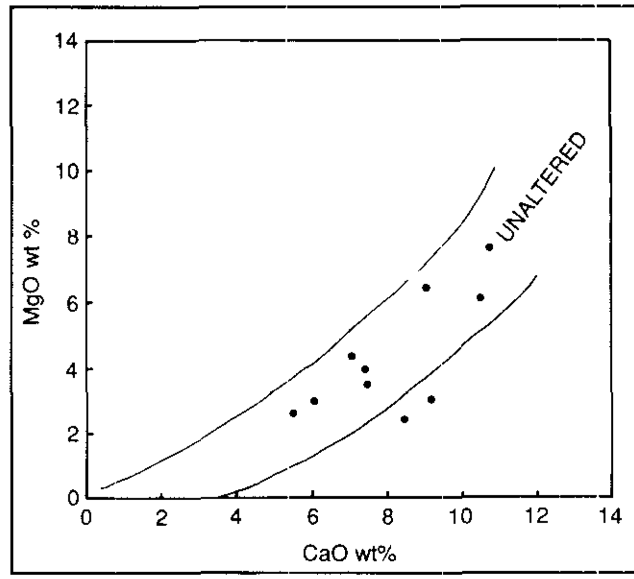


Figure 1-1-6. MgO/CaO plot designed to screen altered rocks (from de Rosen-Spence, 1976; Ray and Spence, 1986).

regimes begin to predominate. The variety of lithologies recognized in this study, and the variability in chemical composition indicates, however, that the tectonic setting of Rossland volcanic rocks is considerably more complex than previously recognized.

Summary and Discussion

The Elise Formation is dominated by a series of interfingering lenses of massive to brecciated flows and tuffs of variable composition. The basal succession comprises

TABLE 1-1-3
WHOLE-ROCK CHEMICAL ANALYSES OF ELISE FORMATION VOLCANIC ROCKS

Sample Number	31833	31834	31835	31836	31837	31838	31839	31840	31841	31842
Unit Number	Je_9	Je_7	Je_3	Je_3	Je_8	Je_6	KTd	Je_9	Je_7	Je_7
Oxides as Determined										
SiO_2	47.81	47.78	47.64	47.41	48.60	52.38	45.85	49.70	46.83	50.64
TiO_2	0.76	0.76	0.78	0.81	0.64	0.68	1.08	0.75	0.97	0.77
Al_2O_3	15.70	16.94	14.51	14.89	16.50	16.96	16.00	18.53	17.14	17.57
Fe_2O_3*	10.77	9.98	12.38	11.86	9.33	8.50	9.17	9.33	11.52	8.48
MnO	0.16	0.18	0.20	0.21	0.15	0.12	0.16	0.16	0.17	0.16
MgO	4.98	4.21	6.75	6.25	3.18	2.78	7.92	3.75	2.59	3.09
CaO	7.69	7.89	9.87	10.83	9.76	5.87	10.62	7.87	9.33	6.46
Na_2O	2.21	3.37	1.33	1.79	3.09	3.55	2.75	2.19	1.95	4.20
K_2O	2.25	1.64	1.09	1.89	2.52	2.27	1.42	2.59	2.62	2.81
P_2O_5	0.29	0.29	0.24	0.31	0.31	0.29	1.29	0.37	0.32	0.34
L.O.I.	6.99	6.64	5.33	3.30	5.72	6.75	3.15	4.15	6.93	5.67
Total	99.61	99.68	100.12	99.55	99.80	99.47	99.41	99.39	100.37	100.19
Oxides Recalculated Volatile-Free										
SiO_2	44.47	44.61	45.10	45.85	45.82	49.20	44.41	47.64	43.58	47.77
TiO_2	0.71	0.71	0.74	0.78	0.60	0.64	1.05	0.72	0.90	0.73
Al_2O_3	14.60	15.82	13.74	14.40	15.56	15.93	15.50	17.76	15.95	16.57
Fe_2O_3*	10.02	9.32	11.72	11.47	8.80	7.98	8.88	8.94	10.72	8.00
MnO	0.15	0.17	0.19	0.20	0.14	0.11	0.15	0.15	0.16	0.15
MgO	4.63	3.93	6.39	6.04	3.00	2.61	7.67	3.59	2.41	2.91
CaO	7.15	7.37	9.34	10.47	9.20	5.51	10.29	7.54	8.68	6.09
Na_2O	2.06	3.15	1.26	1.73	2.91	3.33	2.66	2.10	1.81	3.96
K_2O	2.09	1.53	1.03	1.83	2.38	2.13	1.38	2.48	2.44	2.65
P_2O_5	0.27	0.27	0.23	0.30	0.29	0.27	1.25	0.35	0.30	0.32
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Analyses by X-ray fluorescence, Analytical Laboratory, B.C. Ministry of Energy, Mines and Petroleum Resources.

* Total iron is reported as Fe_2O_3.

mainly massive flows and flow breccias of probable alkali basalt composition. It is overlain in the upper Elise by a number of cyclical sequences that typically comprise lapilli tuff and blocky tephra overlain by crystal tuff and ash tuff (*see* Figure 1-1-4). These volcanic cycles have variable composition, but in general, the upper Elise Formation is dominated by "intermediate" flows and tuffs at the base and top with a sequence of more mafic volcanics near the centre. The mafic volcanics are similar to those in the lower Elise; they are lavas and flow breccias that are overlain by dominantly ash tuff. These units interfinger extensively and, in detail, several units may be represented in a single outcrop (Figure 1-1-7); hence units in Figure 1-1-2 are named according to the dominant lithology.

The Silver King porphyry and other similar intrusive lenses are interpreted to be subvolcanic intrusions of similar age to the host Elise volcanics. They are sheared and foliated, generally conformable, and appear to be areally restricted to the Elise Formation. The most compelling evidence for a subvolcanic origin is the presence of feldspar porphyry clasts, megascopically similar to the Silver King porphyry, within Unit Je_{10}.

HALL FORMATION

The Hall Formation is a sequence of interbedded conglomerate, grit, siltstone and argillite exposed in the southwest part of the map area; this is the type locality of the Hall Formation as defined by Drysdale (1917). A disconformable relationship between the Hall and Elise formations is proposed by Little (1982) on the basis of pebbles resembling Elise lavas within Hall conglomerate. The top of the Hall is not seen because the formation is exposed in a syncline; however, the section is at least 1400 metres thick.

Cursory examination of the Hall section was undertaken in 1987. The basal Hall is dominated by coarse grits which fine upwards within 100 metres into interbedded graphitic argillite and sandstone with minor limy argillaceous layers. Several small (less than 50 metres) coarsening-upward sequences of argillite, sandstone and grit culminate in a clastic succession of pebble conglomerates that is up to 200 metres thick. Siltstone, silty argillite and argillite characterize the top of the Hall and are invariably interbedded with minor impure limestone layers.

PLUTONIC ROCKS

Small plutons similar to the Jurassic Nelson batholith intrude the Elise and Hall formations in the southern half of the map area. These plutons are subdivided compositionally into east and west intrusive equivalents. The more easterly intrusions are characterized by a nonporphyritic medium-grained equigranular texture. On the basis of modal analyses [60 per cent plagioclase (An_{90-92}), 5 per cent quartz, 15 per

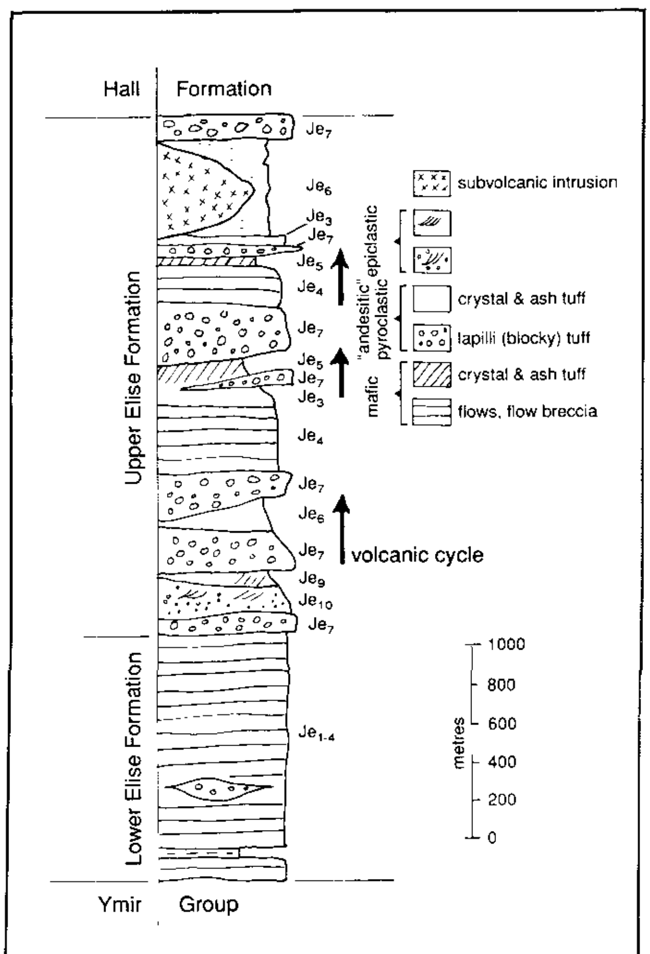


Figure 1-1-4. Composite volcanic succession, Elise Formation.

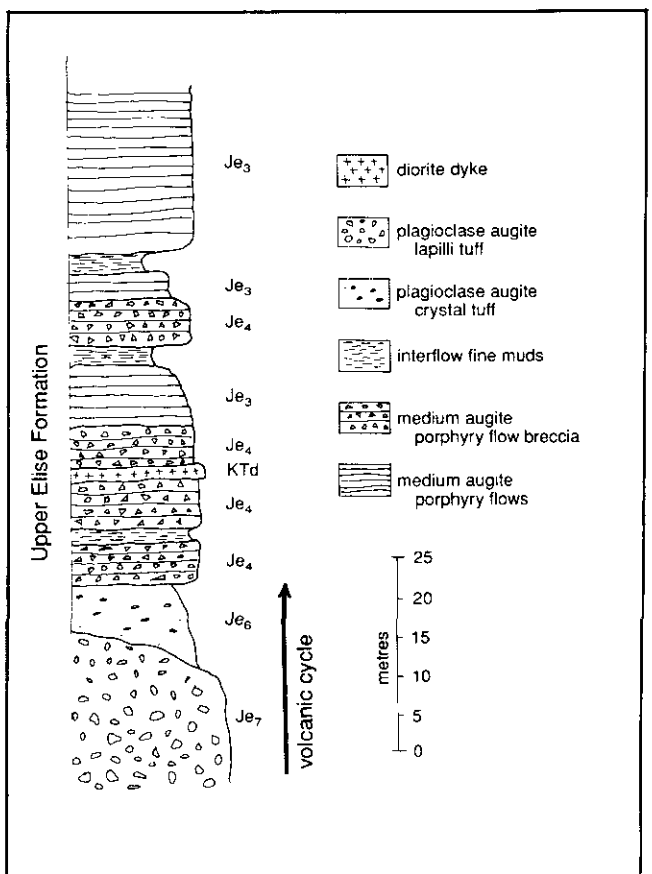


Figure 1-1-7. A detailed stratigraphic section in the upper Elise, station R33-13, on Highway 6, 6 kilometres north of Ymir.

TABLE 1-1-4
MINERAL PROPERTIES WITH PAST PRODUCTION OR EXTENSIVE DEVELOPMENT, HALL CREEK–APEX CREEK AREA

Map No.	MINFILE No.	Name	Commodities	Status	Reference
1	—	—	(Au, Pb, Zn)	Showing (adit)	—
2	—	—	(Cu, Au, Ag)	Showing (adit)	Little, 1964
3	—	—		Showing (adit)	
79	82FSW-079	Gold Cup	Au, Ag, Cu	Past producer	MINFILE
185	82FSW-185	Golden Age	Au, Ag, W, Pb, Zn	Past producer	MINFILE
186	82FSW-186	Euphrates	Au, Ag, Pb, Zn	Past producer	MINFILE
4	—	Lost Cabin	(Au, Ag, Cu)	Past producer?	Drysdale, 1917
237	82FSW-237	Kena	Cu, Au	Showing (diamond drilling)	MINFILE
5	—	Jennie Bell	Au, Ag, Pb	Past producer	Drysdale, 1917

cent orthoclase, 10 per cent biotite, 5 per cent hornblende and 3 per cent opaques], these intrusions are compositionally classified as granodiorites. Western intrusions are referred to as diorite porphyries by Little (1982). These fine-grained diorites are characterized by plagioclase (An_{66-84}) and hornblende phenocrysts.

Lamprophyric and dioritic dykes of probable Cretaceous or Tertiary age crosscut all map units. Several lamprophyric dykes crop out within the Ymir Group in the northeastern part of the map area. Diorite dykes striking north-northeast, approximately parallel to stratigraphy, form a subparallel swarm which straddles the Elise/Hall contact in the southwestern part of the map area. The diorite is typically medium grained with distinctive glomerocrysts of plagioclase variably replaced by calcite and epidote.

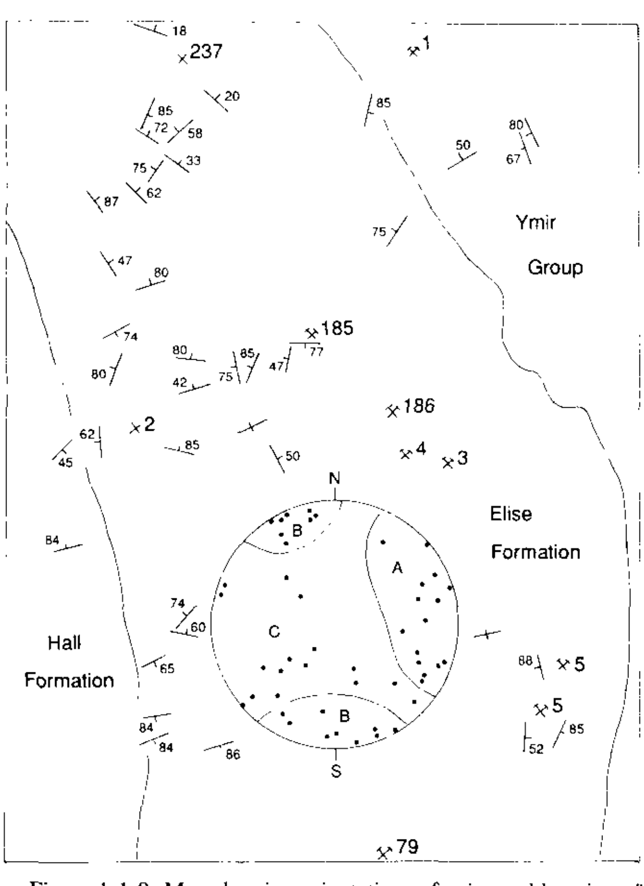


Figure 1-1-8. Map showing orientations of veins and location of mineral deposits, Hall Creek–Apex Creek area. Stereonet plots poles to quartz veins in the area. Deposits are listed in Table 1-1-3.

MINERALIZATION

Mineral occurrences in the map area include auriferous quartz veins and, on the Kena claims, conformable silicified zones carrying copper and gold. These occurrences (Table 1-1-4), as well as numerous other quartz veins, are plotted in Figure 1-1-8.

Quartz veins vary from massive white bull-quartz to quartz-carbonate. Accessory silicate minerals include plagioclase, tourmaline, epidote, chlorite, muscovite, actinolite and axinite. Common sulphide minerals include pyrite and chalcopyrite; in veins that have had some development work, covellite, bornite, tetrahedrite, galena and sphalerite are also recognized. Scheelite occurs with tourmaline and axinite in a quartz-carbonate vein on the Golden Age property.

Although the veins appear to be highly variable in strike and dip, a number of preferred orientations are apparent. A large number (set A, stereonet in Figure 1-1-8) trend north-northwest and dip variably toward the west, essentially parallel to bedding or the prominent regional foliation. A second set (B) is perpendicular to the gentle south to north-plunging lineation, parallel to prominant AC jointing. Most other veins (C) are parallel to extension joints, striking northwest but dipping to the east at a high angle to bedding. These orientations indicate that the veins are structurally controlled. However, their spatial distribution on a regional scale, near the margins of large intrusions, and the general lack of tectonic fabric within them suggest that they are post-tectonic and formed during intrusion of the Nelson batholith and related rocks. Their orientations are at least partially controlled by a pre-intrusive structural fabric. Lead-lead isotope analyses of galenas, detailed geochemistry and fluid inclusion studies will further clarify the controls of vein emplacement in Rossland rocks.

CONCLUSIONS

The central part of the Rossland Group, the Elise Formation, is readily subdivided into a number of distinct and mappable units. Mafic augite porphyry flows and flow breccias dominate the lower Elise and probably record a period of tectonic extension, perhaps in a back-arc basin, prior to more explosive volcanism typical of the upper Elise.

The upper Elise comprises dominantly thick accumulations of lapilli tuff and blocky tephra that grade laterally and vertically to crystal tuff and ash tuff. These cyclical sequences interfinger extensively, indicating the presence of distinct and separate explosive vent areas. Less abundant in the upper Elise are mafic flows similar to those in the lower Elise; these may grade laterally and vertically to mafic ash tuffs.

Conformable, locally sheared plagioclase porphyry bodies in the upper Elise, including the Silver King porphyry, are interpreted to be coeval subvolcanic intrusions. A dominantly epiclastic unit near the base of the upper Elise is composed largely of clasts of intrusive plagioclase porphyry. It hosts a number of vein deposits (Figure 1-1-8) emphasizing a genetic link between comagmatic intrusions and mineralization.

The presence of at least two volcanic centres in the Rossland Group here, and in the Rossland mining camp (Fyles, 1984), extensive epiclastic deposits west of Salmo (Fitzpatrick, 1985), and variable chemistry and lithology indicate a complex tectonic setting for Rossland Group rocks, probably including both arc development and rifting.

ACKNOWLEDGMENTS

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GEOLOGY AND MINERAL EVALUATION OF KOKANEE GLACIER PROVINCIAL PARK, SOUTHEASTERN BRITISH COLUMBIA

(82F/11, 14)

By D. A. Brown and J. M. Logan

KEYWORDS: Economic geology, Kokanee Glacier Park, Kootenay arc, Slocan Group, Rossland Group, Nelson batholith, mesothermal veins, geochemistry, Slocan fault zone.

INTRODUCTION

The Geological Survey Branch is conducting a 2-year program of geological mapping and mineral evaluation of Kokanee Glacier Park. This includes 1:50 000 mapping, examination of mineral occurrences in the park, rock and silt geochemistry, lead isotope analyses of mineralization, and compilation of previous work.

Kokanee Glacier Provincial Park was established in 1922 and named in 1924. From 1940 to 1965 it was a "Class A" park, but in 1965 it was changed to "Class B" to allow mineral exploration on valid claims. In 1973 a moratorium banned any exploration or development in Provincial Parks. New park boundaries were established in the spring of 1987. New additions to the park, together with the 46 existing mineral claims, were designated as "Recreation Areas", where mineral exploration and development are permitted. This study is being conducted to provide mineral resource data to help determine the eventual classification and boundaries of the park. The park, located 35 kilometres northeast of Nelson, is accessible by gravel roads from Highways 3A, 6 and 31A. Logging roads provided access to most of the map area. A helicopter was used to reach more remote areas.

PREVIOUS WORK

Areas of previous work are outlined in Figure 1-2-1. The mapping of Cairnes (1934 and 1935) was recompiled by Little (1960) with no significant changes. A map of Slocan Group sedimentary rocks and their structure in the Sandon area was produced by Hedley (1952). Detailed mapping of Paleozoic to Mesozoic stratigraphy and structure was conducted by Fyles (1967) in the Ainsworth area. Klepacki and Wheeler (1985) have documented stratigraphic and structural relationships within the Milford, Kaslo and Slocan groups northwest of Kaslo. The Valhalla complex, which was mapped by Reesor (1963), has been recently reinterpreted, based on geochronology (Parrish, 1984; Carr *et al.*, 1987). Lithoprobe (Cook *et al.*, 1987) detected a reflector, interpreted to be the Slocan Lake fault, that dips gently (about 30 degrees east) beneath the Nelson batholith.

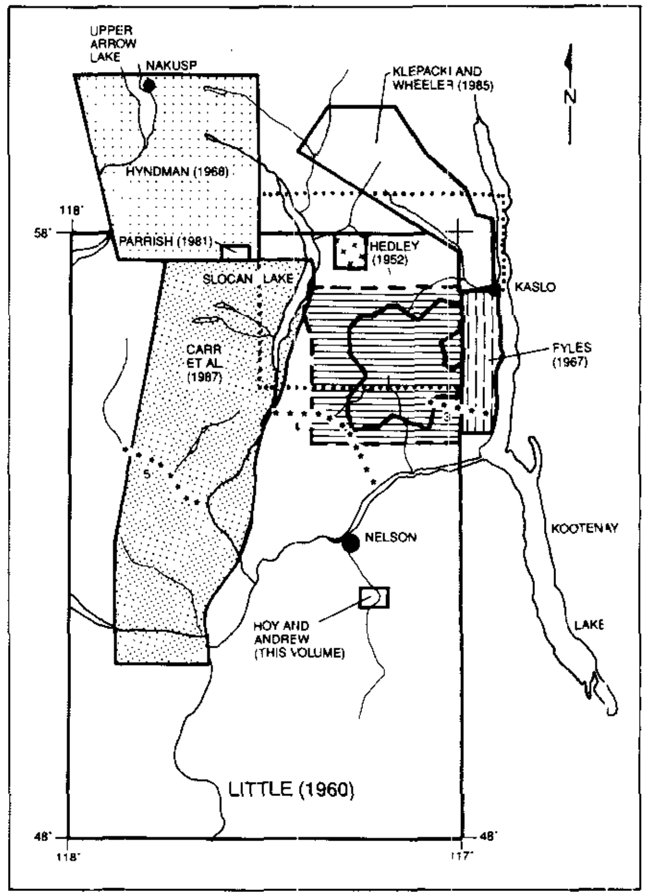

Figure 1-2-1. Location map with areas of previous work, Kokanee Glacier Provincial Park area, British Columbia. Region discussed in this paper is the area of horizontal lines enclosed by dashed lines. The dotted area refers to Cairnes (1934 and 1935). Area outlined for Carr *et al.* (1987) includes older work by Carr (1986), Reesor (1963), Parrish (1987), Parrish (1981) and Parrish *et al.* (1985). *** = Lithoprobe seismic lines (Cook *et al.*, 1987): Line 3 = Coffee Creek, Line 4 = Duhamel and Lemon creeks, and Line 5 = Koch Creek.

REGIONAL GEOLOGY AND GEOCHRONOLOGY

The park is located on the western edge of the Kootenay arc, in allochthonous rocks of the Quesnel terrane. The region is dominated by the late to post-tectonic I-type Nelson batholith, intruded into Slocan Group sedimentary rocks and Rossland Group sedimentary and volcanic rocks. Paleozoic

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

to Upper Mississippian pericratonic rocks are exposed to the east (Fyles, 1967) and the Valhalla complex which includes three Cretaceous to Tertiary gneissic sheets lies to the west (Carr *et al.*, 1987). Easterly directed ductile and brittle fabrics, the Valkyr shear zone and Slocan Lake fault zone, are exposed along Slocan Lake (Carr *et al.*, 1987) and form the western contact of the Nelson batholith. The stratigraphic sequence includes Lower Cambrian Hamill quartzite, exposed on the west shore of Kootenay Lake, to Lower Jurassic Rossland Group, near Slocan Lake (Table 1-2-1; Fyles, 1967).

Numerous geochronometric studies have been published on the region. A Middle Jurassic zircon uranium-lead date was reported for the Kuskanax batholith, an alkaline to peralkaline aegerine augite quartz monzonite (Parrish and Wheeler, 1983; Read, 1973). Uranium-lead and potassium-argon dates bracket the age of Nelson batholith emplacement between 160 and 172 Ma. Middle Jurassic (169 and 165 Ma) zircon uranium-lead dates for the Nelson batholith were reported by Carr *et al.* (1987) and Ghosh (1986). Duncan *et al.* (1979) report a hornblende potassium-argon date of 164 Ma for the Mount Carlyle stock. Younger

TABLE 1-2-1
TABLE OF FORMATIONS AND GEOLOGICAL EVENTS NEAR NELSON BATHOLITH, KOKANEE GLACIER PROVINCIAL PARK AREA

PERIOD	STRATIGRAPHY	METAMORPHISM	DEFORMATION–METAMORPHISM	MINERALIZATION
TERTIARY	not present in map area	Lamprophyre, rhyolite Coryell 51.7±0.5 Ma (2) post-tectonic Ladybird gn. 56.5±1.5 Ma (2) deformed Ladybird gn. 59±1 Ma (2) Airy quartz monzonite, 62±1 Ma (2)	45 SLFZ (2) 54 VSZ (2) 59 53 Ma greenschist (4) 75 Ma Paleocene	? Potential ? epithermal ?
CRET.		Mulvey gneiss 100±5 Ma (4)	eastward thrusting (1 and 8) Late Cretaceous	? ?
JURASSIC		Nelson bath. 169±3 Ma (2) Kuskanax bath. 173±5 Ma (9)	151 greenschist to silm-ksp grade (3) 168 Buckling (3) 173	Mesothermal quartz-siderite veins
	Rossland Group: Hall Formation (Toarcian; 10) Elise Formation (Pliensbachian; 10) Archibald Formation (Sinemurian; 10)	Feldspar porphyry Quartz latite porphyry 194±3 Ma (5) Hb diorite 195 Ma (7)	188 Phase I and II folding (3) Quesnellia convergence	Volcanogenic breccia pipe
TRIASSIC	Slocan Group (Late Triassic; 6)			
	unconformity			
PERMIAN	Kaslo Group (Early Permian; 6)			
MISS.-PENN.	Milford Group (Early Pennsylvanian–Early Mississippian; 6)			
	unconformity			
	Lardeau Group (Cambrian-Mississippian; 3)			
	Badshot limestone and Hamill Group (Lower Cambrian; 3)			

LEGEND

Abbreviations:
- bath = batholith
- gn = granite
- hb = hornblende
- ksp = potassium feldspar
- monz = monzonite
- silli = sillimanite
- SLFZ = Slocan Lake fault zone
- VSZ = Valkyr shear zone

(1) Archibald *et al.* (1984)
(2) Carr *et al.* (1987)
(3) Fyles (1967)
(4) Mathews (1983)
(5) McMillan (*written communication*, 1987)
(6) Orchard (1985)
(7) Parrish (*personal communication*, 1987)
(8) Parrish (1987)
(9) Parrish and Wheeler (1983)
(10) Tipper (1984)

potassium-argon dates probably reflect partial resetting or overprinting by Cretaceous or Tertiary thermal events (Archibald *et al.*, 1983; Duncan *et al.*, 1979). Hornblende and biotite $^{40}Ar/^{39}Ar$ age spectrum analyses conducted by Harrison (1985) indicate dates for Nelson phases between 153 and 160 Ma. Biotite in the northwest part of the batholith closed with respect to ^{40}Ar by 154 Ma and lost minor ^{40}Ar between 50 and 60 Ma (Harrison, 1985). In contrast, biotites in the south did not close with respect to ^{40}Ar until 50 to 60 Ma (Harrison, 1985). A rubidium-strontium plagioclase date of 137 ± 10 Ma and a hornblende potassium-argon date of 139 ± 5 Ma for potassium-feldspar porphyritic monzonite from Duhamel Creek are reported by Duncan *et al.* (1979), however, it is uncertain whether these results represent a Late Cretaceous phase or partial resetting. Uranium-lead, potassium-argon and rubidium-strontium data from the Valhalla complex and Nelson batholith were discussed by Carr *et al.* (1987).

PARK GEOLOGY

The park is dominated by extensive exposures of Nelson batholith enclosing narrow horizons and tabular blocks of pelitic and psammitic metasedimentary rocks, tentatively correlated with the Late Triassic Slocan Group. Rocks are well exposed above 2000 metres elevation but below this is a cover of glacial-fluvial gravels.

STRATIGRAPHY

SLOCAN GROUP

The Slocan Group underlies the northeastern corner of the map area, in Keen Creek valley, and also occurs as irregular tabular blocks and screens enclosed in the Nelson batholith. It comprises a thick accumulation of variably deformed and metamorphosed shale, argillite, siltstone, quartzite and limestone. Stratigraphic thickness is unknown. Within the batholith, brown-weathering aligned blocks of Slocan Group sediments contrast sharply with the grey-coloured granite. Blocks and screens vary in size up to 100 metres thick, and are mappable along strike for about 8 kilometres. To the north and east, bedding in the sediments is concordant with the main batholith contacts (Figure 1-2-2; Fyles, 1967). Granitic sills, common in the metasedimentary horizons and tabular blocks, have sharp, planar intrusive contacts, subparallel to bedding.

Black shale, grey siltstone and rare limy beds exposed in the Keen Creek valley are crosscut by plagioclase-porphyritic quartz monzodiorite dykes and sills. Biotite hornfels extends less than 10 metres from the dyke and sill contacts. Near the Bismark mine (MINFILE 082FNW-096) pure, recrystallized limestone bands, up to 60 metres thick, lie against the batholith with little calc-silicate formation. The well-bedded and grey-weathering limestone contains minor quartzitic sandstone beds and lenses. The sandstone beds have an unknown provenance.

Siliceous micaeous siltstone and quartzite are common as blocks in the batholith. Siltstone is laminated to finely bedded and locally contains stratabound coarse disseminated pyrite. Rare limy beds have calc-silicate skarn mineral assemblages, including garnet, diopside and wollastonite. Local stratigraphy near Woodbury cabin comprises 20 metres of fine-grained quartzite, overlain by about 25 metres of mauve sandstone and 15 metres of micaeous siltstone. Petrographic studies of these metasediments are in progress.

Another section through four parallel, moderately west-dipping metasedimentary blocks and granite sills, located west of Coffee Creek, begins with interbedded white quartzite and light grey limy quartzite. Wollastonite-bearing marble horizons occur within the quartzite. These are overlain by interbedded, 5 to 10-centimetre-thick, pinkish quartzose sandstone that alternates with 2 to 5-centimetre-thick rusty weathering micaeous silty sandstone. A 5-metre-thick potassium-feldspar porphyritic granite sill separates the lowermost interval from three upper metasedimentary units. The lowest (4 metres thick) and uppermost (3 metres thick) intervals are greenish grey, slightly rusty, thinly bedded siltstone and biotite-bearing quartzite. The middle layer, 3 metres thick, is greenish biotite schist, porphyritic amphibolite and green quartzite. Boudinaged beds parallel metasedimentary horizons. Total stratigraphic thickness is about 120 metres.

The stratigraphy and structure of the Slocan Group remain enigmatic due to its recessive nature, lack of marker horizons and complex structure. Hedley (1952) provided the best attempt at elucidating the Slocan Group near Sandon. If the isolated blocks within the batholith are correlative with Slocan Group, then there appears to be a facies change from shale-argillite to more silicic siltstone-sandstone from Keen Creek to the central part of the park.

Orchard (1985) reports Late Triassic (Carnian and Norian) conodonts from Slocan Group limestone near Retallack, 15 kilometres north of the map area. The Slocan Group unconformably overlies Early Permian Kaslo Group volcanic rocks (Klepacki, 1983; Orchard, 1985) that outcrop east and north of the map area, and are unconformably overlain by Early Jurassic Rossland Group volcanic and sedimentary rocks.

ROSSLAND GROUP

Exposures of Rossland Group are confined to pendants within the Nelson batholith. The largest pendant hosts the Willa gold-copper deposit, in the northwestern corner of the map area (Figures 1-2-2 and 1-2-5). Isolated metavolcanic blocks extent southward, along strike, into the Ymir map area, where Höy and Andrew (this volume) have mapped Rossland stratigraphy in detail.

Tipper (1984) divided the Rossland Group into three formations: (1) Archibald Formation–Sinemurian sedimentary rocks; (2) Elise Formation–lower Sinemurian volcanic rocks; and (3) Hall Formation–Toarcian shallow-water siltstone, greywacke and conglomerate. Based on lithologic and age constraints, volcanic rocks of the Willa area have been tentatively correlated with the Elise Formation.

INTRUSIVE ROCKS

Three intrusive episodes are: (1) Early Jurassic intermediate porphyries, coeval with Rossland volcanics (Table 1-2-1); (2) Middle Jurassic Nelson plutonic suite; and (3) Tertiary dykes. Seven hundred square kilometres (98 per cent) of the

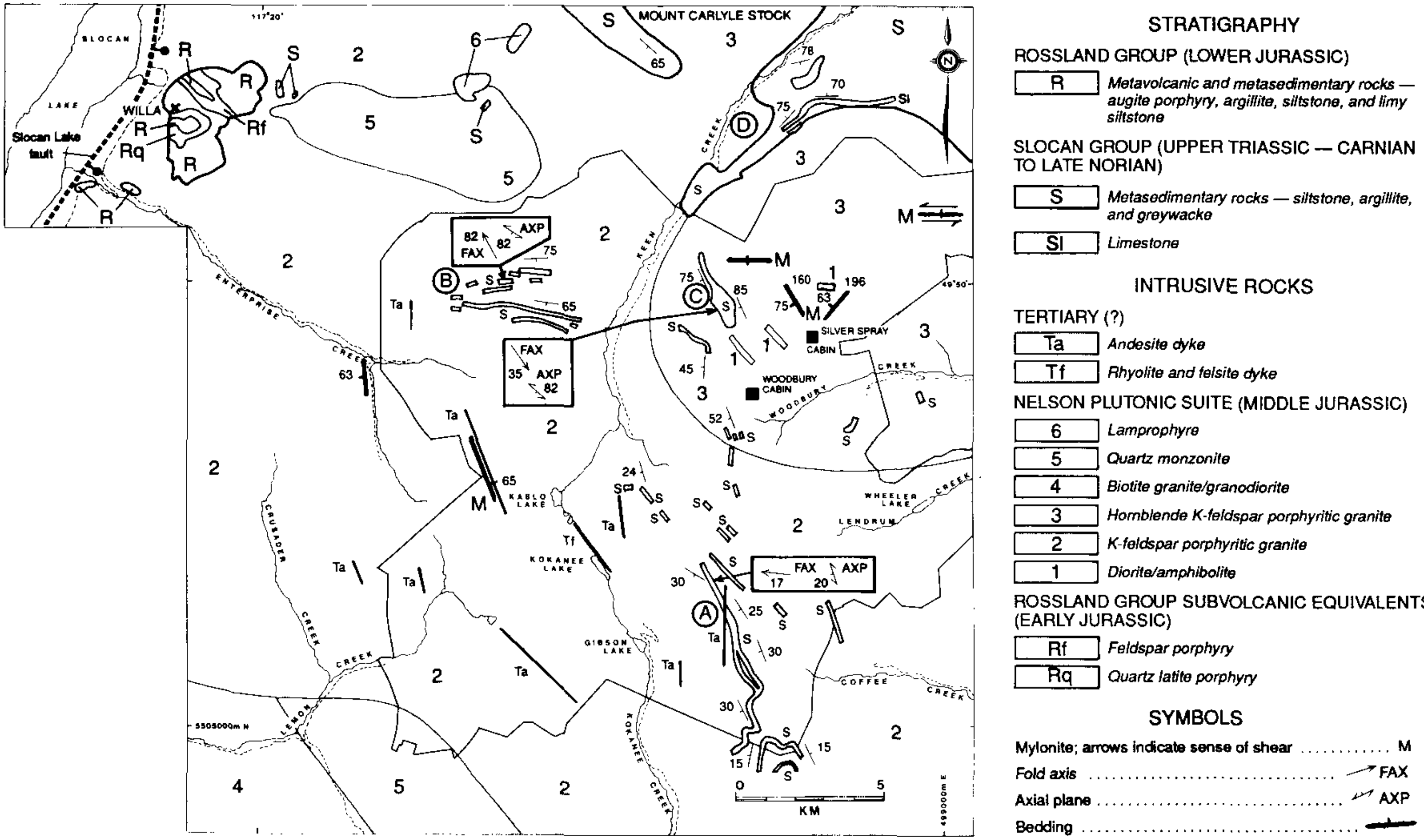

Figure 1-2-2. Geology of Kokanee Glacier Provincial Park area, southeastern British Columbia.

map area is underlain by the composite Nelson batholith. Mineral deposits tend to be spatially associated with the batholith.

EARLY JURASSIC PLUTONIC SUITE

Epizonal intrusive rocks, comagmatic and coeval with Rossland volcanics, intrude Rossland andesitic volcanic rocks. Three varieties of feldspar porphyry and quartz latite porphyry have been mapped at the Willa deposit (Heather, 1985). Pipe-like heterolithic intrusive breccia that hosts the Willa gold-copper-silver mineralization is contained within these intrusions (Heather, 1985).

Zircons extracted from quartz latite porphyry yielded a 194 ± 3 Ma uranium-lead isotopic age (W.J. McMillan, written communication, 1987). Zircons contain a large amount of inherited xenocrystic lead of Proterozoic age (P. van der Heyden, written communication, 1987). Plagioclase porphyry collected by McMillan is currently being processed for zircon uranium-lead dating. Andesitic to basaltic dykes, which crosscut mineralization, were collected for potassium-argon isotopic dating.

NELSON PLUTONIC SUITE (MIDDLE JURASSIC)

Within the map area, the Nelson batholith comprises at least six texturally and compositionally distinct phases (inferred oldest to youngest): (1) diorite/amphibolite, (2) potassium-feldspar granite, (3) hornblende potassium-feldspar granite, (4) fine-grained granite, (5) quartz monzonite and (6) lamprophyre. Areas dominated by a particular phase are indicated on Figure 1-2-2. Intrusive contacts are gradational and irregular. Aplite and pegmatite dykes, believed to be comagmatic, occur throughout the area. The suite is subalkaline, calcalkaline and metaluminous (Ghosh, 1986). Sixteen samples for whole-rock chemistry are being analysed.

Diorite/Amphibolite (Unit 1)

The oldest phase is dark grey to black-weathering mesocratic diorite/amphibolite which occurs as angular to rounded xenoliths in younger leucocratic phases. Xenoliths vary in size from centimetre to decimetre scale and are comprised of massive to foliated, fine to medium-grained diorite. Hornblende is fresh and makes up more than 40 per cent of the diorite. Titanite and apatite are associated with hornblende as euhedral crystals up to 2 millimetres long. The xenoliths are ellipsoidal and locally aligned. Surrounding potassium-feldspar megacrysts may be foliated subparallel to the xenolith contacts, crosscut, or contained within the xenolith. During this year's mapping the xenoliths were interpreted to outline phase boundaries within the batholith, but their distribution now seems to be more random. Xenoliths are abundant along the Springer Creek road and near the Enterprise mine (Minfile 082FNW-148).

Potassium-Feldspar Porphyritic Granite (Unit 2 — "Main phase")

The potassium-feldspar megacrystic, medium to coarse-grained hypidiomorphic granite is the dominant Nelson phase. Massive in outcrop, it covers a 550-square-kilometre area. This phase contains up to 50 per cent white to faintly pink, euhedral, equant to prismatic potassium-feldspar megacrysts (Plate 1-2-1). These megacrysts are up to 10 centimetres long and are locally flow aligned. They are microperthitic to perthitic. Megacrysts contain inclusions of biotite, hornblende, plagioclase and quartz. The inclusions are all smaller than corresponding groundmass minerals, suggesting primary potassium-feldspar crystallization, rather than a metasomatic origin. Size and amount of potassium feldspar are extremely variable at outcrop and map scales. Hornblende and biotite phenocrysts are unaltered, black, subhedral and interstitial to potassium feldspar. Plagioclase is unaltered with albite twins. Hornblende and lesser biotite comprise 15 per cent or less of the granite. Visible honey-coloured euhedral titanite, and apatite, magnetite and opaques are accessories. Myrmekitic blebs occur at some plagioclase–potassium-feldspar grain boundaries.

Plate 1-2-1. Potassium-feldspar porphyritic phase of Nelson batholith, lens cap is 5.5 centimetres in diameter.

Hornblende Potassium-Feldspar Porphyritic Granite (Unit 3 — Caribou Ridge Phase)

This phase is differentiated from potassium-feldspar granite by prominent coarse, prismatic, black, euhedral hornblende phenocrysts. The rock is medium to coarse grained. There is much less biotite relative to hornblende and biotite may be absent. Hornblende is euhedral, up to 1.5 centimetres long and interstitial to megacrysts of tartan-twinned microcline. Titanite is ubiquitously associated with hornblende. Very coarse varieties contain 75 per cent potassium-feldspar megacrysts, up to 5 centimetres long, and interstital plagioclase, quartz and euhedral hornblende. Crystal composition and texture are similar to the potassium-feldspar porphyritic phase.

Biotite Granite/Granodiorite (Unit 4 — Lemon Creek Phase)

There are two varieties of biotite granite, mesocratic and leucocratic. The mesocratic biotite granite is a grey, medium to fine-grained rock with few potassium-feldspar megacrysts (< 5 per cent). The rock is massive with 5 to 10 per cent fresh to slightly chlorite-altered biotite. The leucocratic granite is salmon-pink to grey, fine grained and equigranular. Potassium-feldspar megacrysts are uncommon but smaller tartan-twinned microcline is common. Plagioclase is fresh and myrmekitic grains are abundant. Rare biotite phenocrysts are altered to chlorite. Secondary muscovite is anhedral and has locally grown across grain boundaries. It is important to note that muscovite is secondary; this is not a two-mica granite. All grains are anhedral to subhedral, a xenomorphic texture. This phase was also noted by Little (1960).

Quartz Monzonite (Unit 5 — Alpine phase)

The quartz monzonite is pale grey to white, medium grained and massive. Hornblende and biotite are fresh and constitute up to 2 per cent of the rock. Titanite is an accessory. Little (1960) indicated that this phase intruded the Nelson batholith and included it with "Valhalla plutonic rocks". This designation is dropped here; the monzonite is interpreted to be a late phase of the Nelson plutonic suite.

Biotite Lamprophyre/Diorite (Unit 6 — Comstock Phase)

A brown-weathering, biotite-rich, magnetite-bearing body outcrops near the Comstock mine (MINFILE 082FNW-077). It is fine to medium grained, heavy and hard. Biotite blades are up to 2 centimetres long. At the Comstock portals, iron carbonate alteration and limonitic weathering are common.

Tertiary (?) Intrusive Rocks

Inferred Tertiary intrusive rocks occur as narrow rhyolite, felsite, andesite and lamprophyre dykes. The dykes are steeply dipping, north and north-northwest striking, and commonly parallel to airphoto linears.

Andesite dykes are brown-weathering, fine-grained, magnetite-bearing rocks. In the Coffee Pass area, a 3-metre-wide andesite dyke is coarsely vesicular with chilled aphanitic margins. Andesite dykes crosscut rhyolite dykes at the Republic mine, 10 kilometres west of the map area (468039E 5516036N; MINFILE 082FNW-168). Andesite contains resorbed quartz phenocrysts, aligned plagioclase laths and subrounded inclusions of granite, up to 5 centimetres wide.

Rhyolite float was found near the Scranton-Pontiac mine. The rhyolite is quartz phyric, fine grained to aphanitic and cream coloured, with manganese staining along fractures. Quartz phenocrysts are distinctly equant and angular, in an aphanitic felsic groundmass.

STRUCTURE

The structures of the Slocan Group or older metasedimentary rocks in the park are discussed below for four distinct areas (A, B, C and D on Figure 1-2-2). The areas are defined geographically and by structural geometry.

Area A, at the head of Coffee Creek and east of Kokanee Glacier, comprises at least four distinct layers of up to garnet-biotite grade pelitic and psammitic metasediments. They can be traced over 10 kilometres along strike. Beds are gently west to southwest dipping; southern exposures are subhorizontal, hence the irregular outcrop pattern (Figure 1-2-2). Inclined minor folds have shallow west-plunging fold axes and shallow west-dipping axial planes. Folds with similar geometry occur near the Olsen mine (MINFILE 082FNW-187). Locally, minor asymmetric folds are north verging. More competent beds and granitic sills are boudinaged.

Two phases of granite intrusion are evident: an older, deformed granite lacking potassium-feldspar megacrysts, and younger, undeformed potassium-feldspar megacrystic granite sills.

Area B, Bear Grass basin, contains silicic metasedimentary layers and granitic sills along a strike length of about 4 kilometres. Granitic sills are boudinaged in two directions, indicating significant east-west and vertical extension parallel to bedding/sill planes. These centimetre-scale boudins are mimicked by decimetre and larger map-scale metasediment blocks that are pulled apart along an easterly trending axis. Minor folds are tight with angular closures, steeply dipping axial planes and steeply northwest-plunging fold axes.

Area C, northeast of Revenue mine (MINFILE 082FNW-106), is underlain by a band of biotite-grade metasediments about 2.5 kilometres long. Folds are: (1) asymmetrical, suggesting an antiformal closure west of Revenue mine or (2) tight to isoclinal with angular closures, and (3) open warps. Folded granitic sills, with amplitudes of 10 centimetres, indicate pre to syntectonic intrusion. The axial planes have consistently steep southwest dips with fold axes of variable plunge (Plate 1-2-2). Near Silver Spray cabin, psammites are folded into tight to isoclinal folds with rounded to subangular closures at decimetre scale. Boudinaged fine-grained granitic sills, less than 1 metre wide, occur locally. Potassium-feldspar megacrystic granite dykes cut the folded and boudinaged sediments and sills.

Plate 1-2-2. View southeast, down plunge to folded granitic sill and siltstone, indicating early phases of Nelson batholith were syntectonic. Fold axes = 148°/33°; axial plane = 142°/72° SW.

Area D, extending north of the park boundary near Keen Creek, contains poorly exposed, more argillaceous rocks than areas A, B, and C. Folds and fabrics are diverse. Contrasting deformation intensity and metamorphic grade are characteristic. Shale, phyllite and mica schist are repeated, possibly due to faulting. Recrystallized pure limestone horizons and pelitic and psammitic beds parallel the batholith contact. Sandstone layers contained within the limestone are disharmonically folded.

Early minor folds are tight to isoclinal with moderate east-plunging, southeast-inclined axial planes. Open and disharmonic folds are intermediate in age. Younger folds are coarsely crenulated phyllites and mica schist with shallow west-southwest-plunging fold axes and subhorizontal axial planes.

Nelson Batholith Deformation

The oldest fabric in the batholith is primary flow alignment of potassium-feldspar and hornblende crystals; it is coplanar with metasedimetary layers and amphibolite lenses.

Most of the northern Nelson batholith is undeformed and post-tectonic. In contrast, the southern end [(LeClair, 1983) and the eastern margin (Fyles, 1967)] of the batholith are late-synkinematic with deformed margins. Discrete zones of chlorite-grade proto to ultramylonite (less than 50 centimetres wide) occur in the map area. Mylonites are of limited areal extent and their significance is uncertain. Mylonitic granite outcrops 5 kilometres north of Woodbury Creek and 2 kilometres northwest of Kaslo Lake (indicated by an "M" on Figure 1-2-2). Asymmetric potassium-feldspar augen and C-S fabrics (Simpson and Schmid, 1983), north of Woodbury Creek, suggest a left-lateral sense of shear along steep northerly dipping mylonitic foliations. North of Woodbury cabin, steep southwesterly dipping mylonite zones 2 to 5 centimetres wide contain potassium-feldspar megacrysts that display both brittle and ductile deformation textures. The ductile fabric is cut by younger, undeformed granitic dykes of unknown age. The Kaslo Lake mylonites are steep northwesterly dipping.

The most prominent fracture system in the park is a limonitic-weathering brittle fault zone that parallels the Kaslo mylonite. The altered zone is less than 50 metres wide and hosts the Silver Ranch quartz vein mineralization (MINFILE 082FNW-215). The Molly Gibson, Smuggler and Blackburn deposits also lie parallel to a prominent set of linears (Plate 1-2-3). Rocks along these linears are not altered. Jointing within the batholith is well developed. Comparisons of joint measurements, vein attitudes and fault orientations are currently underway.

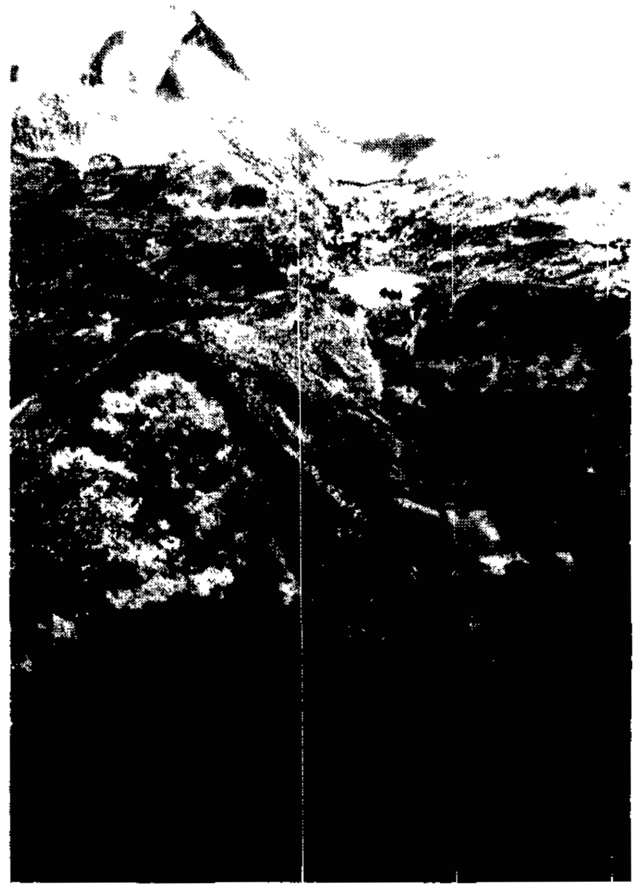

Plate 1-2-3. View southeast to Molly Gibson, Smuggler and Blackburn deposits which occur along prominent northwest-trending linears, Kokanee Provincial Park.

METAMORPHISM

Low-grade regional metamorphism has affected the Slocan Group. Pelitic rocks preserve primary bedding and display phyllitic and schistose foliations. Sedimentary blocks within the batholith are medium-grade garnet-biotite schists. Higher grade, kyanite and sillimanite-bearing rocks occur east of the map area, along the west shore of Kootenay Lake (Fyles, 1967). The metamorphic grade decreases westward toward Slocan Lake (Fyles, 1967). However, at the Revenue mine (Figures 1-2-2, 1-2-3) a foliated metasedimentary pendant contains sillimanite, staurolite and muscovite. The block could have been derived from deeper structural levels, hence correlative with Fyles' (1967) Lardeau Group (Table 1-2-1). Alternatively, Slocan sediments may have reached medium-grade conditions locally, but this has not been documented in the area. Work continues to determine which is more probable.

A contact metamorphic aureole extends 300 to 800 metres from the batholith and is superimposed on the regional metamorphism (Cox, 1979; Childs, 1968; Fyles, 1967). The assemblage includes biotite and andalusite which indicates pressures not greater than bathozone 2, as defined by Carmichael (1978). The contact assemblage reported by Childs (1965) around the Mount Carlyle stock is transitional between bathozones 2 and 3.

MINERALIZATION

Spatial density contours for vein deposits in and near the north end of the Nelson batholith (Goldsmith, 1984) outline the centres of the Slocan, Slocan City and Ainsworth mining camps. Kokanee Park map area occupies a central position between these three historic camps and contains mineralogic, isotopic and geometric characteristics of each. Fifty-three mineral occurrences with greater than 1 tonne recorded pro-

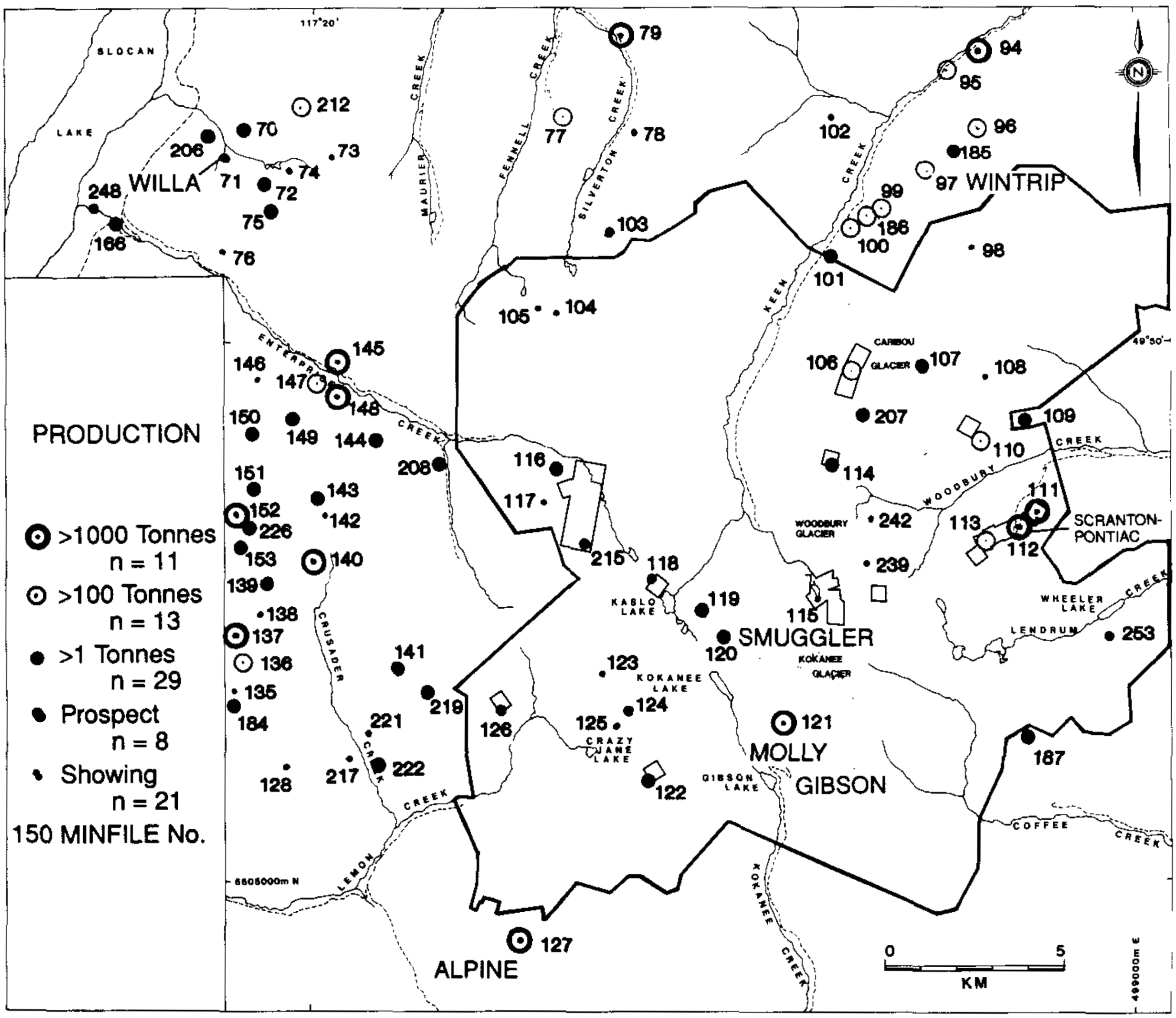

Figure 1-2-3. MINFILE numbers and locations for past producers, prospects and showings near Kokanee Glacier Provincial Park.

duction, 8 prospects and 21 showings are located in the map area (Figure 1-2-3). Vein attitude, host lithology, grades and production data are presented in Tables 1-2-2 and 1-2-3.

Mineral deposits in the Kokanee map area can be divided into three groups based on mineralogy, age and geometry. These are: (1) mesothermal silver-lead-zinc ± gold-bearing quartz-siderite veins; (2) mesothermal gold-silver-bearing quartz veins; and (3) a gold-copper-silver-bearing volcanic breccia pipe. Brief descriptions of the more productive mineral deposits follow.

MESOTHERMAL QUARTZ-SIDERITE VEINS

Vein mineralization of Group 1 is subdivided into sediment and batholith-hosted, as characterized by deposits in the Slocan and Slocan City camps respectively. The most productive vein attitudes follow a northeasterly striking joint system (Cairnes, 1934).

Sediment-hosted deposits are generally lead and zinc-rich, with a siderite and quartz gangue. In the Slocan Mining Camp, 15 kilometres north of the map area, sediment-hosted deposits average between 10 000 and 100 000 tonnes of ore mined. In the map area, sediment-hosted deposits account for less than 15 per cent of past production. Batholith-hosted veins are generally low in base metal sulphide content and relatively enriched in silver minerals in a quartz gangue. In the Slocan City mining camp, 15 kilometres west of the map area, the deposits are also enriched in gold.

WINTRIP MINE (MINFILE 082FNW-097):

The Wintrip is one of nine sediment-hosted deposits which occupy bedding-parallel, northeast-striking, steeply dipping lode structures in the Keen Creek metasedimentary re-entrant. Mineralization is chiefly wallrock replacement and is better developed where lodes crosscut calcareous horizons.

The Wintrip workings are located east of Keen Creek and north of the park boundary, in a narrow belt of Slocan Group sediments. The first shipment of ore was recorded in 1895 as 13 tonnes averaging 228 grams silver per tonne and 78 per cent lead. Over the life of the mine, a total of 613 tonnes of ore yielded 62 grams gold, 367 388 grams silver, 103 771 kilograms lead and 57 318 kilograms zinc. Most production occurred from 1926 to 1928. The workings have since collapsed and are now inaccessible.

Six or seven adits were driven to explore two parallel structures, the "A" and "B" lodes. A third unexplored lode "C" is reported 75 metres southeast of the "B" lode (Cairnes, 1935). The "A" and "B" lodes are about 100 metres apart, strike 225 degrees and dip 75 degrees northwest, conformable with the enclosing metasediments. The metasediments comprise abundant recrystallized limestone, biotite schist and, in places, thinly bedded argillite and quartzite. The lodes are sheared and brecciated zones, 0.6 to 1.5 metres wide, comprised of cataclasite and fault gouge. Mineralization is composed of disseminated sphalerite, galena and pyrite associated with siderite and minor quartz. Assays on grab samples of dump material from the two portals are presented in Table 1-2-4.

MOLLY GIBSON MINE (MINFILE 082FNW-121)

The Molly Gibson mine was developed on a mineralized fissure hosted by potassium-feldspar porphyritic granite. It was the largest producer in the area and follows a northwest-striking joint set, in contrast to the general northeast strike for most productive veins of the area.

The Molly Gibson property is located at the head of Kokanee Creek, approximately 20 kilometres north from Highway 3A. The Consolidated Mining and Smelting Company of Canada, Limited acquired the claims from La Plata Mines Ltd. in 1910, continued operating until 1950 and held the claims in good standing until 1973, when the claims lapsed. Production between 1899 and 1950 totalled 55 860 tonnes of ore and yielded 372 grams gold, 31.1 million grams silver, 2.3 million kilograms lead and 9242 kilograms zinc. Ninety per cent of the production was completed by 1913.

Underground workings explored two veins, the Florence and Aspen. They strike 145 degrees and dip 75 degrees southwest in potassium-feldspar megacrystic granite. The Florence vein averages 1.5 metres wide while the Aspen vein, located about 15 metres to the southwest, is less than 0.75 metre wide. The veins were developed on five levels, above 2105 metres elevation. The distribution of stopes suggests ore shoots plunge to the southeast at about 45 degrees (McKechnie, 1967).

Dump material contains pervasive propylitic and argillic alteration. Hematite alteration is also present. Vein mineralogy, based on hand specimen examination, comprises galena, sphalerite, arsenopyrite, pyrite and chalcopyrite in a gangue of brecciated buff to pink siderite and quartz. Sulphide petrography is underway to identify silver-bearing minerals. Sulphides occur as irregular open-space fillings parallel to vein walls. Banding and cockade texture are common in these layers and rimming breccia fragments. Coarsely crystalline sphalerite and galena blebs are rimmed by quartz, fine pyrite, coarser euhedral to subhedral arsenopyrite and in places chalcopyrite.

Vein gangue is chiefly manganese-rich siderite that weathers to a bluish black manganese oxide. Chalcedonic to euhedral quartz crystals rim fragments and line fractures, and commonly post-date siderite. Late-stage calcite fills open spaces.

The analytical results for three chip samples from the hangingwall, vein and footwall at 3-level portal (1940-metre elevation), and a single grab sample from the dump below the 1790-metre level crosscut, are given in Table 1-2-5. Grab sample (2-1) metal values are comparable with the vein channel sample (170-2) except for silver.

The Smuggler workings (MINFILE 082FNW-120; Figure 1-2-3) are 2 kilometres northwest and on strike with the Molly Gibson veins. The 1.8-metre-wide Smuggler vein strikes 150 degrees, dips 80 degrees southwest and contains vein mineralogy and morphology indistinguishable from that at Molly Gibson. The ore is galena and lesser sphalerite with arsenopyrite (to 5 per cent) in a manganese-siderite quartz breccia vein healed with chalcedonic quartz. Similar mineralogy, structural continuity and similar lead isotope ratios (Logan *et al.*, this volume) suggest Molly Gibson and Smuggler are part of the same vein system.

TABLE 1-2-2. VEIN CHARACTERISTICS OF OCCURRENCES LISTED IN MINFILE

MINFILE	Property	Production (Tonnes)	Recovered Grade Au (g/t)	Ag (g/T)	Pb (%)	Zn (%)	Host Lithology	Vein Attitude
082FNW-121	Moly Gibson	55860	0.01	556.0	4.05	0.02	K-spar por gn	154/67 SE
082FNW-152	Arlington	19217	0.04	1635.5	4.48	0.62	K-spar por gn	034/67 SE
082FNW-094	Cork Province	19144	0.10	850.3	30.54	47.19	Pel phy/sch/lst	050/65 SE
082FNW-127	Alpine	15551	22.90	14.2	0.32	0.11	Quartz monzonite	270/30 N
082FNW-148	Enterprise	10687	0.19	3057.6	15.67	9.89	K-spar por gn	056/72 SE
082FNW-112	Scranton	8136	14.40	429.9	15.72	14.88	Hb por granite	035/20 SE
082FNW-145	Westmont	3149	0.65	3520.1	6.34	2.09	K-spar por gn	060/75 SE
082FNW-137	Meteor	2645	4.97	1780.3	0.02	0.03	K-spar por gn	285/35 NE
082FNW-140	Slocan Prince	1754	0.00	3481.8	3.45	0.19	K-spar por gn	205/20 NW
082FNW-111	Pontiac	1160	5.34	511.2	6.41	0.38	Hb por granite	025/20 SE
082FNW-079	Fisher Maid	1132	0.03	2048.6	5.21	5.29	K-spar por gn	170/75 W
082FNW-095	Black Fox	886	0.21	60.1	0.66	8.40	Pelitic phy/sch	060/65 SE
082FNW-096	Bismark	868	0.00	2862.1	4.98	0.00	Pel phy/sch/lst	235/70 NW
082FNW-186	Silverbell	644	0.00	3956.3	16.36	1.73	Pelitic phy/sch	east/low
082FNW-097	Wintrip	613	0.10	599.3	16.93	8.37	Pelitic phy/sch	225/75 NW
082FNW-147	Neepawa	461	0.00	4002.4	2.00	0.16	K-spar por gn	—
082FNW-100	Silverbear	459	0.20	1723.5	2.23	1.94	Pelitic phy/sch	040/65 SE
082FNW-077	Comstock	456	0.07	3113.8	37.19	0.00	Qtz monz/lamp	070/40 SW
082FNW-106	Revenue	244	0.89	2605.0	28.21	8.47	Hb por granite	195/80 NW
082FNW-212	LH	196	17.61	9.8	0.00	0.00	Meta sed/vol	270/55 N
082FNW-099	BNA	173	1.14	2748.2	6.64	6.57	Pel phy/sch/lst	200/85 NW
082FNW-136	Howard Fraction	162	5.57	1025.8	0.00	0.00	K-spar por gn	270/12 N
082FNW-113	Sunset	145	16.09	2160.5	39.65	0.00	Hb por granite	030/65 SE
082FNW-110	Ontario #2	143	0.22	11421	10.52	0.05	Hb por granite	255/60 NW
082FNW-143	Hampton	90	0.00	16817	0.00	0.00	K-spar por gn	NE/steep
082FNW-150	Bondholder	63	0.00	7124.6	6.98	0.00	K-spar por gn	065/58 SW
082FNW-109	Baltimore	60	0.52	5867.1	9.35	0.22	Hb por granite	250/80 NE
082FNW-141	Marmion	50	28.00	144.3	0.05	0.03	K-spar por gn	—
082FNW-070	Little Daisy	44	64.80	62.9	0.00	0.00	Feldspar por	—
082FNW-153	Lily B	41	0.76	2748.5	5.63	0.00	K-spar por gn	090/55 S
082FNW-226	Silver Leaf	40	0.00	19.2	14.50	15.67	K-spar por gn	065/84 SW
082FNW-184	Joan	38	0.82	130.8	0.40	0.00	K-spar por gn	—
082FNW-207	Sun	31	0.00	2729.0	39.80	0.00	Hb por granite	—
082FNW-151	Speculator	26	0.00	987.0	22.87	1.59	K-spar por gn	034/67 SE
082FNW-208	Mary/Jumbo	25	6.24	660.6	6.30	6.66	K-spar por gn	—
082FNW-101	Index	20	0.00	1967.3	44.31	9.47	Pelitic phy/sch	125/85 SW
082FNW-222	Gem	19	37.63	1659.9	0.00	0.00	K-spar por gn	—
082FNW-185	Gold Cure	18	0.00	3455.9	50.40	0.00	Pelitic phy/sch	040/80 SE
082FNW-144	Riverside	18	0.00	1534.4	2.52	2.33	K-spar por gn	225/75 NW
082FNW-139	Alice S	15	0.00	2745.3	14.81	0.00	K-spar por gn	070/85 SE
082FNW-166	Kalispell	15	0.00	8229.8	2.15	0.95	Pelitic/psammitic	020/55 SE
082FNW-105	Para*	15	0.68	4064.5	—	4.09	Qtz monzonite	—
082FNW-120	Smuggler	13	0.00	9243.8	63.00	0.00	K-spar por gn	150/80 SW
082FNW-075	Highland LGT	10	0.00	8839.4	0.00	0.00	K-spar por gn	310/75 NE
082FNW-206	Get There Eli	9	13.78	11769.4	0.00	0.00	Meta sed/vol	345/15 NE
082FNW-187	Olsen	8	3.88	3483.5	11.32	13.25	K-spar por gn	260/18 N
082FNW-219	Alexandria 2	6	4.50	3990.0	4.80	0.25	K-spar por gn	—
082FNW-107	Violet	4	0.00	8156.8	12.10	0.00	Hb por granite	040/85 SE
082FNW-114	Silvercup	4	7.75	1104.2	22.27	2.95	Hb por granite	184/84 SW
082FNW-119	Slocan Chief	4	0.00	4478.2	57.58	0.00	K-spar por gn	130/40 SW
082FNW-122	Oro Fino	4	15.50	241.0	1.20	2.80	K-spar por gn	029/63 SE
082FNW-149	Mabou Ohio	4	0.00	1197.5	3.40	4.95	K-spar por gn	055/70 SE
082FNW-116	Boomerang	3	0.00	1493.0	4.03	4.10	K-spar por gn	355/80 E
082FNW-072	Ag Nugget	1	0.00	7060.0	0.00	0.00	Meta sed/vol	063/65 SE

* Grade calculated from one grab sample; Minister of Mines, B.C., Annual Report, 1919.

Only deposits with greater than 1 tonne reported production. Grade calculated by dividing metal recovery by tonnage mined. Lithologic abbreviations are: K-spar por gn = potassium-feldspar porphyritic granite, Pel phy/sch/lst = pelitic phyllite/schist/limestone, Hb por = hornblende porphyritic, Qtz monz/lamp = quartz monzonite/lamprophyre, Meta sed/vol = metasedimentary and metavolcanic rocks, Feldspar por = feldspar porphyry

TABLE 1-2-3. VEIN CHARACTERISTICS OF PROSPECTS AND SHOWINGS LISTED IN MINFILE
(Results are from grab sample assays.)

Minfile	Property	Host[1]	Tonnes[2]	Au (g/T)	Ag (g/T)	Pb (ppm)	Zn (ppm)	Cu (ppm)	Mo (ppm)	Vein Attitude
082FNW-071	Willa*	volc br	D P	7.5	9.6	0.0		1.04		---------
082FNW-118	Blackburn	K-spar	P	0.01	0.38	16.4%	4.8%	188	<10	245/85 NW
				0.13	0.25	3.1%	3.6%	244	70	
				0.15	0.51	1.1%	12.1%	670	<10	
082FNW-126	Barnett	K-spar	P	1.8	0.14	0.34%	288	29	<10	215/25 NW
				6.9	0.11	0.14%	47	8	<10	
				3.3	0.50	0.10%	41	9	<10	
082FNW-215	Silver Ranch	K-spar	P	20	48	0.93%	1.7%	33	<10	30/56 SE
				0.30	5	0.32%	0.26%	12	<10	
				21	135	3.2%	0.89%	91	<10	
				7.1	430	7.8%	7.6%	450	<10	
082FNW-253	Al (Wheeler L.)	K-spar	P	26.0	170	15.9%	3.3%	57	<10	north/steep
				0.35	9	300	80	7	<10	
				1.0	26	3.1%	2.0%	11	<10	
				0.21	2	580	445	6	<10	
				7.9	91	18.3%	8.4%	640	<10	
082FNW-248	Kalappa	Fol. gn	P	<0.02	2.0	180	62	15	10	---------
				0.97	23.0	40	88	72	42	
				0.02	0.5	30	38	62	<10	
082FNW-124	Silver Crest	K-spar	P							---------
082FNW-103	Fairmont	K-spar	P							025/50 SE
082FNW-102	Glue Pot	K-spar	S							235/70 NW
082FNW-104	Christina	K-spar	S	<0.02	5.9	147	1920	25	<10	north/mod.
082FNW-108	Cable	Hb por gn	S	0.05	9	67	99	12	<10	192/80 NW
082FNW-115	Joker	K-spar	S	3.80	42	0.94%	0.44%	57	<10	210/89 NW
082FNW-117	*Gold Galena*	*K-spar*	S							358/19 E
082FNW-123	Hudson Boy	K-spar	S	2.40	490	0.26%	0.30%	45	<10	175/85 W
082FNW-125	Soldier Boy	K-spar	S							---------
082FNW-073	Silver Band	K-spar	S							east/unknown
082FNW-239	Black Eagle	K-spar	S							---------
082FNW-074	Mtn Scenery	K-spar	S							065/unknown
082FNW-098	Nome	Hb por gn	S	0.01	3	11	16	79	<10	194/48 NW
082FNW-076	Daisy	K-spar	S							060/65 SE
082FNW-142	Bond River	K-spar	S	0.90	0.16	4.5%	9.58%	0.13%	<10	265/40 N
082FNW-078	Lou Dillon	K-spar	S							045/65 SE
082FNW-128	Crusader	K-spar	S							---------
082FNW-217	*Gold Reef*	*K-spar*	S							---------
082FNW-242	King Solomon	K-spar	S							---------
082FNW-135	Tailholt	K-spar	S							---------
082FNW-138	Elk	K-spar	S							115/30 SW
082FNW-146	Dalhousie	K-spar	S							---------
082FNW-254	King Solomon	Qtz monz	P							---------

Abbreviations:
[1] Fol. gn = foliated granite; Hb por gn = hornblende-potassium feldspar porphyritic granite; K-spar = potassium feldspar porphyritic granite; volc br = volcanic breccia.
[2] D P = developed prospect; P = prospect; and S = showing.
* = grade from reserve data.

TABLE 1-2-4. WINTRIP MINE GRAB SAMPLE ASSAY RESULTS

Sample	Lithology	Easting	Northing	Au (ppb)	Ag (ppm)	Cu (ppm)	Pb (%)	Zn (%)	Mo (ppm)
275-1	*Quartz vein*	*493215*	*5524668*	*210*	*320*	*251*	0.48	3.44	<10
275-1	Quartz vein	493088	5524667	220	490	1800	19.2	15.8	<10

TABLE 1-2-5. MOLLY GIBSON MINE ASSAY RESULTS

Sample	Easting	Northing	Au (ppb)	Ag (ppm)	Cu (ppm)	Pb (%)	Zn (%)	Mo (ppm)
2-1 (5880 level)	489035	5508600	820	940	1200	9.3	4.13	<10
170-1 (3-level)	489300	5509500	<10	29.2	42	0.28	0.1	<10
170-2 (3-level)	489300	5509500	510	2300	2050	9.1	3.93	32
170-3 (3-level)	489300	5509500	50	445	338	1.63	0.65	18

2-1 = Quartz-siderite vein grab sample.
170 = channel sample; 170-1 = hangingwall, 170-2 = vein, 170-3 = footwall.

Scranton/Pontiac/Sunrise (Minfile 082FNW-112,111,113)

The Scranton-Pontiac deposit has silver:base metal ratios and a northeast-striking orientation characteristic of Group 1 deposits. However, the gold production is more suggestive of Group 2 mineralization. The claims are located close to the eastern boundary of the park and are accessible from Highway 31, via Woodbury Creek road. Initial production is reported from the Pontiac claim in 1898, Sunset-Sunrise in 1899 and Scranton in 1948. Combined production totals at least 9441 tonnes (incomplete records) which yielded 125 676 grams gold, 4.4 million grams silver, 1313 kilograms copper, 1.4 million kilograms lead, 1.2 million kilograms zinc and 13 875 kilograms cadmium. Scranton accounts for more than 90 per cent of the gold, lead, zinc, copper and cadmium, and 80 per cent of the silver production. Fifty per cent of Scranton production occurred between 1969 and 1979.

The Pontiac, Scranton, Sunset, Grandview and Sunrise workings (from northeast to southwest) follow a southwest-striking vein system of at least 2.1 kilometres strike length. The vein system comprises sheared zones 10 metres or more in width hosting quartz veins and irregular quartz bodies. Country rock is hornblende potassium feldspar granite and potassium feldspar granite. Hornblende diorite outcrops in Sunrise basin. Biotite-grade thinly bedded siltstone, argillite and recrystallized limestone outcrop on the Scranton claims and quartzite was intersected in underground workings (Little, 1960).

The Scranton mine is on the east side of Pontiac Creek, the Sunset mine on the west side. Both are presumed to be on the same vein. The Scranton zone contains at least two veins. Vein attitude ranges from northeast to east striking and dips average 25 degrees southeast at the southwest end of the vein, steepening to 60 degrees southeast toward the northeast. Vein widths vary from 15 to 60 centimetres in the granite but veins commonly pinch out in the sediments. Vein mineralization is predominantly pyrite, up to 35 per cent, with lesser galena and sphalerite stringers and blebs in a fractured quartz gangue.

The lower Pontiac workings, at the 1920-metre elevation, test a quartz vein striking between 25 and 45 degrees northeast. The workings are inaccessible. Vein material from the dump is massive coarse white carbonate mineralized with blebs and stringers of galena and sphalerite (10 per cent combined) and flooded by (2 to 3 per cent) finely disseminated pyrite (sample 291).

Workings in the Sunrise basin include the Sunrise and Grandview, 215 metres to the northeast. The Sunrise was developed on two levels: the lower level (1975-metre elevation) is wet but apparently accessible; the upper level (2030-metre elevation) is completely collapsed. The vein is less than 1.5 metres wide, limonite stained, fractured and sulphide-poor. The footwall granite is fractured and limonitic over 1 metre or less; the hangingwall is sharply defined and locally sericitized (20-centimetre widths). Galena and sphalerite occur intergrown in layers, blebs and patches. Pyrite occurs as coarse aggregates (2 by 1.5 centimetres) and finely crystalline concentrations rimming galena. Lower level vein material (sample 281), upper level stockpiled ore (samples 278 and 279), and altered wallrock (sample 277) have been analysed. Results are given in Table1-2-6.

The Grandview workings are inaccessible. Vein mineralization similar to the Sunrise vein (sample 283) was collected from the lowermost dump (Table 1-2-6).

One hundred fifty metres southwest of the upper Sunrise portal, on the Granite claim, vein mineralization is exposed in a portal at 2090 metres elevation. The vein is 0.5 metre wide and comprised predominantly of pyrite (to 15 per cent), in patches, intergrown with galena and sphalerite. A grab sample (275) was collected at the portal. Indicated reserves were reported at 17 890 tonnes averaging 9.3 grams per tonne gold, 240.1 grams per tonne silver, 8.2 per cent lead and 8.0 per cent zinc (Northern Miner, January 12, 1978, page 24).

MESOTHERMAL QUARTZ VEINS

Mesothermal gold and silver-bearing quartz veins occur along the western edge of the map area in two localities: adjacent to the Willa property in the north, and a larger area straddling Lemon and Crusader creeks in the south (Figure 1-2-3). The majority of quartz veins occur in the porphyritic potassium-feldspar granite phase. The Alpine and Little Daisy veins are exceptions; they are hosted by fine-grained biotite-hornblende quartz monzonite. The LH deposit occupies a silicified shear zone within metasedimentary and metavolcanic pendants.

Most of the veins strike westerly with shallow to moderate northerly dips. Vein widths vary from a few centimetres up to 1.2 metres. The veins have envelopes of argillic and com-

TABLE 1-2-6. SCRANTON/PONTIAC/SUNRISE MINE ASSAY RESULTS

Sample	Easting	Northing	Au (ppm)	Ag (ppm)	Cu (ppm)	Pb (%)	Zn (%)	Mo (ppm)
275a	494497	5514090	1.1	420	51	15.4	3.55	<10
277b	494594	5514168	0.15	5	4	0.05	0.07	<10
278 b	494591	5514168	180	165	4	0.98	0.005	<10
279 b	494588	5514171	32	310	62	21.2	13.8	<10
281 c	494717	5514290	7.9	245	23	18.7	10.0	<10
283 d	494875	5514424	3.0	1300	50	20.9	3.88	<10
287 e	495663	5514779	2.1	440	212	12.0	12.0	<10
291 f	496325	5515133	41	220	204	12.3	5.58	<10

Assay results for quartz vein grab samples. Locations: a = Granite dump; b = Sunrise upper portal; c = Sunrise lower portal; d = Grandview dump; e = Scranton lower portal; f = Pontiac lower portal.

monly sericite alteration, which in the Barnett (MINFILE 82FNW-126; Minister of Mines Annual Report, 1922) contains gold and silver mineralization.

ALPINE MINE (MINFILE 082FNW-127)

The Alpine property is located at the head of Sitkum Creek along the divide that marks the southern edge of the park. Initial development of the vein was done in 1896 and 1897. Production commenced with a small shipment of ore in 1915 and continued sporadically until 1948. During this period 15 557 tonnes was mined and yielded 356 162 grams gold, 221 453 grams silver, 49 247 kilograms lead, and 17 085 kilograms zinc. Cove Energy Corporation, with Granges Exploration Ltd. as operator, was drilling the vein in October and November, 1987.

The quartz vein, a discrete shear zone striking 255 degrees and dipping moderately north, is traceable over 400 metres on surface. Contacts with hangingwall and footwall monzonite are sharp and variably sericitized. Vein width averages 1.1 metres. The vein is hosted by fine to medium-grained quartz monzonite (Phase 5; Figure 1-2-2). Pre-mineralization aplite and pegmatite dykes are common; post-mineralization lamprophyre dykes are less abundant. Mineralization comprises electrum, silver minerals, pyrite, and lesser galena and sphalerite. Rare clots of molybdenum were identified in altered potassium-feldspar granite from the mine dump. The vein is limonitic weathering and highly jointed and fractured. Textures are massive crystalline, ribboned, or banded and vuggy. Quartz is variably milky, white, grey and colourless, suggesting episodic deposition. Analytical results are listed in Table 1-2-7.

VOLCANIC BRECCIA PIPE

WILLA (AYLWIN CREEK) DEPOSIT (MINFILE 082FNW-071):

Geology and mineralization of the Willa deposit have been described in detail by Heather (1985) and briefly summarized by Schroeter (1987). Development and exploration continued on the Willa deposit in 1987. Northair Mines Ltd., with its joint venture partners BP Minerals Ltd. and Rio Algom Exploration Inc., has started exploration on the East zone, opened an upper level (1100-metre elevation) into the Main zone and driven a decline under the West zone. There are plans to move a mill onto the site. The deposit occurs in a pendant of Rossland Group rocks within the Nelson batholith.

Mineralization comprises chalcopyrite, pyrrhotite and microscopic gold in the intrusive breccia and adjacent host intrusions. Published reserves for the West zone are 549 700 tonnes grading 7.5 grams gold per tonne, 9.6 grams silver per tonne and 1.04 per cent copper (Northair Mines Ltd., 1987).

AGES OF MINERALIZATION

Ages of mineralization are not well established. However, separate mineralizing events are postulated for each deposit type. Epigenetic vein mineralization (Groups 1 and 2) crosscuts Slocan Group and Nelson plutonic rocks and therefore post-dates intrusion of the batholith. Previous studies have related mineralization to intrusion and assumed a Middle Jurassic age for mineralization. Lead isotope age dating (Logan *et al.*, this volume) suggests a separate mineralizing event in the Tertiary. The mineralized breccia vent at Willa (Group 3) is hosted by and related to Rossland volcanics (Early Jurassic) and pre-dates intrusion of the batholith (Middle Jurassic). Potassium-argon isotopic dating of sericite alteration in the Willa deposit gave a 57 ± 4 Ma age (unpublished data; R.L. Armstrong, The University of British Columbia). This alteration post-dates volcanic breccia mineralization and documents a Tertiary hydrothermal event.

GEOCHEMISTRY

A total of 141 stream sediment samples was collected over an area of 800 square kilometres. Samples were analysed for 30 elements by inductively coupled plasma techniques (ICP); gold was determined by fire assay followed by neutron activation analysis. Sample locations are shown in Figure 1-2-4. Results of the stream sediment sampling are available as Open File 1988-11.

Twelve heavy mineral samples were collected from high-energy stream environments using techniques described by Matysek and Saxby (1987). Three size fractions for each sample were analysed for 30 elements by neutron activation methods. Sample locations are presented in Figure 1-2-4.

A total of 122 grab samples and 121 rock chip samples was collected from mine dumps and across veins and alteration envelopes for assay and geochemical analysis respectively. All the samples have been analysed for gold, silver, copper, lead, zinc and molybdenum, and selected samples for mercury, arsenic and antimony. Analytical results unavailable at the time of writing will be released with stream sediment geochemical data.

TABLE 1-2-7. ALPINE MINE ASSAY RESULTS

Sample	Easting	Northing	Au (ppm)	Ag (ppm)	Cu (ppm)	Pb (%)	Zn (ppm)	Mo (ppm)
391 A	481915	5503504	19.2	6	6	0.10	221	<10
394 A	481931	5503399	50	7	<2	0.68	2000	<10
395 A	481782	5503313	19.8	1	<2	0.01	47	176
397 A	481737	5503272	1.6	3	<2	0.07	53	78
404 B	481420	5501625	2.8	8	<2	0.86	60	<10
406 B	481417	5501663	150	55	<2	3.00	11000	<10

Assay results for vein channel and dump grap samples. Locations: A = Alpine and B = King Solomon.

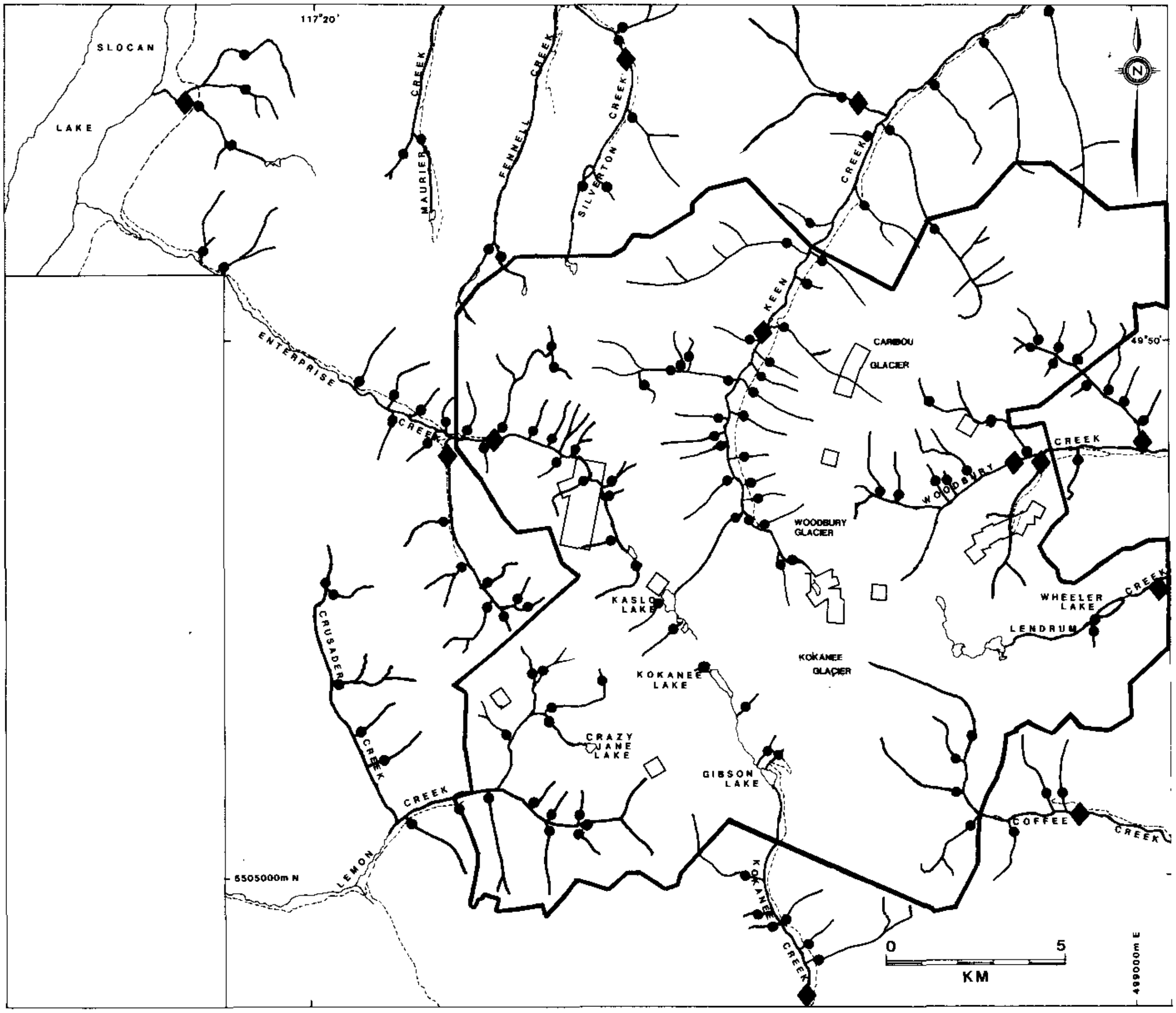

Figure 1-2-4. Stream sediment (solid circles) and heavy mineral sample (solid diamonds) locations, Kokanee Glacier Provincial Park.

Slocan Lake Fault Zone

Rock samples for geochemical analysis were collected from the Slocan Lake fault zone to assess its potential for epithermal gold mineralization. The Slocan Lake fault is a low-angle easterly dipping Eocene normal fault (Parrish, 1984). Lithoprobe seismic reflection profiling shows 30-degree eastward-dipping reflectors interpreted to be the fault (Cook *et al.*, 1987). These reflectors are detected to a depth of at least 15 kilometres below the Nelson batholith and continue eastward under Kootenay Lake.

Carr *et al.* (1987) described the fault zone along the east side of Slocan Lake as closely spaced (about 20 centimetres or less) brittle fractures and faults with lower to middle greenschist grade retrograde alteration. The zone ranges from 100 to 800 metres wide. Nelson granitic rocks in the hangingwall are variably altered to greenschist assemblages, clay-limonite and local quartz stockwork and zones of pyritization. Foliated to mylonitic Cretaceous to Tertiary (Paleocene) granites and older amphibolite to sillimanite-grade metasedimentary rocks in the footwall show little retrograde or hydrothermal alteration.

Limonitic staining is widespread in the hangingwall of the fault zone. Eighteen grab samples were collected along 20 kilometres of the fault zone between Silverton and Slocan (Figure 1-2-5). The majority of samples comprised either chlorite-altered, hematitic or clay-altered limonitic quartz monzonites and porphyritic potassium-feldspar granite. Pyrite occurs as disseminations up to 2 per cent. Four granitic samples comprised quartz stockwork zones with or without sericitic alteration. Five quartz veins, one hosted by footwall Ladybird granite (Carr *et al.*, 1987) were sampled. Tetrahedrite and possible native silver were identified in sample JL-74. Hangingwall fault breccia was sampled at the lookout along Highway 6, 5 kilometres north of Enterprise Creek. The breccia is composed of subangular, matrix-sup-

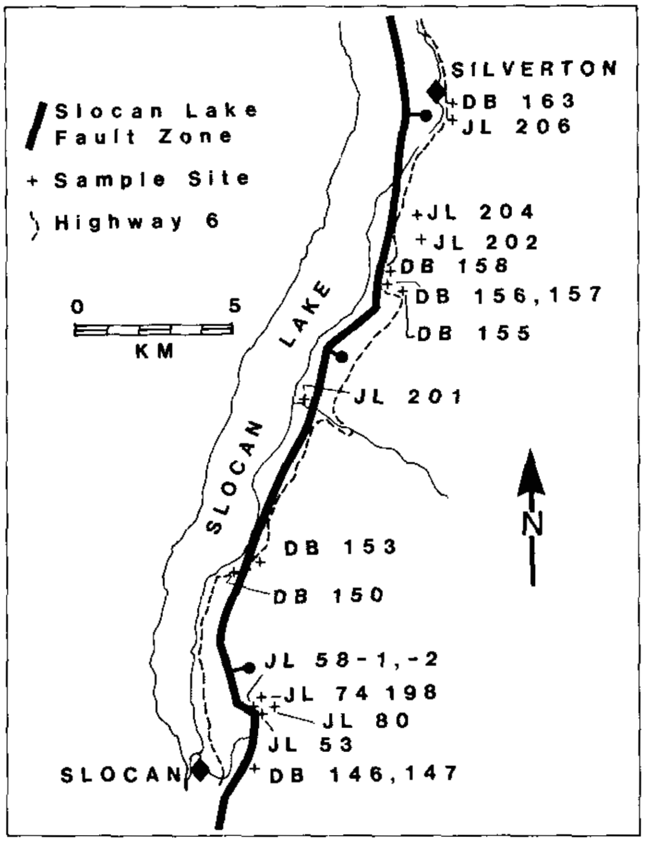

Figure 1-2-5. Slocan Lake fault zone with rock geochemical sample locations. Fault trace compiled from Carr (1986).

ported granitic fragments of variable sizes, less than 10 centimetres in diameter. The matrix has been chloritized and variably silicified. The breccia is more than 10 metres thick and is overlain by argillically altered, bleached and oxidized quartz monzonite. A similar fault breccia outcrops on Springer Creek road (Station JL87-198, Figure 1-2-5). The fault breccia here is overlain by a screen of hornfelsed Slocan Group silty argillite. The sediments are brecciated and healed with euhedral quartz crystals that fill vugs.

A fault breccia is exposed on Red Mountain road directly south of the Ministry of Highways' gravel pit (Station JL87-206, Figure 1-2-5). This southeasterly striking silicified (chalcedonic), pyritized breccia is hosted by hematitic, potassium feldspar megacryst-poor granite.

Geochemical results are given in Table 1-2-8. Gold, silver and molybdenum in most samples are lower than detection limits of 20 ppb, 0.5 ppm and 10 ppm respectively. Gold values of 170 and 150 ppb, with corresponding silver values of 1500 ppm and 8.0 ppm, were obtained from two separate quartz veins (Figure 1-2-5; Table 1-2-8). No enrichment of copper, lead, or zinc is apparent in the fault zone. However, values from quartz vein JL-74 returned 0.26 per cent copper, 3.12 per cent lead and 0.37 per cent zinc. Arsenic concentrations range from less than 1 ppm to 58 ppm. Elevated arsenic values (n = 3) are obtained from quartz veins and a breccia zone. Antimony concentrations range from less than 1 ppm to 17 ppm. Higher values correspond in part with arsenic highs. Mercury values are not yet available.

SUMMARY AND MINERAL POTENTIAL

The rocks underlying Kokanee Park host mesothermal quartz veins. Based on past production, new discoveries are likely to be small, in the order of 10 000 tonnes. The ore

TABLE 1-2-8. SLOCAN LAKE FAULT ZONE GEOCHEMICAL RESULTS

Sample	Description	Au (ppb)	Ag (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Mo (ppm)	As (ppm)	Sb (ppm)
JL-53	chl-hem	<20	<0.5	13	28	50	<10	2.5	2.0
JL-58-1	chl-hem	<20	1.0	13	66	32	<10	7.2	2.3
JL-58-2	ser-qtz-py	80	<0.5	22	40	34	<10	6.5	<1.0
JL-74	qtz vein	170	1500	2600	31200	3700	<10	NA	NA
JL-80	sil-flt br	70	<0.5	15	26	40	<10	58.4	11.0
DB-146	ser	<20	<0.5	20	62	60	<10	<1.0	1.2
DB-147	lim arg	<20	<0.5	22	22	29	<10	<1.0	<1.0
DB-150	qtz vein	<20	<0.5	26	70	38	<10	9.8	17.0
DB-153	ser	<20	<0.5	20	36	49	<10	1.9	1.7
DB-155	chl-py	<20	<0.5	17	34	110	<10	3.2	1.2
DB-156	arg-sil-py	<20	<0.5	20	18	15	<10	11.8	1.5
DB-157	chl-flt br	<20	1.5	22	85	180	<10	2.5	1.5
DB-158	sil-arg-lim	<20	0.5	19	20	65	<10	1.2	<1.0
DB-163	qtz vein py	<20	<0.5	22	14	25	<10	NA	NA
JL-198	sil-flt-br	<20	<0.5	16	69	380	<10	22.6	5.8
JL-201	sil-py-flt	25	0.5	62	30	38	<10	NA	NA
JL-202	sil-aplite	<20	<0.5	12	12	25	<10	3.9	<1.0
JL-204	qtz vein	150	8.0	13	26	55	<10	35.4	<1.0
JL-206	sil-flt br	40	<0.5	31	143	60	<10	35.4	6.9

Samples are potassium-feldspar porphyritic granite unless indicated otherwise.
Abbreviations: arg = argillic; br = breccia; chl = chlorite; flt = fault; hem = hematite; lim = limonite; NA = not analysed; py = pyrite; qtz = quartz ser = sericite; sil = silicified.

TABLE 1-2-9. SUMMARY OF EXPLORATION ACTIVITY NEAR KOKANEE GLACIER PARK

Alpine	Cove Energy Corporation (owner) Granges Exploration Ltd (operator)	Surface drilling (over 700 metres), rehabilating lower level, drifting and underground drilling.
Enterprise	Locke Goldsmith (owner)	Drilling (440 metres).
Comstock	Dragoon Resources Inc. (operator)	Refurbishing workings and camp construction.
Bismark	Eric Denny (owner)	Geophysics and geochemistry.
LH	Andaurex Resources Inc. (owner) Noranda Exploration Ltd. (operator)	Drilling.
Silver Ranch	Don Porteous (owner)	Hand trenching and sampling.
Al claims — Wheeler Lake	Dragoon Resources Inc. (operator)	Proposed drilling.
Willa (Aylwin Creek)	Northair Mines Ltd. (operator), B.P. Minerals Ltd., Rio Algom Exploration Ltd.	Decline to test west zone, underground drilling, and relocate Northair's 350 tonne per day mill.

shoots are unpredictable and lode structures discontinuous. This has made the potential of individual occurrences difficult to evaluate.

About 40 per cent of the park is alpine meadow or felsenmeer with almost complete rock exposure. As a result, few if any surface mineral showings have escaped detection by conventional prospecting methods. Batholith-hosted veins are narrow and in the past have been located only in the well-exposed areas above treeline. Subsequent exploration and development have followed these veins to lower elevations that are generally covered by overburden.

The potential of the park area to host deposits other than mesothermal veins is considered low. The setting is appropriate for Tertiary epithermal mineralization, but none has been located.

The composite nature of the batholith, as characterized by distinct phases, felsic dykes and pegmatites, indicates multiple overlapping intrusive events. Neither alteration haloes nor quartz stockworks which might represent a centre of porphyry-type mineralization were recognized, although a magnetic high in the southwest corner of the map area may represent a blind intrusion. Copper and molybdenum abundances are low with the exception of copper at the Willa deposit. Most of the batholith is unaltered.

The potential for skarn mineralization is low due to lack of calcareous horizons. In the Keen Creek sedimentary re-entrant, calc-silicate assemblages developed in response to contact metamorphism, but no sulphide mineralization was identified in the contact aureole. Galena, sphalerite and pyrite-bearing garnet-diopside skarn occurs in hornfelsed Slocan sediments east of the LH deposit. Similar sulphide-bearing skarns are located west of the park, at the Piedmont deposit.

The absence of Rossland volcanic rocks within the park limits the possibility of discovering "Willa-type" mineralization.

Placer gold can be panned from Woodbury Creek, which drains the eastern portion of the park. The gold source may be the Scranton-Pontiac deposit, however, other sources cannot be discounted.

Exploration activity in 1987 is summarized in Table 1-2-9. Most of the work was begun late in the field season. Additional exploration in 1988 is expected in the Recreation Areas, following release of silt and rock geochemistry.

FUTURE WORK

Data compilation and geochemical results will require follow-up during the 1988 field season. More detailed property examinations should utilize low impact evaluation techniques including soil sampling, VLF-electromagnetic and ground magnetometer surveys. Winter laboratory studies will include potassium-argon geochronometry, structural analysis of 1987 field data, fluid inclusion work and sulphide petrography.

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GEOLOGY OF THE AVERILL PLUTONIC COMPLEX, FRANKLIN MINING CAMP* (82E/9)

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KEYWORDS: Economic geology, Averill complex, Franklin mining camp, ultramafic pluton, alkali syenite, concentric zoning, sulphides, platinum.

INTRODUCTION

The Averill plutonic complex is located in the Franklin mining camp situated 70 kilometres north of Grand Forks, British Columbia; the area is accessed by road. This paper summarizes the map relationships of the Eocene rocks of the Averill pluton as established in the 1987 field season. A geological map of the Averill plutonic complex is presented and preliminary research addresses the petrography of the rocks that comprise the Averill intrusions.

A comprehensive understanding of the petrology of the Averill suite will further the tectonic and petrologic knowledge of the area, as well as adding to our understanding of alkali intrusive rocks in general, thus forming a good base from which to further explore petrological, chemical and structural problems. Work which remains to be done includes dating the pluton, petrological studies and investigation of the mineralization in the area.

PREVIOUS WORK

The Averill plutonic complex and surrounding areas have been the site of mineral exploration since the turn of the century. The earliest claims were staked in 1896 over the Averill complex and along its contacts. By 1915 the area was being actively explored for gold. The only mine to be established was the Union mine, which exploited a gold-bearing quartz vein. This mine has now ceased to operate.

Thomlinson (1920) and Freeman (1920) reported high platinum concentrations from the pyroxenite bodies in the Averill complex. Current exploration of the Averill intrusions is focused on the platinum group metal potential.

REGIONAL GEOLOGY

The Averill plutonic complex lies at the southern end of the Omineca crystalline belt (Figure 1-3-1) which includes rocks of the Shuswap terrane and associated gneiss domes and metamorphic rocks (Jones, 1959). At its southern end the belt comprises Jurassic, Cretaceous and Tertiary plutonic rocks, with Jurassic granite batholiths being the most common.

Structurally the area has been affected by tectonism characterized by fractures, joints and dykes oriented subparallel to each other with azimuths varying between 360 and 020 degrees. The Republic graben to the south is one manifestation of the Tertiary tectonic activity.

Detailed mapping of the Averill complex has delineated seven phases of intrusive activity and has determined the nature of their mutual contacts (Figure 1-3-2). Mineralogy, mineral proportions and textural relationships have been established through petrographic work and have been used to determine a tentative crystallization history of the body and a preliminary view of the genetic relationships of the individual phases. However, radiometric age determinations will, in addition to giving absolute ages, help establish the intrusive history.

GENERAL GEOLOGY

The area mapped is underlain by a large northwest-trending alkalic pluton which has been intruded through

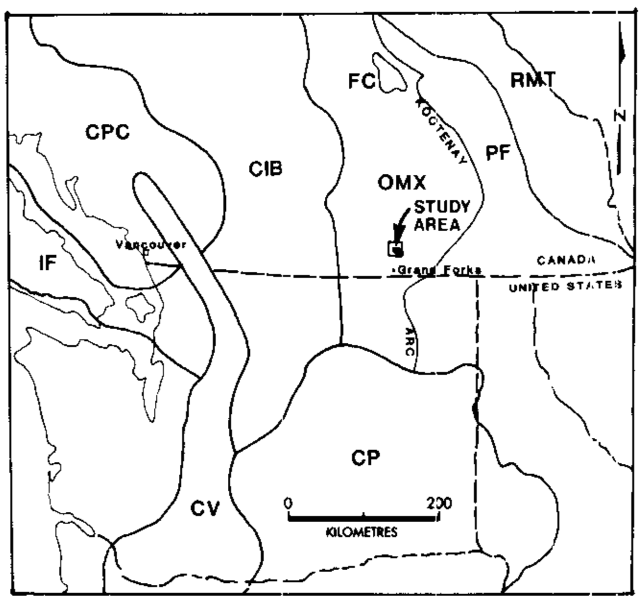

Figure 1-3-1. Index map showing major geologic provinces in the Pacific Northwest [modified from Fox *et al.* (1976) after Wheeler (1970)]. CPC–Coast plutonic complex; IF–Insular fold belt; CIB–Columbian intermontane belt; FC–Frenchmans Cap gneiss dome; OMX–Omineca crystalline belt; PF–Purcell fold belt; RMT–Rocky Mountain thrust belt; CP–Columbia Plateau province; CV–Cascade volcanic province.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

Permo-Carboniferous sediments (Franklin Group) and Mesozoic granites (Figure 1-3-2). The pluton is rimmed by a band of hornfelsed rocks and is concentrically zoned, with a central core of coarsely crystalline alkalic syenite surrounded by an envelope of much finer grained syenite. Lenses of pyroxenite occur within the syenite body. These pyroxenite bodies all have a general northwesterly orientation and some are enveloped by lenses of monzogabbro or monzodiorite. The main syenite body is partially surrounded by monzodiorites. To the southwest the monzodiorites form the margin of the pluton while to the northeast they are transitional to a less mafic alkalic unit, the monzonite. The contacts between the monzonites, monzodiorites, monzogabbros and pyroxenites are gradational and based on an increase in mafic content. This alkalic complex is cut by two later sets of dykes, a trachyte and a feldspar porphyry.

PETROLOGY

The main lithologies of the Averill alkaline suite are described following. These are preliminary results and further detailed thin section, X-ray diffraction and probe work are planned to determine the compositions of the various phases in the rocks.

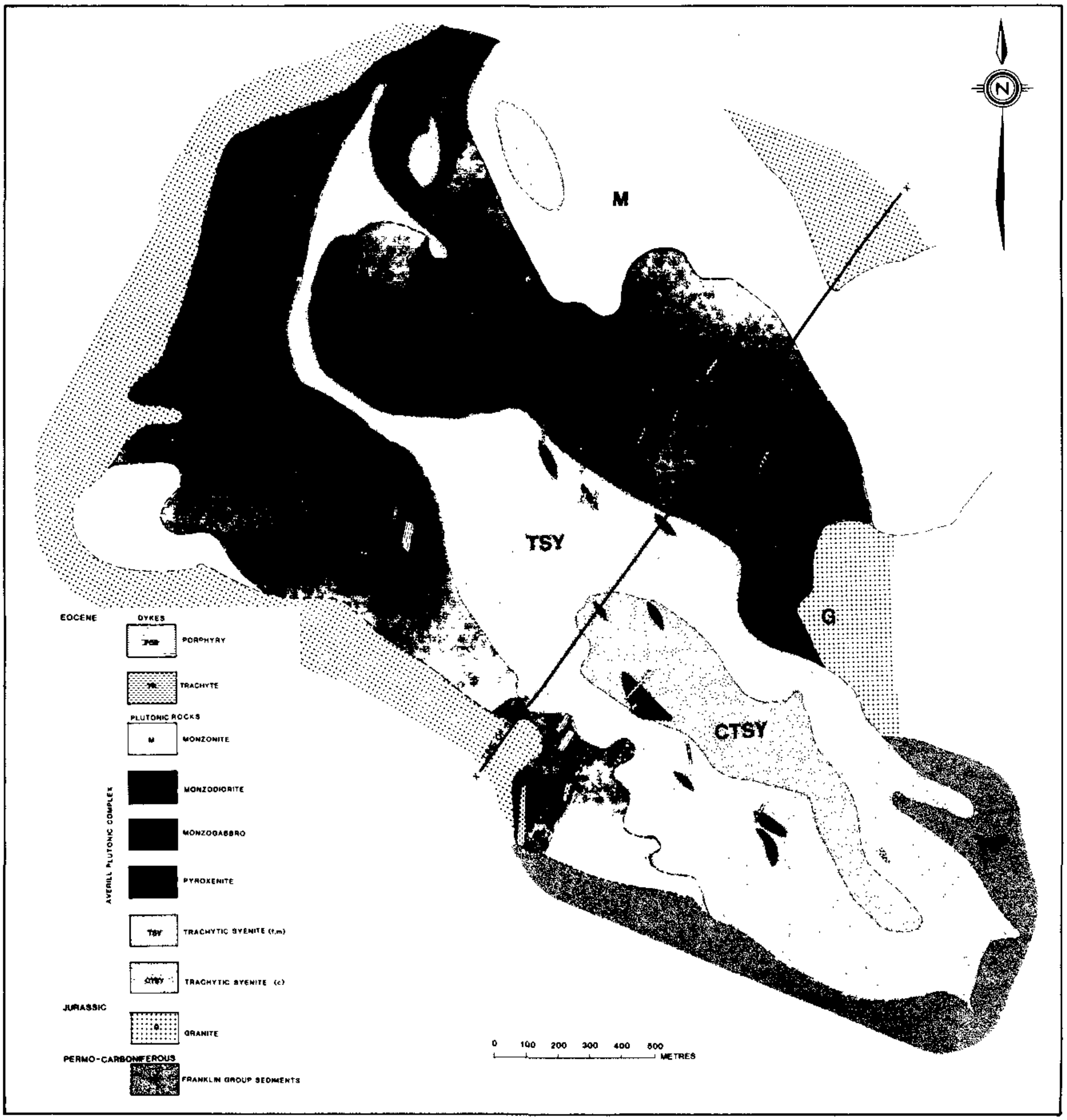

Figure 1-3-2. Geologic map of the Averill plutonic complex, showing line of section X-X'.

TRACHYTIC SYENITE

The trachytic syenites form the central part of the complex and can be crudely subdivided in terms of grain size. The field terms "fine", "medium", "coarse" and "very coarse" trachytic syenite are defined by feldspar laths less than 1 centimetre, 1 to 2 centimetres, 2 to 4 centimetres and greater than 4 centimetres respectively.

The mineralogy of these syenites, as seen in the field, is uniform and the series grades from fine grained at the margin to a core of coarse, slowly cooled trachytic syenite. The syenites consist mainly of euhedral laths of alkali feldspar which define a well-developed foliation. In thin section, many of these alkali feldspar grains are seen to be perthitic, containing coarse (millimetre scale) exsolution lamellae. The proportion of alkali feldspars can be as high as 80 per cent by volume. Plagioclase occurs only as exsolution lamellae.

Clinopyroxene (aegirine augite and/or acmite), hornblende, biotite and epidote occur as interstitial grains; opaque minerals including pyrite, chalcopyrite and magnetite are always seen in close association with these minerals. In the fine-grained syenite some of the groundmass is replaced by carbonate. The coarser grained syenites are characterized by an increase in modal abundance of amphibole and the presence of garnet. These garnets may be primary or hydrothermal. Sphene, occurring as millimetre-sized euhedral crystals, and apatite are very common as accessory minerals. A visual estimate of the mode of the trachytic syenite is given in Table 1-3-1.

MONZONITE, MONZODIORITE AND MONZOGABBRO

The monzonites, monzodiorites and monzogabbros form a gradational sequence which was subdivided in the field on the basis of the proportions of mafic minerals (colour index), and the terminology follows Streckeisen (1976). They may represent a comagmatic suite.

The monzonite is generally a fine-grained rock containing two feldspars with mafic groundmass grains commonly filling interstices. Plagioclase is the most abundant mineral, often showing original compositional zoning, modified by antiperthite exsolution. A few individual grains of alkali feldspar are also present. Mafic phases include clinopyroxene phenocrysts which are partially replaced by hornblende and biotite. Opaque minerals such as pyrite and chalcopyrite are present and apatite and sphene are very common accessory minerals. One or two grains of quartz with undulatory extinction were observed. The mode is given in Table 1-3-1.

TABLE 1-3-1.
MODAL PROPORTIONS OF MINERALS IN ROCKS OF THE AVERILL COMPLEX (VISUALLY ESTIMATED)

	Primary Mineralogy									Secondary Mineralogy				
	qz	alk	pl	amph	px	ov	gnt	bi	ep	clc	chl	apt	ti	op
TSY		60		10	10			(10)					(10)	
M	(10)		50	10	5			10				10		5
MD		15	30	10	20			10				5		10
MG			5		35	5		25	5	20				5
PYX		5		15	70								(10)	
TR	5	45						<5		45				<5
POR	<		15					15	<5	30	35			

The monzodiorite has essentially the same mineralogy but displays a weak foliation and has an increased amount of mafic minerals. As yet it is unclear whether the foliation is igneous or tectonic. The original clinopyroxene phenocrysts are large, display strong zoning and simple twinning, and are better preserved than the pyroxenes in the monzonites. The plagioclase laths in the monzodiorite groundmass are smaller than in the monzonites, and the amount of antiperthite has decreased while phenocrysts of alkali feldspar are more abundant. Quartz is no longer part of the mineral assemblage.

The monzogabbro is generally coarse grained and has pyroxene-rich schlieren running through it. There are also many small veins and veinlets of alkali feldspar which cut the schlieren with visible offset. The mineralogy of these rocks is slightly different from the monzonites and the monzodiorites. Olivine is a primary mafic phase in the rock and amphibole is absent. The amount of plagioclase is much less and alkali feldspar and antiperthites are not observed. Secondary replacement of the groundmass by carbonate is pervasive. The mode is given in Table 1-3-1.

PYROXENITES

The pyroxenite varies in character throughout the area. It is seen as both very fine-grained pyroxenite with minor biotite, and as a very coarse-grained friable biotite-rich rock. The biotite-rich variety contains up to 90 per cent biotite and may represent either the effects of hydrothermal alteration of the original pyroxenite or a primary igneous assemblage. The biotite-poor phase is comprised of amphibole and clinopyroxene, with a small amount of alkali feldspar occurring mainly as veins. Apatite, sphene and opaque minerals form the accessory phases, and secondary carbonate veins cut the rock. The modal mineralogy is listed in Table 1-3-1.

LATE DYKE ROCKS

TRACHYTE

Trachyte dykes are vertical in orientation and trend from northeasterly in the northeast part of the complex, to northerly in the southwest. The trachyte weathers to a buff colour. The mode (Table 1-3-1) consists of alkali feldspar which forms most of the groundmass and the phenocrysts. In places the feldspar is replaced by carbonate, although pseudomorphs of the original large laths are present. The remainder of the rock consists of biotite, opaque minerals and sparse grains of quartz. The biotite and the opaques are interstitial.

PORPHYRY

This rock has a distinctive spotted appearance and consists of secondary calcite and chlorite after plagioclase phenocrysts and biotite microphenocrysts, in a grey aphanitic groundmass. Plagioclase and biotite are almost completely replaced, although ghosts of the original lath-shaped plagioclase grains are still visible. The groundmass consists of the replacement minerals chlorite and calcite, together with epidote and quartz (Table 1-3-1).

MINERALIZATION

Sulphide mineralization is present in all rocks of the plutonic suite and also in the later dykes. Pyrite and chalcopyrite are ubiquitous, and other minerals such as bornite, malachite, azurite and magnetite are sometimes present. Their concentration on fracture surfaces and in and around crosscutting veins of alkali feldspar suggests that at least one phase of hydrothermal mineralization has occurred.

Many occurences of platinum were reported during early exploration of the pyroxenite bodies. Assay values obtained during the 1920s exploration period range from 0.69 gram per tonne (Thomlinson, 1920) to 15.4 grams per tonne (Freeland, 1920). These assays were obtained from pyroxenites in the general vicinity of the Averill intrusions. Assays from pyroxenite bodies within the pluton ranged from 2.74 to 6.51 grams per tonne (Thomlinson, 1920). More recent soil geochemical work is reported to indicate a tendency for platinum/palladium soil anomalies to be associated with areas of high copper concentration. One objective of studying the petrology of the Averill rocks is to ascertain the causes and controls of platinum mineralization.

GEOLOGICAL HISTORY

The Averill intrusive complex consists of a mineralogically gradational plutonic suite ranging in composition from pyroxenite to monzonite. Pyroxenite bodies occur as lenses in the centre. The outcrop pattern can be explained by topography and suggests vertical zonation, with pyroxenite at the base and monzodiorite at the top (Figure 1-3-3).

As this suite of mafic to ultramafic rocks cooled, it was intruded by a body of alkalic syenite. The nature of the contacts between the ultramafic pluton and the syenites suggests that the two intrusions were almost contemporaneous. The intrusion of the syenites into an unsolidified pyroxenite caused the pyroxenite and syenite to mix mechanically, generating a variety of textures. Slow cooling of the syenite body produced the coarsely crystalline core of the intrusion (Figure 1-3-4). The syenites may be the source of subsequent hydrothermal mineralization in the area.

The syenites and ultramafic rocks were cut by two later phases of dyke intrusion. These dykes do not intersect, have a close spatial relationship, have similar trends and contact relationships and are probably coeval. They also contain disseminated sulphides including pyrite and chalcopyrite.

The last phase of igneous activity in the area is volcanic and comprises trachytes, rhyolites and volcaniclastics which are exposed at higher topographic elevations.

SUMMARY

A vertically zoned ultramafic pluton, ranging in composition from pyroxenite to monzonite, is intruded by a body of alkali syenite. This intrusion caused the remobilization of the lower layers of the ultramafic pluton. All intrusions are cut by later dykes.

Future work is directed along two lines. Firstly, analytical data, including whole-rock and mineral chemistry are being acquired to characterize the intrusive rocks and constrain the igneous processes. Secondly, the relationships between alkali magmatism and platinum group metal mineralization will be investigated to determine whether the mineralization derives from magmatic processes or late-stage hydrothermal activity.

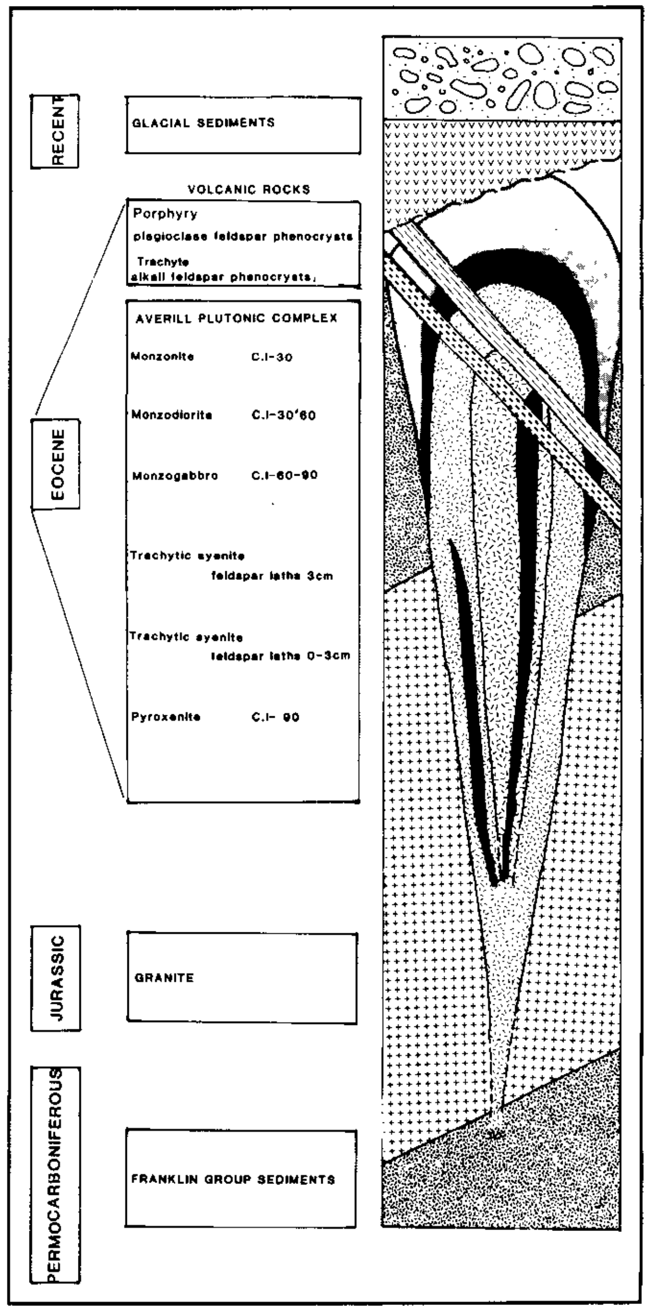

Figure 1-3-3. Schematic stratigraphic section through the Averill plutonic complex showing relative age and contact relationships.

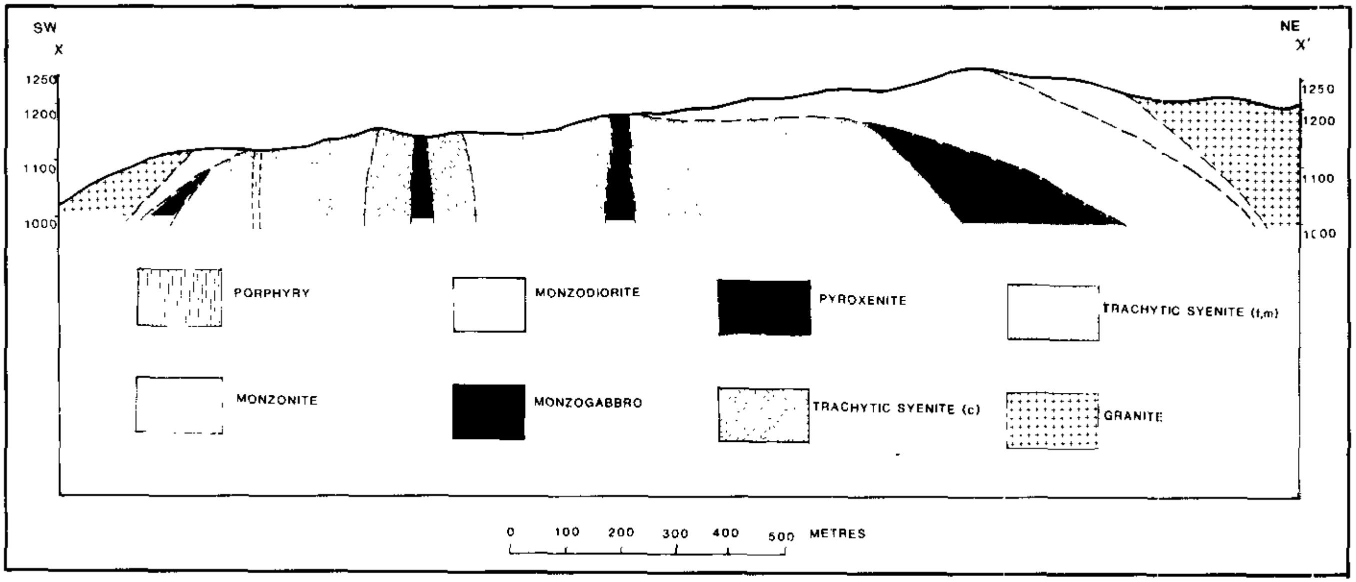

Figure 1-3-4. Schematic cross-section through the Averill plutonic complex from southwest to northeast along line X-X'.

ACKNOWLEDGMENTS

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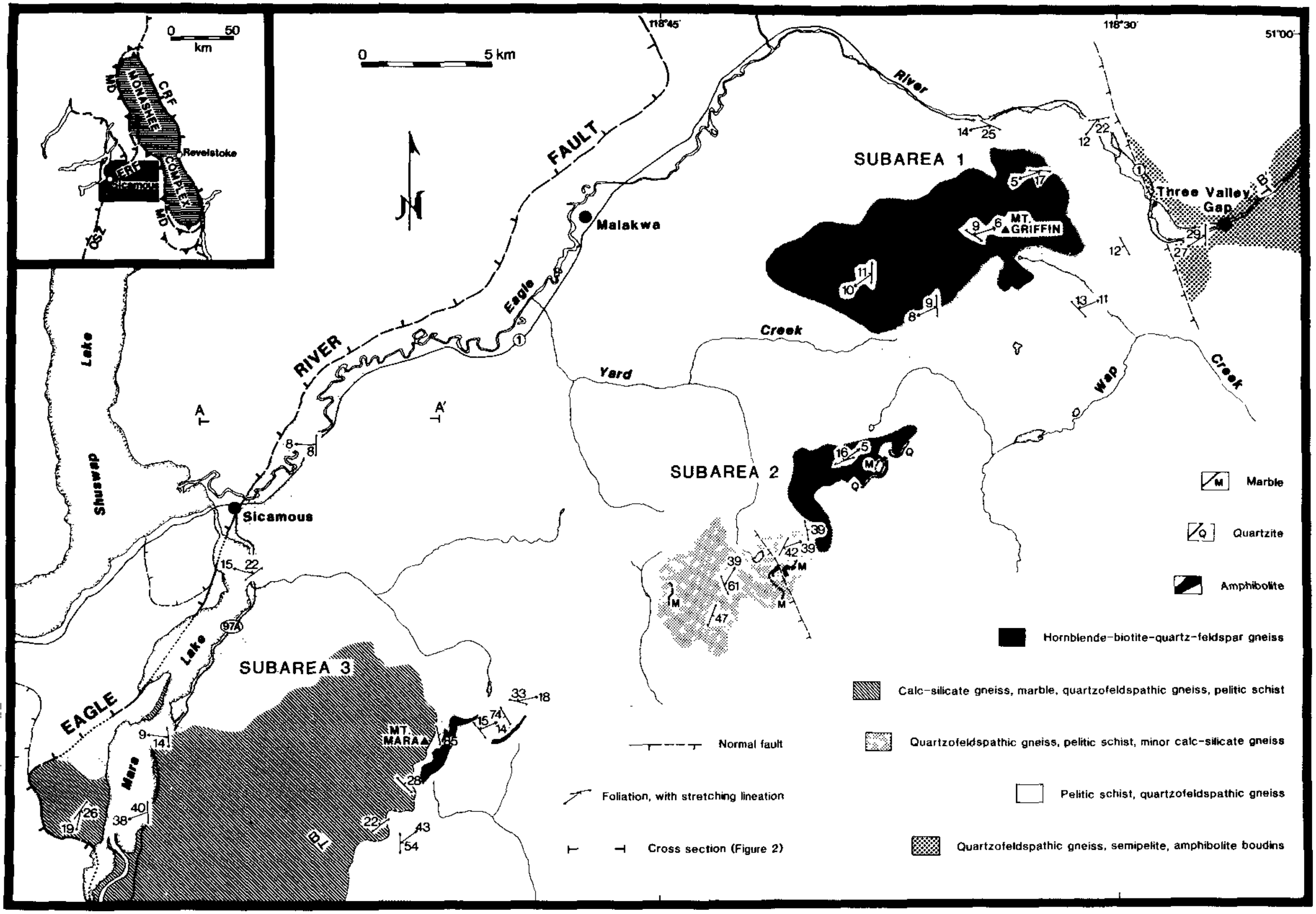

Figure 1-4-1. Geological map of the northern Hunters Range; location shown (black) in inset. Inset: Regional tectonic map, modified after Journeay and Brown (1986). CRF: Columbia River fault zone; ERF: Eagle River fault; MD: Monashee décollement; OSZ: Okanagan shear zone.

British Columbia Geological Survey
Geological Fieldwork 1987

PROGRESS REPORT: STRATIGRAPHY AND STRUCTURE OF THE SHUSWAP METAMORPHIC COMPLEX IN THE HUNTERS RANGE, EASTERN SHUSWAP HIGHLAND (82L)

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KEYWORDS: Structural geology, stratigraphy, Shuswap complex, Tertiary extension, Eagle River fault, Hunters Range, Selkirk allochthon, Mesozoic compression.

INTRODUCTION

In the interest of exploring the role of Tertiary extension in the development of metamorphic core complexes in the southern Omineca Belt, fieldwork was undertaken in 1987 to examine the geology of the Eagle River fault in the eastern Shuswap Highland. The Eagle River fault is a west-side-down low-angle normal fault that juxtaposes low to medium-grade metasedimentary and metavolcanic rocks of the Paleozoic Mount Ida Group atop high-grade gneisses of the Shuswap metamorphic complex (Figure 1-4-1 inset).

Regional geology of the Shuswap Highland was first mapped by Jones (1959). He subdivided the metamorphic rocks into two groups of low-grade rocks (Mount Ida and Chaperon), and a group of high-grade rocks (Monashee) that approximately coincides with what commonly is called the Shuswap metamorphic complex (see Okulitch, 1984). Geology of the Shuswap metamorphic complex in the Monashee Mountains north of 51° north latitude was mapped by Wheeler (1965). Fyson (1970) examined the structural geology of the Shuswap Lake – Mara Lake area, where he described four phases of deformation. Nielsen (1982) investigated the stratigraphy, structure and metamorphism of the Mount Ida Group and the Shuswap Complex around Mara Lake. His study supported a report by Okulitch (1974) that rocks of the Mount Ida Group have high-grade equivalents in the Shuswap Complex. Okulitch (1979) proposed that part of the Mount Ida Group (Eagle Bay assemblage) is correlative with North American pericratonic rocks, based on his examination of the stratigraphy, structure, paleontology and geochronology of rocks in the Shuswap Lake area. The Eagle Bay assemblage has been studied in detail by Schiarizza and Preto (1984).

Jones (1959) was the first to recognize that the Mount Ida Group was separated from the high-grade gneisses of the Shuswap metamorphic complex by a fault, but he inferred this fault to dip steeply. Journeay and Brown (1986) noted that the fault, which they named the Eagle River detachment, was a gently dipping, west-side-down normal fault. They inferred it to have formed in response to Tertiary extension, and suggested that it is connected to the Okanagan shear zone (Figure 1-4-1 inset).

Mapping at 1:50 000 scale in 1987 was concentrated in the Hunters Range of the eastern Shuswap Highland (82L/16, 15, 14, 11, 10), focusing on the geology of rocks of the Shuswap metamorphic complex that lie structurally above the Monashee complex (Read and Brown, 1981; Figure 1-4-1 inset) and beneath the Eagle River fault. These rocks are part of an allochthonous sheet (Selkirk allochthon) that was carried eastward over the Monashee complex along the Monashee décollement, a major ductile shear zone related to mainly Mesozoic crustal shortening (Brown *et al.*, 1986).

STRATIGRAPHY

The rocks of the Hunters Range have been subjected to upper amphibolite facies metamorphism, as indicated by sillimanite + potassium-feldspar mineral assemblages in pelitic schists. Generally these minerals appear fresh, except in the notheastern Hunters Range near Mount Griffin, where retrograde muscovite is abundant. Metamorphic rocks throughout the Hunters Range are intruded by pegmatites, which commonly form 50 per cent of the total rock volume. The stratigraphy of each of three subareas is described here; there is not yet sufficient data from intervening areas to demonstrate relationships between them (Figure 1-4-1).

SUBAREA 1: THREE VALLEY GAP – MOUNT GRIFFIN

A long roadcut along the Trans-Canada Highway at Three Valley Gap exposes a southwest-dipping succession of quartzofeldspathic gneiss, semipelite and minor diopsidic quartzite, that contains truck-sized boudins of garnet amphibolite. These rocks structurally overlie a chaotic assemblage that is truncated below by the Monashee décollement (Bosdachin and Harrap, in press). They therefore represent part of the deepest structural level of the Selkirk allochthon in the area of study. The amphibolite boudin-bearing unit is separated from rocks to the west by a vegetated topographic lineament that was mapped by Jones (1959) as a high-angle fault. Because the rocks west of this lineament have no known equivalents at deeper structural levels, they are inferred to have originated from a structurally higher level than the amphibolite boudin-bearing unit. The lineament is therefore interpreted as a high-angle, west-side-down normal fault (Figure 1-4-1). West of this lineament are quartzofeldspathic gneisses with interlayered sillimanite-biotite and muscovite-biotite schists. These are overlain by a thick, monotonous

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

succession of hornblende-biotite-quartz-feldspar gneiss which forms Mount Griffin.

SUBAREA 2: RIDGES SOUTH OF YARD CREEK

A generally eastward-dipping succession of quartzofeldspathic gneiss and sillimanite-biotite schist with minor marble, diopsidic calc-silicate gneiss and amphibolite is exposed on ridges south of Yard Creek (Figure 1-4-1). The upper part of this succession consists of hornblende-biotite-quartz-feldspar gneiss with interlayered thin quartzite and marble units.

SUBAREA 3: MOUNT MARA – MARA LAKE

On Mount Mara a distinctive thick, locally diopsidic amphibolite is overlain by psammitic paragneiss, pelitic garnet-sillimanite schist and minor quartzite. These grade into a succession that contains diopsidic calc-silicate gneiss, marble and amphibolite. The latter calcareous assemblage is tenatively correlated with similar rocks exposed in roadcuts on Highway 97A, along the southeast side of Mara Lake.

STRUCTURAL GEOLOGY: DUCTILE STRUCTURES

A strong penetrative foliation is in most places subparallel to compositional layering. The layering is deformed by tight to isoclinal folds with axial surfaces that are parallel to the foliation. Hinges of these folds are subparallel to a strong east-northeast and west-southwest-plunging stretching lineation which is defined by mineral aggregates and by alignment of inequant minerals, such as sillimanite and hornblende, on foliation surfaces. Most folds of this type display southward vergent asymmetry, as was noted by Jones (1959). In the Mount Griffin area the overturned short limbs of some of these folds are about 100 metres long, although they are typically smaller.

A younger set of open, upright to overturned, westward verging folds deforms the early folds, the foliation and the stretching lineation. These folds plunge gently to the north-northwest or south-southeast and have east-northeast-dipping axial surfaces. They increase in scale and abundance from northeast to southwest across the Hunters Range: in the Mount Griffin area they are virtually absent; in the ridges south of Yard Creek they are common, with amplitudes of a few metres; and from Mount Mara to Mara Lake, westerly verging folds with amplitudes of over 100 metres are abundant and closely spaced.

Many of the rocks in the Hunters Range display mylonitic fabrics. Sheared pegmatites and migmatitic pelites in the Three Valley Gap – Mount Griffin area and in the ridges south of Yard Creek display C/S fabrics and rotated feldspar porphyroclasts indicative of easterly directed shear (the sense of shear is here described in terms of relative motion of the upper member of the simple shear couple). South of Yard Creek, such rocks are cut by discrete shear zones within which C/S fabric, rotated porphyroclasts and shear bands indicate westerly directed sense of shear. Westward verging folds at Mount Mara locally are cut by shear zones of this type (Figure 1-4-2). Biotite in the westerly directed shear zones is commonly chloritized, although the other minerals (for example, sillimanite) appear fresh. Westerly directed shear zones are extensively developed in migmatitic pelites along Mara Lake and along the Trans-Canada Highway near Sicamous. In contrast to the shear zones south of Yard Creek, these migmatites display little retrograde chloritization.

BRITTLE STRUCTURES

Steep north-northwest-striking extension fractures, ranging in scale from millimetre-wide cracks to extensive regional lineaments, are developed throughout the area. The thin cracks occur in parallel sets in many of the schists and generally are filled with chlorite. Some of the larger fractures, notably those in ridges south of Yard Creek, are filled with undeformed quartz feldspar porphyry dykes. Several tens of metres of normal or oblique slip have occurred along some of the fractures.

Schists between Three Valley Gap and Mount Griffin contain zones of extensive brittle deformation, expressed

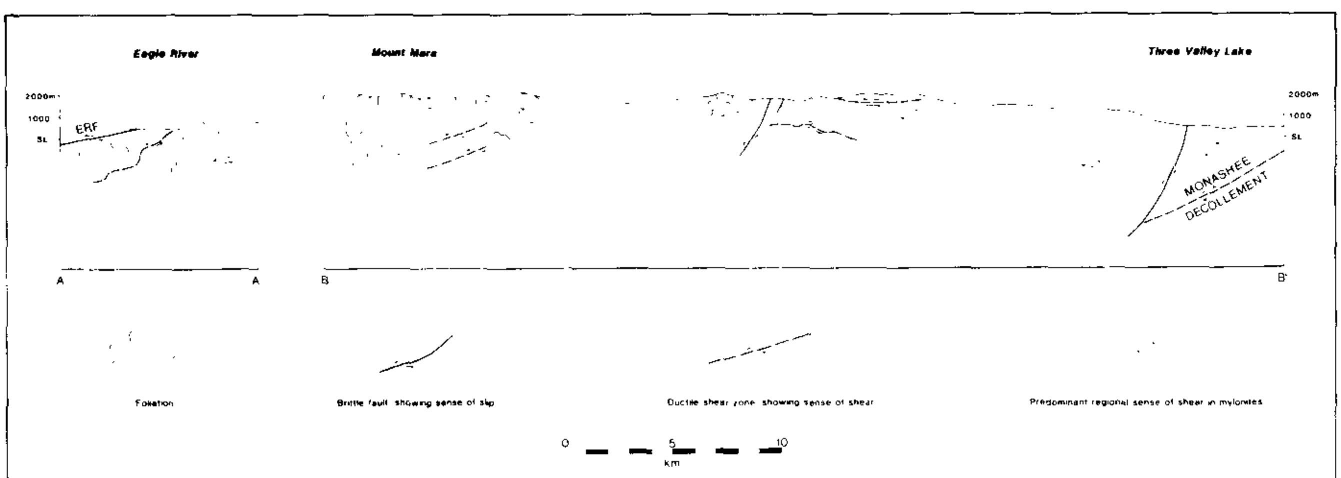

Figure 1-4-2. Schematic structural cross-sections A-A′ and B-B′, showing fold styles and kinematics of shear zones. The composite section A-A′ – B-B′ represents a transect from the hangingwall of the Eagle River fault (ERF) through progressively deeper levels of its footwall. *See* Figure 1-4-1 for locations.

both as discordant fractures and as layer-parallel zones of clay gouge and fault breccia. These zones have a characteristic rusty appearance due to oxidation of iron in biotite and sulphide minerals. The deformation is probably related to the inferred normal fault discussed previously. The amount of displacement on this fault is unknown.

DISCUSSION

Stratigraphic relationships between and within the three subareas are uncertain, but a few preliminary speculations are offered here. The homogeneous texture and hornblendic mineralogy of the gneisses of Mount Griffin (Subarea 1) suggest that they were derived from igneous protoliths. Subarea 2 contains hornblendic gneiss of probable igneous origin and a metasedimentary package that is predominantly siliciclastic but which has a minor calcareous component. Subarea 3 contains a shelf-like assemblage with both siliciclastic and carbonate components. Rocks of Subarea 1 represent the deepest structural level within the study area, and westward verging folds in the central and western parts of the Hunters Range expose progressively higher structural levels to the west. If structural levels correspond to stratigraphic levels, then the overall succession could represent an evolving "passive" continental margin, beginning with a volcanic rift stage (Subarea 1) and evolving through a transitional stage (Subarea 2) into a marine shelf setting (Subarea 3).

The oldest preserved structures are probably related to Mesozoic compression. Synmetamorphic tight to isoclinal folds, with hinges that are subparallel to the stretching lineation related to easterly directed mylonitic fabric, are consistent with the structural style of rocks that overlie the Monashee décollement elsewhere (for example, Journeay, 1986; Bosdachin and Harrap, in press). By analogy with structures described by Journeay (1986), the mylonitic fabric and lineation are presumed to be expressions of Mesozoic easterly directed thrusting, and the folds are inferred to have been formed either before or during the early stages of thrusting.

Westerly directed shear fabrics, which locally overprint the easterly directed fabrics, are most prominent in the western part, and hence the highest structural level, of the study area (Figure 1-4-2). Westerly verging open folds (also most prominent in the west) locally are cut by discrete westerly directed shear zones that contain syntectonic sillimanite, but they deform sillimanite lineations in other westerly directed mylonites. Therefore, the late folds and mylonites apparently are products of the same synmetamorphic, westerly directed shearing event. Because the intensity of this deformation seems to increase up structural section toward the Eagle River fault, it likely is a ductile manifestation of Tertiary extension. A sample of sheared pegmatite was collected from Sicamous so that this hypothesis can be tested against uranium-lead zircon geochronology.

Unless it is a contact metamorphic effect due to the emplacement of swarms of porphyry dykes, the retrograde chloritic overprint that characterizes westerly directed shears in the central part of the Hunters Range implies that these shears were active at higher crustal levels than were the mylonites now exposed near Mara Lake. This could mean that Tertiary extensional deformation propagated eastward as the footwall of the Eagle River fault was uplifted. The extensive brittle deformation west of Three Valley Gap is consistent with this hypothesis.

Fieldwork planned for 1988 will focus on mapping the Eagle River fault north and south of Sicamous, and on more detailed mapping of specific areas within the Hunters Range

ACKNOWLEDGMENTS

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Geological Fieldwork 1987

GEOLOGY, GEOCHEMISTRY AND METALLOGENIC ZONING IN THE HEDLEY GOLD-SKARN CAMP (92H/08; 82E/05)

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and
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KEYWORDS: Economic geology, gold skarn, Nickel Plate, Mount Riordan, arsenopyrite, tellurides, cobalt, tungsten, garnet, pyroxene, mineral zoning, ore controls.

INTRODUCTION

This paper is an update to the preliminary results presented by Ray *et al.* (1987) for the Hedley mapping project conducted by the British Columbia Geological Survey Branch. The Hedley district encompasses an area of 525 square kilometres and is situated in southern British Columbia, approximately 40 kilometres east-southeast of Princeton (Figure 1-5-1).

The Hedley area has a long history of gold mining (Camsell, 1910; Billingsley and Hume, 1941; Dolmage and Brown, 1945) and between 1902 and 1955 approximately 51 million grams of gold were won from several gold-copper skarn orebodies (Table 2-10-1, Ray *et al.*, 1987). More than 95 per cent of the gold production in the camp came from one deposit which was worked at the Nickel Plate and Hedley Mascot mines; only smaller amounts were obtained from the French, Goodhope and Canty auriferous skarn deposits. Exploration interest in the Hedley gold camp has been revitalized by the recent reopening of the Nickel Plate mine by Mascot Gold Mines Limited as a 2450-tonne-per-day open-pit operation.

The gold-skarn mineralization is hosted in Upper Triassic Nicola Group rocks and is genetically related to a suite of dioritic intrusions of probable early Jurassic age. A series of facies changes recognized within the Nicola succession is related to deposition across a fracture-controlled basin margin; it is economically important as the gold-skarn mineralization is lithologically, stratigraphically and structurally controlled.

A district-wide metallogenic zoning may exist in the Hedley camp with gold and arsenic-rich skarns developed in the west and tungsten-rich and gold and arsenic-poor skarns in the east. This type of zoning may have exploration significance elsewhere in the North American Cordillera.

DISTRICT GEOLOGY

The Hedley camp lies within the Intermontane Belt of the Canadian Cordillera and the overall geology of the district is presented in Figure 1-5-1. The geology has been described by Bostock (1930, 1940a, 1940b) and more recently by Ray *et al.* (1986, 1987; Ray and Dawson, (1987, 1988).

The southeastern margin of the area is underlain by highly deformed ophiolitic cherts, argillites, tuffaceous siltstones, greenstones and minor limestones of the Apex Mountain complex, containing Upper Devonian, Carboniferous and Middle to Late Triassic microfossils (Milford, 1984; J.W.H. Monger, personal communication, 1985). The complex and the supracrustal rocks further west are separated by either intrusive rocks or major faults, and it is uncertain whether their original contact represents an unconformity or a suture zone.

The area between Winters and Whistle creeks is largely underlain by sedimentary and volcaniclastic rocks of the Upper Triassic Nicola Group and the Lower Cretaceous Spences Bridge Group; the generalized stratigraphy of these sequences in the district is shown in Figure 1-5-2.

Three distinct stratigraphic packages are recognized within the Nicola Group. The oldest, informally called the Peachland Creek formation*, comprises massive, mafic, quartz-bearing andesitic to basaltic ash tuff and minor chert-pebble conglomerate. Locally the formation contains large disrupted limestone units which are interpreted to be olistoliths. This previously unrecognized basal unit of the Nicola Group is poorly exposed in the Hedley district but is identified in several localities, notably as a small fault slice adjacent to the Bradshaw fault northeast and southwest of Hedley township, just north of Winters Creek, in the vicinity of the French and Goodhope mines, and south-southeast of the Nickel Plate mine where it is exposed adjacent to the Cahill Creek fracture zone (Figure 1-5-1).

The Peachland Creek formation is stratigraphically overlain by a sedimentary sequence 100 to 700 metres thick in which a series of east-to-west facies changes are recognized. This sequence progressively thickens westward (Figure 1-5-2) and the facies changes probably reflect deposition across the tectonically controlled margin of a northwesterly deepening late Triassic marine basin.

The easternmost and most proximal facies, informally called the French Mine formation (Figures 1-5-2 and 1-5-3), has a maximum thickness of 150 metres and comprises massive to bedded limestone interlayered with thinner units of calcareous siltstone, chert-pebble conglomerate, tuff, limestone-boulder conglomerate and limestone breccia. The

* This is named after a major tuffaceous sequence which underlies the Hedley Formation in the Pennask Mountain area, approximately 30 kilometres west of Peachland (Dawson and Ray, 1988).

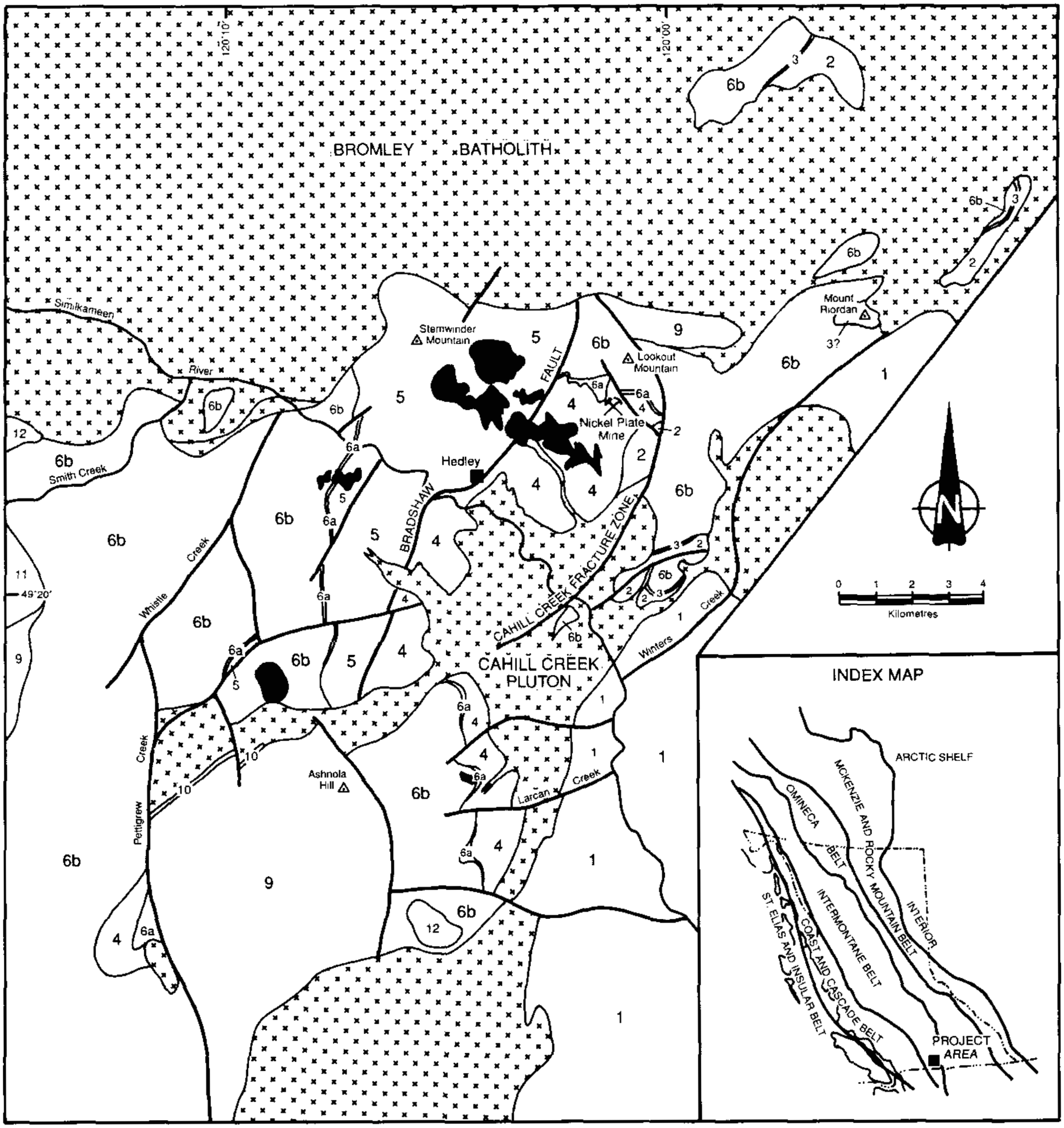

Figure 1-5-1. Regional geology of the Hedley district, southern British Columbia. Legend on facing page.

formation hosts the auriferous skarn mineralization at the French and Goodhope mines (Figure 1-5-2).

Further west, rocks stratigraphically equivalent to the French mine formation are represented by the informally named Hedley formation which hosts the gold-bearing skarn at the Nickel Plate mine. The Hedley formation is 400 to 500 metres thick and characterized by thinly bedded, turbiditic calcareous siltstone and units of pure to gritty, massive to bedded limestone that reach 75 metres in thickness and several kilometres in strike length. The formation also includes lesser amounts of argillite, conglomerate and bedded tuff; locally the lowermost portion includes minor chert-pebble conglomerate.

The westernmost, more distal facies is represented by the Stemwinder Mountain formation (Figures 1-5-2 and 1-5-3) which is at least 700 metres thick and characterized by a monotonous sequence of black, organic-rich, thinly bedded calcareous argillite and turbiditic siltstone, minor amounts of

LEGEND

TERTIARY

12 **Basaltic flows**

EROSIONAL UNCONFORMITY

EARLY CRETACEOUS

11 VERDE CREEK INTRUSION – *granite and microgranite*

10 RHYOLITE INTRUSION – *quartz porphyry*

9 SPENCES BRIDGE GROUP – *andesitic to dacitic pyroclastics and flows with minor sediments*

CONTACT UNCERTAIN

EARLY JURASSIC

8 BROMLEY BATHOLITH AND CAHILL CREEK PLUTON – *granodiorite to quartz monzodiorite*

7 HEDLEY INTRUSION – *quartz diorite, diorite, and gabbro*

INTRUSIVE CONTACT

NICOLA GROUP

LATE TRIASSIC

6b WHISTLE CREEK FORMATION – *bedded to massive ash and lapilli tuff, minor tuffaceous siltstone*

6a Copperfield Conglomerate – *limestone boulder conglomerate*

5 STEMWINDER MOUNTAIN FORMATION (WESTERN FACIES) – *thinly bedded argillite and limestone*

4 HEDLEY FORMATION (CENTRAL FACIES) – *thinly bedded siltstone, thick limestone beds and minor tuffs*

3 FRENCH MINE FORMATION (EASTERN FACIES) – *limestone, limestone breccia and pebble conglomerate*

2 PEACHLAND CREEK FORMATION – *basaltic ash tuffs and flows with minor limestone and chert-pebble conglomerate*

CONTACT OCCUPIED BY CAHILL CREEK PLUTON

PALEOZOIC

1 APEX MOUNTAIN COMPLEX – *ophiolite sequence of cherts, greenstones, siltstones, argillites and minor limestones*

siliceous fine-grained tuff and dark impure limestone beds that seldom exceed 3 metres in thickness.

Conodonts of Late Carnian to Middle Norian age were obtained from limestones in the Hedley and Stemwinder Mountain formations (M.J. Orchard, personal communications, 1985, 1986; Ray and Dawson, 1987). Paleocurrent measurements suggest that the rocks in both formations were derived from an easterly source. The French Mine formation was laid down in a proximal, shallow, possibly forereef marine environment that received deposition of angular limestone breccias and chert-pebble conglomerates. Deposition of the more distal Hedley formation involved slower, more turbiditic sedimentation with the occasional influx of coarser conglomerate, tuff and coarse gritty limestone. The limestones and calcareous siltstones are characterized by a general absence of both bioturbation and shelly fossils, although some crinoid ossicles, rare solitary corals, bivalve fragments and belemnites are present.

Deposition of the Stemwinder Mountain formation was characterized by fine-grained, slow sedimentation, a high organic content and only very minor limestone development. Although laid down in deeper water, the formation is not oceanic, but was probably deposited within the deeper part of a relatively shallow back-arc basin that formed east of the main Nicola volcanic arc.

The sedimentary rocks of the Stemwinder Mountain, Hedley and French Mine formations pass stratigraphically upward into the Whistle Creek formation (Figures 1-5-2, 1-5-3) which is probably late Triassic in age. The formation is 700 to 1200 metres thick and distinguishable from the underlying rocks by a general lack of limestones and a predominance of andesitic volcaniclastic material. Its lower portion contains tuffaceous, often turbiditic siltstone and rare argillite, but the uppper part of the succession is characterized by bedded to massive crystal ash and lapilli tuff with minor volcanic breccia. The tuffs commonly contain augite and plagioclase crystals that show no evidence of mechanical transport or physical abrasion. The base of the Whistle Creek formation is often marked by the Copperfield conglomerate (Figures 1-5-2, 1-5-3), a limestone-boulder conglomerate that forms the most distinctive and important stratigraphic marker horizon in the district. The conglomerate is well developed west of Hedley where it forms a northerly trending, steeply dipping unit that is traceable for over 15 kilometres along strike. The same conglomerate outcrops in small areas within upfaulted slices along Pettigrew Creek to the south, and as outliers near Nickel Plate and Lookout mountains to the east (Figure 1-5-1).

The Copperfield conglomerate is described in detail by Ray *et al.* (1987). It locally reaches 200 metres in thickness but is often less than 10 metres wide. It varies from clast to matrix-supported and is characterized by abundant, well-rounded to angular pebbles, cobbles and boulders of limestone, generally up to 1 metre in diameter. Rare limestone blocks up to 15 metres in diameter are locally present, usually at the base of the unit. Some limestone boulders contain crinoid ossicles and, in one instance, fragments of a Triassic shallow-water marine bivalve possibly belonging to the family *Carditidae* (H. Tipper, personal communication, 1987; Geological Survey of Canada Location No. C-143201). Conodonts extracted from some limestone clasts give Carnian ages (M.J. Orchard, personal communication, 1985, 1986), while radiolaria of Permian age were collected from one chert pebble (F. Cordey, personnel communication, 1985). To determine the locations of these fossiliferous samples *see* Ray and Dawson, 1987.

The Copperfield conglomerate is interpreted to be an olistostrome (Ray *et al.*, 1987), presumably derived from an upslope source to the east. Locally, the larger limestone blocks were autobrecciated during their catastrophic downslope movement and some large siltstone clasts exhibit soft-sediment deformation structures, suggesting they were unconsolidated when incorporated into the conglomerate.

Although the main tuffaceous sequence of the Whistle Creek formation is widely developed and overlies the Stemwinder Mountain, Hedley and French Mine formations, the Copperfield conglomerate has only been identified overlying the Stemwinder Mountain and Hedley formations (Figure

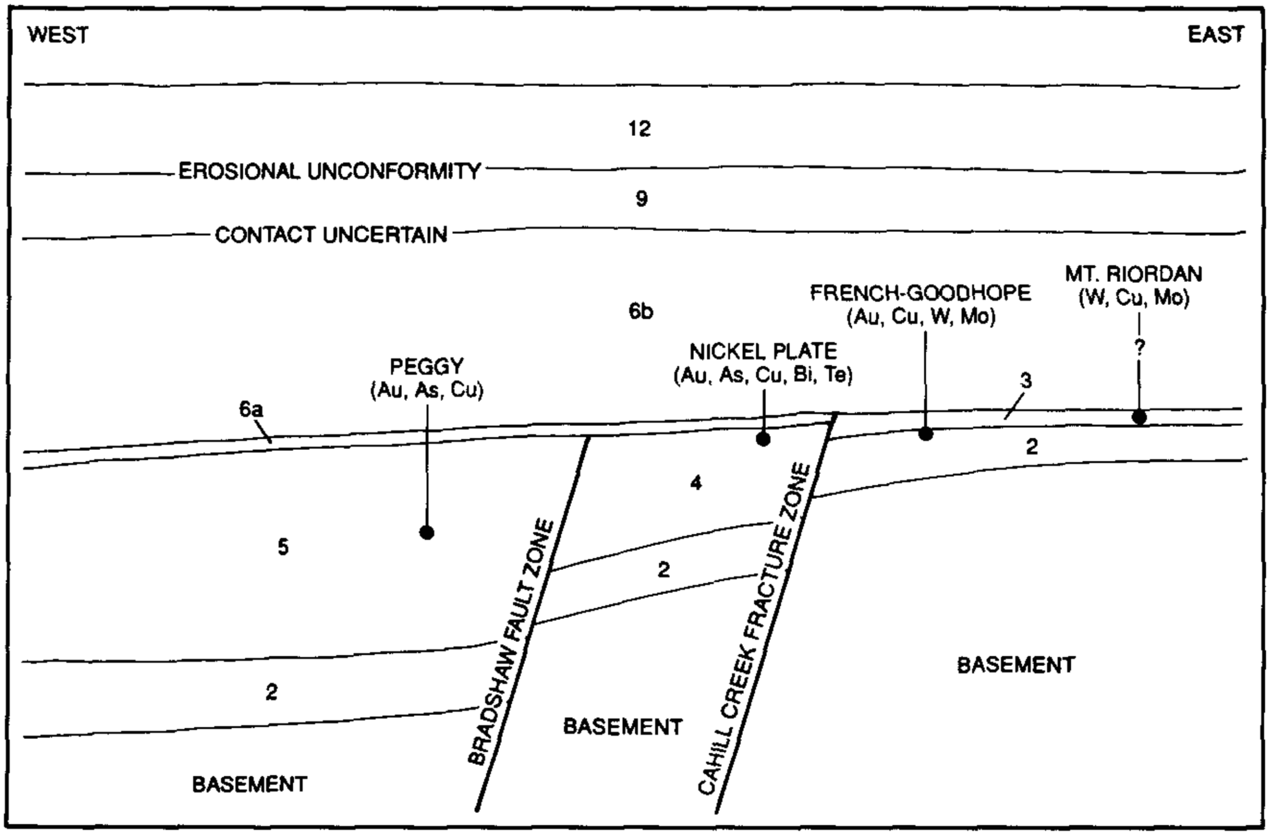

Figure 1-5-2. Schematic east-west stratigraphic section of the Hedley district showing location of skarn mineralization in relation to sedimentary facies changes (*see* Figure 1-5-1 for legend).

1-5-3). However, angular limestone breccias and conglomerates within the French Mine formation were possibly the source material for the Copperfield conglomerate. No east-to-west facies changes are recognized in the main tuffaceous sequence of the Whistle Creek formation.

The Whistle Creek formation is overlain by volcaniclastic rocks that may belong to the Early Cretaceous Spences Bridge Group (Figure 1-5-2). Two different sequences are recognized whose relationship to one another is unknown. One of these lies between Smith and Whistle creeks on the western edge of the map sheet (Figure 1-5-1) and comprises dark-coloured, massive dacitic flows with lesser amounts of dacitic ash, and dust tuff and pale to maroon-coloured ignimbritic rocks. Many ignimbrites display fiammé textures and welded features; in some localities they are associated with thin units of heterogeneous, coarsely clastic rocks that are interpreted to be lahars. The other suite of Spences Bridge Group contains two distinct stratigraphic units but no volcanic flows. It occurs as outliers at two separate localities; the smallest covers less than 4 square kilometres and lies east of Lookout Mountain, while the other covers 40 square kilometres surrounding Ashnola Hill* (Figure 1-5-1). The lowest stratigraphic unit in this suite, which is present in both outliers, has a maximum thickness of 300 metres and largely comprises massive grey-coloured ash and crystal tuffs of probable dacite composition. These tuffs contain rounded, highly embayed quartz crystals and sporadic angular lapilli of dacite, rhyolite and quartz porphyry. Some fiammé-textured welded tuffs, minor tuffaceous siltstones and bedded crystal tuffs are also present locally.

In the southern outlier, west of Ashnola Hill, the lowermost quartz-bearing dacitic tuff unit is stratigraphically overlain by a sequence of fresh, massive, dark green crystal lithic tuffs 200 metres thick. This uppermost unit in the Spences Bridge Group is characterized by abundant large euhedral plagioclase crystals, and is of andesitic to basaltic composition.

The Ashnola Hill outlier occupies a broad syncline, plunging gently to the north, that is cut by faults along the northern, western and eastern margins. It is uncertain whether the contact between Spences Bridge Group and the underlying rocks represents an unconformity or a thrust plane. In the Princeton area, west of the Hedley district, Preto (1979) mapped subaerial flows, ash flows and lahars in the Spences Bridge Group and noted a basal unconformity; these rocks resemble the Spences Bridge suite between Smith and Whistle creeks. No unconformity is identified in the Hedley district and no evidence of paleoweathering is observed in the underlying rocks. The Lookout Mountain outlier forms a thin, flat-lying unit that locally overlies plutonic rocks, yet it shows no signs of thermal hornfelsing. Both outliers may represent thrust slices.

* Ashnola Hill is an unofficial name given to the hill surmounted by the British Columbia Telephone Company microwave tower.

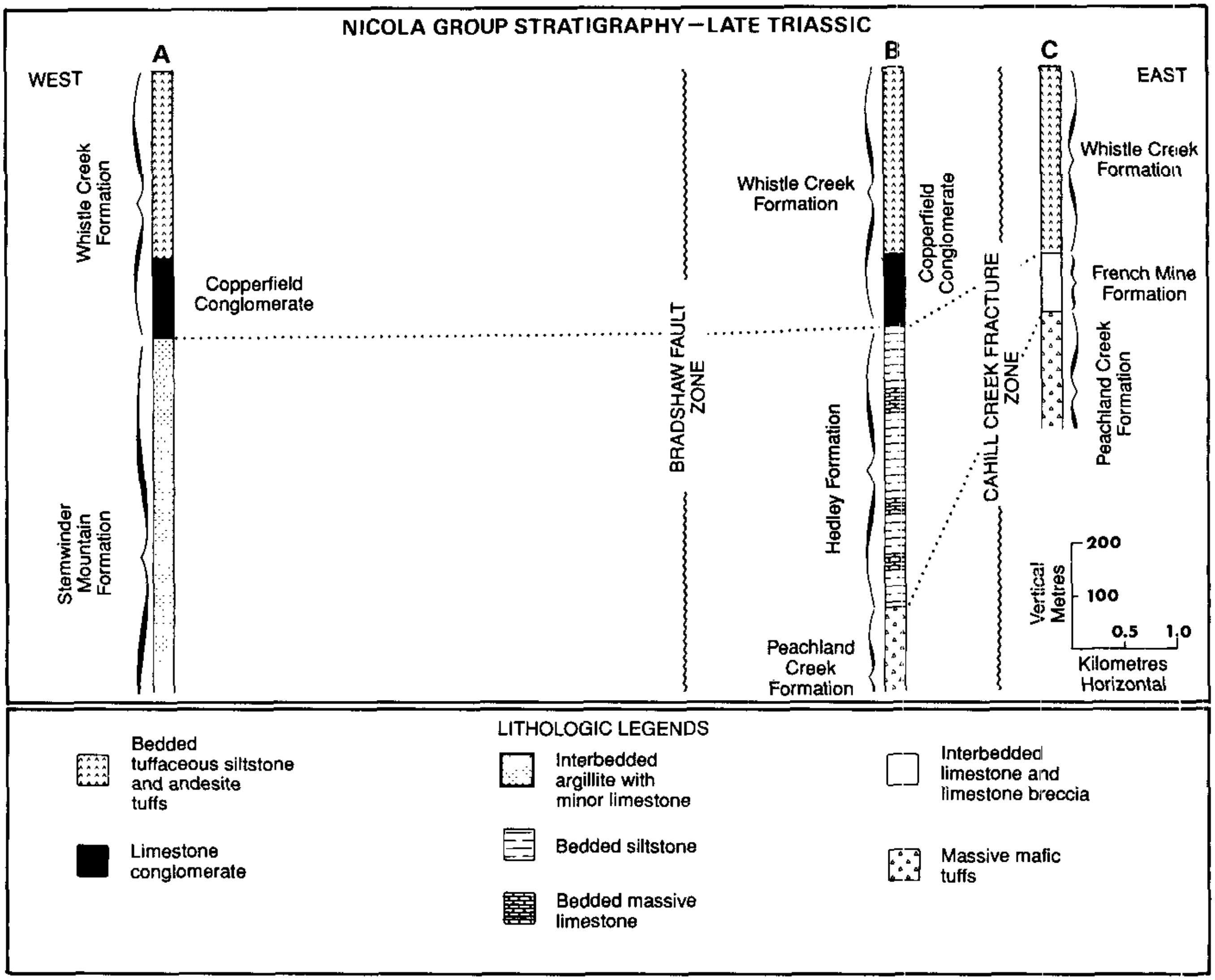

Figure 1-5-3. Comparative east-west stratigraphic sections in the Nicola Group, Hedley district: A = Stemwinder Mountain area west of Peggy mine; B = Nickel Plate mine area; C = French mine area.

Three plutonic suites are recognized in the area. The oldest, the Hedley intrusions, is economically important and probably Early Jurassic in age. It forms major stocks up to 1.5 kilometres in diameter and swarms of thin sills and dykes up to 200 metres in thickness and over 1 kilometre in length. The sills and dykes are coarse grained and massive diorites and quartz diorites with minor gabbro, while the stocks range from gabbro through granodiorite to quartz monzonite. Many of the sills and dykes are porphyritic and characterized by coarse phenocrysts of hornblende and zoned plagioclase. When unaltered they are dark coloured, commonly contain minor disseminations of pyrite and pyrrhotite and are often rusty weathering. By contrast, the skarn-altered diorite intrusions are usually pale coloured and bleached.

The Hedley intrusive suite is absent in the Apex Mountain complex, but invades the Upper Triassic rocks over a broad area. Varying degrees of sulphide-bearing calcic skarn alteration are developed within and adjacent to many of these intrusions, particularly the dyke and sill swarms. Some previous workers (Billingsley and Hume, 1941; Dolmage and Brown, 1945) considered this plutonic suite to be genetically related to the skarn-hosted gold mineralization in the district, including that at the Nickel Plate, Hedley Mascot, French and Goodhope mines; the geochemical and mapping results presented in this paper support this conclusion.

The second plutonic suite comprises coarse-grained, massive biotite hornblende granodiorite to quartz monzodiorite of presumed Early Jurassic age. It generally forms large bodies, for example, the Bromley batholith (Monger, personal communication, 1987) which outcrops northwest of Hedley, and the Cahill Creek pluton which generally separates the Nicola Group rocks from the highly deformed Apex Mountain complex further southeast. North of Ashnola Hill a dyke-like apophysis of the Cahill Creek pluton is controlled by a west-southwest extension of the Cahill Creek fracture zone. Other narrow, elongate apophyses intrude the Nicola Group southwest and east of Hedley and are also controlled by northwesterly to westerly trending lineaments. Country rocks up to 1.5 kilometres from the margins of the Bromley batholith and Cahill Creek pluton are hornfelsed; some minor skarn alteration is also locally present adjacent to the pluton, but it is generally sulphide poor and not auriferous.

Most potassium-argon dates from the Cahill Creek pluton range from 150 to 160 Ma (Roddick *et al.*, 1972). However, a $^{207}Pb/^{206}Pb$ dates for two discordant zircon fractions give dates of 196 and 199 Ma respectively (P. van der Heyden, personal communication, 1987).

The third and youngest intrusive suite includes two rock types that are possibly coeval and related to the formation of the dacitic volcaniclastic rocks within the Spences Bridge Group. One of these, the Verde Creek stock (J.W.H. Monger, personal communication, 1987), outcrops at the western edge of the map sheet, south of Smith Creek. It comprises a fine to medium-grained, massive leucocratic microgranite that contains minor biotite. The other type is represented by fine-grained, leucocratic, felsic quartz porphyry that contains rounded, deeply embayed quartz phenocrysts up to 4 millimetres in diameter. Sills and dykes, generally less than 3 metres wide, are widespread but not abundant in the area. However, west of Ashnola Hill a dyke-like body of quartz porphyry, 100 to 200 metres wide, follows the margin of the Cahill Creek pluton for a distance of 3.3 kilometres (Ray and Dawson, 1987). The phenocrysts in these rocks are identical to the embayed quartz crystals in the lower dacite tuff unit of the Spences Bridge Group, and it is possible that the dykes and sills were feeders for the Spences Bridge volcaniclastic rocks.

Some of the quartz porphyry intrusions and the Spences Bridge Group around Ashnola Hill are overprinted by narrow zones of silicification containing minor pyrite, abundant epidote (as veinlets and large clots) and trace amounts of small euhedral blood-red garnet crystals.

GEOLOGICAL AND STRUCTURAL HISTORY

The postulated sequential geological history of the area is as follows:

(1) Deposition of the presumed Triassic mafic extrusive rocks of the Peachland Creek formation. The depositional environment is unknown, however, the presence of rare limestone olistoliths suggests tectonic instability.

(2) Late Triassic deposition of the Stemwinder Mountain, Hedley and French Mine formations by westerly to northwesterly directed paleocurrents across a tectonically controlled basin margin. This shallow marine basin deepened to the northwest; the Stemwinder Mountain rocks were laid down on the more distal, deeper basin floor, while the Hedley and French Mine formations were deposited in a shallower environment closer to the shoreline.

(3) Sudden collapse of the basin margin, possibly due to the initiation of the Nicola arc further west, led to the widespread deposition of the Whistle Creek formation, including the initial, gravity-slide deposits represented by the Copperfield conglomerate.

(4) Following lithification of the Nicola Group rocks, two distinct phases of folding took place but the relative age of these phases is uncertain. One phase resulted in a major, north-northeasterly striking, easterly overturned asymmetric anticline which is the dominant structure in the district. The axial plane of the fold dips steeply west, the axis runs subparallel to Cahill Creek, and the core of the anticline is occupied by both the Cahill Creek pluton and rocks of the Peachland Creek formation. A related, but poorly developed, northerly striking axial planar cleavage is present in some argillites and the axes of smaller scale folds related to this deformation dip gently north and south.

The asymmetric anticlinal folding was accompanied by the development of several high-angle, easterly directed, northerly striking reverse faults. The largest of these faults makes up the Cahill Creek fracture zone (Figure 1-5-1) which runs subparallel to both Cahill Creek and the axial plane of the major antiform. Along the Cahill Creek fracture zone, rocks of the Peachland Creek formation were upthrown eastwards against overturned, easterly younging Whistle Creek formation; this suggests an overall vertical movement of at least 400 to 500 metres (the estimated thickness of the Hedley formation at this location). Further west, a similar westerly dipping fracture, the northerly trending Bradshaw fault, is related to a major monoclinal flexure in the sedimentary rocks. Along the Bradshaw fault, steeply dipping rocks of the Stemwinder Mountain formation are upthrown against the gently dipping Hedley formation to the east.

The other phase of folding recognized in the district is economically important as it took place during the emplacement of the Hedley intrusions and partly controlled the late-magmatic auriferous skarn mineralization. It produced the small-scale northwesterly striking, gently plunging fold structures that are an ore control at the Nickel Plate mine (Billingsley and Hume, 1941; Dolmage and Brown, 1945) as well as a series of westerly to northwesterly trending fractures. Although there was little movement along these fractures, they did control the emplacement of the Hedley intrusive dykes and the elongate Banbury, Stemwinder and Toronto stocks.

(5) Emplacement of the Hedley intrusions was shortly followed by intrusion of the Cahill Creek pluton; this probably occurred more than 200 million years ago and it is possible that the two magmatic episodes were genetically related. Both the Hedley intrusions and the Cahill Creek pluton were intruded after the main movement occurred along the Bradshaw fault.

(6) Deposition of the Early Cretaceous Spences Bridge Group and the intrusion of some related quartz porphyries followed a period of uplift and erosion.

(7) Some outliers of the Spences Bridge Group may represent thrust slices, suggesting that the Hedley area underwent a post-Early Cretaceous phase of regional thrust faulting. The Spences Bridge Group has been gently warped and folded by open, northeast-striking folds with subhorizontal axes.

(8) The younger tectonism in the district involved reactivation of the Bradshaw fault and Cahill Creek fracture

zone, as well as some faulting along Whistle and Pettigrew creeks (Figure 1-5-1). The Spences Bridge Group was cut by a series of northerly trending normal faults; some of the very old northwesterly to westerly striking fractures which controlled the Hedley intrusive dykes at the Nickel Plate mine were also reactivated during this episode.

GEOLOGICAL UPDATE ON THE NICKEL PLATE MINE

The following data are based both on older studies (Camsell, 1910; Warren and Cummings, 1936; Billingsley and Hume, 1941; Dolmage and Brown, 1945; Lee, 1951) and on more recent work by the geological staff of Mascot Gold Mines Limited.

The Nickel Plate and Hedley Mascot mines were largely developed on a single, very large, westerly dipping skarn-related gold deposit. It was discovered in 1898 and mined in several underground operations until 1955; it produced approximately 48 million grams of gold from 3.6 million tonnes of ore. Open-pit production resumed in April 1987 at a rate of 2450 tonnes of ore per day; on November 18, 1987 Mascot Gold Mines Limited reported calculated mineable reserves of 8.9 million tonnes grading 4.56 grams gold per tonne.

The gold deposit is hosted within the upper part of the Hedley formation where a zone of garnet-pyroxene skarn alteration, up to 300 metres thick and over 6 square kilometres in area, is developed peripherally to the Toronto stock and swarms of Hedley intrusion dykes and sills. The alteration zone is subcircular in outcrop shape and westerly dipping, subparallel to, but locally crosscutting the gently dipping host rocks which comprise calcareous and thin-bedded siltstone with some impure limestone. Swarms of Hedley diorite porphyry sills 1 to 15 metres in thickness, locally make up to 40 per cent of the skarned interval. In addition, several diorite porphyry dykes have followed west to northwesterly trending fault zones and the mineralization and alteration tends to follow these dykes, forming deep keels of skarn that extend below the main alteration envelope. Skarn development is mostly confined to the Hedley formation, but alteration does extend upwards into the overlying Copperfield conglomerate.

The main episode of skarn development occurred during a period of northerly striking fold deformation shortly after the emplacement of the diorite sills. Most of the sills and dykes within the skarn envelope are bleached and altered. The exoskarn is dark green to brown coloured and typically consists of alternating layers of garnet-rich and clinopyroxene-rich material which reflect the original sedimentary bedding. The concentric mineralogical zoning observed in other small skarn envelopes in the district (Ray *et al.*, 1987) is not clearly defined at the Nickel Plate mine, probably due to large-scale multiple and complex overprinting of the skarn alteration. Garnet-rich skarn is usually found in the cores of the alteration envelopes but metasomatic overprinting has eliminated most of the initial biotite hornfelsing, resulting in a generally sharp transition from pyroxene skarn to unaltered sediment. This transition represents the economically important "marble line" described by Billingsley and Hume (1941). Preliminary studies suggest that at least two stages of mineral growth are present in the skarn. The main minerals formed during the early stage were iron-rich pyroxene, garnet, quartz, wollastanite, scapolite and carbonate. The pink to brown-coloured garnet is generally poorly crystalline except where it grew adjacent to carbonate. The later stage of skarn alteration is largely restricted to the outer and lower margins of the envelope, normally within 100 metres of the skarn front. This late-stage alteration is rarely seen in the central or upper part of the skarn zone, except along fractures or dyke and sill margins. It resulted in the introduction of sulphides and gold, accompanied by the growth of calcite and quartz with minor amounts of epidote, chlorite, clinozoisite and local late-stage axinite. However, the ferro magnesian minerals at the Nickel Plate mine, and in other skarns throughout the district, are remarkably unaltered and display little evidence of widespread propyllitic alteration.

The gold-bearing sulphide zones normally form semiconformable, tabular bodies situated less than 100 metres from the outer and lower skarn margin. They are both lithologically and structurally controlled along northwesterly plunging minor folds, fractures and sill-dyke intersections (Billingsley and Hume, 1941; Dolmage and Brown, 1945)

There is significant geochemical and mineralogical variation throughout the deposit. The main Nickel Plate ore zone, in the northern part of the deposit, consists primarily of arsenopyrite, pyrrhotite and chalcopyrite with calcite, diopside and quartz. Arsenopyrite often forms coarse, wedge-shaped crystals up to 1 centimetre in length and the sulphides occur as disseminations and fracture fillings within the exoskarn. The Sunnyside ore zones in the central part of the deposit are strongly controlled by either sill-dyke intersections or fold hinges. Although the sulphide mineralogy and textures resemble those in the Nickel Plate zone, pyrrhotite dominates in the Sunnyside zones. The Bulldog zone, in the southern part of the deposit, comprises lenses and pods of massive to semimassive sulphide mineralization; it is noticeably richer in chalcopyrite and contains higher silver and zinc values.

Grain boundary relationships suggest the following three stages of sulphide deposition: (1) pyrite; (2) arsenopyrite and gersdorffite (NiAsS); and (3) pyrrhotite, chalcopyrite and sphalerite. Gold mineralization is related to the latter two stages, and minor amounts of magnetite are associated with the first and last sulphide phases. Pyrrhotite and arsenopyrite are the most common sulphides. Present in lesser amounts, but locally dominant, are pyrite, chalcopyrite, gersdorffite and cadmium-rich sphalerite with minor amounts of magnetite and cobalt minerals. Trace minerals include galena, native bismuth, gold, electrum, tetrahedrite, native copper, marcasite, molybdenite, titanite, bismuth tellurides (hedleyite, tetradynite), cobaltite, erythrite, pyrargyrite and breithauptite. Trace amounts of maldonite (Au_2Bi) have recently been identified (A.D. Ettlinger, personal communication, 1987) but no scheelite has been seen in the deposit. The native gold, with hedleyite, occurs as minute blebs, generally less than 25 microns in size, within and adjacent to grains of arsenopyrite and gersdorffite. In the Bulldog zone, electrum occurs in close association with chalcopyrite, pyrrhotite, sphalerite and native bismuth; it tends to be concentrated in microfractures within and around the sulphides.

A recent preliminary statistical study, based on analyses of over 300 samples from various ore zones in the Nickel Plate deposit, showed the following correlation coefficients:

Au:Bi	=	0.94
Ag:Cu	=	0.84
Bi:Co	=	0.62
Au:Co	=	0.58
Au:As	=	0.46
Au:Ag	=	0.28
Au:Cu	=	0.17

The strong positive correlation between gold and bismuth reflects the close association of native gold with hedleyite, while the moderate positive correlation between gold, cobalt and arsenic confirms the observed association of gold, arsenopyrite and gersdorffite. The high positive correlation between silver and copper may indicate that some silver occurs as a lattice constituent in the chalcopyrite. The gold and silver values are relatively independent of each other despite the presence of electrum, and there is generally a low correlation between gold and copper. Gold to silver ratios in the Nickel Plate and Sunnyside zones are greater than 1 with silver averaging 2 ppm. By contrast, in the Bulldog zone where electrum is present, the gold:silver ratio is less than 1, with silver averaging 17 ppm.

Bismuth averages 20 ppm but may reach several hundred ppm in areas with higher gold values. Nickel and cobalt values normally range from 100 to 200 ppm but both locally exceed 2 per cent in areas containing abundant visible erythrite and high gold values. Copper commonly exceeds 0.5 per cent over intervals of several metres, particularly in the sulphide-rich Bulldog zone. Secondary gold enrichment is also present in some weathered, near surface, oxide-rich zones and along certain faults. The resulting red hematitic clay zones may carry gold grading over 34 grams per tonne.

GEOLOGY AND GEOCHEMISTRY OF THE HEDLEY INTRUSIONS

The Hedley intrusions occur as narrow dykes and sills that may form dense swarms, and larger stocks exceeding 1 kilometre in diameter. The stocks are widely scattered throughout the district; they include the Pettigrew, Aberdeen and Larcan stocks, which are subcircular in shape, as well as the Banbury, Toronto, and Stemwinder stocks which are elongate along westerly to northwesterly trending lineaments (Figure 1-5-1).

In addition to their larger dimensions, the stocks are texturally and compositionally distinct from the dykes and sills and are economically less important. The stocks tend to be equigranular and of variable composition; in addition to diorite, quartz diorite and gabbro, they include large amounts of biotite and hornblende granodiorite. These granodiorite components are indistinguishable from the rocks in the younger Cahill Creek pluton and Bromley batholith and locally the margins of the pluton and batholith are dioritic and resemble the Hedley intrusions. This suggests that the older Hedley intrusions and younger Cahill Creek pluton may be close together in age and possibly genetically related to one another. Two discordant zircon fractions collected from the Cahill Creek pluton during this survey give $^{207}Pb/^{206}Pb$ dates of 196 and 199 Ma respectively (P. van der Heyden, personal communication, 1986). The Hedley and Stemwinder formations, are *circa* 225 Ma, based on the Late Carnian–Early Norian conodont dating, which suggests that lithification, regional folding, emplacement of the Hedley intrusion and Cahill Creek pluton, and development of the auriferous skarns all occurred within a 25-million-year interval.

In contrast to the stocks, the Hedley dykes and sills tend to be porphyritic and of less variable composition, ranging from diorite to quartz diorite and minor gabbro. Also, unlike the stocks which are largely unaltered, a significant number of dyke and sill swarms are enveloped by varying amounts of calcic skarn alteration that may, in rare instances, carry gold mineralization. However, most of the Hedley dykes and sills are unaltered and the immediately adjacent sedimentary rocks show few signs of either skarn alteration or hornfelsing, other than narrow siliceous or bleached selvages generally a few centimetres in width. Many of these unaltered sills and dykes contain disseminated pyrite and pyrrhotite which is responsible for the characteristic rusty red-weathering appearance of these rocks.

The coarse primary phenocrysts in the sills and dykes include dark-coloured hornblende and minor augite as well as abundant crystals of compositionally zoned plagioclase. With increasing skarn alteration many sills become bleached and the primary ferromagnesian minerals are replaced by colourless augite and pale-coloured tremolite-actinolite (Dolmage and Brown, 1945).

TABLE 1-5-1
UNALTERED HEDLEY INTRUSIONS

Field No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O
50.00	54.21	0.79	19.20	9.25	0.17	4.49	9.90	2.69	0.83
61.00	60.45	0.46	17.12	5.72	0.12	2.55	6.41	3.48	1.67
52.00	54.29	0.83	19.53	8.11	0.15	3.24	9.16	3.12	0.93
60.00	56.81	0.60	17.50	7.03	0.12	3.81	7.98	3.03	1.64
62.00	54.08	0.68	18.35	8.77	0.17	4.03	9.25	2.91	1.11
63.00	62.71	0.36	18.24	3.31	0.07	1.94	6.71	3.68	2.03
64.00	52.94	0.65	19.89	7.93	0.15	4.04	10.15	3.40	1.24
65.00	59.48	0.53	17.86	6.41	0.11	2.51	6.66	3.28	2.00
66.00	53.27	0.72	19.02	8.75	0.16	3.93	9.12	3.10	1.35
67.00	50.82	0.65	20.24	8.39	0.17	4.18	10.30	2.90	0.75
68.00	59.46	0.51	17.99	5.83	0.13	2.88	7.24	3.72	2.01
69.00	54.27	0.64	19.33	7.66	0.17	3.27	9.19	3.20	1.55
70.00	49.13	0.80	20.18	9.07	0.16	5.09	11.46	2.55	1.17
71.00	55.92	0.58	18.41	7.27	0.14	3.13	8.14	3.22	1.66
72.00	54.85	0.65	18.72	8.08	0.15	3.54	8.73	3.06	1.65
73.A	57.68	0.67	18.60	7.91	0.15	3.10	8.23	3.22	1.80
60.00	57.24	0.62	18.01	7.13	0.13	3.86	8.04	3.04	1.65
73.B	55.38	0.66	18.61	8.05	0.15	3.06	8.00	3.21	1.78
130.00	54.01	0.68	18.39	8.74	0.15	4.44	8.93	2.66	1.21
131.00	54.60	0.66	18.79	8.32	0.13	4.18	8.14	2.81	1.53
156.00	54.83	0.67	18.81	7.98	0.14	4.83	8.00	3.20	0.64
157.00	55.56	0.66	18.71	7.53	0.16	4.16	7.13	3.28	1.37
158.00	53.33	0.56	19.24	8.19	0.14	4.45	9.47	2.77	1.17
159.00	55.61	0.61	18.38	7.35	0.12	3.69	8.12	2.91	1.00
161.00	54.12	0.65	18.22	8.32	0.14	4.10	8.32	2.72	1.01
162.00	53.36	0.68	18.57	7.31	0.12	4.23	8.32	2.77	1.10
163.00	54.13	0.62	17.55	6.64	0.09	3.99	6.48	4.79	2.13
164.00	56.38	0.58	18.37	6.29	0.10	3.41	7.10	4.06	1.01
218.00	54.31	0.61	18.29	6.01	0.07	3.83	7.45	3.34	2.08

TABLE 1-5-2
ALTERED HEDLEY INTRUSIONS (ENDOSKARN)

Field No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O
84.00	59.79	0.50	15.68	4.97	0.14	3.04	11.43	3.73	1.07
85.00	61.87	0.55	18.16	3.76	0.04	2.41	7.63	3.62	2.28
155.00	60.37	0.46	18.01	5.62	0.12	2.66	6.03	3.37	2.13
160.00	60.47	0.43	18.34	4.46	0.07	2.29	6.03	4.51	0.96
401.04	51.17	0.63	17.09	6.57	0.12	6.36	10.20	3.38	2.14
401.12	47.99	1.02	18.15	8.97	0.11	4.70	9.72	2.70	2.43
401.16	52.57	0.61	15.94	7.66	0.06	3.57	8.25	2.05	5.11
401.21	51.18	0.65	17.96	6.69	0.09	4.35	8.54	3.87	2.12
401.23	54.89	0.62	18.51	6.37	0.09	4.54	7.74	3.99	1.48
401.24	54.58	0.63	18.61	7.66	0.11	4.49	7.52	3.11	1.36
403.02	57.22	0.60	17.08	6.22	0.09	2.71	6.14	3.33	3.03
73.13	53.72	0.63	18.03	5.39	0.07	3.98	8.98	4.18	2.66
73.14	54.98	0.63	18.36	3.31	0.06	4.38	10.34	3.96	2.72
73.15	58.81	0.50	16.34	3.91	0.08	3.10	8.15	3.76	3.44
73.17	55.55	0.50	17.68	3.22	0.07	3.67	8.29	3.93	4.33
73.19	50.95	0.50	11.12	10.76	0.38	4.72	17.87	1.29	2.04
73.21	57.39	0.47	17.50	2.43	0.08	3.50	7.45	4.50	4.20
73.26	49.67	0.39	14.00	11.90	0.39	2.77	13.92	3.78	1.13
73.28	57.03	0.53	18.08	4.68	0.09	3.04	9.03	4.12	1.48
73.32	54.15	0.65	18.38	6.12	0.10	4.01	7.64	4.23	2.01
73.17	57.29	0.55	17.34	3.24	0.06	3.65	8.37	3.83	4.40
261.03	59.23	0.44	16.63	2.99	0.09	2.10	6.67	1.73	9.88
261.04	61.24	0.46	16.94	2.60	0.06	2.60	7.18	3.75	3.84
261.05	63.55	0.46	17.29	1.56	0.04	2.19	7.64	4.37	2.94
261.11	57.32	0.54	18.29	3.11	0.09	3.18	8.67	5.24	2.05
261.17	36.44	0.20	3.66	12.71	0.40	1.55	27.20	0.01	1.80
261.25	59.96	0.50	16.24	4.60	0.06	3.07	7.20	3.66	2.25
261.27	55.50	0.70	18.09	3.99	0.07	3.52	9.55	3.41	3.49

The temporal and genetic relationships between the stocks and the sills and dyke swarms are unknown. Most stocks are not spatially associated with sills and dykes; however, it is postulated (Billingsley and Hume, 1941; Dolmage and Brown, 1945) that the dykes and sills responsible for the Nickel Plate gold deposit emanated from the nearby Toronto stock.

Geochemical data on major oxides from unaltered and skarn-altered (endoskarn) Hedley intrusions are presented in Tables 1-5-1 and 1-5-2 respectively. The unaltered samples were collected from the Stemwinder stock and from dykes and sills throughout the district. The endoskarn samples were taken mainly from drill holes at the Nickel Plate mine and represent skarn-altered sills and dykes. No examples of altered stocks were collected.

Normative plots in Figure 1-5-4A, using data presented in Table 1-5-3, illustrate the relatively uniform quartz diorite composition of Hedley intrusions and the quartz monzodiorite composition of the Cahill Creek pluton. In contrast, the gold-skarn related intrusions in the Tillicum Mountain camp (Roberts and McClintock, 1984; Ray *et al.*, 1986b) are of different composition, ranging from quartz monzonite to quartz monzodiorite (Figure 1-5-4B).

Alkali-silica plots of the unaltered intrusions in the Hedley district (Figure 1-5-5A) demonstrate the subalkaline character of both the Hedley intrusions and the Cahill Creek pluton. For comparison, similar plots of the intrusive rocks associated with precious-metal skarns at Tillicum Mountain and some iron skarns in British Columbia are presented in Figures 1-5-5B and 1-5-5C respectively; these, like the

TABLE 1-5-3
CIPW NORMS OF UNALTERED HEDLEY INTRUSIONS

Field No.	50	61	52	60	62	63
Q	5.92	16.00	7.14	9.96	6.00	17.59
or	4.83	10.07	5.53	9.84	6.60	12.11
ab	22.41	30.04	26.56	26.02	24.78	31.43
an	37.31	26.71	36.79	29.76	33.96	27.53
di	9.08	4.68	7.35	8.48	10.05	4.77
hy	15.04	8.34	11.08	11.23	13.49	3.04
mt	3.27	2.90	3.40	3.09	3.18	2.72
il	1.48	0.89	1.59	1.16	1.30	0.69
AN =	62.47	47.07	58.07	53.36	57.82	46.70

Field No.	64	65	66	67	68	69
Q	0.73	13.76	3.47	1.69	10.58	4.75
or	7.30	11.96	8.02	4.50	11.91	9.23
ab	28.65	28.07	26.38	24.93	31.54	27.26
an	35.23	28.45	34.21	40.66	26.53	34.06
di	12.21	4.09	9.29	9.24	7.70	9.75
hy	11.00	9.26	13.38	13.95	7.51	10.07
mt	3.10	2.98	3.24	3.17	2.92	3.13
il	1.23	1.02	1.38	1.25	0.97	.22
AN =	55.15	50.33	56.46	61.99	45.69	55.54

Field No.	70	71	72	73A	60	73B
Q	0.00	8.13	5.86	8.72	9.70	6.90
or	6.94	9.96	9.81	10.49	9.78	10.64
ab	21.65	27.66	26.03	26.87	25.79	27.45
an	40.33	31.37	32.67	30.53	30.72	31.47
di	13.66	7.91	8.95	8.00	7.55	7.15
hy	5.24	10.28	11.73	10.44	11.72	11.39
ol	6.64	0.00	0.00	0.00	0.00	0.00
mt	3.35	3.06	3.13	3.10	3.08	3.17
il	1.53	1.12	1.24	1.26	1.18	1.27
AN =	65.07	53.14	55.65	53.23	54.37	53.41

Field No.	130	131	156	157	158	159
Q	6.58	6.72	7.35	7.70	4.58	10.76
or	7.21	9.12	3.82	8.21	6.96	6.04
ab	22.68	23.97	27.31	28.15	23.59	25.17
an	34.95	34.44	35.40	32.77	36.87	34.92
di	7.95	5.14	3.78	2.54	8.53	5.12
hy	15.51	15.59	17.32	15.66	14.80	13.16
mt	3.19	3.16	3.17	3.18	3.01	3.13
il	1.30	1.26	1.28	1.27	1.07	.13
AN =	60.65	58.96	56.45	53.79	60.98	58.11

Field No.	161	162	163	164	218
Q	8.72	7.94	0.00	8.18	5.53
or	6.12	6.74	13.05	6.13	12.80
ab	23.57	24.29	42.02	35.30	29.43
an	35.39	36.29	20.86	29.74	29.99
di	5.66	5.28	10.10	5.24	6.85
hy	15.48	14.34	5.58	10.77	10.62
ol	0.00	0.00	3.53	0.00	0.00
mt	3.19	3.28	3.19	3.10	3.19
il	1.26	1.34	1.22	1.13	1.21
AN =	60.02	59.90	33.17	45.72	50.47

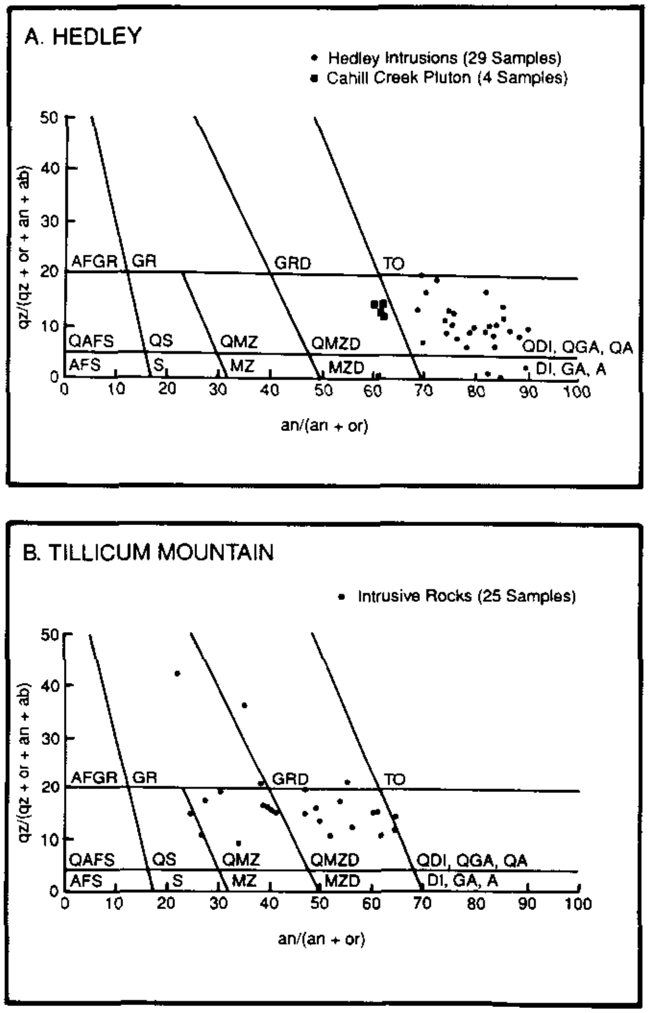

Figure 1-5-4. Chemical composition of plutonic rocks plotted on normative diagram of Streckeisen and Lemaitre (1979): A = Hedley; B = Tillicum Mountain (unpublished data from Ray); qz = quartz, or = orthoclase, an = anorthite, ab = albite, AF = alkali feldspar, S = syenite, MZ = monzonite, MZD = monzodiorite, DI = diorite, GA = gabbro, A = anorthosite, GR = granite, GRD = granodiorite, TO = tonalite.

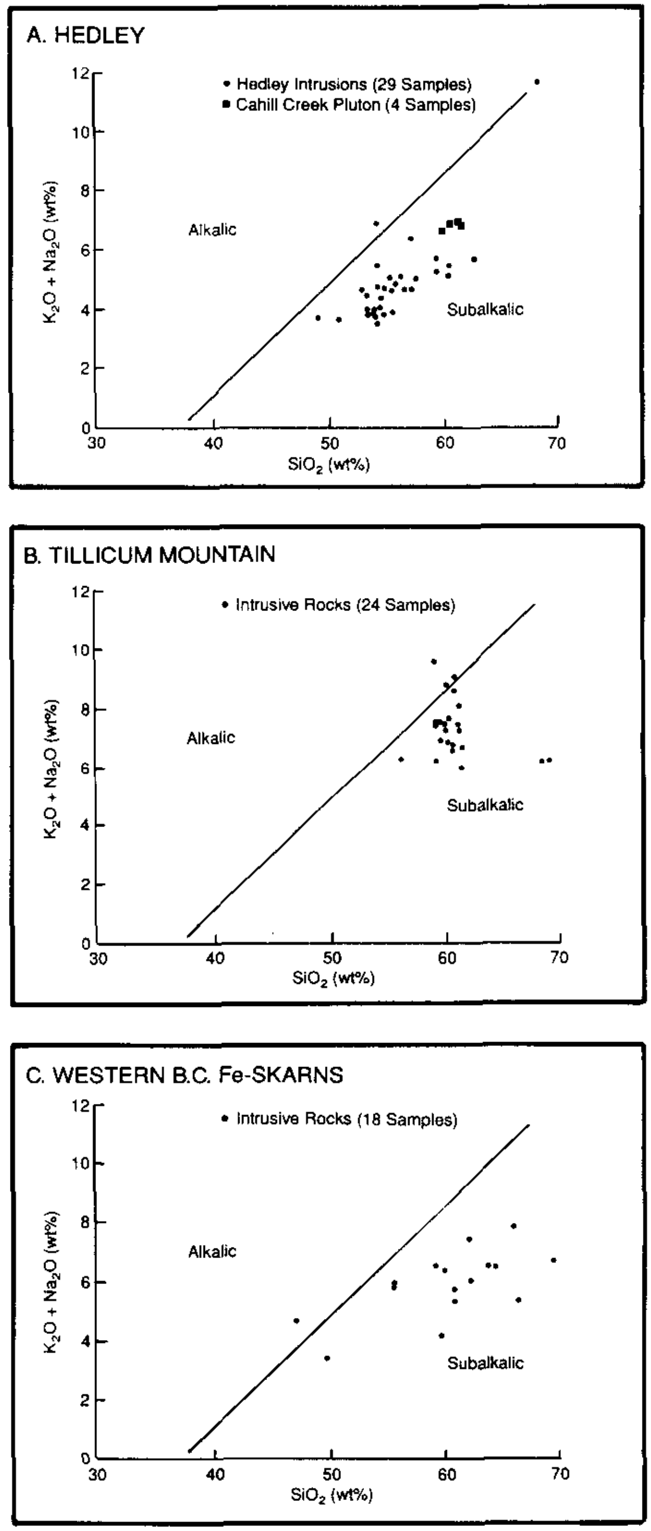

Figure 1-5-5. Alkalis versus silica plot (after MacDonald, 1968): A = Hedley; B = Tillicum Mountain (unpublished data from Ray); C = Western B.C. iron skarns (data from Sangster, 1969; Meinert, 1984).

Hedley intrusions, are subalkaline in character. AFM plots for these various intrusive rocks (Figures 1-5-6A, 1-5-6B and 1-5-6C) illustrate their common calcalkaline composition.

Figures 1-5-7A and 1-5-7B compare alkali-silica plots of the unaltered, skarn-related intrusions at Hedley with those at Tillicum Mountain. The relevant compositional fields for iron, copper and tungsten-skarn-related intrusive rocks, as determined by Meinert (1983), are also outlined. The Hedley intrusions fall largely within the iron-skarn field (Figure 1-5-7A) even though it is clear from both mineralogical and geochemical evidence that the Hedley skarns are not true iron skarns. By contrast, the Tillicum Mountain rocks fall largely within the copper-skarn field (Figure 1-5-7B) although the Tillicum Mountain gold skarns are not copper rich (Ray *et al.*, 1986b). It appears that gold skarns cannot be satisfactorily classified or differentiated using the base metal skarn plot of Meinert (1983), although the geochemical data do suggest that gold skarns are possibly related to, and found in the same geological regimes, as iron and copper skarns.

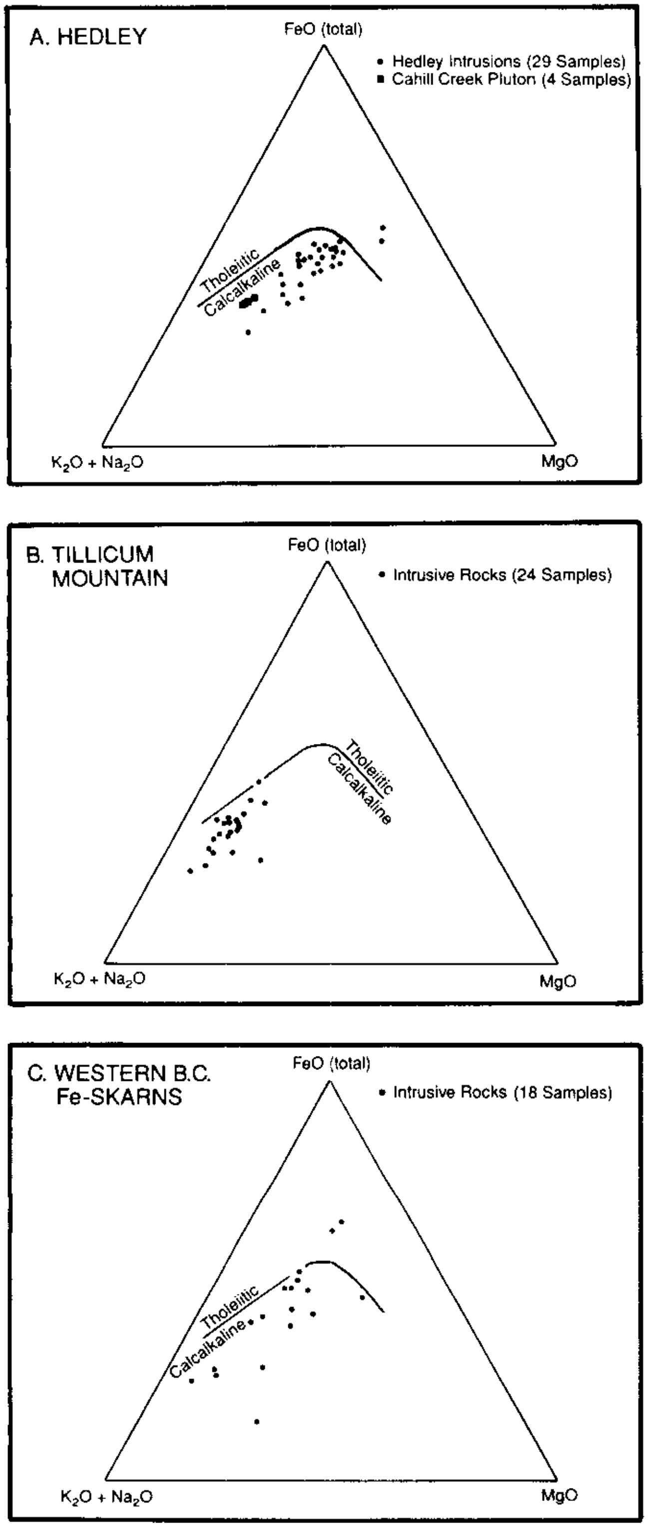

Figure 1-5-6. AFM diagram (after Irvine and Baragar, 1971) showing the calcalkaline trends of the intrusive rocks from three skarn camps: A = Hedley; B = Tillicum Mountain (unpublished data from Ray); C = Western B.C. iron skarns (data from Sangster, 1969; Meinert, 1984).

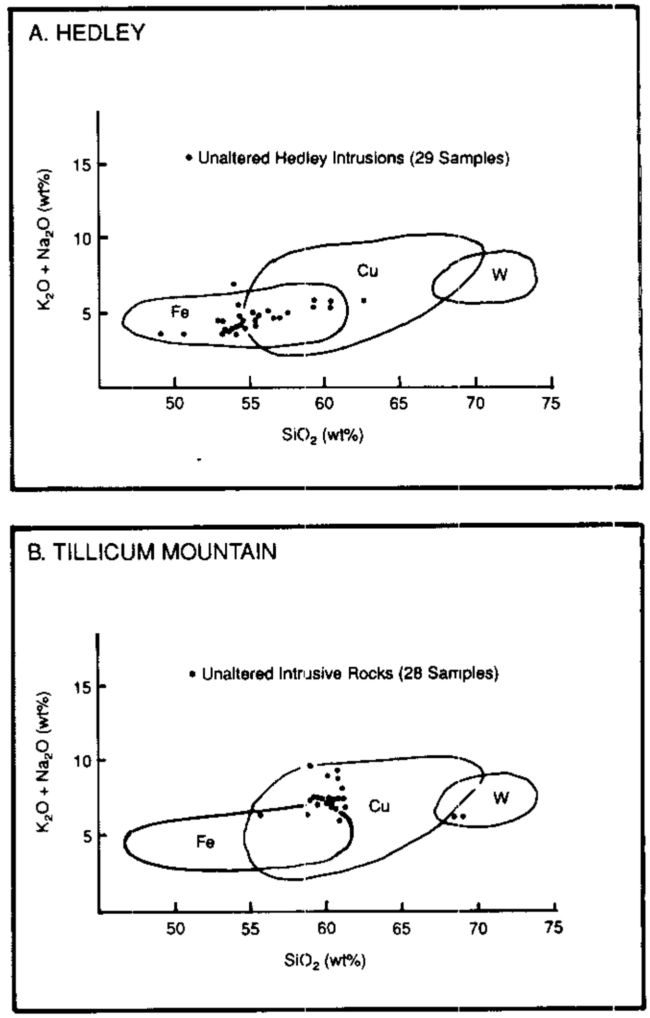

Figure 1-5-7. Alkali versus silica plot comparing skarn-related intrusive rocks at A. Hedley and B. Tillicum Mountain (unpublished data from Ray); skarn class boundaries modified after Meinert, 1983.

MINERALOGICAL ZONING IN THE SKARNS

Skarn and skarn-related alteration containing pyroxene-garnet assemblages are common and widely distributed in Nicola Group rocks throughout the Hedley district. Alteration varies considerably in grain size, intensity and extent; it ranges from narrow veinlets or irregular patches only centimetres or metres in diameter, up to huge alteration envelopes several hundred metres thick, such as that associated with the Nickel Plate deposit (Figure 1-5-8).

On an outcrop scale, a consistent concentric zoning of gangue mineralogy is recognized which is described by Ray *et al.* (1987). These small-scale zones are commonly the result of reaction between carbonate-rich beds and the skarn-forming fluids and range from the inner, coarse-grained, more intensely altered skarn assemblages, to the outer, finer grained margins of the envelope. In the ideal form the alteration zones initially develop along fractures adjacent to carbo-

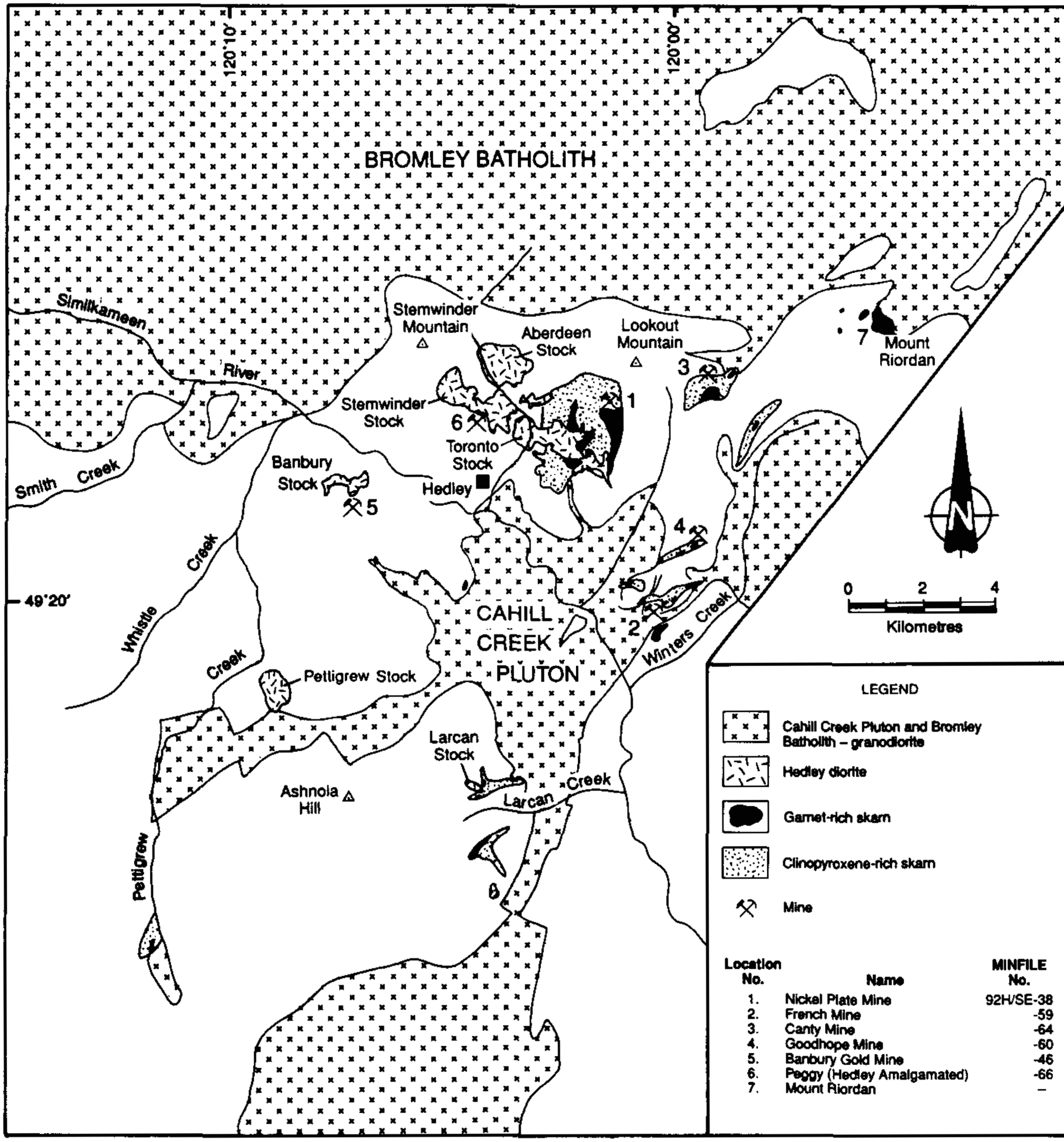

Figure 1-5-8. Areas of major skarn development in the Hedley district.

nate-rich beds or marble clasts. A central carbonate-rich core is commonly surrounded by a pinkish brown, garnet-rich section which passes outwards across a sharp contact to a green-coloured, generally wider, clinopyroxene-rich section. The clinopyroxene-rich zone may be separable into an inner, dark green, coarser grained assemblage and an outer pale green, siliceous, finer grained portion consisting largely of fine-grained clinopyroxene and quartz. The clinopyroxene-rich zone may pass outwards to a narrow section containing pink potassium feldspar and quartz. This potassium feldspar zone is often only a few centimetres thick and is absent in many outcrops.

The outermost alteration zone is of variable thickness and characteristically comprises a dark brown, siliceous, massive and fine-grained biotite hornfels. Contacts between the inner clinopyroxene-rich and outermost biotite hornfels zones are generally sharp, except where they are separated by thin reaction zones containing potassium feldspar and

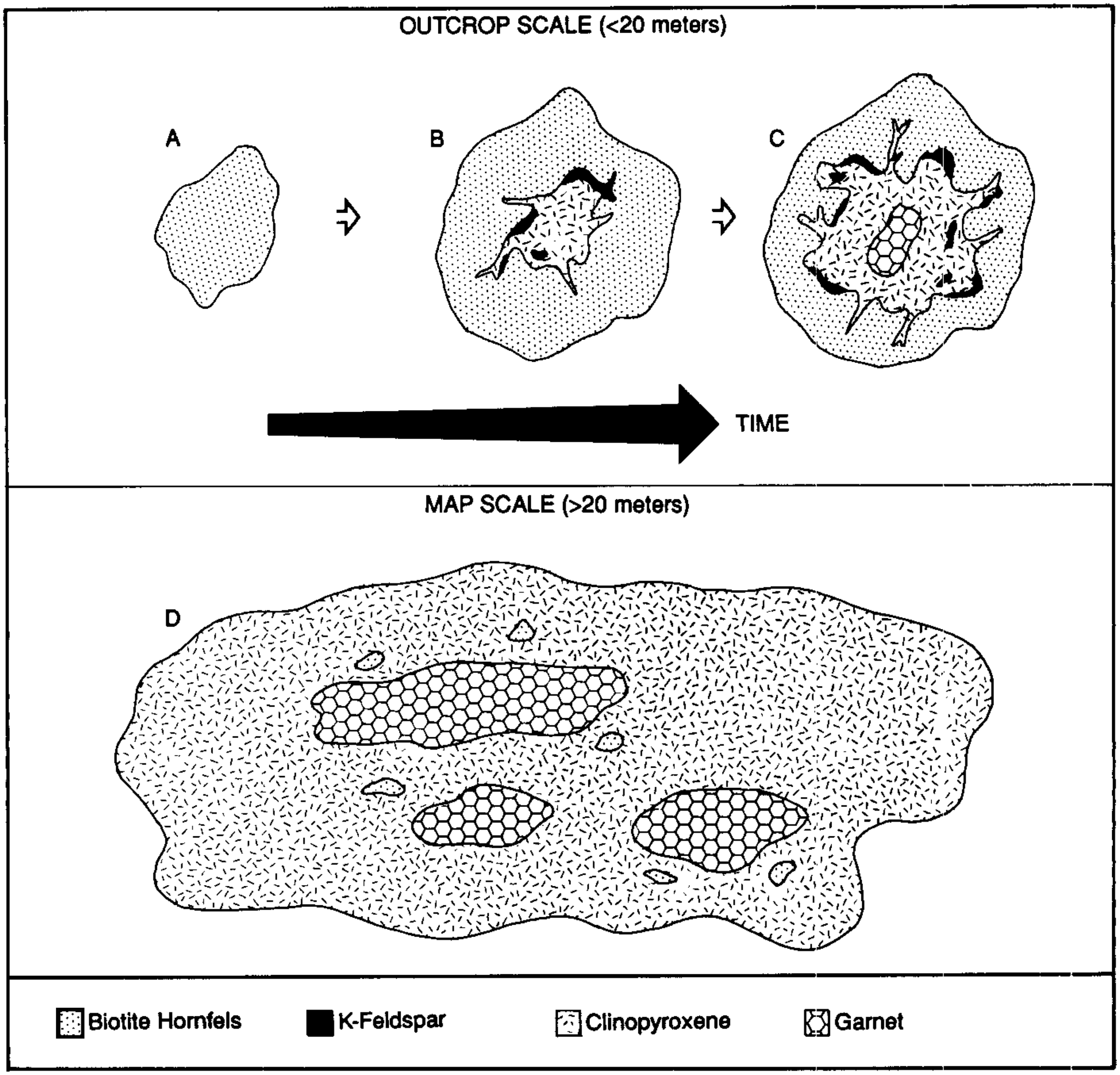

Figure 1-5-9. Progressive development of mineralogical zones in the Hedley gold skarns.

quartz. The outermost biotite hornfels is commonly cut by a network of thin, light-coloured veinlets of pyroxene and minor amphibole. These fine-grained pyroxene-rich veinlets may be irregular, but in many outcrops they show a preferred orientation and have followed pre-existing microfractures.

A temporal sequence of skarn development is recognized in the Hedley district and is illustrated in Figure 1-5-9. Initiation of the skarn process on a small scale commenced with formation of the siliceous biotite hornfels as an irregular patch of alteration (Figure 1-5-9A) often centred about a bedding plane fracture or crosscutting fault. It is emphasized that this hornfels alteration is **not** a thermal metamorphic feature related to the intrusion of the Hedley sills and dykes, but represents the preliminary stage of the skarning process and results from passage of the early, very hot, skarn-forming fluids along pre-existing fractures. Locally, some Hedley intrusions are also overprinted by the biotite hornfels-type alteration which emphasizes the post-magmatic, rather than the syn-magmatic, nature of this alteraton. The initial fracture control suggests that parts of this early hornfels-type alteration did not form under isochemical conditions.

As skarn-forming fluids continued to pass through the sedimentary host rock, clinopyroxene-rich alteration began to develop and the surrounding biotite hornfels aureole grew slowly outward (Figure 1-5-9B). With time, the area affected by the clinopyoxene-rich alteration grew steadily larger and development of a central zone of garnet-rich alteration began (Figure 1-5-9C). The garnet-rich alteration, which also steadily expanded outward, always began within the pre-existing pyroxene-rich zone, developing either along a fracture or as a reaction rim adjacent to an original carbonate-rich sedimentary bed.

When the biotite hornfelsic aureole reached a certain diameter, which in some outcrops can be measured in tens of metres or less, its development either slowed or stopped. However, both the garnet-rich and pyroxene-rich alteration zones continued their steady growth until they overprinted and completely replaced the hornfelsic aureole. This replacement often resulted in the development of the thin reaction zones of pink potassium-feldspar and quartz that separate the pyroxene and biotite hornfelsic zones (Figures 1-5-9B and C). The larger skarn envelopes, in contrast to the outcrop-sized skarns, have no peripheral biotite hornfelsic aureoles and the pyroxene-rich alteration passes directly outward into unaltered host rocks. In many cases the envelope of pyroxene-rich alteration contains small, irregularly distributed remnants of the earlier biotite and potassium feldspar alteration (Figure 1-5-9D).

Most of the very fine-grained, pyroxene-rich alteration in the Hedley district resembles what some geologists call "calc-silicate hornfels". However, the fracture-controlled nature of the pyroxene alteration suggests that metasomatism occurred on a local scale and thus it is regarded as "skarn" *sensu lato*. Alteration of this type is particularly well developed within the hangingwall portions of the larger skarn envelopes. An example of this hangingwall alteration is the "upper siliceous beds" which lie above the Nickel Plate deposit and are characterized by very fine-grained clinopyroxene, quartz and occasional potassium feldspar replacement of the thin-bedded sedimentary rocks. The presence of similar widespread alteration elsewhere in the district, such as that currently being explored by Chevron Minerals Ltd. east of Ashnola Hill (L. Dick, personal communication, 1987), may mark the presence of major skarn systems at depth.

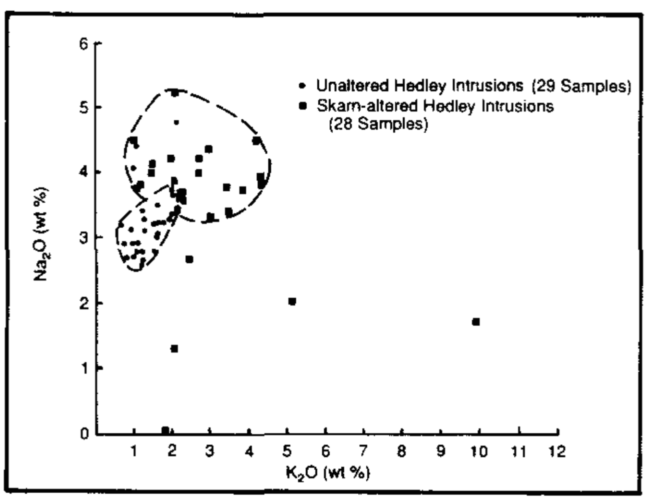

Figure 1-5-10. Plot of the Na_2O versus K_2O illustrating increases in sodium and potassium in skarn-altered Hedley intrusions compared to unaltered Hedley intrusions.

GEOCHEMICAL CHANGES ASSOCIATED WITH SKARN ALTERATION AND MINERALIZATION

Many previous workers, including Camsell (1910), Billingsley and Hume (1941) and Dolmage and Brown (1945), noted a spatial association between the Nickel Plate auriferous skarn mineralization and the Hedley intrusions, leading them to suggest a genetic relationship. Preliminary geochemical data presented in this report indirectly support this conclusion and suggest that the iron in the skarns was derived from the intrusions.

Data presented in Tables 1-5-1 and 1-5-2 demonstrate that many major elements including calcium, aluminum and titanium show little or no variation between the unaltered and skarn-altered dioritic Hedley intrusions. Some elements, however, notably total iron, and to a lesser extent silica, potassium and sodium, exhibit progressive compositional changes during the skarning process. Figure 1-5-10 shows that, compared to unaltered Hedley diorites, the skarn-altered (endoskarn) intrusions gain potassium and sodium. Likewise, Figure 1-5-11A illustrates that the skarning pro-

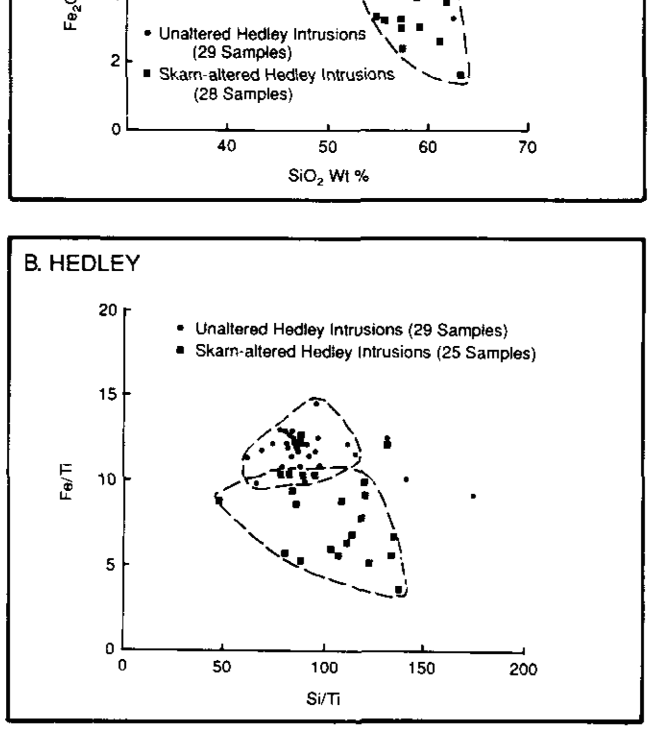

Figure 1-5-11. Comparing unaltered and skarn-altered Hedley intrusions; A = Fe_2O_3 (total) versus SiO_2 weight per cent; B = Fe/Ti versus Si/Ti.

cess results in a considerable loss of total iron and a modest gain in silica; this conclusion is supported by a plot of total iron/titanium against silica/titanium (Figure 1-5-11B). The genetic implications of this iron loss are illustrated by Figure 1-5-12 which compares endoskarn and exoskarn samples from three drill holes that intersect different parts of the Nickel Plate deposit. All the samples collected from these holes exhibit varying degrees of skarn alteration; the endoskarn samples are dioritic Hedley intrusions while the exoskarn is largely represented by altered calcareous siltstones and limestones of the Hedley formation (Table 1-5-4). Note that DDH 401 was collared outside the open-pit perimeter and intersected barren, generally fine-grained pyroxene-rich skarn; DDH 73 intersected subeconomic skarn-hosted mineralization west of the open-pit boundary; while DDH 261 contained ore-grade skarn mineralization and was collared within the planned open-pit area (Figure 1-5-12A).

Within the barren intersection (Figure 1-5-12B) the two fields outlining the iron-silica contents of the exoskarn and endoskarn are relatively close together, and the endoskarn is the more iron-rich. By contrast, in the subeconomic and economic intersections (Figures 1-5-12C and 1-5-12D) the iron content of the exoskarn greatly exceeds that of the endoskarn. In these two holes the exoskarn shows a major increase in iron and decrease in silica, matched by a corresponding drop in iron and rise in the silica in the endoskarn.

To summarize, progressive skarn alteration of the Hedley diorite intrusions results in no change in the calcium content, a modest increase in the sodium, potassium and silica contents and a major decrease in total iron. The adjacent skarn-altered sedimentary rocks (exoskarns) are correspondingly enriched in iron and depleted in silica. These preliminary results suggest three things. First, that relatively few metasomatic geochemical changes took place in the outer parts of the Nickel Plate skarn envelope and that the most dramatic metasomatism occurs in the mineralized parts of the skarn where there was presumably greater fluid movement. Second, the Hedley intrusive dyke and sill swarm was the source of the iron enrichment in the adjacent exoskarn, and thus may

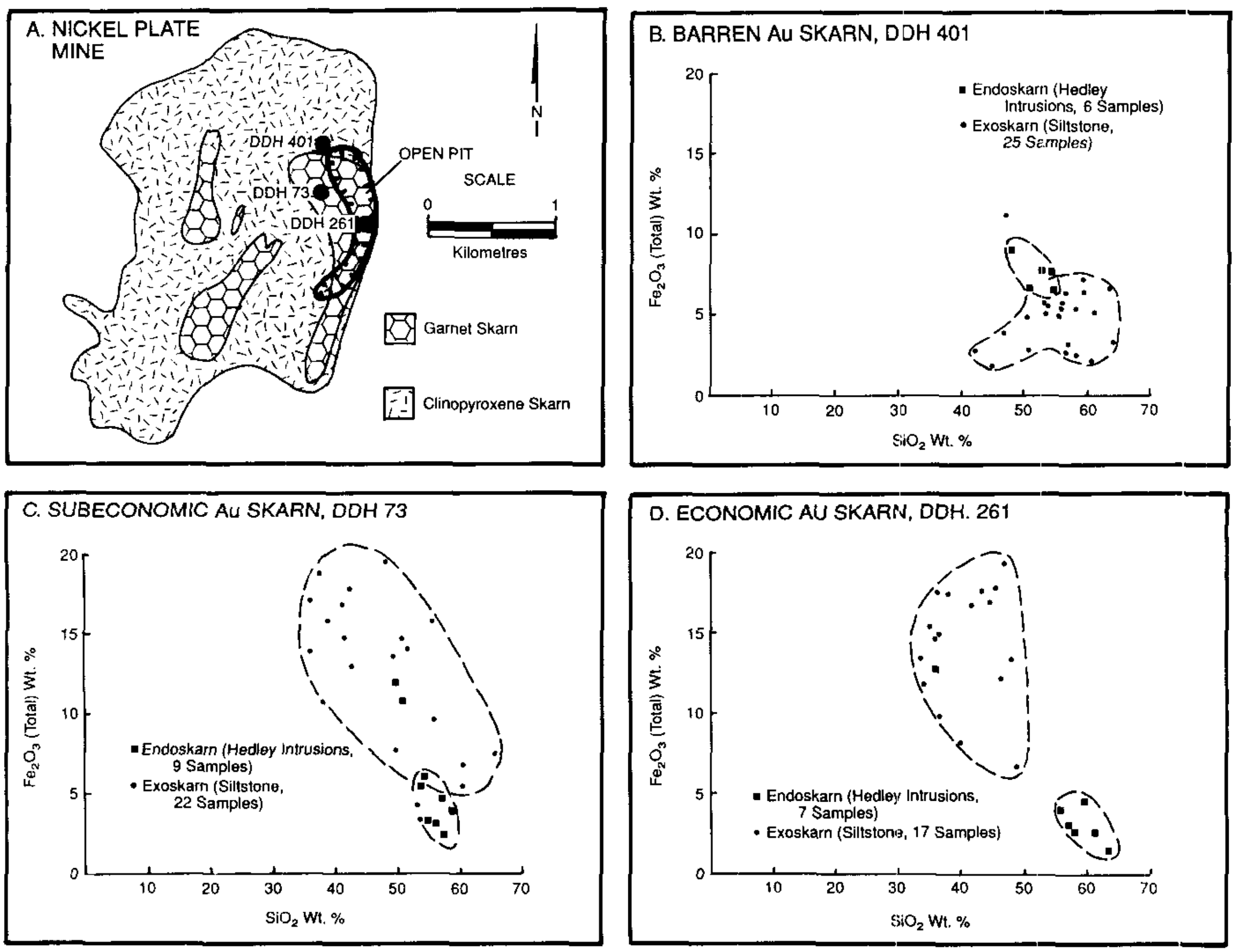

Figure 1-5-12. Plot of Fe_2O_3 (total) weight per cent versus SiO_2 weight per cent comparing barren, subeconomic and economic skarn from three diamond-drill holes at Nickel Plate mine: A = Nickel Plate mine showing location of drill holes in relation to the open pit and skarn zone; B = barren skarn, DDH 401; C = subeconomic skarn, DDH 73; D = economic skarn, DDH 261. Note: passage from barren to auriferous skarn is accompanied by a decrease in iron in the endoskarn Hedley intrusions and a corresponding increase in iron in the exoskarn sedimentary rocks.

TABLE 1-5-4
SKARN-ALTERED HEDLEY FORMATION (EXOSKARN)

Field No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O
401.01	47.27	0.51	8.77	11.14	0.20	6.40	17.92	0.00	3.18
401.02	58.17	0.57	16.06	2.56	0.08	3.46	6.91	2.19	7.11
401.03	53.36	0.73	15.21	5.69	0.16	4.75	13.38	1.87	3.30
401.05	56.59	0.66	17.04	6.35	0.13	3.33	7.26	3.91	3.14
401.06	57.97	0.63	16.18	5.42	0.08	3.98	6.59	4.12	1.90
401.07	53.68	0.55	13.21	5.55	0.18	4.17	11.52	1.18	5.66
401.08	55.75	0.58	13.82	5.49	0.13	3.48	10.25	0.51	7.72
401.09	55.97	0.54	14.38	5.79	0.12	2.94	8.69	0.61	8.60
401.10	53.45	0.47	14.41	5.11	0.12	3.08	10.42	0.87	7.63
401.11	56.56	0.66	17.75	2.69	0.07	2.76	8.48	3.43	4.97
401.13	58.36	0.59	15.67	3.75	0.10	4.03	8.12	2.42	5.76
401.14	55.28	0.67	18.00	4.80	0.07	4.89	9.57	4.24	1.29
401.15	56.83	0.74	17.23	3.26	0.07	4.27	10.27	2.85	3.76
401.17	51.04	0.68	16.81	6.52	0.11	5.85	14.91	2.89	0.23
401.18	55.88	0.60	16.83	5.52	0.07	3.82	7.11	2.52	4.65
401.19	59.19	0.87	12.62	7.12	0.08	4.05	6.03	1.54	4.67
401.20	63.42	0.86	13.06	6.65	0.07	3.30	4.16	1.80	5.05
401.22	42.02	0.23	4.59	2.77	0.19	3.80	27.62	0.00	1.04
401.25	63.95	0.33	6.12	3.29	0.12	3.20	11.24	0.12	3.82
401.26	59.20	0.90	17.93	6.42	0.12	2.15	4.44	3.14	3.11
401.27	44.77	0.20	4.89	1.84	0.06	2.59	27.73	0.71	0.85
401.28	60.54	0.25	4.99	2.21	0.06	3.85	15.91	0.65	1.04
401.29	50.80	0.32	6.41	2.77	0.05	2.71	18.62	0.81	1.54
401.31	61.06	0.41	8.66	5.15	0.09	3.57	9.50	0.55	4.63
401.32	46.68	0.28	6.17	3.88	0.10	7.50	24.21	0.48	1.62
73.01	60.52	0.77	11.36	5.40	0.15	3.46	8.84	1.39	6.76
73.02	52.11	0.57	7.89	12.43	0.34	4.79	16.36	1.93	2.48
73.03	42.80	0.52	10.71	12.93	0.48	3.78	25.68	0.75	0.67
73.04	41.61	0.42	9.01	14.65	0.46	2.48	28.04	0.07	0.54
73.05	38.89	0.34	7.10	15.80	0.42	2.32	31.25	0.02	0.01
73.06	41.25	0.39	6.01	16.81	0.51	2.73	28.42	0.06	0.02
73.07	65.68	0.29	5.43	7.48	0.25	4.44	11.80	0.23	3.95
73.08	51.53	0.30	7.20	14.08	0.50	3.60	17.37	0.55	3.99
73.09	53.58	0.65	18.03	3.45	0.12	4.21	12.79	2.02	4.02
73.10	49.63	0.88	19.24	7.73	0.18	4.15	9.74	1.22	4.55
73.11	60.44	0.37	8.53	6.78	0.24	2.36	13.51	0.94	3.66
73.12	50.70	0.30	4.99	14.68	0.63	4.99	20.96	0.76	2.01
73.16	49.21	0.28	7.92	13.58	0.52	2.21	21.79	0.71	2.91
73.18	55.62	0.32	0.44	15.78	0.73	4.17	12.95	1.22	0.84
73.20	55.71	0.47	9.01	9.56	0.41	3.56	13.55	0.49	6.10
73.22	38.16	0.35	9.78	10.79	0.56	2.94	30.51	0.38	0.35
73.23	37.39	0.13	5.65	18.67	0.34	1.67	31.73	0.03	0.01
73.24	42.48	0.22	6.15	17.77	0.62	2.55	27.77	0.02	0.01
73.25	36.07	0.15	6.73	17.08	0.43	1.28	30.28	0.01	0.01
73.27	48.19	0.46	2.95	19.48	0.79	4.04	22.38	0.29	0.80
73.29	36.16	0.30	5.07	13.90	0.45	2.39	27.35	0.63	0.88
73.30	53.18	0.29	5.73	4.26	0.11	3.13	23.65	0.89	1.06
261.01	38.10	0.27	8.03	17.46	0.37	1.31	32.43	0.06	0.05
261.02	36.66	0.13	9.26	14.88	0.32	0.44	33.73	0.05	0.80
261.06	41.61	0.57	5.71	16.79	0.60	2.36	28.61	0.04	0.02
261.07	36.42	0.16	7.16	17.53	0.27	0.77	34.20	0.01	0.33
261.08	35.06	0.18	7.63	15.27	0.29	0.84	34.27	0.01	0.71
261.09	46.28	0.17	2.77	12.20	0.47	1.94	27.04	0.01	0.64
261.10	34.14	0.33	3.99	11.90	0.48	2.02	31.83	0.41	0.93
261.12	43.23	0.36	7.19	17.64	0.61	2.13	26.13	0.06	1.27
261.13	45.36	0.20	3.65	17.85	0.76	3.88	23.94	0.14	0.60
261.14	46.86	0.37	4.19	19.42	0.74	4.12	22.75	0.31	0.45
261.15	33.82	0.11	2.23	13.43	0.46	1.57	26.89	0.01	0.81
261.16	35.99	0.26	6.91	14.60	0.35	2.20	21.83	0.22	2.47
261.18	47.90	0.26	5.42	13.41	0.35	2.40	20.52	0.27	1.26
261.19	44.46	0.41	6.39	16.97	0.35	2.91	16.44	0.21	2.54
261.20	36.67	0.27	5.15	9.84	0.35	2.67	27.16	0.01	1.10
261.21	48.82	0.22	4.64	6.72	0.22	1.53	22.51	0.01	1.50
261.22	39.84	0.41	6.39	8.13	0.22	3.46	23.71	0.12	3.09

also be the primary source of the skarn-hosted gold. Third, outlining areas containing iron-enriched exoskarn adjacent to iron-depleted endoskarn may provide a useful exploration tool for recognizing close proximity to auriferous skarn mineralization in the Hedley district.

GEOLOGY OF THE MOUNT RIORDAN TUNGSTEN-COPPER SKARN

During this study interesting tungsten-copper skarn mineralization was outlined within and adjacent to several Crown-granted mineral claims on Mount Riordan, approximately 7 kilometres east-northeast of the Nickel Plate mine (Figures 1-5-1 and 1-5-8). Although there are numerous old prospect pits on Mount Riordan, it was uncertain at first whether the scheelite mineralization had been recognized by the earlier workers, particularly since there was no evidence of past drilling and the mineralization was not listed in the Ministry of Energy, Mines and Petroleum Resources' MINFILE. Subsequent literature search indicated that the Mount Riordan occurrences were briefly described by McCammon (1953), although the mineralization was largely ignored by industry, even throughout the tungsten boom of the 1970s. W.J. Bromley (personal communication, 1987) indicates that some bulk sampling was undertaken in the 1950s, but since that time little exploration has taken place.

The outcrop geology of the Mount Riordan area is shown on Figure 1-5-13. A massive, fresh biotite hornblende granodiorite, that is characterized by coarse hornblende phenocrysts and sparse pyrite, outcrops to the northeast and east of the mountain. To the south, and presumably separated from the rocks on Mount Riordan by an east-northeastly trending fault, are the highly deformed ophiolitic rocks of the Apex Mountain complex. A very large elongate mass of mainly garnetite skarn, which reaches 900 metres in length and 500 metres in maximum width, is centred on Mount Riordan. The surrounding rocks are mostly obscured by glacial overburden, but to the west are several small exposures of skarn and one of massive, coarse-grained marble (Figure 1-5-13). South of the summit, within the skarn, are minor remnants of altered microdiorite, while the extreme eastern edge of the skarn is in contact with altered epidote-veined outcrops of hornblende-porphyritic granodiorite similar to that occurring further northeast.

Apart from rare marble remnants, the nature of the protolith to the Mount Riordan skarn is uncertain; alteration is also so complete and exposure so poor that the stratigraphic relationship between the protolith and the sequences recognized elsewhere in the district is uncertain, although it probably lies within the limestone-rich French Mine formation. The rare marble layers in the garnetite are flat to gently dipping.

The Mount Riordan skarn differs considerably in appearance from the Nickel Plate skarn and mainly comprises massive, coarsely crystalline andraditic garnetite; almost no original textures are recognizable. Unlike the gold-bearing skarns to the west, no mineralogical zoning or biotite-hornfels rocks have been seen within the Mount Riordan skarn. The garnets vary considerably in colour; black, red, pink, brown, green and yellow-green varieties are present. In a few cases the crystals exceed 6 centimetres in diameter and show prominent growth zonations. Some massive outcrops also display sharply defined, subparallel zones of different coloured garnetite and in one outcrop the pale-coloured garnetite matrix contains "clasts" of dark-coloured garnetite up to 1 metre long and 0.2 metre wide. These clasts have sharp contacts and it is uncertain whether they represent remnants of either an original conglomeratic texture, a tectonic bondinage feature, or the results of two different episodes of garnet growth.

Quartz and epidote together with variable amounts of carbonate, hedenbergite, clinopyroxene and actinolite, and traces of chlorite and wollastonite are also present in the garnetite. Some epidote forms coarse euhedral crystals. Locally, particularly near the summit of Mount Riordan, the skarn is cut by veins, blebs and stringers of either white quartz or coarely crystalline carbonate that may exceed 1 metre in width. In some veinlets, where the quartz and carbonate are intergrown, the quartz forms elongate, well-terminated crystals up to 3 centimetres in length.

Locally the skarn contains pockets, irregular veinlets and disseminations of magnetite intergrown with variable amounts of pyrrhotite, pyrite, chalcopyrite and trace bornite. Magnetite is present within and adjacent to a short adit on the eastern side of Mount Riordan and in the most westerly outcrop of skarn in the area (Figure 1-5-13). Generally the gold values in the skarn are very low (*see* Table 1-5-5); however, the highest assays (up to 1.69 ppm gold) are found in the magnetite-sulphide-rich portions of the skarn.

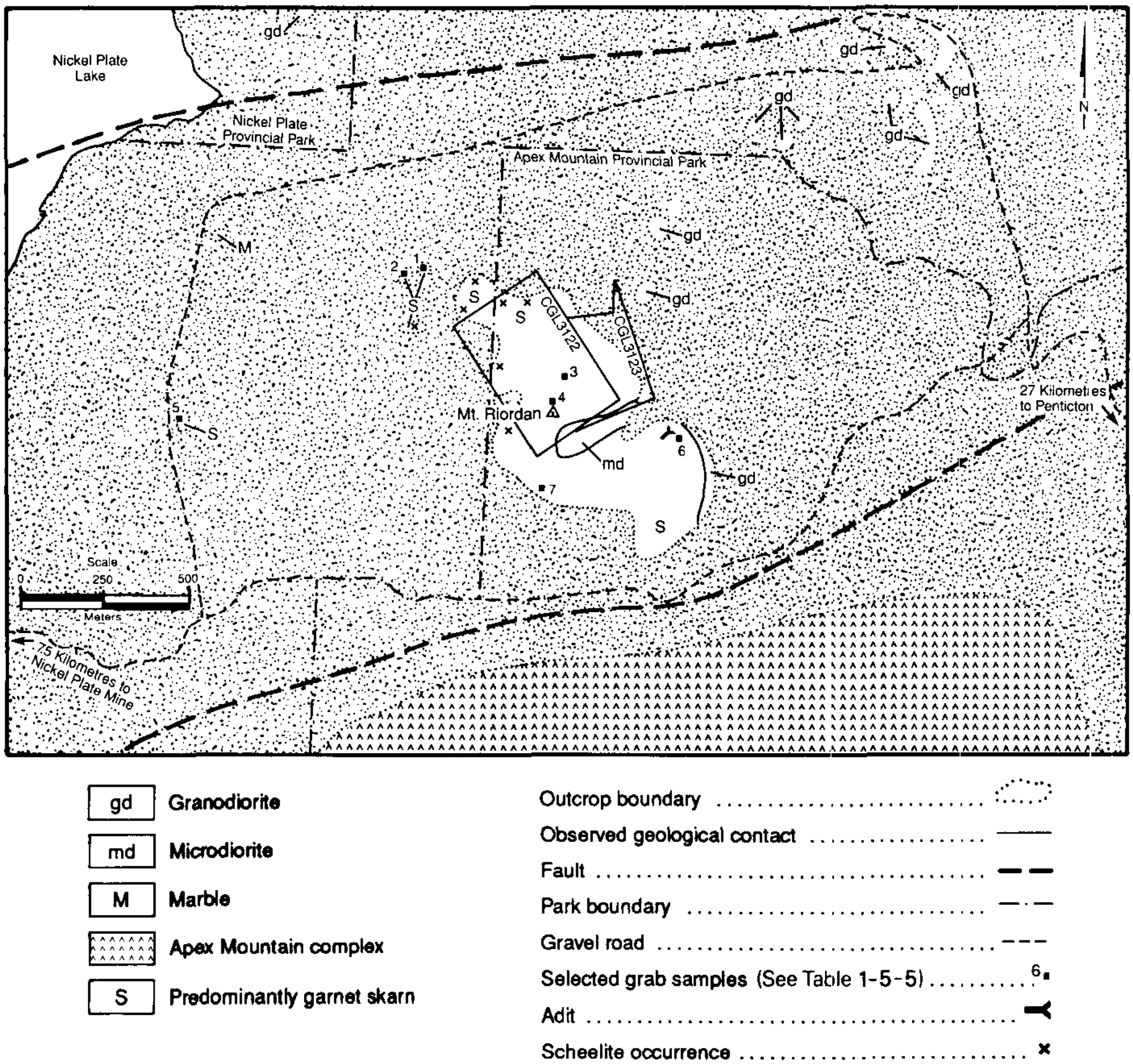

Figure 1-5-13. Outcrop geology of the Mount Riordan area. Note: for assay results of selected grab samples from locations 1 to 7 *see* Table 1-5-5.

TABLE 1-5-5.
ANALYSIS OF SELECTED GRAB SAMPLES FROM MOUNT RIORDAN

Location No.	Lab. No.	W%	Cu ppm	Mo ppm	Au ppb	Ag ppm	Zn ppm
1	33668	0.1	850	5	475	7	75
2	33666	0.25	840	15	339	0.8	210
3	33661	>5.0	600	250	187	0.7	105
3	33662	3.0	0.7%	106	<20	10	357
3	33663	0.1	0.3%	19	161	15	321
3	33664	0.5	0.2%	33	99	9	111
3	33665	0.35	75	310	498	0.5	270
3	33667	0.25	150	145	<20	0.5	258
3	33672	4.0	0.35%	152	122	5	106
3	33673	2.0	0.16%	36	37	1.3	50
4	33670	0.9	118	6	<20	0.6	159
4	33671	0.7	117	17	40	0.5	307
5	33669	0.1	45	5	<20	0.5	73
5	33674	0.1	84	30	<20	0.5	52
6	33676	<0.1	75	5	14	3	138
6	33677	<0.1	0.74%	7	1690	19	0.11%
7	33675	<0.1	0.13%	6	29	0.7	118

Note: W by semi-quantitative emmission spectrophotometry; Cu, Mo, Au, Ag and Zn by AAS analysis).

Visible traces of scheelite are seen over a wide area, both throughout the skarn and as minute detrital fragments in the soils. However, the best developed tungsten mineralization occurs close to the summit of the mountain where numerous old pits and trenches have been dug in an area of approximately 40 by 100 metres. In this area, where the garnet skarn contains abundant coarse quartz and/or carbonate veining and disseminated massive pyrite-pyrrhotite, it is extensively weathered to jarosite.

The scheelite occurs in two forms. The commonest and probably earliest is found as small crystals, generally less than 1 millimetre in diameter, sparsely disseminated or clustered in zones throughout the garnetite. The other, possibly later generation, forms spectacular blebs, coarse crystalline masses and irregular veinlets up to 5 centimetres wide and 300 centimetres in length. This coarser scheelite is usually associated with quartz and carbonate veining and in some instances both the quartz and carbonate enclose rounded masses of scheelite. The distribution of the coarse scheelite is generally irregular, however, in one trench the veinlets form an irregular stockwork. Some scheelite-rich outcrops may also contain minor amounts of powellite [$Ca(Mo,W)O_4$] although this has not been positively identified, together with coarse axinite. Analyses of various mineralized grab samples collected throughout the Mount Riordan skarn are listed in Table 1-5-5.

The age and origin of the Mount Riordan skarn is unknown and it is uncertain whether the microdiorite remnants within the skarn, and the porphyritic granodiorite further east, are related to the skarn alteration and tungsten-copper mineralization. However, epidote veining and alteration indicate that both these intrusions predate the skarn.

DISTRICT-WIDE METALLOGENIC ZONING IN THE HEDLEY DISTRICT

The location and distribution of areas underlain by major skarn alteration in the Hedley district are shown in Figure 1-5-8. All these areas lie within the central and eastern, more proximal facies, lime-rich supracrustal rocks, while skarns are only poorly developed in the deeper basinal facies to the west. The largest area of skarn alteration covers approximately 6 square kilometres and surrounds the Nickel Plate deposit. Other substantial alteration zones include those associated with the Canty, Goodhope and French mines, as well as areas east of Ashnola Hill and at Mount Riordan.

The auriferous deposits in the Hedley camp have formerly been regarded as relatively uniform gold (copper-cobalt-arsenic) skarn mineralization (Camsell, 1910; Billingsley and Hume, 1941, Ray *et al.*, 1987). However, the Mount Riordan skarn is distinct in being gold-poor, tungsten and copper-rich, and garnet-dominant in contrast to the pyroxene-dominant Nickel Plate skarn. The following possible relationships are considered:

(1) The Mount Riordan skarn is unrelated to the gold-rich skarns further west and their relatively close proximity is coincidental.

(2) The two skarn types are related and derived from a common basement source, but were emplaced at different, possibly widely separated times.

(3) The Mount Riordan skarn is temporally and genetically related to the Nickel Plate skarn and other gold skarns in the district.

The third alternative is tentatively favoured, partly because the mineralization and mineralogy in the vicinity of the French and Goodhope mines exhibit geochemical and mineralogical characteristics intermediate to the Mount Riordan and Nickel Plate skarns. For example, the Goodhope skarn contains crystalline, variably coloured garnet similar to Mount Riordan while other skarn occurrences close by are magnetite rich. Both the Goodhope and French mines locally contain abundant fine and coarse-grained scheelite together with the gold and copper. Underground chip sampling along a 35-metre, gold-rich skarn section at the French mine averaged 0.68 per cent WO_3 with maximum values of 1.32 per cent over 3 metres (Westervelt Engineering Ltd., unpublished report, January 12, 1978). Thus the Hedley camp probably possesses a district-wide metallogenic zoning with gold-rich, tungsten-poor skarns in the west through to tungsten-rich, gold and arsenic-poor skarns in the east. This has important implications elsewhere in the Cordillera, as some tungsten skarn districts, particularly those associated with fracture-related basin margins, may have gold skarn potential. The east-to-west metallogenic zoning is also accompanied by changes in skarn mineralogy, hostrock geology and composition of the skarn-related intrusions (Table 1-5-6). The skarns in the western and central parts of the district are clinopyroxene-rich and epidote-poor, while the Mount Riordan skarn is garnet and epidote-rich and clinopyroxene-poor. The nature and colour of the garnets also vary across the district; in the western skarns, including those at the Nickel Plate mine, they are generally poorly crystalline and uniformly pink to brown coloured, while at the Goodhope mine and Mount Riordan they are coarsely crystalline and highly variable in colour.

The composition of the skarn-related intrusions varies across the district from diorite at the Nickel Plate, Canty, Goodhope and French mines to possible granodiorite at

TABLE 1-5-6.
CHARACTERISTICS OF EAST–WEST SKARN VARIATION
ACROSS THE HEDLEY DISTRICT

FEATURES	WEST NICKEL PLATE MINE	FRENCH AND GOODHOPE MINES	EAST MOUNT RIORDAN
Skarn mineralogy	Banded, clinopyroxene-dominant skarn. Garnets – generally noncrystalline and brown	Locally clinopyroxene or garnet-dominant skarn. Crystalline and noncrystalline garnet	Massive, garnet-dominant skarn. Crystalline garnet with highly variable colour
Degree of skarn overprinting	Sedimentary structures often preserved in skarn	Sedimentary structures locally preserved	No sedimentary structures preserved
Skarn metallogeny	Au, As, Cu, Co, Bi, Te, Ag, Ni	Au, Cu, W, Co, Mo, Bi, As, Ag	W, Cu, Ag
Skarn-related intrusions	Associated with I-type dioritic Hedley intrusions	Associated with I-type dioritic Hedley intrusions	Associated with I-type granodiorites that do not resemble the Hedley intrusions
District hostrock geology	Siltstones and limestones of the Hedley formation	Limestone breccia and limy sediments of the French Mine formation	Probably massive limestone of the French Mine formation

Mount Riordan (Table 1-5-6). These variations in skarn mineralogy and intrusion composition probably reflect east-to-west changes in the basement rocks that underlie the Nicola Group which presumably represents the source of the skarn-related intrusions.

CONCLUSIONS ON THE HEDLEY DISTRICT

- The Upper Triassic Nicola Group rocks of the Hedley district contain a recognizable stratigraphic succession. At the bottom and top of this succession are volcaniclastic rocks of the Peachland Creek and Whistle Creek formations. Separating these tuffaceous sequences is a 100 to 700-metre sedimentary succession which paleocurrent indicators and facies changes suggest was deposited across the northeasterly trending, tectonically controlled margin of a northwesterly deepening, shallow marine basin. From east to west, the progressively thickening facies sequences are represented by the predominantly carbonate-bearing French mine, siltstone-dominant Hedley and argillite-dominant Stemwinder Mountain formations.
- The two main intrusive episodes in the district, the older dioritic Hedley intrusions and the younger granodioritic Cahill Creek pluton, may be genetically related and were emplaced shortly after one another during a folding episode. Intrusion took place post-225 Ma (the age of the hosting sedimentary rocks based on Carnian-Norian microfossils) and pre-200 Ma (the preliminary $^{207}Pb/^{206}Pb$ zircon date obtained from the Cahill Creek pluton).
- The Hedley intrusions are spatially associated with two contrasting but probably coeval types of gold mineralization. The first type is widespread, more economically significant and associated with deeper level contact metasomatic pyroxene-garnet-carbonate skarn alteratior assemblages. The other type is more restricted, is less economically important and is associated with higher level, tension-fracture quartz-carbonate vein systems. The volume of skarn alteration developed throughout the district varies in scale from narrow, fracture-related halos only centimetres in thickness to huge alteration envelopes several hundred metres in width similar to that surrounding the Nickel Plate – Hedley Mascot deposit.
- A small-scale, consistent, concentric zoning of gangue mineralogy is present at many skarn outcrops and a temporal sequence of skarn alteration is recognized. On the small scale the initial skarn process involves development of a biotite hornfels-type alteration which may locally overprint both the sedimentary rocks and the Hedley intrusion sills. This is followed by the sequential development of pyroxene-rich followed by garnet-rich assemblages which, as the alteration envelope enlarges, eventually replace and obliterate the earlier biotite hornfelsic aureole. Replacement of the biotite aureole by the pyroxene alteration often results in development of a thin intervening reaction zone containing potassium feldspar. It is uncertain whether the potassium was introduced with the skarn-forming fluids or represents remobilized and concentrated potassium that was originally present in the sediments.
- The economic auriferous skarn mineralization is structurally, lithologically and stratigraphically controlled. The Hedley intrusion sills and dykes are more often associated with the skarn mineralization than the larger stocks. Economic gold values tend to be confined to the exoskarn

while the endoskarn is generally barren. Most of the auriferous skarns are confined to the shallower marine, limestone-bearing Hedley and French Mine formations and are more commonly developed in flat-lying or gently dipping beds. Other controlling features include sill-dyke intersections, fractured sill margins and small-scale fold hinges, as noted by Billingsley and Hume (1941) at the Nickel Plate mine, as well as close proximity to the Copperfield conglomerate, a limestone-boulder olistostrome which overlies the Hedley formation.

- Both the skarn-related Hedley intrusions and the Cahill Creek pluton represent I-type, calcalkaline intrusions. During the skarning process, the altered diorite sills (endoskarn) gain sodium, potassium and silica but undergo a considerable loss of total iron. Comparative whole-rock geochemistry suggests the Hedley intrusions are the source of the iron enrichment present in the exoskarns and may also be the source of the gold.
- The Nickel Plate gold deposit is hosted in calcareous and tuffaceous siltstones in the upper part of the Hedley formation. It is associated with a skarn envelope that exceeds 300 metres in thickness and 6 square kilometres in outcrop area. The gold-bearing and arsenopyrite-rich zones normally occur as semiconformable tabular bodies situated less than 100 metres from the outer and lower skarn margin. There is significant geochemical and mineralogical variation throughout the deposit and the gold and sulphide mineralization postdates the garnet-clinopyroxene-carbonate skarn alteration, although there is surprisingly little propyllitic alteration of the ferromagnesian minerals. Three stages of sulphide deposition took place, namely: (i) pyrite; (ii) arsenopyrite and gersdorffite; (iii) pyrrhotite, chalcopyrite and sphalerite. Gold, occurring as blebs less than 25 microns in diameter, was introduced with the latter two phases and is associated with the bismuth telluride, hedleyite. Statistically, gold shows a strong to moderate positive correlation with bismuth, cobalt and arsenic and a low correlation with silver and copper.
- The Hedley camp does not, as formerly believed, consist solely of uniform, gold-copper-arsenic-cobalt-enriched skarn mineralization. An east-to-west district-wide metallogenic zoning of the skarns may exist with gold-cobalt-arsenic-rich skarns occurring in the west (Nickel Plate) and tungsten-copper-magnetite-rich gold-poor skarns developing in the east (Mount Riordan). Mineralization in the central part of the district (French and Goodhope mines) has some intermediate mineralogic and metallogenic characteristics. The metallogenic zoning, which also parallels changes in the original geological environment (deeper basinal in the west, shallower marine to the east) probably reflects east-to-west changes in the composition of the basement rocks which underlay the Nicola Group and controlled the Late Triassic basin margin. This suggests that some tungsten skarn camps in the North American Cordillera, particularly those developed along fracture-controlled, island arc-related marine-basin margins, could have the potential for gold-skarn mineralization similar to the Nickel Plate deposit.

GENERAL CONCLUSIONS ON GOLD SKARNS

A comparison between the gold skarns at Tillicum Mountain (Ray *et al.*, 1986b), Texada Island and the OKA property (Ettlinger and Ray, 1988, this volume) and Hedley suggests the following features:

- All are hosted in island-arc sequences that include limy sediments and either volcanic or volcaniclastic rocks of andesitic to basaltic composition. Regionally, the volcanic rocks at Tillicum Mountain (Rossland Group), Hedley and OKA (Nicola Group) include potassium-rich shoshonites.
- Fault-controlled marine-basin margins may have good exploration potential for gold skarns because:
  - (a) They often contain sedimentary lithologies (calcareous sediments, limestone boulder conglomerates) suitable for skarn development.
  - (b) The deep basement structures localize intrusive activity that may result in auriferous skarn formation.
- Gold in skarn varies from very coarse grained and visible (Tillicum Mountain) to micron sized (Hedley).
- To date, all of the gold skarns studied in British Columbia are associated with calcalkaline I-type intrusions and it is not known whether there are any gold skarns in the province related to alkalic rocks. However, some alkalic, high-level intrusions in the Nicola Group are associated with a class of gold-bearing porphyry copper deposit, such as Copper Mountain (Fahrni *et al.*, 1976) and Cariboo-Bell (Hodgson *et al.*, 1976) that locally contain some garnet-pyroxene-epidote-scapolite skarn-like alteration features.
- The Hedley, Tillicum Mountain and OKA areas involved similar intrusive sequences characterized by early skarn-related intrusions of generally small volume and dioritic to gabbroic composition, followed by large amounts of barren granodioritic material forming major batholiths which enclose the skarn-hosting sequences and leave them as roof pendants. Preliminary dating suggests these two sequences at Hedley (the Hedley intrusions and the Cahill Creek pluton) are close together in age; it is possible that they are related and originated from the same magma source.
- At the Hedley, Tillicum Mountain and Texada Island gold camps there are suggestions that the skarns are metallogenically zoned on a district scale. Metallogenic zoning is also reported at some other skarns such as the large Fortitude deposit in Nevada (G. Myers and A. Ettlinger, personal communication, 1988). However, the Hedley area is believed to be the first major skarn camp in which gold-to-tungsten zoning is recognized.
- There is a highly variable trace element association with the gold in gold skarns. Some are enriched in cobalt, arsenic, antimony, tellurium, bismuth, molybdenum, tungsten and copper. Some, such as those in the Hedley camp, contain most or all of these elements, while in others these elements may be absent. At present no general rule can be made concerning trace element enrichment in gold skarns.

- The amount of skarn alteration associated with gold mineralization varies considerably from the narrow alteration envelopes present at Texada Island, Tillicum Mountain and the OKA properties, up to the immense volumes of alteration developed in the Hedley camp. Generally, the amount of skarn alteration developed appears to be proportional to the amount of gold present in the system. Thus, large tonnage gold deposits are more likely to be found in areas containing large skarn alteration envelopes.

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GEOLOGY OF THE CHEMAINUS RIVER–DUNCAN AREA, VANCOUVER ISLAND*
(92C/16; 92B/13)

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

KEYWORDS: Regional geology, Vancouver Island, Sicker Group, McLaughlin Ridge Formation, Karmutsen Formation, Nanaimo Group, Cowichan uplift, thrusts, massive sulphides, rhodonite, gold.

INTRODUCTION

In 1986, a program of 1:50 000-scale regional mapping was initiated by the Geological Survey Branch in southern

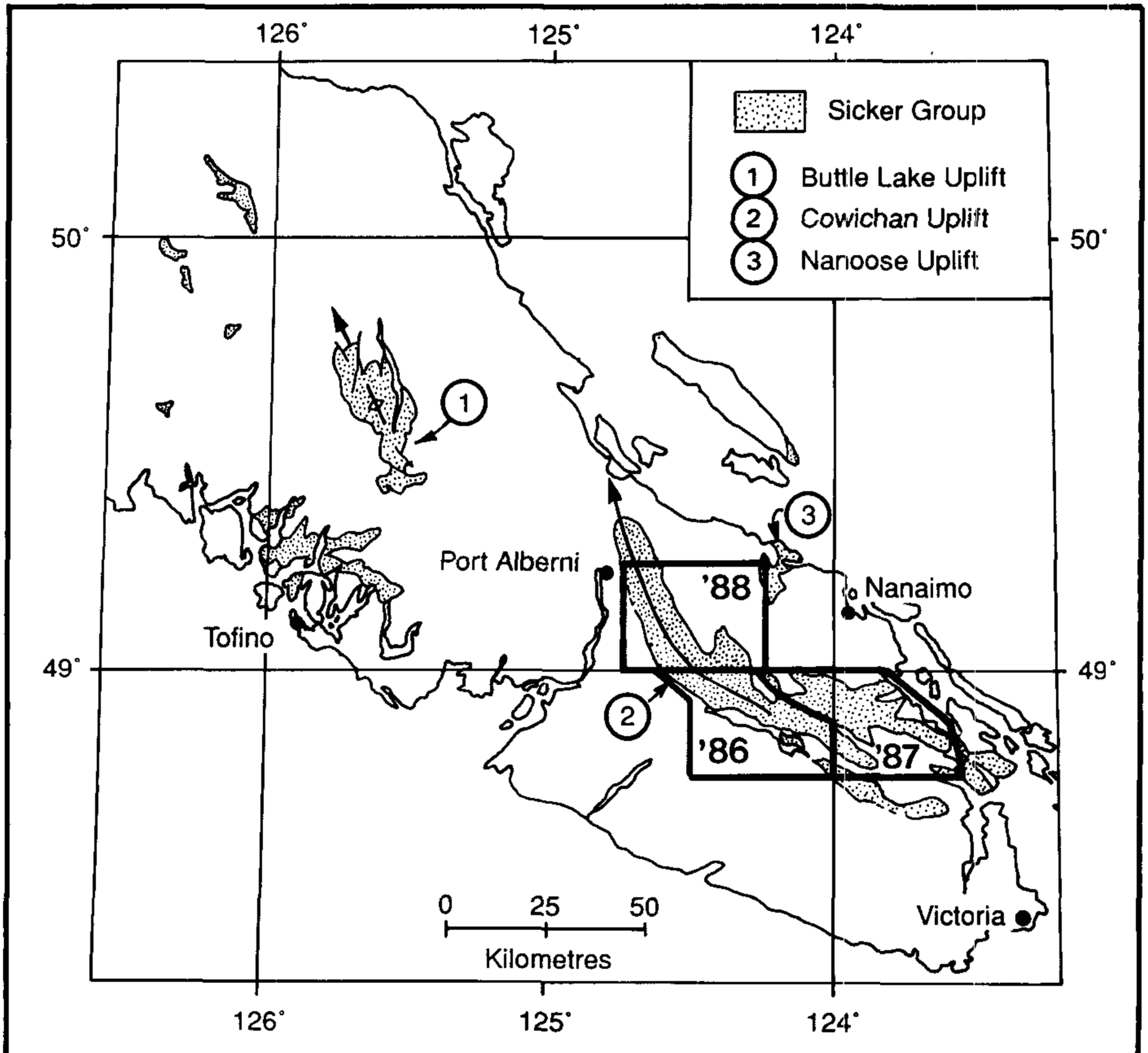


Figure 1-6-1. Location of the Sicker Project area, southern Vancouver Island, in relation to the three major geanticlinal uplifts cored by Sicker Group rocks (after Brandon *et al.*, 1986). Planned field seasons are indicated.

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

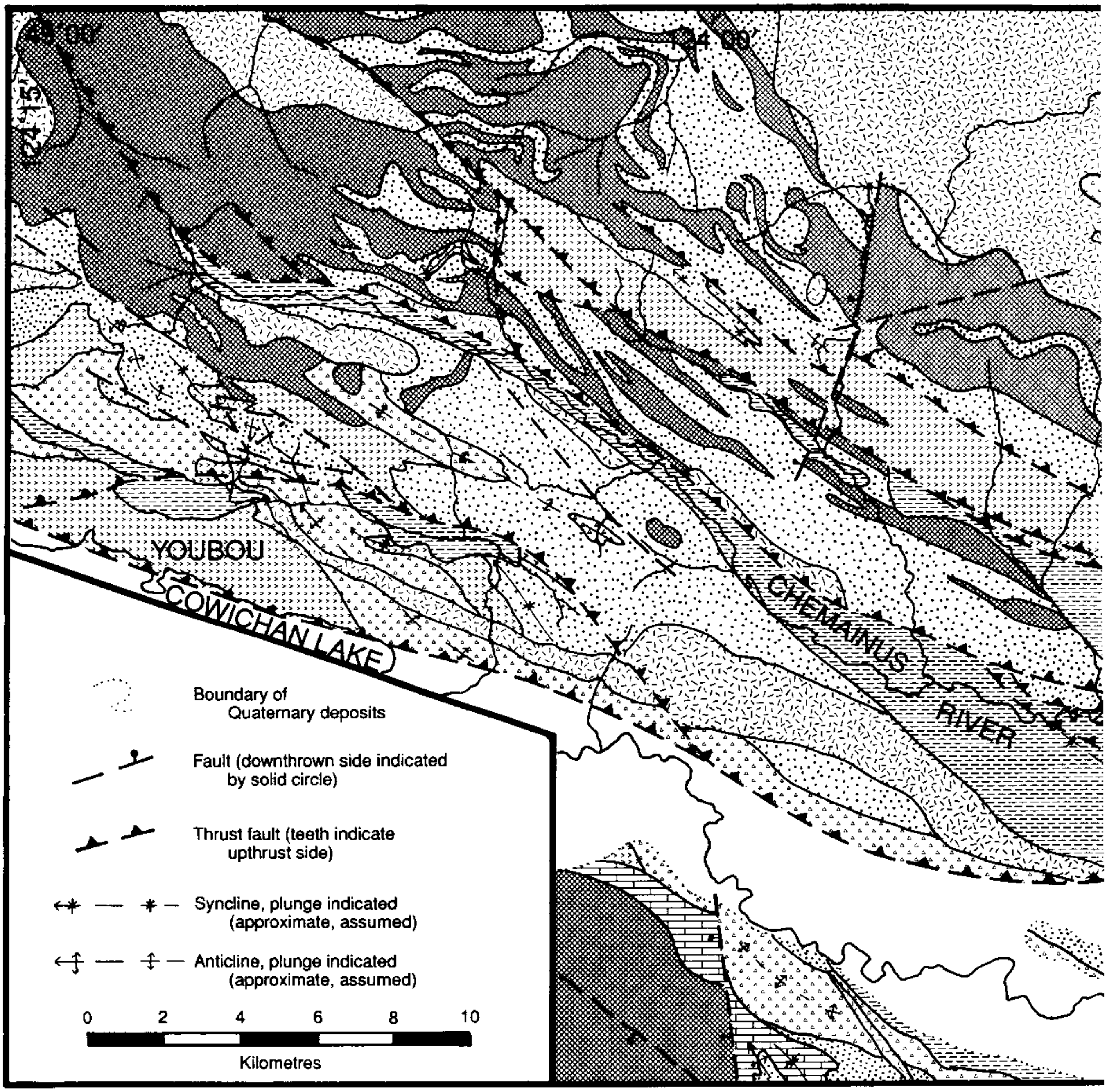


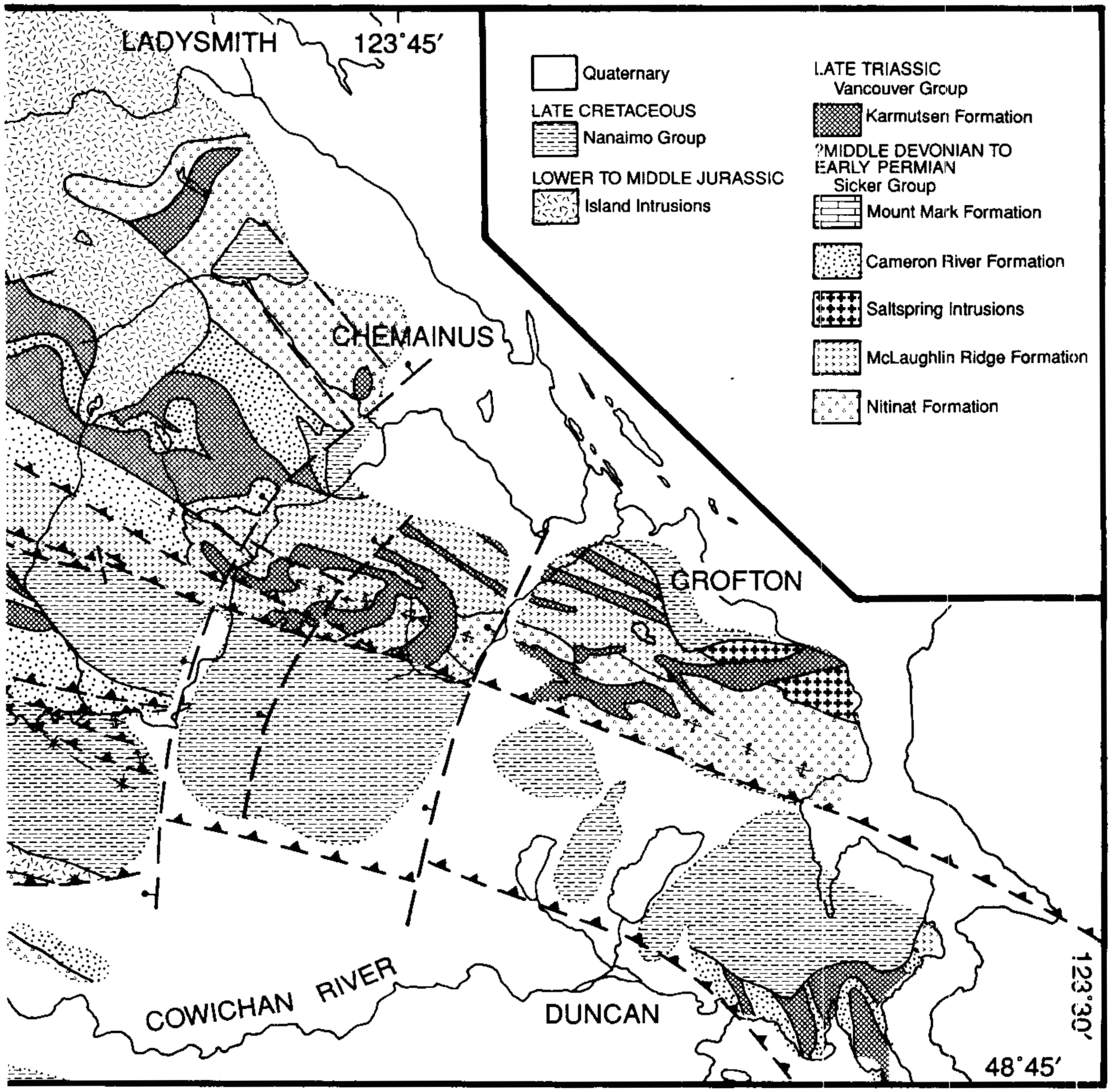
Figure 1-6-2. Geology and structure of the Duncan and Chemainus River areas (see also facing page).

Vancouver Island, emphasizing the Paleozoic Sicker Group. A 4-year program was planned, covering three 1:50 000 NTS sheets centred on the main Sicker Group outcrop area within the Cowichan uplift (Figure 1-6-1). Initial mapping in the Cowichan Lake area (92C/16) was reported on last year (Massey and Friday, 1987) and released as Open File 1987-2 (Massey *et al.*, 1987).

During the 1987 field season, fieldwork was extended into the northeastern quadrant of the Cowichan Lake sheet and eastwards into the Duncan map sheet (92B/13), excluding the Gulf Islands. Road access in the area is excellent with the main Island Highway running northwards through the eastern margin of the area. Many other paved roads are present in the east and south within the municipalities of North Cowichan and Ladysmith. Access to the western half of the area is provided by an extensive network of logging roads in various states of upkeep. Shoreline exposures are easily accessible by boat.

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 Duncan and Cowichan areas (Muller, 1982, 1985). Detailed investigations of small areas around Duncan have also been reported on by Eastwood (1979, 1980, 1982).

Stratigraphic studies of the Sicker Group were conducted by Yole (1964, 1965, 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-scale 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 Chemainus River–Duncan area straddles the eastern end of the Cowichan uplift, one of a series of major geanticlines typical of the structural fabric of southern Vancouver Island (Figure 1-6-1). 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 Jurassic Bonanza Group) overlapped by Upper Cretaceous sediments of the Nanaimo Group.

STRATIGRAPHY

The oldest rocks in the area belong to the Paleozoic Sicker Group (Figure 1-6-2) which contains volcanic and sedimentary units ranging in age from Middle Devonian (?) to Early Permian. These are intruded by mafic sills coeval with overlying basaltic volcanics of the Late Triassic Karmutsen Formation. All of 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.

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), have thrown some doubt on these subdivisions and their applicability in the Cowichan uplift. New stratigraphic subdivisions have been proposed by Sutherland Brown (in preparation) based on work in the Alberni area. These formational subdivisions have proven to be applicable in the Cowichan Lake and Duncan areas also and have been adopted for this project.

NITINAT FORMATION

The lowermost unit in the Sicker Group is a volcanic package characterized by pyroxene-feldspar porphyritic basaltic andesites, typically occurring as agglomerates, breccias, lapilli tuffs and crystal tuffs. However, extensive pyroxene-phyric, amygdaloidal flows are developed in the Banon Creek area. Pyroxenes are large, up to 1 centimetre diameter, are euhedral to subhedral, and comprise 5 to 20 per cent of the rock. Plagioclase is equally abundant, but phenocrysts are usually smaller, ranging up to 5 millimetres in diameter. Amygdules present in flows and some clasts in coarser pyroclastics are infilled with chlorite, quartz, epidote or calcite. Minor laminated tuff and tuffaceous sandstone are present locally. Massive and pillowed aphyric and diabasic mafic flows are also developed, particularly on the north slope of Coronation Mountain and Fairservice Mountain.

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

MCLAUGHLIN RIDGE FORMATION

The Nitinat Formation is overlain, apparently conformably, by a heterogeneous sequence of intermediate to felsic volcanics and volcaniclastic sediments. In the Alberni and Cowichan Lake areas, the McLaughlin Ridge Formation is characterized by the development of thickly bedded, massive tuffites and lithic tuffites with interbedded laminated sandstone, siltstone and argillite. 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.

However, within the Duncan area, the McLaughlin Ridge Formation is dominated by volcanics with only minor tuffaceous sediment. The volcanics are predominantly intermediate to felsic pyroclastics, commonly feldspar crystal-lapilli tuffs and heterolithic lapilli tuffs and breccias. A thick package of quartz-crystal, quartz-feldspar-crystal and fine dust tuffs is developed in the Chipman Creek–Mount Sicker area and is host to polymetallic sulphide mineralization. This package thins to the west where it interfingers with andesitic lapilli tuffs and breccias. It appears to be stratigraphically high within the formation. A distinctive maroon schistose heterolithic breccia and lapilli tuff forms the uppermost unit within the McLaughlin Ridge Formation and is seen in the Chipman Creek–Rheinhart Creek area. Most contacts with overlying formations are faulted.

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 sedimentary package. This is found most often in fault contact with the lower volcanic units, but is conformable on the McLaughlin Ridge Formation south of Sansum Point and in the Chipman Creek–Rheinhart Creek area. The Cameron River Formation sediments lie unconformably on the Nitinat Formation on Hill 60 Ridge, near Paldi and Fairservice Mountain. A similar unconformable relationship is suspected west of Banon Creek.

In the south of the area (Hill 60 and the Paldi inlier) the base of the sedimentary unit is marked by a 100 to 200-metre-thick sequence of ribbon cherts, laminated cherts and cherty tuffs that continues westward into the Cowichan Lake area. This sequence passes upwards into monotonous thinly bedded, turbiditic sandstone-siltstone-argillite intercalations. The basal ribbon cherts are absent north of the Chemainus River, where the thinly bedded turbiditic clastic sediments dominate. However, cherty tuffs and argillites are found at the base of the formation at Sansum Point. Thicker beds of sandstone, granule sandstone and conglomerate containing clasts of cherty material, volcanic lithic clasts and feldspar and pyroxene crystals are also found within the formation. Thin crinoidal calcarenites and limestones are interbedded with sandstone and argillite near the top of the formation at Mount Brenton, at Separation Point and in the Haslam Creek area.

In contrast to the Alberni–Cowichan Lake area, limited volcanism appears to have continued during early Cameron

River Formation sedimentation in the Mount Whymper–Rheinhart Creek area. This produced a bimodal suite of aphyric basalts and rhyolites, generally forming sills and dykes though some amygdaloidal basalt flows occur. Similar aphyric basaltic dykes also intrude the underlying McLaughlin Ridge volcanics.

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).

Mount Mark Formation

Massive and laminated crinoidal calcarenites with chert and argillite interbeds occur in the Fairservice Mountain area, south of the Cowichan River. They directly overlie Nitinat Formation volcanics in the west but are underlain by Cameron River Formation sediments to the east. The limestones are the uppermost unit in the Sicker Group of the map area, though they are absent north of the Cowichan River where the Cameron River Formation is overlain unconformably by Karmutsen Formation basalts or Nanaimo Group sediments.

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

VANCOUVER GROUP

Karmutsen Formation

Basaltic volcanics of the Karmutsen Formation underlie Mount Whymper and the Mount Landalt–El Capitan area. They comprise 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. Amygdules are common and are infilled with chlorite, calcite or epidote.

The intrusive component increases toward the base of the sequence, which passes downward into diabase and gabbro bodies with intervening screens of Cameron River Formation sediments (Figure 1-6-3). These mafic sills and dykes are widespread in the area, occurring at deeper structural levels, though they are most commonly found intruding the Cameron River Formation (in the informal "sediment-sill unit" of Muller, 1980). They are medium to coarse-grained diabase, gabbro and leucogabbro with minor diorite, commonly porphyritic with feldspar phenocrysts often being glomeroporphyritic clusters up to 3 centimetres in diameter. Mafic phenocrysts are generally absent. Equigranular gabbros are also common and coarse varieties contain frequent pegmatitic veins and pods. Thick gabbro bodies under Mount Hall and Coronation Mountain show layering of porphyritic and nonporphyritic lithologies.

The intrusive bodies vary in size and form. Sill-like bodies are subconcordant with bedding within the sediments, though they usually follow the foliation where this is strongly developed. They thus show a variety of attitudes from shallow dipping to vertical. They may be as little as a few metres or up to 200 metres thick. Discordant dykes are also common, varying from 10 centimetres to about 50 metres wide.

The numerous intrusions are believed to have occurred during dilation of the Sicker Group basement in the Late Triassic, and acted in part as feeders to the overlying volcanics (Figure 1-6-3). Elsewhere in Wrangellia the Karmutsen Formation volcanics overlap onto the basement and evidence of the rifting is covered.

NANAIMO GROUP

Clastic sediments of the Nanaimo Group unconformably overlie older volcanic units and the Island Intrusions. They are most thickly developed in the Maple Bay to Mount Prevost area, the Cowichan and Chemainus River valleys and the shoreline from Crofton to Ladysmith. The sediments of the Nanaimo Group constitute major fining-upward cycles (Muller and Jeletzky, 1970), of which the first two, the Comox–Haslam and Extension-Protection–Cedar District, are developed in the Duncan map sheet.

Comox Formation

The basal Benson member of the Comox Formation is a coarse, poorly bedded cobble and boulder conglomerate varying from about 100 metres thick in the Mount Tzuhalem and Stone Hill area in the east to absent in other locations.

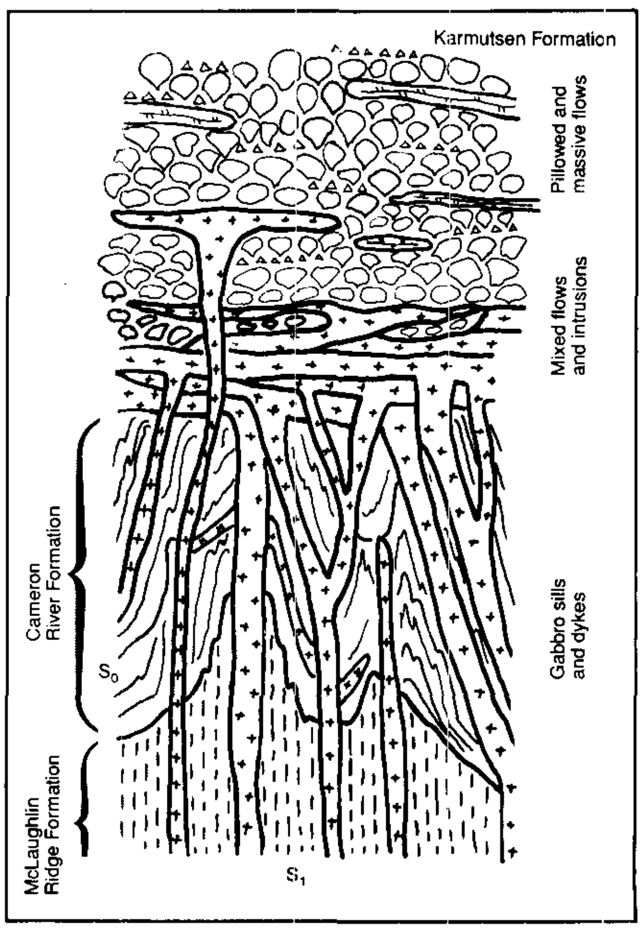


Figure 1-6-3. Diagrammatic cross-section, not to scale, showing the relationship of Karmutsen Formation volcanic and intrusive rocks to the rifted Sicker Group basement in the Mount Whymper–Rheinhart Creek area.

The conglomerates have rounded clasts which consist of a variety of volcanic and intrusive lithologies of immediate local origin; larger boulders are often angular.

Overlying sandstones are medium to coarse grained, grey with rusty weathered surfaces. They contain feldspar crystals and abundant lithic fragments, mostly volcanic of local provenance. Black plant-fragments are characteristic of many beds. Calcareous cement is common and locally concretions up to 1 metre diameter are developed. 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. The thickness of the Comox Formation is estimated to vary from 0 to 350 metres.

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 are found within the argillites in the upper parts of the formation (Cowichan member, Ward, 1978). They vary in thickness up to 1 metre for massive to flaggy beds, though the more common graded sandstone-argillite turbidites average about 10 centimetres thick. 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. The thickness of the Haslam Formation may reach up to 600 metres in the Cowichan Valley (Ward, 1978).

Extension-Protection and Cedar District Formations

Conglomerates of the Extension-Protection Formation conformably overlie Haslam Formation argillites on top of Mount Prevost, representing the start of the second depositional cycle within the Nanaimo Group. Similar conglomerates are also found south of the Chemainus River and between Ladysmith and Chemainus. These pebble to cobble conglomerates are very similar to the Comox Formation conglomerates being polymictic, subrounded to rounded clasts in a coarse sandstone matrix. Perhaps the only significant difference is the presence of clasts of white quartz in the Extension-Protection Formation, which are rare in the Comox Formation. Grey, medium to coarse-grained sandstones are interbedded with and overlie the conglomerates.

Argillites of the Cedar District Formation, which overlie the Extension-Protection Formation, are not exposed within the map area. However, an unusual section of Nanaimo Group sediments is exposed in the incised gorge along the Chemainus River just below its confluence with Chipman Creek. Argillites assigned to the Haslam Formation coarsen upwards through turbiditic sandstones into pebble conglomerate which is in turn succeeded by a fining-upward sequence of sandstones and argillites lithologically indistinct from the lower beds. The stratigraphic position of this sequence remains uncertain. The coarse-grained beds may be the Extension-Protection Formation, though it usually has basal conglomerate sitting directly on Haslam Formation argillite without the intervening sandstones; the upper argillites may belong to the Cedar District Formation.

INTRUSIONS

Saltspring Intrusions

Coeval with the felsic volcanics in the McLaughlin Ridge Formation is a suite of granodiorite stocks and quartz porphyry dykes collectively known as the Saltspring intrusions.

The northern quarter of Maple Mountain is underlain by the westerly extension of the Mount Maxwell stock, centred on Saltspring Island. This body consists of light grey to green, weak to moderately foliated, medium-grained granodiorite with local fine-grained dacitic phases and a marginal feldspar porphyry. It intrudes Nitinat Formation volcanics and is itself cut by a large Late Triassic gabbro.

Quartz and quartz feldspar porphyry dykes, previously termed the Tyee Porphyry (Clapp and Cooke, 1917), are contemporaneous with the granodiorite, though never seen in contact with it. They were probably feeders for felsic crystal tuffs in the McLaughlin Ridge Formation in the Chipman Creek–Mount Sicker area. The porphyries are usually well foliated and difficult to distinguish from the crystal tuffs when contact relationships with host volcanics are not clear. Quartz phenocrysts are up to 1 centimetre in diameter, rounded to ovoid in shape, and may be stretched in the foliation. They comprise up to 20 per cent of the rock. Plagioclase phenocrysts are smaller and vary in shape from euhedral laths to rounded. They are sporadically altered to epidote.

Island Intrusions

Several granodioritic stocks of Middle Jurassic age occur in the area. With the exception of the large Ladysmith stock, these granodiorite bodies are elongate in shape. The dominant lithology 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. However, in the Ladysmith stock large (up to 8 millimetres) rounded quartz grains are ubiquitous. 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. Biotite is common in the Hill 60 and Ladysmith stocks. 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 stocks 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, but within the Ladysmith stock some zones of inclusions have a parallel to subparallel arrangement.

Minor Intrusions

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.

A suite of pale grey, fine-grained, aphyric dacite dykes of unknown age intrudes Cameron River Formation sediments and Triassic gabbro in the Sansum Narrows and Genoa Bay area.

STRUCTURE AND TECTONICS

Southern Vancouver Island has undergone a complex tectonic history involving at least six major deformational events, often rejuvenating previous structures. The present map pattern in the Duncan area is dominated by the effects of Late Cretaceous thrusting, though older events are important in establishing relationships within individual thrust slices.

PHASE 1: LATE DEVONIAN

Syn-Sicker Group deformation produced large-scale open folds in the Nitinat and McLaughlin Ridge Formation volcanics in the Cowichan Lake area and the southwestern part of the Duncan map sheet. Uplift and erosion subsequent to this event are reflected by the unconformity below the Cameron River Formation.

PHASE 2: POST-LOWER PERMIAN–PRE-MIDDLE TRIASSIC

The second deformational event affected all Sicker Group rocks producing a series of west-northwest-trending, southwest-verging, asymmetric folds with abundant parasitic minor folds. Major fold axes are often difficult to locate in the field but can be estimated from regional patterns and the results of exploration drilling programs. Overturning of beds is rarely observed. However, on the west slope of Rheinhart Creek, a sliver of McLaughlin Ridge Formation breccias occurs between Cameron River Formation sediments in an apparently overturned anticline. However, the structurally lower sediments are right-way-up suggesting a thrust and nappe structure is more likely.

Penetrative fabrics (schistosity in volcanics and cleavage in sediments) axial planar to the folds are well developed throughout most of the central part of the map area. They have moderate to steep northeasterly dips. Intense flattening normal to the foliation is observed within volcanic rocks, whereas Cameron River Formation sediments behaved more competently and lack flattening fabrics. Lineations due to bedding-foliation intersections and elongation of crystals and clasts are well developed. Plunges of the lineations are usually shallow, 5 to 15 degrees, and may be to the west-northwest or east-southeast. Within the more schistose volcanic rocks, a crenulation cleavage is sporadically observed normal or slightly oblique to the axial schistosity. This second foliation is particularly well developed in structural depressions and culminations marked by change in azimuth of lineations and appears to be axial to later broad open warps.

PHASE 3: LATE TRIASSIC

Extensive crustal dilation accompanied the evolution of Karmutsen Formation lavas and intrusions. Deformation specifically associated with this event has not yet been documented. Shear zones within gabbros, and especially along their margins, may be contemporaneous or later.

PHASE 4: POST-MIDDLE JURASSIC–PRE-LATE CRETACEOUS

Pre-Nanaimo Group deformation resulted in regional-scale warping of Vancouver Island, producing the three major geanticlinal uplifts cored by Sicker Group rocks (Figure 1-6-1), including the Cowichan uplift. Faulting, often axial, accompanied the folding and is most easily seen south of the Cowichan River in the Cowichan Lake map area. Pre-Nanaimo Group faults are suspected north of the Cowichan River but are obscured by later events. Uplift and erosion followed this deformational phase, establishing the pre-Nanaimo Group topography.

PHASE 5: LATE CRETACEOUS

Large-scale west-northwesterly trending thrusts cut the Cowichan uplift into several slices (Figure 1-6-4). Where exposed, these are high-angle reverse faults which dip between 45 and 90 degrees to the north-northeast, paralleling the earlier axial foliation in Sicker Group rocks. Slip planes are relatively sharp and narrow, though wide schistose zones have formed in receptive lithologies. 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 unknown but are probably small, of the order of 1 to 10 kilometres, so as to maintain the integrity of the Cowichan uplift. Direction of motion is also unknown. The regional map pattern suggests movement directed to the west-southwest; slickensides on fault planes indicate latest movement was horizontal and westerly directed. Minor imbricate faults are developed along most of the thrusts, particularly where Nanaimo Group sediments occur in the footwall.

The age of thrusting is believed to be Campanian (Dorn, 1986) and certainly involves the Extension-Protection Formation and possibly the Cedar District Formation along the Chemainus River (*see* previous discussion of stratigraphy).

PHASE 6: ? TERTIARY

Several north-northeast crossfaults offset the Late Cretaceous thrusts within the Duncan area. They are all subvertical with downthrows to the west. The age of faulting is unknown, although the similar trending Yellows Creek fault in the Alberni area deforms a Late Eocene intrusion (Yorath, personal communication, 1987).

Regional tilting of all Vancouver Island has taken place since the Late Eocene emplacement of terranes outboard of Wrangellia.

METAMORPHISM

The metamorphic grade in the area is generally quite low, but increases with the age and structural position of the rocks.

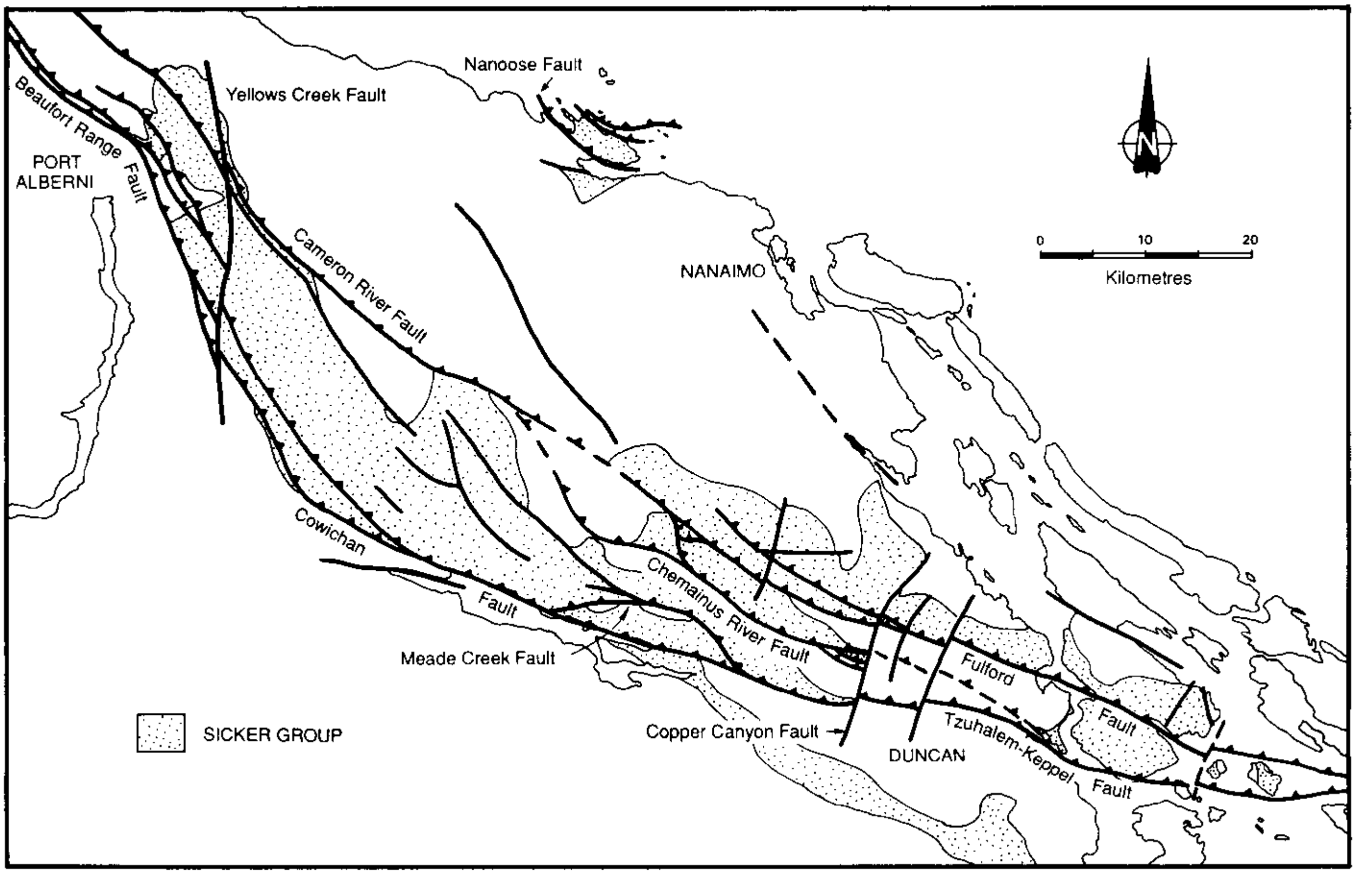


Figure 1-6-4. Late Cretaceous thrust system of southern Vancouver Island with Tertiary (?) cross faults. Sicker Group outcrop area includes younger intrusions.

Nanaimo Group sediments are essentially unmetamorphosed showing only diagenetic alterations 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 Cameron River Formation are essentially unmetamorphosed except where involved in intense shearing when chlorite and sericite develop along foliation planes. Volcanic rocks of the McLaughlin Ridge and Nitinat Formations in the Chipman Creek to Maple Mountain belt, however, show the effects of greenschist facies metamorphism. The felsic volcanics develop sericite, talc and chlorite along foliation planes and are interbedded with minor chlorite schists. Intermediate to mafic rocks have chloritic schistose matrixes with epidote alteration of feldspars. Lithic lapilli may show almost complete replacement by epidote. Nitinat volcanic rocks in the Banon Creek area, however, are little altered though amygdules are infilled with chlorite, quartz and epidote.

Island Intrusion stocks often have contact metamorphic aureoles developed around their perimeters. Porphyroblasts of chiastolite or biotite are developed in Cameron River sediments around several stocks, and hornblende and pyroxene porphyroblasts are present in Nitinat Formation lapilli tuffs in contact with the Ladysmith stock near Holland Lake.

MINERAL DEPOSITS

Exploitation of the mineral resources of the Duncan area has been undertaken since the late nineteenth century, though originally restricted to nonmetallic deposits. The turn of the century saw commencement of exploration for gold and base metals, particularly in the Chemainus River and Copper Canyon areas. Production was limited except for three small mines on Mount Sicker (Lenora, Tyee and Richard III). A lull in activity occurred between the world wars and all mine production ceased. The Twin J (Lenora) mine on Mount Sicker was returned to production from 1943 to 1947. Over the next 30 years only sporadic exploration activity took place in the area for gold, base metals, manganese and iron ore. All areas of Sicker Group outcrop have since been staked and numerous exploration targets defined by major and junior mining companies and local prospectors.

Several types of mineral deposit are present in the Duncan area (Figure 1-6-5; Table 1-6-1):

Volcanogenic, polymetallic massive sulphides: These are the principal target in the Sicker Group rocks following the success of exploration at Westmin Resources Limited's Buttle Lake mine. The massive sulphides are hosted within the felsic volcanic tuffs of the McLaughlin Ridge Formation and restricted to a belt running from Chipman Creek to Mount Richards, in the hangingwall of the Fulford fault. Major occurrences are found on the Mount Sicker and Lara properties.

On Mount Sicker, massive sulphides were discovered in 1898 and production issued from three separate mines (Lenora, Tyee and Richard III) for several years. The combined property is presently under exploration by Minnova Inc. (formerly Corporation Falconbridge Copper). Baritic laminated sulphides are located within a distinctive thinly bedded package of intercalated siliceous argillaceous sediments and tuffs up to 70 metres thick. The local stratigraphy is, however, disrupted by folding, faulting (pre-Triassic as well as Late Cretaceous) and the intrusion of two thick Late Triassic gabbro sills.

Exploration by Abermin Corporation on the Lara property started in 1981. Volcanic rocks of the McLaughlin Ridge Formation in the northern part of the property are thrust over a panel of Cameron River Formation sediments, late Triassic gabbros and Nanaimo Group sediments to the south. The volcanic package contains a lower felsic tuff, a middle andesitic crystal-lapilli tuff and an upper felsic crystal tuff. Significant mineralization is hosted by the lower felsic tuff at two, possibly three, stratigraphic levels of which the Coronation zone is the most promising. Mineralization consists of disseminated and bedded pyrite-sphalerite-chalcopyrite-galena within quartz crystal tuffs. Silica and carbonate are the principal gangue minerals; barite is lacking. The Coronation zone has been delineated by drilling for about 2 kilometres along strike, with intersections up to 14 metres and averaging 6 metres. Low-grade sphalerite-pyrite-chalcopyrite mineralization is also found in the upper felsic crystal tuffs in which carbonate alteration is widespread.

Other massive sulphide showings have been reported in the Chipman Creek area (the Anita, MINFILE designation 37), in Copper Canyon (Sharon, 40; Copper Canyon, 86) and on Mount Richards (Yreka, 38; Jane [New Ironclad], 49).

Gold-bearing pyrite-chalcopyrite-quartz-carbonate veins along shears: Many of the faults and shears cutting the Sicker Group and late Triassic gabbros are veined by rusty weathering quartz-carbonate. The age of the veining is uncertain, several events being suspected. Some veins are localized along the Late Cretaceous thrusts and Tertiary (?) crossfaults, but others may be older structures and mineralizing events. The veins are variable in lateral extent, and range up to about 1 metre wide, although quartz-carbonate alteration along some faults may be several metres wide. Commonly reported sulphides are pyrite, pyrrhotite, chalcopyrite and arsenopyrite. The carbonate is principally ankerite and calcite. Carbonate appears to be less common to the east. Though numerous veins have been investigated in the past, none have proven economic potential.

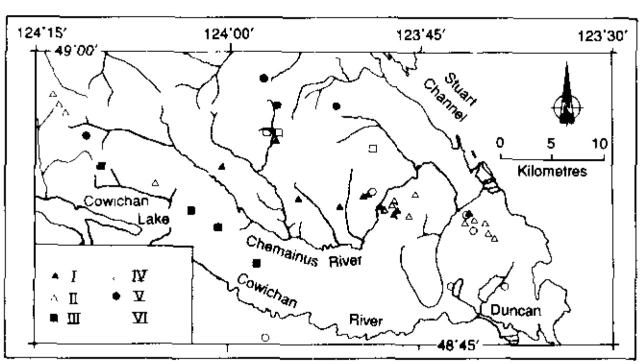


Figure 1-6-5. Distribution of mineral deposits in the Duncan–Chemainus River area. (I) Volcanogenic polymetallic massive sulphides; (II) Gold-bearing veins along shears; (III) Manganese (rhodonite) deposits; (IV) Jaspers; (V) Copper-molybdenum veins and skarns; (VI) Other mineral deposits.

TABLE 1-6-1.
MINERAL OCCURRENCES IN THE DUNCAN MAP AREA

Name	Minfile No.	Economic Minerals
I. Volcanogenic polymetallic massive sulphides		
(1) Mount Sicker	092B-001, 002	py, cpy, sphl, gln, ba
(a) Lenora-Tyee (Twin J)		
(b) Richard III	092B-003	py, cpy, sphl, gln, ba
(c) Victoria	092B-004	py, cpy, Au, Ag
(2) Anita	092B-037	cpy, py, Ag
(3) Sharon (Pauper, Mons, Brent)	092B-040	cpy, py, Au, Ag
(4) Waterpower-Brenton (Mildred)	092B-041	cpy, Ag
(5) Lara		
(a) Coronation Zone		sphl, py, cpy, gln, Au, Ag
(b) Coronation Extension Zone		sphl, py, cpy, gln, Au, Ag
(c) Randy North Zone		sphl, py, cpy, tet
(d) Hope	092B-110	cpy, py, sphl, gln, Au, Ag
(6) Pogo	092B-074	cpy, gln, sphl
II. Gold-bearing veins along shears		
(1) Mount Sicker area		
(a) Key City	092B-087	py, cpy
(b) Queen Bee (Seattle)	092B-088	py, Au
(c) Belle	092B-089	cpy
(d) Westholme	092B-090	?cpy
(e) Northeast Copper Zone	092B-099	py, cpy
(2) Mount Richards area		
(a) Cornucopia	092B-038	cpy, Au, Ag
(b) Yreka	092B-039	cpy, Au, Ag
(c) Jane (New Ironclad)	092B-049	cpy, sphl, talc
(d) Lucky Strike	092B-091	cpy
(e) Sally 2	092B-092	py, cpy
(f) Sirius	092B-096	cpy
(3) Copper Canyon	092B-076	cpy, py
(4) Candy	092C-076	cpy, po
(5) El Capitan — Landalt area		
(a) Cottonwood	092C-020	cpy, apy, erythrite, Au, Ag
(b) Silver Leaf	092C-021	cpy, apy, po, Au, Ag
(c) Paint Pot	092C-043	cpy, Ag, Au
(d) El Capitan	092C-019	cpy, Au, Ag
III. Manganese (Rhodonite) deposits		
(1) Hill 60	092B-027	rhodonite
(2) Rocky (Widow Creek, Cottonwood)	092C-113	rhodonite
(3) Meade	092C-115	rhodonite
(4) Stanley Creek (Lookout Locality)	092C-116	rhodonite
(5) Striker		rhodonite
IV. Jaspers		
(1) Lady A, A-B	092B-029	mag, spec, hem, jasper
(2) Lady A, C	092B-033	mag, spec, hem, jasper
(3) Fly	092B-076	mag, spec, jasper
V. Copper-molybdenite veins and skarns		
(1) BJ	092B-131	py, cpy
(2) Ant	092B-133	py, cpy, po, mo
(3) Coronation	092B-104	cpy, py, po
(4) Comego (Cascade, Anne, Kitchener)	092C-018	py, cpy, mo, mag, ю, tet, Au, Ag
VI. Others		
(1) Rose	092B-028	mica
(2) Sally	092B-093	limonite
(3) Skutz Falls	092B-120	limestone
(4) Duncan	092B-126	clay
(5) Quamichan Lake	092B-130	diatomite
(6) Jane (New Ironclad)	092B-049	talc

Manganese deposits: Manganese minerals have been reported in several places as fracture coatings or lenticular masses in the cherts of the Cameron River Formation. Rhodonite is the principal manganese mineral; manganese garnets, rhodochrosite and manganite have also been reported. All occurrences are in the aureoles of Jurassic granodiorite intrusions and owe their origin to the contact metamorphism of manganiferous sediments and are associated with ribbon chert. The protolith manganiferous sediment may have been of a exhalative origin (Cowley, 1979), though the lack of contemporaneous volcanism in the area mitigates against this. Oxidized deposits near Hill 60 were worked for manganese ore in 1919-20, but the main potential for these and other deposits is for lapidary uses.

Jaspers: Jasper occurs at many stratigraphic levels within the Sicker Group, principally associated with Nitinat Formation in the Banon Creek area (for example, Utah Mines Limited, JRM property) and McLaughlin Ridge Formation in the Chipman Creek–Rheinhart Creek area (for example, the Lady A [29] and Trek properties). Jasper beds are also found within the Cameron River Formation, often associated with manganese deposits, but also alone. The jasper deposits consist of laminated hematite and magnetite in red or grey chert. Several deposits were investigated in the 1950s for taconite iron ore but found to be too small. Recent exploration has concentrated on the potential for the volcanic-hosted jaspers to contain gold.

Copper-molybdenum quartz veins: Sulphide-bearing quartz veins occur in granodiorite and adjacent country rock on several properties in the Cowichan Lake area but are rarely reported from the Duncan area. However, chalcopyrite-pyrite veining is reported in Nitinat Formation tuffs at the RJ occurrence near Holland Lake, and a chalcopyrite-molybdenite-pyrrhotite-bearing skarn breccia is reported in a drill hole on the ANT property on Chipman Creek. Both of these occurrences are adjacent to the Ladysmith stock as is the Coronation showing described by Clapp and Cooke (1917).

Other deposits: Various nonmetallic deposits have been exploited in the Duncan area, particularly Quaternary clays for brickmaking and gravels for aggregate. Subeconomic grades of mica, talc, diatomite, limestone and limonite have been reported in the area.

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GEOLOGICAL RECONNAISSANCE IN THE BRIDGE RIVER MINING CAMP (92J/15, 16, 10; 92O/02)

By B.N. Church, R.G. Gaba, M.J. Hanna and D.A.R. James

KEYWORDS: Economic geology, Bridge River camp, stratigraphy, intrusive rocks, hydrothermal systems.

INTRODUCTION

The Bridge River mining camp comprises five former producing mines and numerous currently active mining prospects. The camp may be roughly defined as those properties lying within the Bridge River drainage basin bounded by the Coast plutonic complex on the southwest and the Shulaps ultrabasic complex on the northeast. Reconnaissance work by ministry field parties in 1986 and 1987 covers approximately 1500 square kilometres of mapping. This includes all of the Bralorne map sheet (92J/15) and parts of the Bridge River (92J/16), Birkenhead (92J/10) and Noaxe (92O/02) sheets (Figure 1-7-1).

GEOLOGICAL HISTORY

The geological history of the Bridge River area began in the Paleozoic era with the deposition of a thick succession of mostly cherty oceanic sediments. These rocks are now known as the Fergusson Group and comprise a highly deformed metamorphic basement complex exposed throughout the region (Plate 1-7-1). During Permian time this basement was intruded along major fractures by Bralorne plutonic rocks.

A diverse assemblage of volcanic and sedimentary formations of the Upper Triassic Cadwallader Group was deposited on this relatively simple terrane. These strata, and some younger Jurassic/Cretaceous buchia-bearing beds of the Relay Mountain Group, were preserved as scattered remnants in the downfaulted basement complex.

In the Jurassic period, the emplacement of dyke-like bodies and large masses of ultrabasic rocks such as the Shulaps and President intrusions accompanied major dislocations.

In the Lower Cretaceous, the uplifted Fergusson Group and younger, poorly lithified Mesozoic formations, provided a ready source of coarse clastic sediments that now comprise the Taylor Creek Group.

Toward the end of the Cretaceous period, uplift of the Coast Ranges coincided with the emplacement of major granitic plutons attended by thermal and dynamic metamorphism. This was also a time of much mineralization such as quartz veining, skarn development and the dispersion of pyrite in country rocks adjacent to the igneous intrusions.

The Rex Peak porphyry of early Tertiary age marks the last major intrusive event. Late downfaulting has preserved a few nearby wedges and patches of felsic volcanic rocks which appear to be the effusive equivalent of this intrusive.

GEOLOGICAL UPDATE

Re-evaluation of the geology of the Bridge River mining camp is based on observations from approximately 3000 geological stations established during the 1986 and 1987 field seasons. As a result of this study some additions and changes are made, building on the previous work of McCann (1922), Cairnes (1937, 1943) and the more recent contributions of Potter (1983, 1986) and Rusmore (1985). The new interpretations apply to the stratigraphy, structure and mineralization.

FERGUSSON GROUP

The name Fergusson Group is an adaptation of "Fergusson Series" which was introduced by Cairnes (1937) in reference to the oldest strata in the area. These are mainly recrystallized and silicified ribbon cherts (in part radiolaria bearing) with intercalated phyllites, micaceous schists and thin marble bands (Plate 1-7-1). The antiquity of these rocks is proven by their intense metamorphic state, the crosscutting relationships of igneous intrusions such as the Bralorne gabbro (Permian), and the superposition and infaulted condition of younger beds.

The Bridge River Series, named by Drysdale (1915) and applied to a major map unit by McCann (1922), is mostly equivalent to the Fergusson Group, however, much of the stratigraphic sense of the term was lost by inclusion of younger beds. For example the area along the Truax Valley, shown by McCann (1922) to be entirely underlain by Bridge River Series, contains sedimentary and volcanic units of the Cadwallader Group (Triassic) and buchia-bearing beds correlated with the Relay Mountain Group (Jurassic/Cretaceous). Elsewhere, such as in the Shulaps Range in the northeast part of the map area, Cadwallader-type strata are also included in the Bridge River assemblage (Leech, 1953; Potter, 1986).

"Bridge River terrane" is a relatively new conceptual term of broad time-stratigraphic and regional tectonic significance (Kleinspehn, 1984; Rusmore, 1985). The terrane includes the Fergusson Group and units correlative with the Cadwallader Group throughout the Bridge River mining camp and the area to the southeast.

CADWALLADER GROUP

The name Cadwallader Group used by Roddick and Hutchison (1973) is an adaptation of the Upper Triassic Cadwallader Series of McCann (1922). The group comprises

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

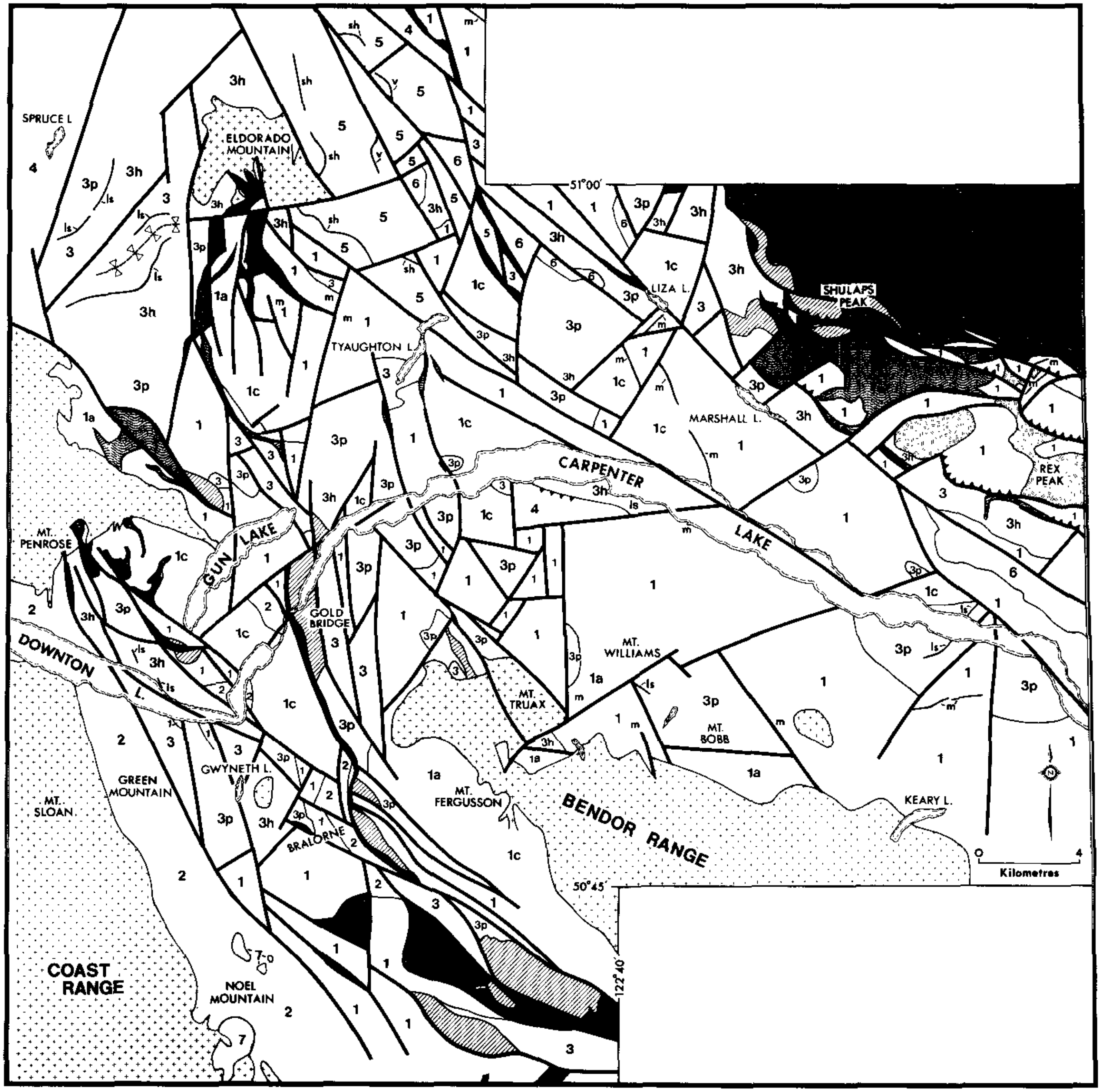

Figure 1-7-1. Geology of the Bridge River mining camp (see page opposite for legend).

the Pioneer, Noel and Hurley formations, and ranges from several hundred metres to a few thousand metres thick. These units are well exposed in cuts on the Slim Creek logging road east of the north end of Gun Lake.

The Pioneer Formation is a widely distributed but somewhat discontinuous basal unit consisting of amygdaloidal basalts, pillow lava and breccia (Table 1-7-1, columns 1 and 2), small limestone lenses, and a few chert bands resting on Fergusson basement rocks.

The Noel Formation consists mostly of thinly bedded black argillites and siltstones which are best developed in the southwest part of the map area where the beds have been locally sheared and grouped with the laminar-bedded cherts and dark phyllites of the Fergusson assemblage.

The Hurley Formation is best developed in the northwest part of the map area where the rocks are folded into a large northeasterly trending syncline. The unit consists of a diversity of volcanic breccias, polymictic conglomerates, sandstones, argillites and limestone beds. The clastic components are mostly a variety of chert, schist and diorite fragments derived from the nearby Fergusson Group and Bralorne intrusions. The age of the Hurley Formation, as

LEGEND
BEDDED ROCKS

TERTIARY

7 *(Miocene?) "Plateau Volcanics", basaltic lavas and breccias*

6 *(Eocene?) Lavas, pyroclastics and minor sedimentary rocks*

LOWER CRETACEOUS

5 TAYLOR CREEK GROUP: *mostly boulder and pebble conglomerate and sandstone with some intercalated shale marker beds (sh) and volcanics (v)*

UPPER JURASSIC

4 RELAY MOUNTAIN GROUP: *buchia-bearing grey shales, siltstones, tuffaceous and polymictic conglomerate*

UPPER TRIASSIC

3 CADWALLADER GROUP: *comprising the Pioneer Formation (3p) consisting of basaltic pillow lava,aquagene breccia, tuffs and amygdaloidal lava, and the Hurley Formation (3h) consisting of brown, black and green argillites (siliceous and calcareous) with sandstones, polymictic conglomerates and limestone marker beds (ls); inclusive of all or part of Noel argillites*

PALEOZOIC

2 *(Permian?) dark argillites, turbidites previously assigned to the Noel Formation*

1 FERGUSSON GROUP: *mostly ribbon chert (lc), phyllite ranging to biotite quartz gneiss, some marble (m) marker bands, chloritic schist, and fine grained amphibolite (la)*

INTRUSIVE IGNEOUS ROCKS

TERTIARY

REX PEAK PORPHYRY: *a felsic phase of the (Eocene) Mission Ridge pluton*

UPPER CRETACEOUS

COAST PLUTONIC COMPLEX: *biotite and hornblende-bearing diorite, granodiorite and granite stocks and plutons; including the outlying Bendor and Eldorado stocks*

LOWER JURASSIC

Ultrabasic Rocks: comprising the Shulaps and President hartzburgite, peridotite, dunite, serpentine and listwanite bodies

PALEOZOIC

BRALORNE INTRUSIONS: *heterogeneous fine and medium-grained diorite and gabbro stocks characterized by a reticulation of felsic veinlets*

determined by M. Orchard of the Geological Survey of Canada, is Norian (Upper Triassic) based on conodont fossils collected by the writers from limestone pebbles in a conglomerate bed 0.2 kilometre east of the north end of Gwenyth Lake. These fossils, *Epigondolella abneptis* and *Neogondolella* sp., also occur in the collections of Rusmore (1985) from the Eldorado basin.

RELAY MOUNTAIN GROUP

The Relay Mountain Group, originally described by Jeletzky and Tipper (1968), is mostly a monotonous sequence of buchia-bearing shales, siltstones and greywackes of Middle

Figure 1-7-1. Biotite quartz gneiss phase of Fergusson Group, on southeast spur of Mount Fergusson, 4 kilometres east of Bralorne.

Jurassic to Early Cretaceous age. These rocks are up to 650 metres thick and occur along the southeasterly trending axis of the Tyaughton trough (Jeletzky and Tipper, 1968). In the Spruce Lake area, south of the type section, steeply dipping buchia and ammonite-bearing beds are overlain by massive sandstones. Elsewhere in the map area, an unusual occurrence of buchias in conglomerate is exposed on the Grey Rock road west of Truax Creek (Church and MacLean, 1987a). Here the Relay Mountain Group consists of several hundreds of metres of polymictic conglomerate overlain to the east by a few hundred metres of grey siltstone and argillite. The exact origin of chert and graphite clasts in the conglomerate is unknown, however, a westerly source would appear to fit the paleogeographic setting of the deposit, marking the early uplift of the Coast Mountains. This gives a much earlier age for the development of the southwest margin of the Tyaughton basin than the mid-Cretaceous time proposed by Kleinspehn (1984).

TAYLOR CREEK GROUP

The name Taylor Group of Cairnes (1943) was expanded to Taylor Creek Group by Jeletzky and Tipper (1968) in reference to what is believed to be the marine equivalent of the Lower Cretaceous (Albian) Jackass Mountain Group located further east. In the Bridge River mining camp these rocks extend easterly and northeasterly from Eldorado Mountain to Tyaughton Creek. The beds are mainly steep westerly dipping pebble and boulder conglomerates with thin intercalations of siltstone and shale and a few volcanic rocks. A dark grey silty argillite, about 50 metres thick, occurring in the upper part of the section on the ridges north and south of Taylor Creek, is one of the few marker horizons in the succession (Plate 1-7-2).

A narrow zone of interbedded basaltic tephra exposed on the east and northeast midslopes at Eldorado Mountain is a local stratigraphic marker horizon.

The clasts in the conglomerate facies are mostly well-rounded chert pebbles and boulders which are accompanied by accessory sandstone and shale clasts and a few igneous rocks reworked from nearby weakly consolidated members of the Cadwallader Group and older metamorphic basement

TABLE 1-7-1
ANALYSES OF EFFUSIVE IGNEOUS ROCKS

	1	2	3	4	5	6	7
Oxides recalculated to 100:							
SiO_2	49.19	49.96	72.43	51.39	59.48	64.68	70.29
TiO_2	2.05	2.99	0.25	1.49	0.88	0.63	0.56
Al_2O_3	15.47	16.13	14.03	19.08	17.31	17.69	15.04
Fe_2O_3	2.70	2.82	1.43	6.93	2.36	2.73	0.84
FeO	6.98	9.57	0.60	2.89	3.73	1.82	4.63
MnO	0.15	0.18	0.02	0.28	0.12	0.07	0.13
MgO	7.87	6.46	1.88	3.56	4.24	1.85	1.30
CaO	11.74	7.72	2.84	9.23	6.18	4.94	0.72
Na_2O	3.35	2.43	4.01	3.96	4.03	4.26	5.96
K_2O	0.50	1.74	2.51	1.19	1.67	1.33	0.53
	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oxides as determined:							
H_2O+	2.94	2.37	2.34	1.09	0.49	1.99	1.02
H_2O-	0.17	0.14	0.60	0.25	0.32	0.20	0.12
CO_2	1.04	0.14	1.40	0.63	0.14	2.57	0.69
P_2O_5	0.23	0.39	0.05	0.41	0.19	0.13	0.08
S	0.04	0.01	0.01	0.01	0.01	0.02	0.14
Molecular norms:							
Qz	—	0.6	28.7	1.9	9.2	20.0	25.1
Or	2.9	10.5	14.9	7.1	9.9	7.9	3.1
Ab	30.0	22.1	36.1	35.9	35.9	38.2	53.4
Ne	—	—	—	—	—	—	—
An	25.6	28.5	12.9	31.1	24.1	24.6	3.6
Wo	13.0	4.2	0.5	6.0	2.6	—	—
En	6.5	18.1	5.2	9.9	11.7	5.1	3.6
Fs	1.8	8.8	—	—	2.9	0.1	5.8
Fo	11.4	—	—	—	—	—	—
Fa	3.2	—	—	—	—	—	—
Il	2.8	4.2	0.4	2.1	1.2	0.9	0.8
Mt	2.8	3.0	0.9	3.6	2.5	2.9	0.9
He	—	—	0.4	2.4	—	—	—
Cm	—	—	—	—	—	0.3	3.7

Key to Analyses:

1 – Pillow basalt, Pioneer Formation; on peak of hill 0.8 kilometre south of Mowson Pond; UTM 5170 56388.

2 – Aquagene basalt breccia, Pioneer Formation; 1 kilometre northwest of Gwyneth Lake; UTM 5084 56277.

3 – Rhyodacite breccia, Cadwallader Group; 2 kilometres southwest of Windy Pass; UTM 5047 56484.

4 – Basalt, Tertiary volcanic rocks; 0.5 kilometre west of Tyaughton Creek; UTM 5173 56499.

5 – Andesite lava, Tertiary volcanic rocks; 0.5 kilometre east of Hurley River; UTM 5061 56217.

6 – Feldspar porphyry dyke, Tertiary effusive; 1 kilometre north of mouth of Gun Creek; UTM 5160 56384.

7 – Aphyric dacite dyke, Tertiary effusive; 1.2 kilometres north of Gun Creek; UTM 5110 56406.

complex. No granitic clasts were observed. Accessory white mica in some interlayered sandstone beds is believed to have been derived from schistose and phyllitc members of the Fergusson metachert. Yellow limonitic clasts, conspicuous in some of the upper pebble conglomerate members, appear to have been derived from some basic volcanic or listwanitic ultrabasic source.

TERTIARY BEDDED ROCKS

Tertiary bedded rocks comprise a few small scattered volcanic outliers. The oldest of these, estimated to be early Tertiary age, is a narrow panel of felsic lava and tuff which

Plate 1-7-2. A westerly dipping mid-section in the Taylor Creek Group, on east spur of Eldorado Mountain, north of Taylor Creek.

follows the west side of the Marshall Creek fault from the east boundary of the map area to a point north of the mouth of Marshall Creek. Other volcanics of about the same age occur near the confluence of Taylor Creek and Tyaughton Creek. These rocks, and numerous related dykes found throughout the map area, range from basalt to dacite composition (Table 1-7-1, columns 4 to 7).

Small remnants of "plateau lava" of mid-Tertiary age occur at high elevations on the north and south spurs of Noel Mountain (Plate 1-7-3). These are horizontally layered basalts 100 to 150 metres thick, similar to the tiered lava flows forming the summit area of Cardtable Mountain and on Castle Peak in the Noaxe area to the north.

BRALORNE INTRUSIONS

The "Bralorne Intrusions" of Cairnes (1937) comprise augite diorite of the Bralorne-Pioneer belt and a number of associated phases including hornblende diorite and gabbro (Table 1-7-2, column 3). These rocks are notable in being the oldest igneous intrusions* and the primary host rocks

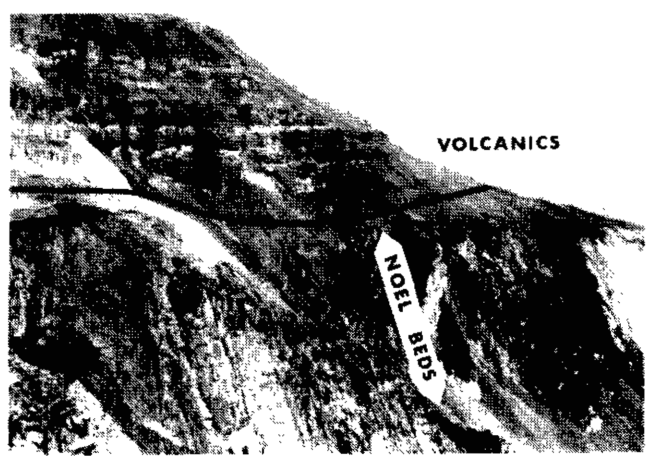

Plate 1-7-3. Tertiary basaltic volcanics (horizontal beds) resting unconformably on steeply dipping Triassic argillites and siltstones (Noel Formation).

*Determination of amphibole from a diorite phase of Bralorne intrusions exposed in the B.C. Hydro quarry north of Gold Bridge, yielded a potassium-argon age of 287 ±20 Ma (Permo-Carboniferous) – R.L. Armstrong, *The University of British Columbia*, from Potter, 1983, page 27).

TABLE 1-7-2
ANALYSES OF PLUTONIC ROCKS

	1	2	3	4	5	6	7	8
Oxides recalculated to 100:								
SiO_2	40.54	53.25	49.27	61.14	64.28	66.98	75.06	77.43
TiO_2	0.01	0.07	0.27	0.75	0.72	0.65	0.26	0.08
Al_2O_3	0.35	2.19	19.53	16.74	16.20	16.11	12.94	12.82
Fe_2O_3	6.83	1.28	0.92	1.07	1.16	1.02	0.78	0.23
FeO	3.92	6.12	3.92	4.79	3.86	2.95	2.20	0.43
MnO	0.19	0.16	0.10	0.10	0.07	0.06	0.06	0.01
MgO	48.10	19.80	9.67	3.82	3.35	2.06	1.03	0.08
CaO	0.05	17.09	14.26	5.78	4.42	3.80	2.92	0.68
Na_2O	0.00	0.04	1.62	3.70	3.89	3.83	4.46	2.55
K_2O	0.01	0.00	0.44	2.11	2.05	2.54	0.29	5.69
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oxides as determined:								
H_2O+	8.81	1.47	2.10	0.43	0.28	0.26	1.33	0.02
H_2O-	0.11	0.12	0.10	0.09	0.17	0.15	0.10	0.07
CO_2	6.94	0.56	0.35	0.14	0.69	0.69	0.07	0.28
P_2O_5	0.00	0.01	0.00	0.13	0.12	0.13	0.03	—
S	0.14	0.02	0.02	0.01	0.01	0.02	0.04	0.01
Molecular norms:								
Qz	—	—	—	10.9	16.2	20.7	36.5	36.9
Or	0.1	—	2.5	12.5	12.1	15.1	1.7	34.1
Ab	—	0.4	14.3	33.3	34.9	34.4	40.5	23.3
Ne	—	—	—	—	—	—	—	—
An	0.2	5.7	43.8	22.8	20.7	18.9	14.6	3.4
Wo	—	31.0	10.2	2.3	0.5	—	—	—
En	13.9	51.9	14.6	10.5	9.2	5.7	2.9	0.2
Fs	0.1	8.1	2.8	5.6	4.2	3.0	2.6	0.4
Fo	78.3	1.3	8.8	—	—	—	—	—
Fa	0.8	0.2	1.7	—	—	—	—	—
Il	—	0.1	0.4	1.0	1.0	0.9	0.4	0.1
Mt	6.4	1.3	0.9	1.1	1.2	1.1	0.8	0.2
He	—	—	—	—	—	—	—	—
Cm	0.2	—	—	—	—	0.2	—	1.4

Key to Analyses:

1 – Hartzburgite, President intrusions; north bank of Cadwallader Creek by Pioneer mine; UTM 5154 56231.

2 – Websterite, President intrusions, on ridge 0.4 kilometre west of Jewel Creek; UTM 5038 56389.

3 – Gabbro, Bralorne intrusions; in B.C. Hydro quarry 1 kilometre north of Gold Bridge; UTM 5110 56340.

4 – Diorite, Coast intrusions; on ridge 1.5 kilometres southwest of Green Mountain; UTM 5044 56246.

5 – Granodiorite, Eldorado intrusion; 0.9 kilometre southwest of Eldorado Peak; UTM 5098 56498.

6 – Granodiorite, Bendor intrusion; immediately west of Truax Peak; UTM 5200 56297.

7 – Granite, "soda granite"; in highway cut 0.4 kilometre north of Gold Bridge; UTM 5111 56334.

8 – Granite, Coast intrusions; on ridge 1.2 kilometres north of Dickson Peak; UTM 5010 56391.

for mineralization in the area. They resemble outlying diorite-gabbro bodies at Lajoie Lake, near the headwaters of Sumner Creek and Steep Creek, and a series of small gabbro bodies in the Shulaps Range described by Leech (1953).

The typical Bralorne rocks are mottled grey-green, medium to fine grained, and characterized by a reticulation of felsic stringers. In contrast, the feeder gabbroic intrusions of the younger Triassic Pioneer basaltic lavas are generally fresh, relatively homogeneous and commonly distinguished by a light rust weathering.

The elongated outline of many of the individual intrusions, and the linear arrangement of these bodies in the Cadwallader-Hurley valley, suggest emplacement on a major fracture system.

ULTRABASIC ROCKS

An unusual abundance of ultrabasic rocks occurs in the Bridge River mining camp. These are an assortment of small talc-carbonate and serpentine lenses on steeply dipping faults, and large bodies of mixed peridotite, pyroxenite and dunite composition associated with possible thrust zones, such as the main President intrusion and the Shulaps complex.

According to Leech (1953) and Wright (1971), hartzburgite, consisting of a mixture of orthopyroxene and olivine (Table 1-7-2, column 1), is the most common rock type in the major ultramafic bodies. This rock is readily identified in the field by rust-orange weathering on a warty surface. Dunite is less common and clinopyroxene-rich rocks such as websterite (Table 1-7-2, column 2) are uncommon.

Although these ultrabasic bodies have been classified as massive "alpine type", Leech (1953) found that parts of the Shulaps complex show rhythmical layering of hartzburgite, dunite and pyroxenite. A similar feature is seen in the President intrusion (Plates 1-7-4 and 1-7-5). Wright (1974) as-

Plate 1-7-4. Finely layered structure in President ultramafic body, Sunshine Mountain area south of Cadwallader Creek

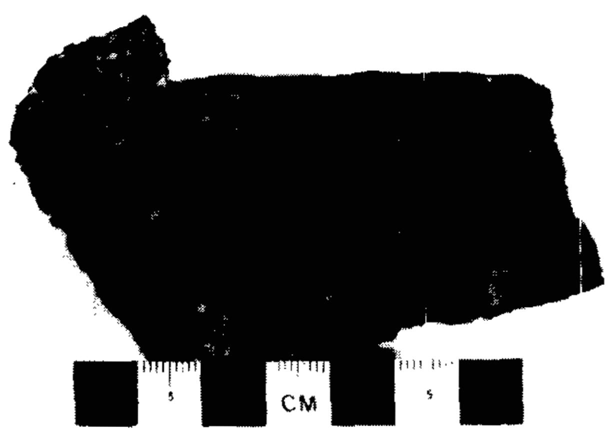

Plate 1-7-5. Cumulate chromite in President ultramafic body, Sunshine Mountain area.

cribes this prominent layering to tectonic forces "resulting from plastic deformation and recrystallization accompanied by metamorphic differentiation producing alternate olivine and orthopyroxene-rich layers". However, there is no completely satisfactory explanation of the chromite bands by this method. Consequently some magmatic or crystal mush origin is suspected. This magmatic attribute is further suggested by the apophyses and dyke-like form of some phases of the ultrabasic rocks, the presence of reaction selvages around gabbroic xenoliths, and evidence of thermal metamorphism along some contacts as indicated by Potter (1986).

The writers find no evidence that the ultrabasic rocks are volcanic in origin as suggested by McCann (1922). There seems to be little doubt that the ultrabasic rocks gained entry to the country rocks along major fissure systems both on thrusts and steeply dipping faults, and that these rocks were affected by renewed episodes of movement.

The age of emplacement of the Shulaps ultrabasic body is known to postdate the Late Triassic Cadwallader Group rocks which it cuts, and predates Lower Jurassic chromite-bearing sedimentary rocks in the Yalakom Valley discovered by Leech (1953).

COAST PLUTONIC COMPLEX

The Coast plutonic complex comprises the contiguous granitic terrane marking the southwest extremity of the Bridge River mining camp and including the outlying Bendor and Eldorado plutons to the east and smaller related plugs and dykes scattered throughout the region. The composition of these rocks varies from diorite to granodiorite, granite and aplite, biotite hornblende granodiorite being most common. The quartz content of these rocks ranges from less than 11 to more than 36 per cent and the total ferromagnesian content ranges from about 1 to 20 per cent (Table 1-7-2, columns 4 to 8).

Small bodies of soda granite are found on the Bralorne-Pioneer lineament, commonly associated with the older Bralorne diorite/gabbro intrusions (Plate 1-7-6). At the Bralorne mine the soda granite appears to expand with depth, forming a cupola from which quartz veins and mineralization appear to emanate.

The age of the Coast intrusions, based on several potassium-argon dates, varies from 59 to about 80 Ma. A recent analysis of the Eldorado Peak stock by K. Dawson of the Geological Survey of Canada yields 63.7 Ma (personal communication, 1987).

The soda granite, assigned to the "Bralorne Intrusives" by Cairnes (1937), is now thought to be much younger. This rock could be the source of the granite pebbles found in the Relay Mountain Group near the Truax Valley or just another phase of the Coast intrusions.

DISCUSSION

Similarities were noted by Campbell (1975) comparing the Bridge River camp and the Mother Lode camp of California: "the two camps not only have striking similarities in ore, vein mineralogy, wallrock alterations and wallrocks, but also are remarkably similar in the association of the ore veins with a major fault along a belt of elongate serpentine bodies that flank the margin of a granite batholith."

Plate 1-7-6. Apophysis of soda granite in Bralorne intrusive complex, highway cut 0.4 kilometre north of Gold Bridge.

The allochthonous terrane theory of Umhoefer (1987) and others would place the Bridge River terrane juxtaposed with Baja California in pre-Upper Cretaceous time. This gives an improved spatial fit to Campbell's observations. Such a hypothesis might also relocate the Greenwood mining camp of south-central British Columbia which is similar in many ways to the Bridge River camp (Table 1-7-3).

In each camp an intricate system of fractures is thought to control movement of the ore-bearing solutions; the most profound crustal rents are commonly the main solution channelways and also the loci of repeated igneous intrusions. For example, in the Bridge River camp the Cadwallader "break", on which the principal mines are situated, hosts several Bralorne diorite stocks, a belt of ultrabasic rocks and the soda granite bodies.

The source of the mineralizing solutions was considered by Cairnes (1937) to be magmatic – a process of differentiation which also produced the soda granite. The Bralorne diorite 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 faults and the brittle, fissure-sustaining character of the rocks.

TABLE 1-7-3
GEOLOGICAL COMPARISON OF THE BRIDGE RIVER AND GREENWOOD CAMPS

Age	Lithology	Bridge River Camp	Greenwood Camp
U. Cret.	granitic plutons	Coast plutonic	Greenwood - Wallace
L. Cret.	granitic plutons	complex	Cr. plutons
Jur./Cret.?	ultrabasic rocks	Shulaps and President intrusions	unnamed ultramafic bodies
U. Trias.	clastics, shale, limestone, volcanics	Cadwaller Gp.	Brooklyn Gp.
Permian	black argillites	lower Noel Fm.	Attwood Gp.
M.-L. Perm.	gabbro, diorite stocks	Bralorne intrusions	"Old Diorite"
Paleozoic	deformed ribbon chert-schist basement complex	Fergusson Gp.	Knob Hill Gp.

In the present study, a genetic relationship between the soda granite and the Bralorne diorite is not proven.

In the Greenwood camp linear coherence of lead isotope ratios from the diverse mineral deposits suggests single cycle mixing of the ore solutions. It is thought that the plutons served principally as heat engines in a convecting hydrothermal system. A similar model may hold for the Bridge River camp.

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THE DOUBLE DERIVATIVE INTERPRETATION OF REGIONAL MAGNETIC FIELDS IN THE BRIDGE RIVER MINING CAMP (92J/15, 16)

By B. N. Church and D. A. R. James

KEYWORDS: Aeromagnetic data, double derivative, regional geology, structure, alteration.

INTRODUCTION

The double derivative method of screening aeromagnetic data assists regional geological interpretations. According to theory, the "second vertical derivative" maps the rate of curvature of magnetic fields. The zero contour on the calculated surface has special geological significance and coincides with inflection points on the original magnetic profiles. These inflections commonly trend subparallel to lithological or mineralized boundaries and fault zones.

In the Bridge River mining camp the federal-provincial aeromagnetic maps, Tyaughton Lake (92J/15) and Bridge River (92J/16), at 1:63 360 scale, provide a ready base for analysis. Regional geological control is provided by current mapping and by the Geological Survey Branch (Open File Map 1987-11, *Geology of the Gold Bridge Area*) and previous work by Leech (1953), Roddick and Hutchinson (1973) and Potter (1986).

GEOLOGY

The magnetic signatures of the principal geological formations underlying the Bridge River camp depend on several factors such as the iron content, mineralogy, alteration and metamorphic conditions of the rocks. Ultimately the amount of magnetite and grain size are the most important factors. Generally, igneous rocks have the greatest magnetic susceptibility, having more combined magnetite and ilmenite and coarser grain size than the sedimentary units. Table 1-8-1 gives the total iron, magnetite and ilmenite percentages for a selection of igneous rocks from the area.

The Pioneer volcanic rocks comprise the lowest formation in the Upper Triassic Cadwallader Group. The unit consists mostly of basaltic pillow lavas and breccias ranging up to several hundred metres thick. These volcanics are sandwiched between thick sedimentary sequences characterized by relatively low magnetic susceptibility; the older Fergusson cherts and phyllites lying unconformably below; the slightly younger Hurley argillites, limestones and clastic beds lying conformably above.

Generally the Pioneer volcanic assemblage has been affected by greenschist-grade metamorphism which has destroyed much of the primary mineralogy. Calcic feldspar has been transformed to more sodic varieties and the ferromagnesian minerals partly replaced by chlorite. Individual magnetite grains may have survived the effects of regional metamorphism, however, much of the iron is contained in very fine-grained opaque dust associated with the decomposition of the original mineral and vitreous components. In areas of mineralization, the basaltic walls of quartz veins are commonly carbonated and much of the iron is tied to siderite, hematite and pyrite. These altered rocks have low magnetic susceptibility.

The ultramafic rocks of the President and Shulaps intrusions cut units of the Cadwallader and Fergusson groups. These intrusive bodies, consisting mostly of iron-rich harzburgite (with lesser amounts of diorite and websterite), contain much granular magnetite. The common high magnetic susceptibility of these rocks is in sharp contrast to the low magnetic susceptibility of the adjacent formations. The primary magnetite does not appear to be much changed by serpentinization of the ultramafic rocks, although much new fine-grained, opaque iron oxide has resulted from the conversion of pyroxene to serpentine and talc.

The Bralorne intrusions are relatively small Paleozoic diorite and gabbro bodies that appear to have been emplaced on major rifts in the Fergusson terrane. These plutonic rocks have relatively low iron content and have been extensively affected by retrograde metamorphism resulting in lower than expected magnetic susceptibility.

The Coast intrusions are Upper Cretaceous biotite hornblende granodiorite plutons with diorite and granite phases. These rocks are typically fresh with hypidiomorphic granular texture. The magnetic susceptibility of these rocks is generally low because of low ferromagnesian content, however, the occurrence of magnetic anomalies in adjacent country rocks may be due to the development of skarns and hornfels zones during intrusion.

METHOD OF ANALYSIS

The preparation of second vertical derivative maps is in accordance with the mathematical theory and procedures of Henderson and Zeitz (1949, page 512). The general equation for this purpose:

$$\overline{\Delta T}(r) = \Delta T_0 - \frac{r^2}{4}\frac{\partial^2 \Delta T}{\partial z^2} + \frac{r^4}{64}\Sigma\, \mu_k{}^4 A_k + \cdots$$

reduces to a nine-point system in a square grid

$$\frac{\partial^2 \Delta T}{\partial z^2} = 2(3\Delta T_0 - 4\overline{\Delta T}_1 + \Delta T_2)$$

where T_0 is gamma value at each cell centre in the map grid, T_2 the value at each corner of the cell, and T the value at the mid-points on the sides of the grid.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

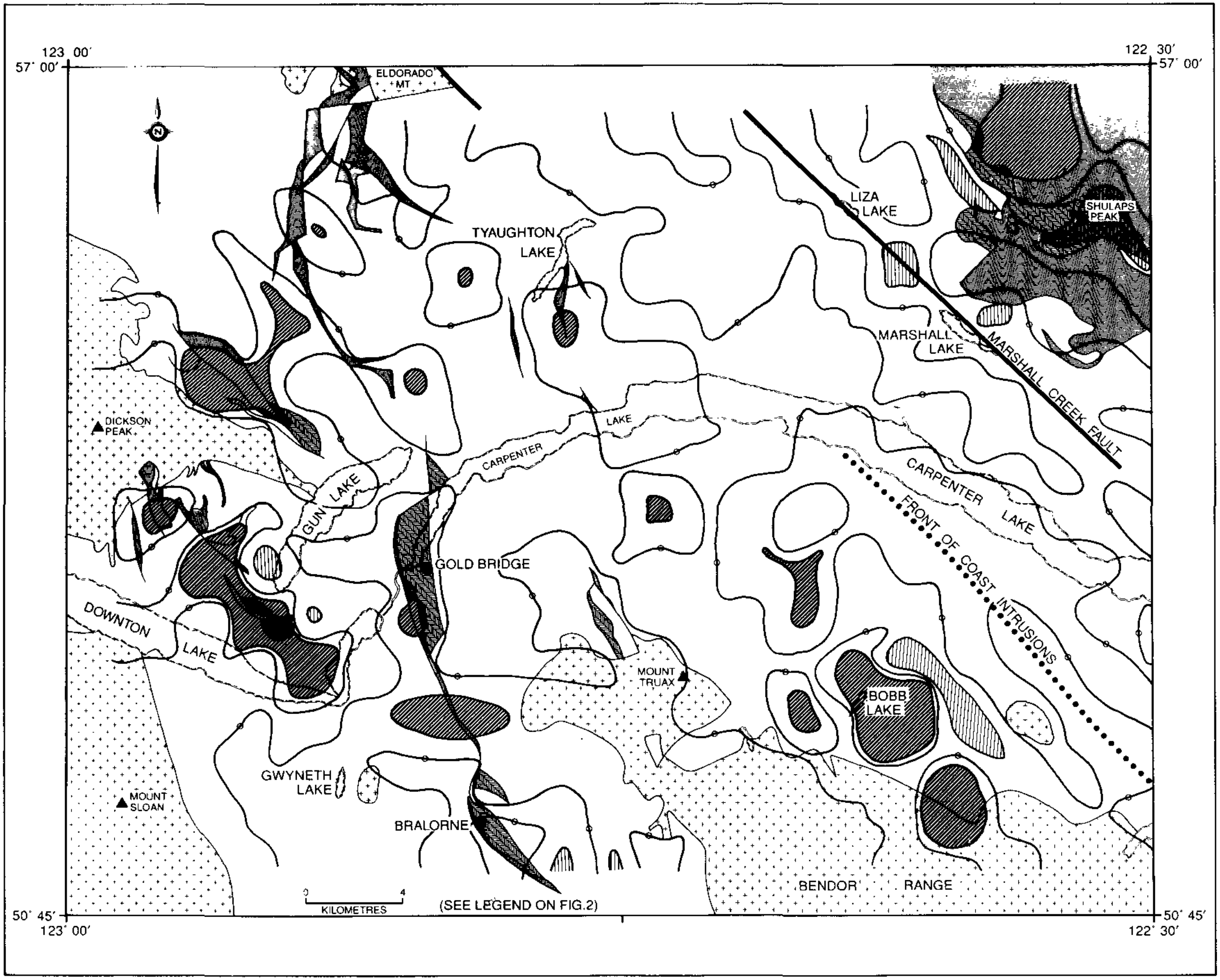

Figure 1-8-1. Tyaughton area (92J/15) showing the principal igneous intrusions and second vertical derivative contours of the total magnetic intensity (computed on a 1-mile grid interval from data on Geological Survey of Canada Map 8552G).

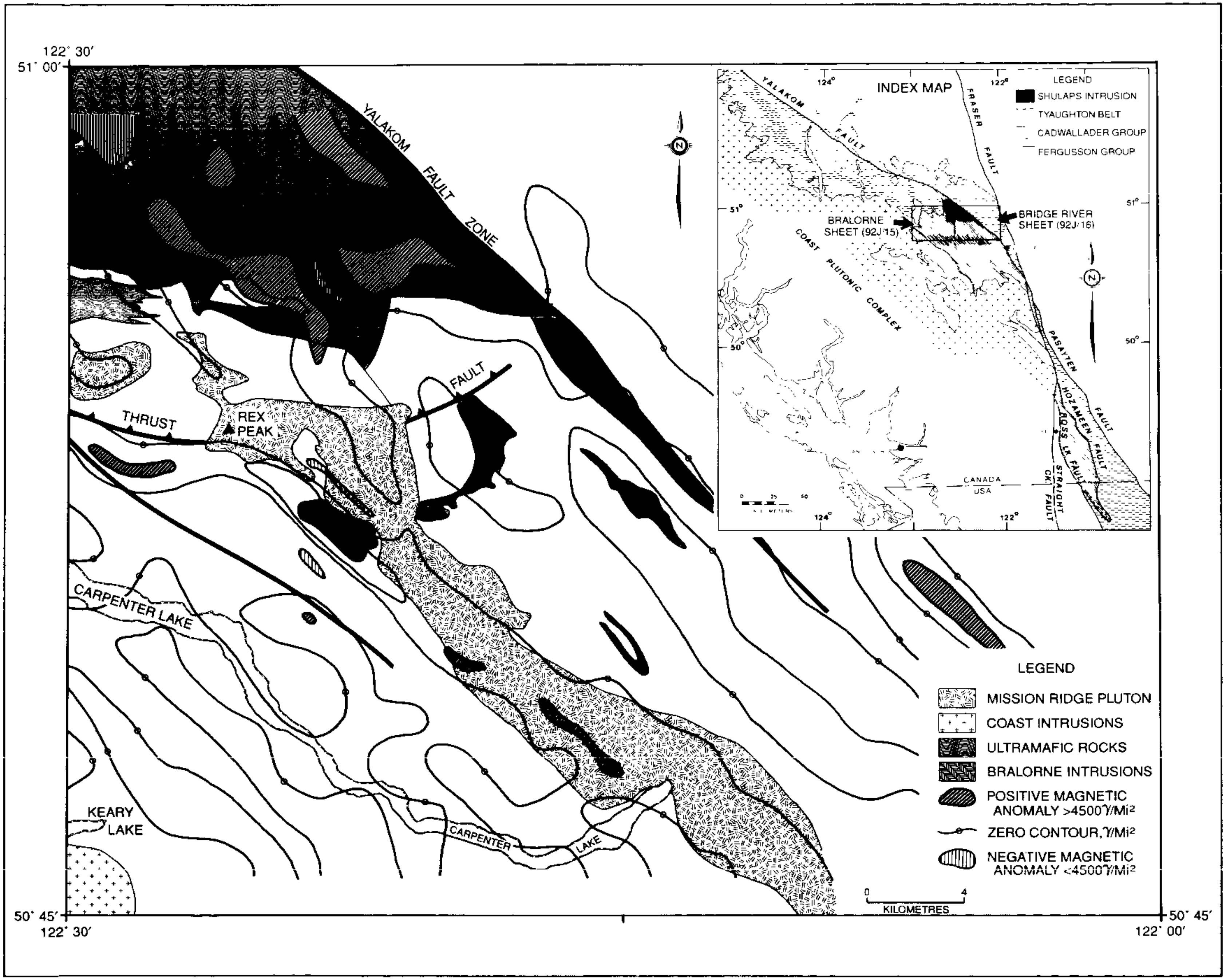

Figure 1-8-2. Bridge River area (92J/16) showing the principal igneous intrusions and second vertical derivative contours of the total magnetic intensity (computed on a 1 mile grid interval from data on Geological Survey of Canada Map 8548G).

For the Bridge River mining camp an orthogonal north-south, east-west grid with a 1-mile spacing is superimposed on the available aeromagnetic maps. A total of 792 grid points is necessary to cover the combined Tyaughton–Bridge River map sheets, each sheet measuring approximately 22 miles east-west and 18 miles north-south. The following general formula (algorithm) is applied to compute the second vertical derivative across the map area. Gamma values are interpolated and recorded at the grid points.

$$\begin{aligned} X(I,J) = {} & 12X(I,J,) - 4[X(I-1,J) + X(I,J-1) + X(I+1,J) \\ & + X(I,J+1)] + X(I+1,J-1) + X(I-1,J-1) \\ & + X(I-1,J+1) + X(I-1,J+1) \end{aligned}$$

for the interval X(1,1) to X(1,22) through X(18,1) to X(18,22); where I and J represent the rows and columns in the matrix of gamma readings (X). The final product is a contoured map showing gammas per square mile (*see* examples, Figures 1-8-1 and 1-8-2).

DISCUSSION OF RESULTS

The registration of the double derivative contours on the principal geological features of the Bridge River mining camp appears to be very good (*see* Figures 1-8-1 and 1-8-2). For example, the strong northwest-trending fabric delineated by the zero contour across the Bridge River sheet (92J/16) and the easterly part of the Tyaughton sheet (92J/15) conforms with the direction of the Yalakom and Marshall Creek faults and the front of the Coast intrusions. Also conforming well with this pattern is the young (Tertiary age) Mission Ridge pluton. The most anomalous magnetic zones coincide with the Shulaps and President ultramafic intrusions. A series of positive magnetic anomalies follows the hornfelsed margins of the Bendor and Dickson Peak granitic plutons and a series of negative anomalies occurs near a number of small Bralorne "diorite" bodies associated with the Shulaps ultramafic complex.

The broad magnetically flat area northeast of the Yalakom fault is underlain mostly by Cretaceous sedimentary formations characterized by low magnetic susceptibility.

It is concluded that the double derivative method of processing primary magnetic data provides some clear insight into regional structural patterns and lithology continuities in the Bridge River mining camp that may have useful potential for mineral exploration. The various igneous intrusions and adjacent fracture lineaments delineated on the double derivative maps point to possible prospecting targets.

ACKNOWLEDGMENTS

Many thanks are owing to Debbie James who performed the computations and much of the drafting for this report. Discussions with Bryan Muloin led to a better understanding of the mathematics of double derivatives and procedures for calculations.

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TABLE 1-8-1
IRON, MAGNETITE AND ILMENITE PERCENTAGES FOR SELECTED IGNEOUS ROCKS

	Fe %	Magnetite + Ilmenite %
Basalt (Pioneer Formation)	0.3–9.4	5.6–7.2
Ultramafic rocks (President intrusions)	5.7–7.8	1.3–6.5
"Diorite" (Bralorne intrusion)	4.5	1.3
Dioritic rocks (Coast intrusions)	3.0–4.5	2.0–2.2
Granitic rocks (Coast intrusions)	0.5–2.3	0.3–1.2

GEOLOGY OF THE NOAXE CREEK MAP AREA* (92O/02)

By J. K. Glover, P. Schiarizza and J. I. Garver

KEYWORDS: Regional geology, Noaxe Creek, Warner Pass, Bridge River terrane, Cadwallader terrane, Tyaughton trough, Yalakom fault, Shulaps ultramafic complex, wrench faults.

INTRODUCTION

The Noaxe Creek map area lies 200 kilometres north of Vancouver on the eastern margin of the Coast Mountains, and covers an area of 1000 square kilometres within the Chilcotin Range. The topography and vegetation vary from alpine to subalpine in the west, southeast and northeast, where elevations range up to 2850 metres, to rolling tree-covered ridges with intervening broad river valleys in the central part of the area.

Approximately 70 per cent of the area, mostly north of Tyaughton and Noaxe creeks, was mapped at a scale of 1:20 000 by a four-person field crew during the 1987 season. This was augmented by results from independent detailed mapping in the western part of the area by Paul Umhoefer and in the western and southern parts of the area by John Garver during 1985, 1986 and 1987.

Approximately 50 rock samples were collected from zones of alteration and mineralization for trace element analysis.

This report covers the second year of a 4-year regional mapping project, begun in 1986, and funded by the Canada/British Columbia Mineral Development Agreement in order to provide 1:50 000-scale geology maps and mineral potential overlays of the Taseko–Bridge River area as an aid to exploration.

REGIONAL GEOLOGY

The study 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, to the east of the Coast plutonic complex (Figure 1-9-1). This zone comprises several fault-bounded tectonostratigraphic units, some of which are coeval, as outlined below:

The Bridge River Terrane: Oceanic rocks of the lower Jurassic and older (?) Shulaps ultamafic complex and Middle Triassic to Lower Jurassic Bridge River complex (Potter, 1986).

The Cadwallader Terrane: Volcanic arc-related rocks of the Upper Triassic Cadwallader and Tyaughton groups (Rusmore, 1987), and lower to middle Jurassic sediments (H.W. Tipper, personal communication, 1987).

The Tyaughton Trough: Marine sedimentary strata of the Middle Jurassic to Lower Cretaceous Relay Mountain Group and the mid-Cretaceous Taylor Creek and Jackass Mountain groups (Jeletzky and Tipper, 1968).

An Upper Cretaceous succession, which comprises laterally discontinuous, nonmarine basinal deposits that grade up into continental volcanic arc-related rocks, overlies the older marine strata of the the Tyaughton trough with local pronounced angular unconformity (Glover and Schiarizza, 1987).

The Bridge River terrane and Tyaughton trough are thought to have been offset from their correlatives to the south, the Hozameen Group and Methow basin, by at least 70 kilometres of right-lateral strike-slip movement along the north-trending Fraser – Straight Creek fault system during Late Cretaceous (?) and Early Tertiary time (Monger, 1985). Earlier, post-Albian fragmentation of the Tyaughton-Methow basin occurred along the Yalakom-Hozameen fault system, along which 80 to 190 kilometres of right-lateral offset has been postulated (Tipper, 1969). The Yalakom fault crosses the map area from southeast to northwest, from where it has been traced, north of Taseko and Chilko lakes, to the Tatla Lake area in the Mount Waddington map area (Tipper, 1969, 1978; McLaren, 1986, 1987).

Mesozoic strata are intruded by mid-Cretaceous quartz diorite to quartz monzonite of the Coast plutonic complex in the southwest part of the belt (McMillan, 1976) and by widespread equigranular and porphyritic granitic stocks and dykes of probable late Cretaceous and Eocene age; they are unconformably overlain by Eocene volcanic and sedimentary rocks and by Pliocene and Miocene plateau basalts (Mathews and Rouse, 1984).

LOCAL GEOLOGY

Figure 1-9-2 outlines the general geology of the Noaxe Creek map area. Previous regional mapping by Tipper (1978) and detailed biostratigraphy (Tozer, 1967; Jeletzky and Tipper, 1968) form the basis of divisions within much of the Mesozoic strata; division of Cretaceous rocks into the Taylor Creek and Kingsvale groups, defined for the Taseko Lakes map area by Jeletzky and Tipper, has been modified based on field relationships recognized during the 1986 and 1987 seasons. Results from two independent structural and stratigraphic studies of the Tyaughton and Relay Mountain groups by P.J. Umhoefer, and of the Taylor Creek Group by J. I. Garver are incorporated in Figure 1-9-2 (Umhoefer, Garver and Tipper, in preparation), together with a limited amount of data from assessment reports. The geology along the southern margin of the map sheet has been compiled from

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

previous work (Cairnes, 1943; Leech, 1953; Tipper, 1978; Rusmore, 1985), with the addition of data supplied by B.N. Church (Church *et al.*, this volume).

LITHOLOGY

THE SHULAPS ULTRAMAFIC COMPLEX AND RELATED SERPENTINITE ZONES

The Shulaps ultramafic complex, which extends into the southeastern part of the map area, is located in the Shulaps Range, southwest of the Yalakom River and north of the Bridge River. The complex and its contact relationships were 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, along fault zones to the west and northwest. Later workers (Monger, 1977; Nagel, 1979; Wright *et al.*, 1982) suggested that the Shulaps ultramafic and Bridge River complexes together constitute a dismembered ophiolite. Potter (1983,

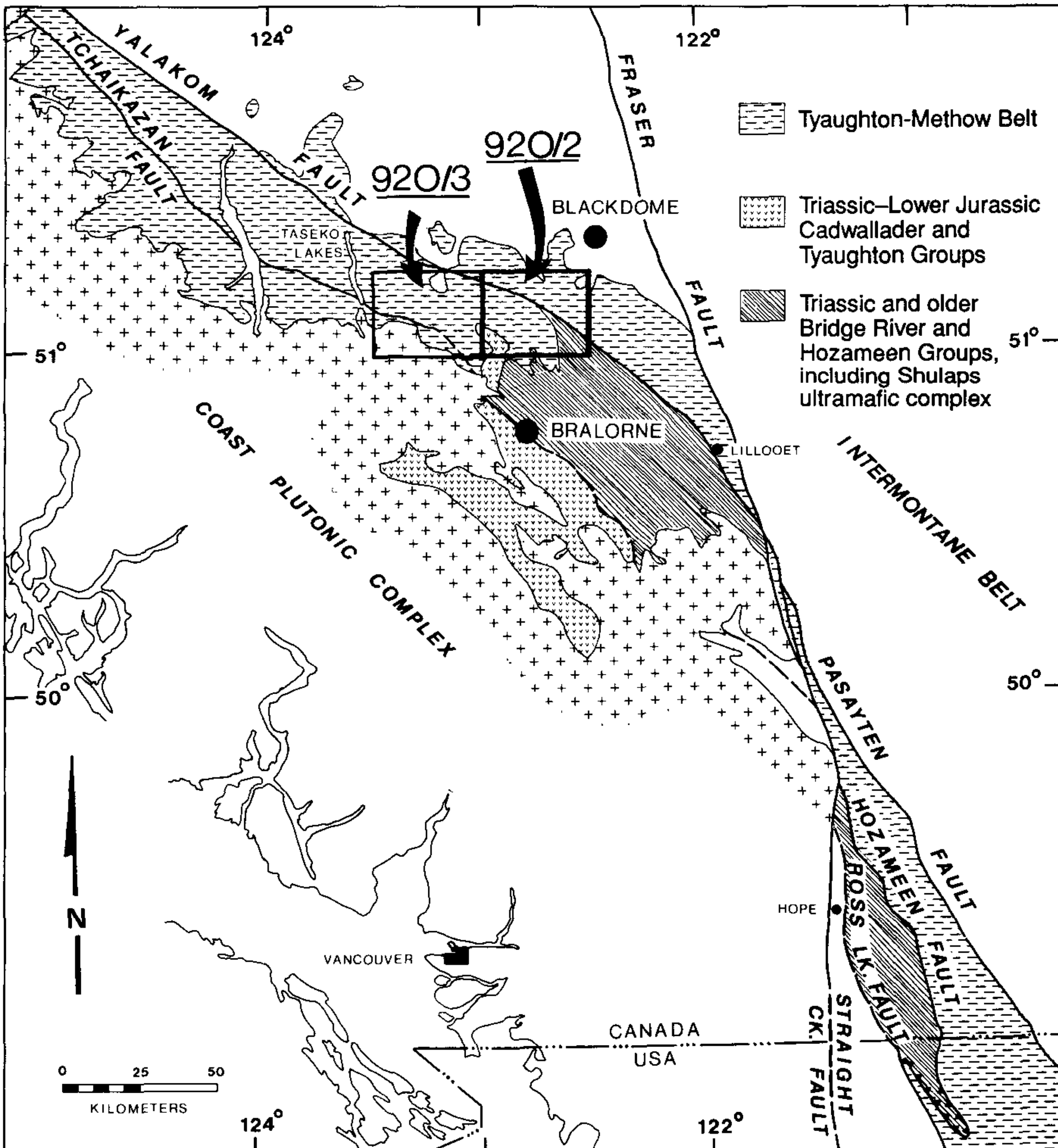
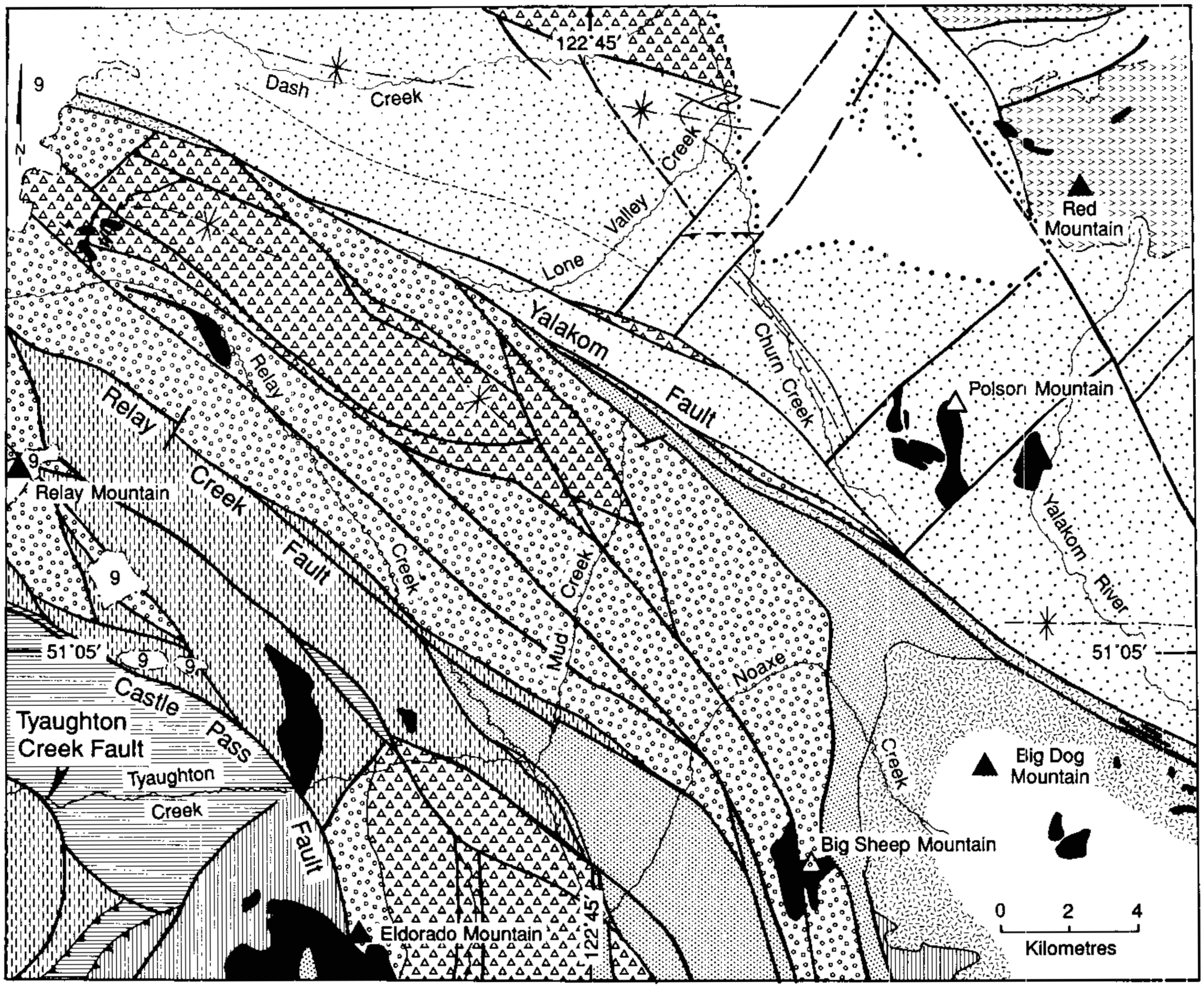


Figure 1-9-1. Location and geological setting, Noaxe Creek and Warner Pass map areas (92/02 and 92O/03).



LEGEND

MIOCENE/PLIOCENE

9 *Plateau lava, basalt flows*

EOCENE (Unit 8)

>>> *Aphyric to porphyritic andesitic to dacitic flows; rhyolite flows and flow breccias; minor volcanic sandstone and siltstone*

UPPER CRETACEOUS

BATTLEMENT RIDGE GROUP (Units 6 and 7)

Polymict conglomerate, sandstone; epiclastics; andesitic flows, volcanic breccia and lapilli tuff

LOWER CRETACEOUS

TAYLOR CREEK GROUP (Units 4 and 5)

Shale, siltstone and sandstone; volcanic conglomerate; chert-pebble conglomerate; micaceous sandstone

JACKASS MOUNTAIN GROUP (Unit 3)

Lithic sandstone and wacke; arkosic sandstone; polymict conglomerate and conglomeratic sandstone; siltstone and shale

MIDDLE JURASSIC TO LOWER CRETACEOUS

RELAY MOUNTAIN GROUP (Unit 2)

Interbedded dark grey shale, grey-brown siltstone, green-grey greywacke and lithic sandstone; grit and conglomerate

UPPER TRIASSIC TO LOWER JURASSIC

TYAUGHTON GROUP (Unit 1)

Massive limestone; red conglomerate; grit and conglomerate interbedded with green sandstone and shale; dark grey to black shale and argillite

UPPER TRIASSIC

CADWALLADER GROUP (Unit UTc)

Mafic volcanics and volcaniclastics; conglomerate; limestone and grey to black argillite

MIDDLE TRIASSIC TO LOWER JURASSIC (Unit BRc)

BRIDGE RIVER COMPLEX

Ribbon and massive cherts; greenstone; argillaceous mélange, argillite and limestone; minor altered gabbro to diorite

PLUTONIC ROCKS

EOCENE AND OLDER

Equigranular to porphyritic quartz diorite to quartz monzonite

Peridotite, harzburgite, dunite, serpentinized peridotite

Figure 1-9-2. Generalized geology map, Noaxe Creek map area.

1986), working along its southern margin, documented a thrust zone at the base of the complex which juxtaposes it against underlying rocks of the Bridge River complex that contain an inverted metamorphic gradient and a transposed foliation; he concluded that thrusting occurred during mid-Jurassic time while the ultramafic rocks were still hot.

Only the northeastern margin of the Shulaps ultramafic complex has been mapped during the present study; here, its contact with rocks of the Jackass Mountain Group to the northeast is defined by a broad, poorly exposed zone of serpentinization along the Yalakom fault. This zone continues to the northwest of the complex for a distance of 16 kilometres. Two other slivers of serpentinite occur elsewhere: along the Yalakom fault in the northwestern part of the map area, and along a fault zone on the west margin of a panel of Bridge River complex, in the vicinity of Tyaughton Creek.

Leech (1953) estimated the main body of the complex to comprise 85 per cent harzburgite, with dunite making up the remainder; variable serpentinization of these rocks is ubiquitous. Pods and lenses of relict harzburgite within foliated serpentinite were observed in the study area north of Quartz Mountain along the Yalakom fault zone, and at the confluence of Mud Creek with Relay Creek, along the fault zone west of the Bridge River complex.

Serpentinized ultramafic rocks associated with some of the major faults in the map area are extensively carbonatized and silicified. These rusty to orange-weathering rocks are composed of silica and magnesian carbonate with fuchsite. Quartz, some of which is chalcedonic, occurs in anastamosing veinlets and irregular masses in a carbonate matrix, with some late, crosscutting veinlets of euhedral magnesite. All stages of hydrothermal alteration of serpentinite can be found in these zones.

THE BRIDGE RIVER COMPLEX (UNIT BRC)

The Bridge River complex (Potter, 1983) includes all rock types previously assigned to the Bridge River Group by Roddick and Hutchison (1973) and to the Fergusson series by Cairnes (1937, 1943) and later, by Church (1987). In this report the term complex is preferred because internal structural complexities and small-scale variability of lithology prohibit measurement of a meaningful type section.

This unit outcrops in the southern and southeastern parts of the area where its thickness is unknown. It comprises, in order of decreasing abundance, intercalated and structurally juxtaposed ribbon chert, greenstone, melange, black argillite, limestone and minor altered gabbro or diorite. Ribbon chert is generally grey, with less common red, brown and green varieties. Individual beds vary from 1 to 10 centimetres thick and are separated by argillaceous partings, but massive chert occurs locally. Greenstone is grey-green to chocolate-brown weathering, generally massive, with rare pillows, and is fine grained, but locally contains amygdules and altered ferromagnesian phenocrysts; volcanic breccias occur in places. These rocks represent submarine volcanism of probable basaltic to andesitic composition. Scattered pods and lenses of light grey, massive crystalline limestone, generally less than 10 metres thick, occur within ribbon chert, argillite and melange. They are rarely traceable for more than 20 metres, but one, located north of the confluence of Relay Creek with Mud Creek, extends for a strike length of 3 kilometres. Melange comprises pods and lenses of all the above lithologies in a foliated argillaceous matrix; the fabric is generally coplanar with bedding in adjacent ribbon chert. These rocks, together with the Shulaps ultramafic complex, are interpreted as an accretionary prism of oceanic provenance (Price *et al.*, 1985; Potter, 1986). No fossils have been obtained from the complex in the study area, but to the south, on the north side of Carpenter Lake, conodonts from carbonates and radiolaria from cherts give a range in age from Middle Triassic to Early Jurassic (Cameron and Monger, 1971; Cordey, 1986).

THE CADWALLADER GROUP (UNIT UTc)

Rocks of the Cadwallader Group are confined to two areas along the southern margin of the map sheet, neither of which was mapped during the present study; their distribution, outlined on Figure 1-9-2, is based on previous work.

The Cadwallader Group, as defined by Roddick and Hutchison (1973) for the Pemberton (east half) map area, to the south of the present study, comprises the Noel, Pioneer and Hurley formations of Cairnes (1937, 1943). Subsequent work by Rusmore (1985, 1987) indicates that the Noel Formation is not a coherent unit and should be abandoned. The revised stratigraphy of the group, based on sections south of Tyaughton Creek and west of Eldorado Mountain (map sheets 92O/02 and 92J/15), comprises a mafic volcanic unit, the Pioneer Formation, at the base, overlain by a lower volcaniclastic member and an upper turbidite member of the Hurley Formation; an estimated total thickness of at least 2000 metres (Rusmore, 1987). Conodonts from the Hurley Formation give a range in age from latest Carnian or earliest Norian to Middle Norian (Rusmore, 1987).

Rocks of the Cadwallader Group have been mapped along the southwest margin of the Shulaps Range by various workers (Leech, 1953; Roddick and Hutchison, 1973; Church *et al.*, this volume). However, contact relationships with adjacent rocks of the Bridge River and Shulaps ultramafic complexes are poorly defined.

THE TYAUGHTON GROUP (UNIT 1)

Cairnes (1943) originally confined the Tyaughton Group to rocks of Triassic age. We also include a distinct unit of overlying Lower to Middle Jurassic sediments, following Tipper (1978), pending its formal separation as a group (H.W. Tipper, personal communication, 1987). The Tyaughton Group is exposed in the southwest part of the map area where it occurs within a structurally complex panel on the north and south sides of Tyaughton Creek.

The lower part of the group is the most extensively exposed and has a minimum composite thickness of 500 metres, based on two measured sections north of Tyaughton Creek (P.J. Umhoefer, personal communication, 1987). It comprises red-weathering interbeds of conglomerate with limestone and volcanic clasts, conglomeratic sandstone and sandstone at the base, overlain by light grey to buff-weathering, massive to thinly bedded limestone with corals and megalodont bivalves. This is in turn overlain by limestone conglomerate with a sandy matrix. The upper part of this unit has a green-weathering sandstone with conglomeratic seams containing volcanic clasts, overlain by green sandstone intercalated with coquina beds of *Cassianella lingulata* (the "Cassianella beds" of Tozer, 1967). At the top, green sandstone and conglomeratic sandstone with pebbles of volcanic rock occur. The depositional environment of these rocks fluctuated between shallow marine and fluvial; provenance of the clastic rocks was probably a volcanic arc, perhaps related to the Cadwallader Group (Rusmore, 1987). The age of this lower unit is from mid to latest Norian (Late Triassic).

The upper part of the Tyaughton Group is exposed along the southwest and northeast margins of the belt and in a structural window along Tyaughton Creek. Its contact with the lower unit is either faulted or not exposed. It also outcrops within an apparently isolated fault sliver to the east of the main belt (H.W. Tipper, personal communication, 1986). The thickness of this unit is unknown due to poor exposures and small-scale folding. It comprises dark grey to black calcareous shale and argillite that contain ammonites of Sinemurian (Early Jurassic) to Early Bajocian (Middle Jurassic) age (Tipper, 1978).

THE RELAY MOUNTAIN GROUP (UNIT 2)

Marine strata of the Relay Mountain Group were first described in detail by Jeletzky and Tipper (1968); they estimated a total thickness of 1500 to 2700 metres in sections north of Relay Mountain. Lithological divisions are, on the whole, difficult to implement because of lateral facies changes and lack of distinctive marker units, with the exception of a lower shaley unit of Middle Jurassic age; division of the overlying strata is facilitated by a well-defined paleontological zonation that ranges from Late Oxfordian (Late Jurassic) to Barremian (Early Cretaceous), based on *Buchia*, ammonites and *Inoceramus* species (Jeletzky and Tipper, 1968). The Relay Mountain Group is undifferentiated in Figure 1-9-2, but the threefold division of Tipper (1978) into Middle Jurassic, Upper Jurassic and Lower Cretaceous strata is followed on the open file map of the Noaxe Creek map sheet (Glover *et al.*, in preparation).

The thickness of the mid-Jurassic part of the Relay Mountain Group is difficult to ascertain because of poor exposures and structural complications, but probably ranges from 300 to 600 metres (Tipper and Jeletzky, 1968). It is most extensively exposed to the west, on the Warner Pass map sheet (Glover and Schiarizza, 1987), but also occurs at the base of a section north of Relay Mountain and in narrow fault-bounded slivers to the south. Similar rocks of uncertain age occur along the Relay Creek road and have been tentatively assigned to this unit. Rocks of this unit comprise recessive, variably rusty weathering dark grey to black shales with minor thin beds of siltstone; sparse lenticular concretions of dark siliceous shale and siltstone occur as discontinuous beds or isolated pods. A mid-Callovian to early Oxfordian age is attributed to this unit, based on *Cardioceras* sp. in the uppermost beds in two sections studied by Jeletzky and Tipper (1968, page 16).

The most widespread exposures of Upper Jurassic and Lower Cretaceous strata of the Relay Mountain Group occur in the western part of the area within fault-bounded blocks that extend into the eastern part of the Warner Pass map area (Tipper, 1978; Glover and Schiarizza, 1987). A faunal assemblage of Tithonian (Latest Jurassic) age (T. Poulton, personal communication, 1987) was collected from strata of the Relay Mountain Group in a fault sliver that strikes northwest from Mud Creek. These rocks comprise intercalated greenish grey lithic wacke and lithic sandstone, rusty brown-weathering grey-brown siltstone, dark grey shale, grit and thin conglomerate interbeds with well-rounded volcanic, granitic and sedimentary clasts. Minor thin limy interbeds and concretions occur in places. They are characterized by abundant and well-preserved buchias, belemnites and to a lesser extent ammonites, which provide the basis for differentiation of Upper Jurassic from Lower Cretaceous strata, although, in general, Lower Cretaceous rocks appear to be more shaley in the study area.

JACKASS MOUNTAIN GROUP (UNIT 3)

The Jackass Mountain Group (Selwyn, 1872; Duffell and McTaggart, 1952) comprises clastic sedimentary rocks, which outcrop over most of the map area lying northeast of the Yalakom fault. These rocks range in age from Barremian to Albian (Early Cretaceous); they are therefore coeval with rocks of the Taylor Creek Group and (?) the uppermost part of the Relay Mountain Group, which outcrop southwest of the fault (Duffell and McTaggart, 1952; Jeletzky and Tipper, 1968). Rocks of Unit 3 are unconformably overlain by Eocene volcanics at Red Mountain and by Miocene plateau lavas near the headwaters of Dash Creek. They are locally in fault contact with upper Cretaceous volcanic rocks of Unit 7, but are separated from other Mesozoic units by the Yalakom fault.

Continuous sections of strata assigned to the Jackass Mountain Group are not present in the map area; moreover, fossils collected from this group are as yet unidentified. Consequently, the proposed stratigraphic relationships between lithologic units described below are preliminary: **Unit 3v**, believed to be at the base of the succession, comprises predominantly massive, marine, volcanic-rich sandstone; this is locally overlain by fluvial to shallow-marine, organic-rich sandstones of **Unit 3f**; in some places these are overlain by marine boulder-cobble conglomerates of **Unit 3cg**; dominantly arkosic turbidites of **Unit 3ak** locally appear to sit stratigraphically above Unit 3v, and may, in part, be equivalent to or younger than Unit 3cg. The distribution of these units is shown in Figure 1-9-3.

UNIT 3v

Rocks of Unit 3v outcrop in a northwesterly trending belt, bounded by the Yalakom fault and related splays to the southwest, and extending from Poison Mountain to the northwest boundary of the map area. This unit consists predominantly of massive, green volcanic-lithic sandstones. Bedding is rarely evident, but locally may be defined by subtle variations in grain size or by trains of siltstone intraclasts. Locally the sandstone occurs as thick graded beds with flutes and

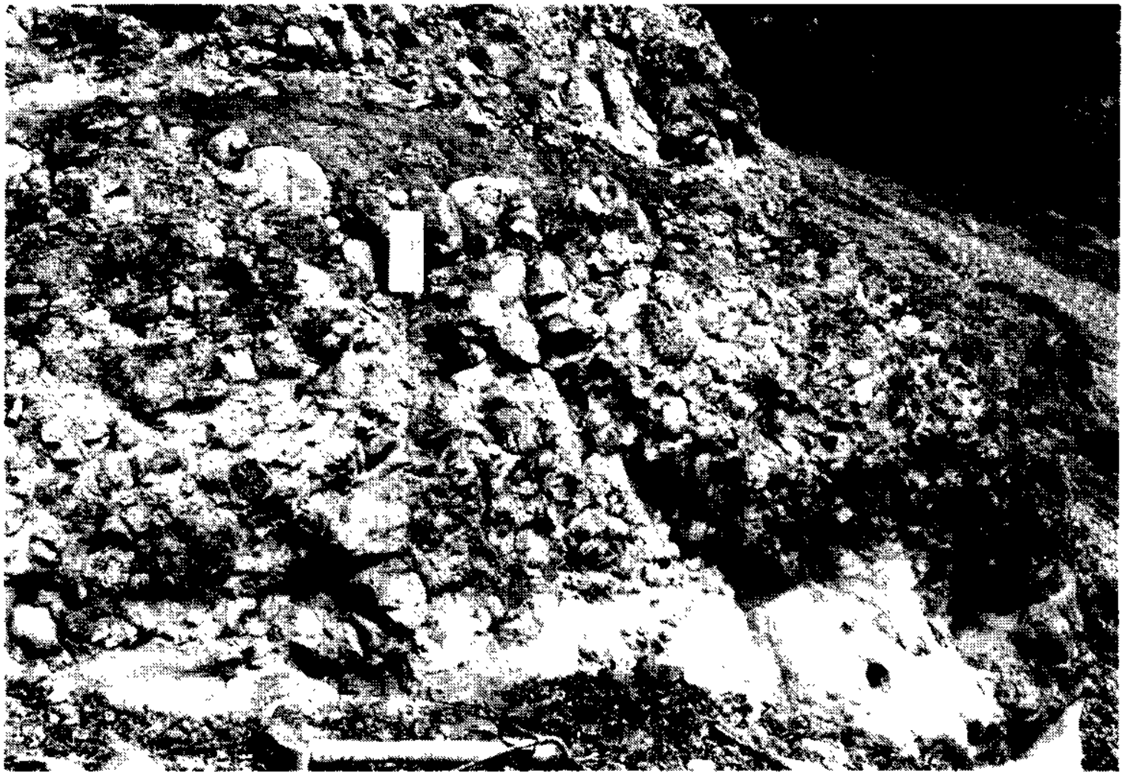


Plate 1-9-1. Interbedded polymict conglomerate and sandstone of the Jackass Mountain Group (Unit 3cg); north of Red Mountain, Noaxe Creek map area.

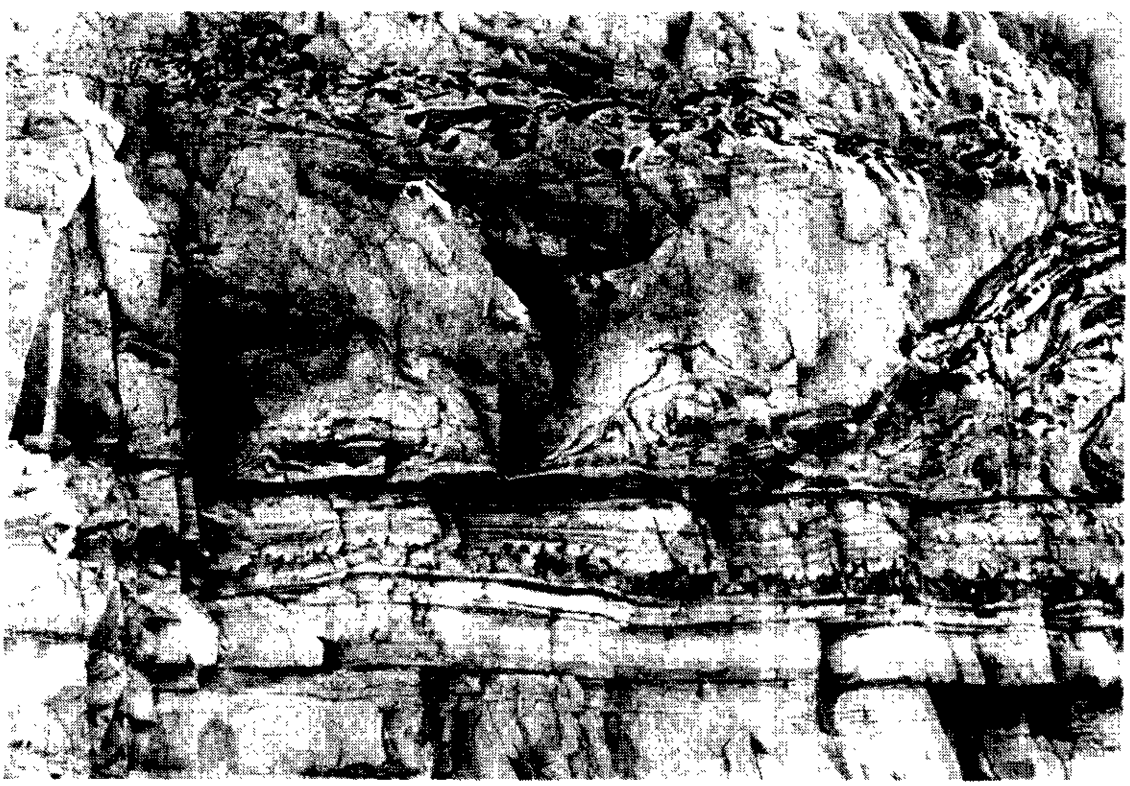


Plate 1-9-2. Arkosic sandstone turbidites of the Jackass Mountain Group (Unit 3ak); Dash Creek, Noaxe Creek map area.

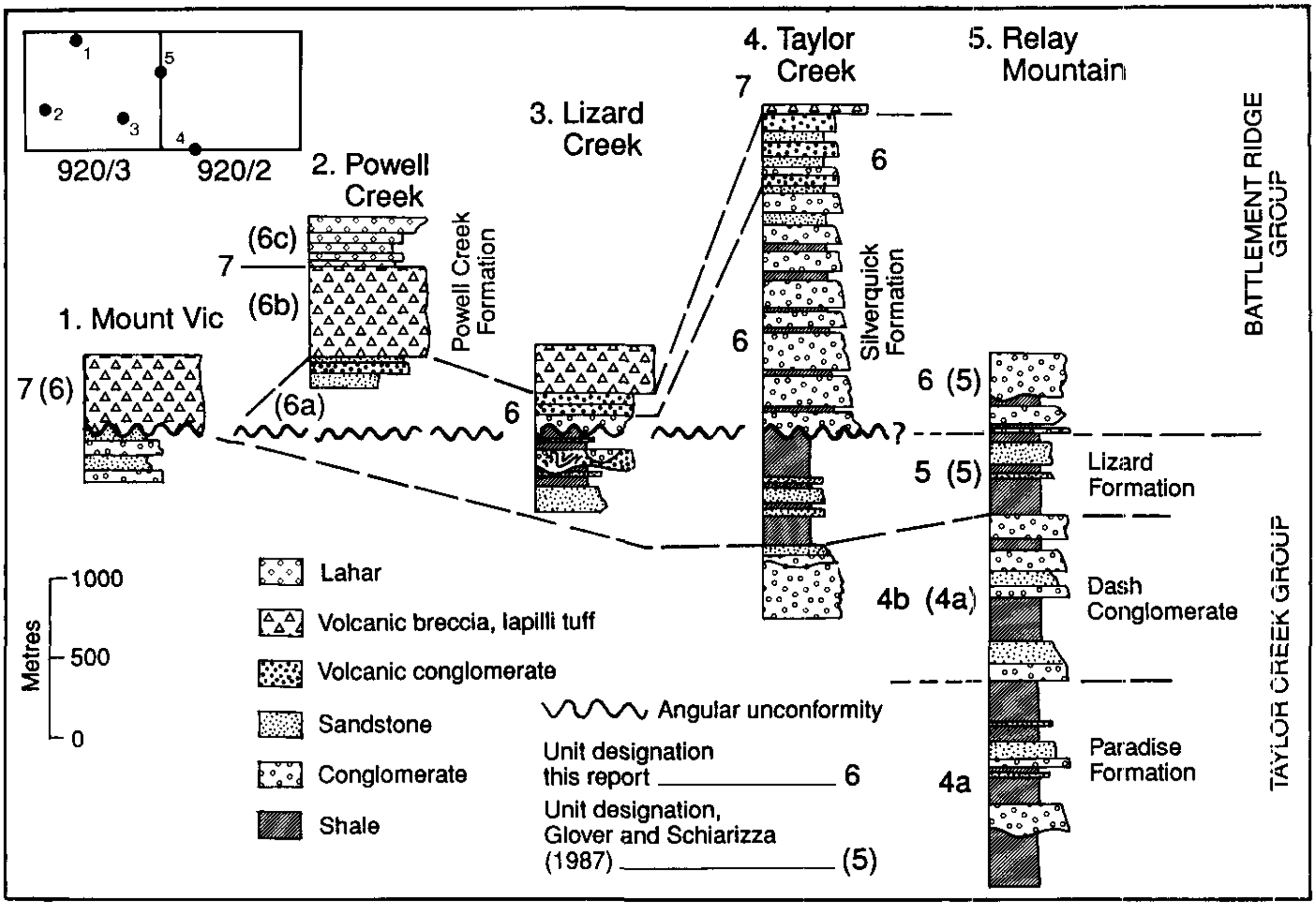


Figure 1-9-3. Stratigraphic sections and correlations within the Cretaceous succession, Noaxe Creek and Warner Pass map areas.

grooves that suggest a turbiditic origin. Dark grey, fine-grained sandstone and siltstone are common in the upper part of the unit where it underlies Unit 3f along the lower reaches of Lone Valley Creek. Several fossil collections, comprising ammonites, pelecypods and gastropods, were made from this area.

Unit 3f

Unit 3f comprises grey to mottled greenish white-weathering, locally crossbedded, volcanic-lithic sandstone which contains abundant tree branches, coal seams, full length fern fossils and other fossil plants. These sediments are typically arranged in fining-upward sequences with basal crossbedded sandstones. Sedimentary structures, facies and fossils suggest fluvial deposition. Unit 3f outcrops north and northwest of Red Mountain, along Lone Valley and Churn creeks south of their confluence, and as a narrow northwest-trending belt west of Poison Mountain. It underlies conglomerates of Unit 3cg in all of these areas and sits above sandstones of Unit 3v in the northern localities; underlying rocks are not exposed in the Red Mountain area.

Unit 3cg

Boulder to cobble conglomerate of Unit 3cg is the most distinctive lithology within the Jackass Mountain Group. It was correlated with similar conglomerates east of the Fraser fault system by Jeletzky and Tipper (1968). The conglomerates contain poorly sorted, predominantly well-rounded clasts of mainly granitic and intermediate volcanic rocks, together with metamorphic and foliated plutonic rocks, chert and clastic sedimentary rocks. In the vicinity of Red Mountain, the conglomerate occurs as beds up to several metres thick which are commonly inverse to normally graded and pass upward into sandstone and siltstone (Plate 1-9-1). These conglomerates probably represent channel deposits within a proximal submarine fan environment. The contact with underlying nonmarine to shallow-marine sandstones of Unit 3f is abrupt and may be an erosional unconformity. This may represent an important time of uplift and subsidence associated with tectonism.

Unit 3ak

Unit 3ak consists mainly of buff-weathering grey arkosic sandstones and gritty to pebbly sandstones, together with minor amounts of pebble conglomerate, siltstone and shale. In most places, its contacts with adjacent units of the Jackass Mountain Group are faulted. However, in the Dash Creek area, where the base of the unit is marked by granitic pebble conglomerates, Unit 3ak apparently sits stratigraphically above massive volcanic-lithic sandstones of Unit 3v.

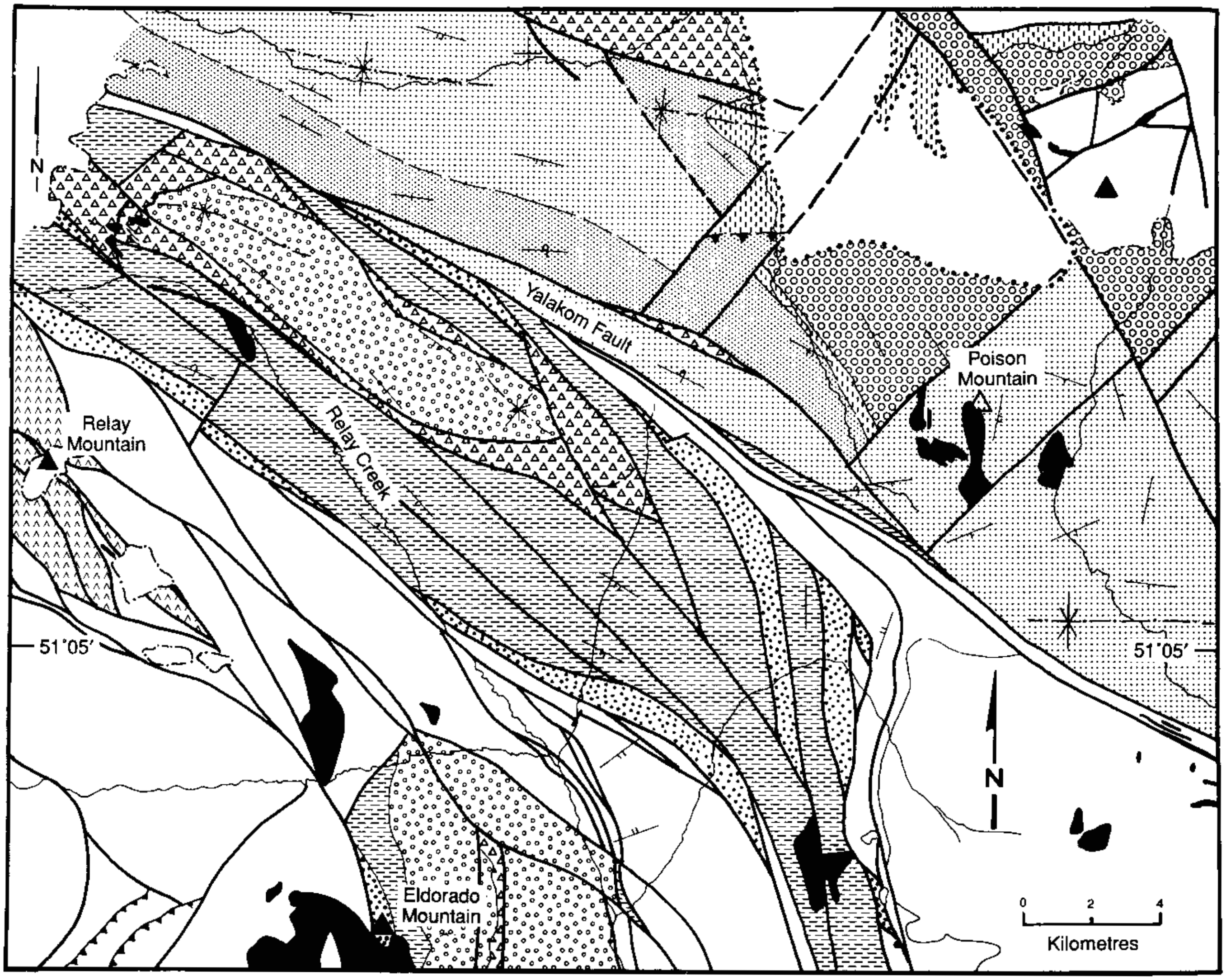


Figure 1-9-4. Distribution of Cretaceous rocks and late Cretaceous and Eocene structural features, Noaxe Creek map area.

The sandstones of Unit 3ak are predominantly coarse-grained arkoses with subordinate volcanic-lithic wackes, commonly containing hornblende, mica (biotite and minor muscovite) and magnetite. Gritty and pebbly sandstones, together with rare beds of pebble conglomerate, contain clasts of feldspar, quartz, granitic rocks, aphyric and feldspar-phyric intermediate volcanics, chert and siltstone. In exposures along the Yalakom River and Dash Creek, the sandstones comprise thick to medium-bedded turbidites with partial and complete Bouma sequences well displayed (Plate 1-9-2); a limited number of measurements suggests that transport was to the west and southwest. Northeast of the Yalakom River these turbidites coarsen upward into thick-bedded sandstone with pebbly seams. Elsewhere they occur mostly as thick, massive or graded sandstone beds with minor shale. Precise stratigraphic relationships cannot be defined between structural panels, but the entire unit belongs to an extensive submarine fan depositional system and may be in part a facies equivalent of Unit 3cg.

THE TAYLOR CREEK GROUP (UNITS 4 AND 5)

The Taylor Creek Group (Cairnes, 1943; Jeletzky and Tipper, 1968) comprises about 2800 metres of lower to upper Albian (mid-Cretaceous) clastic rocks which outcrop southwest of the Yalakom fault. Unbroken stratigraphic sections are not present anywhere in the study area; the stratigraphy has been erected using numerous local sections, facies and provenance analyses and faunal control. The most complete sections are shown in Figure 1-9-4. In this study, the Taylor Creek Group is subdivided into three informal formations defined principally by the composition of clastic material: the Paradise formation (Unit 4a), at the base, overlain by the Dash conglomerate (Unit 4b), which is in turn overlain by the Lizard formation (Unit 5). The dominantly marine strata of the Taylor Creek Group are overlain by a thick section of nonmarine conglomerates at the base of the Upper Cretaceous sequence.

LEGEND

SOUTHWEST OF THE YALAKOM FAULT | NORTHEAST OF THE YALAKOM FAULT

UPPER CRETACEOUS

BATTLEMENT RIDGE GROUP

Southwest of the Yalakom Fault

POWELL CREEK FORMATION
(Unit 7)
Andesitic volcanic breccia and lapilli tuff; fine-grained tuff, basaltic to andesitic flows; epiclastic sediments

SILVERQUICK FORMATION
(Unit 6)
Pebble to cobble polymict conglomerates and minor sandstone; cobble to boulder volcanic conglomerates and volcanic sandstone

Northeast of the Yalakom Fault

Unit 7
Andesitic volcanic breccia, lapilli tuff, fine-grained tuff and epiclastic sediments

LOWER CRETACEOUS

TAYLOR CREEK GROUP

LIZARD FORMATION
(Unit 5)
Interbedded shale and muscovite-rich arkosic sandstone

DASH CONGLOMERATE
(Unit 4b)
Chert-pebble conglomerate, cherty sandstone, siltstone shale and minor tuff

PARADISE FORMATION
(Unit 4a)
Siltstone, shale, sandstone and polymict conglomerate

*JACKASS MOUNTAIN GROUP

Unit 3ak:
Arkosic sandstone, conglomeratic sandstone, siltstone and shale

Unit 3cg:
Polymict boulder to cobble conglomerate, conglomeratic sandstone and sandstone

Unit 3f:
Volcanic-lithic sandstone, siltstone and shale with abundant fossil plant remains

Unit 3v:
Massive, green volcanic-lithic sandstone, minor siltstone and shale

*These units are predominantly lithologic and may not be in stratigraphic order

THE PARADISE FORMATION (UNIT 4A)

The Paradise formation is at least 950 metres thick, comprising a sequence of siltstone, shale, thin-bedded sandstone and conglomerate, all of which were deposited in a submarine fan environment. The conglomerates are dominated by intermediate volcanic clasts but also contain minor metavolcanic, plutonic and chert detritus. Sparse paleocurrent data suggest transport was to the south and southeast. The base of this section is marked by at least 100 metres of concretionary shales which appear to pass transitionally from the underlying Hauterivian shales of the Relay Mountain Group, but this contact is not exposed. Northwest of Relay Mountain thin-bedded turbidites of the upper portion of the Paradise formation pass transitionally into the overlying Dash conglomerate. Similarity in composition and a north-to-south transport direction suggest that this unit may be the lateral equivalent of the volcanic-rich sediments of the Jackass Mountain Group (Unit 3v), northeast of the Yalakom fault.

THE DASH CONGLOMERATE (UNIT 4B)

The Dash conglomerate comprises at least 900 metres of chert-pebble conglomerate, cherty sandstone, siltstone, shale and minor interbedded tuff. Northwest of Relay Mountain, on the eastern margin of the Warner Pass map area, the Dash conglomerate passes upward from turbiditic sands and conglomerates to fossiliferous shallow-marine to nonmarine fan-deltaic deposits. The conglomerates contain 70 per cent chert and metachert, 25 per cent felsic volcanics, and 5 per cent greenstone. Sandstones are dominated by chert, with minor sedimentary and felsic to mafic volcanic grains, and quartz-mica tectonites. Chromite, iron oxides, garnet and aluminosilicates dominate the heavy mineral fraction. Typical of fan-deltaic deposits, the paleocurrents are scattered, but suggest a general westward transport direction. The abundance of chert, metachert, sedimentary rock fragments and common detrital chromite suggests that the source area was the locally uplifted Bridge River and Shulaps ultramafic complexes.

LIZARD FORMATION (UNIT 5)

The Lizard formation, at the top of the sequence, sharply overlies the Dash conglomerate. The basal deposits are characterized by at least 100 metres of shale; the unit passes upward into thin to medium-bedded muscovite-rich quartzofeldspathic sandstones and shales which were deposited in an extensive submarine fan system. In the Taylor Creek drainage the Lizard formation is 850 metres thick (Section 4, Figure 1-9-4); further to the west, near Relay Mountain, it is about 500 metres thick. The sandstones are rich in quartz (28 to 41 per cent), plagioclase (23 to 35 per cent), intermediate to felsic volcanic clasts (14 to 31 per cent) and minor metamorphic clasts; detrital chert is almost absent. Metamorphic clasts, 2.5 per cent muscovite and minor garnet, indicate a partial source of schistose metasedimentary rocks. Paleocurrents are to the northeast everywhere in the basin; measurements were taken from both overturned and upright panels. These shales and turbidites represent a rapid and widespread deepening of the basin that was probably tectonically controlled. The Lizard formation is sharply overlain by predominantly nonmarine conglomerates of the Silverquick formation.

THE BATTLEMENT RIDGE GROUP (UNITS 6 AND 7)

The Battlement Ridge group is proposed as an informal name for sedimentary, volcaniclastic and volcanic rocks of latest Albian (?) (mid-Cretaceous) to late Cenomanian (Late Cretaceous) age, previously assigned to the Kingsvale Group (Rice, 1947) by Tipper and Jeletzky (1968). Thorkelsen (1985), working in the type area near Kingsvale, south of Merritt, has shown that rocks previously attributed to the Kingsvale Group are part of the Spences Bridge Group, based on field relationships and radiometric age determinations. This group comprises a sequence of intercalated andesitic to rhyolitic lavas and clastic rocks of mid-Cretaceous age. It may, in part, be time-equivalent to the Battlement Ridge Group of this report, but is separated from the study area by major tectonic boundaries such as the Fraser and Yalakom fault systems.

The Battlement Ridge group is informally subdivided into a clastic unit at the base, the Silverquick formation (Unit 6), and a gradationally overlying volcanic unit, the Powell Creek formation (Unit 7). The base of the group is defined by an angular unconformity that separates it from the underlying Mesozoic strata; this relationship is well exposed in the Warner Pass map area (Glover and Schiarizza, 1987), and its presence is inferred at the base of the group in the Taylor Creek basin, on the Noaxe Creek map sheet (Figure 1-9-4).

THE SILVERQUICK FORMATION (UNIT 6)

The Silverquick formation comprises two members; the lower member is composed of poorly stratified, clast-supported and locally crossbedded pebble to cobble conglomerates with minor sandstone interbeds (less than 10 per cent). Sandstones are commonly maroon weathering. Finer grained intervals contain abundant stick and leaf fossils. The conglomerates contain mainly chert clasts, together with sedimentary and intermediate volcanic clasts, and a minor proportion of metamorphic and plutonic clasts. Paleocurrents suggest derivation from the east. This member attains a maximum thickness of 1500 metres in the Taylor Creek area; here, these rocks are interpreted as braided river deposits. To the northwest, in the northeast part of the Warner Pass map area, this member is thinner and was probably deposited in a submarine fan environment. This unit also occurs in the core of a syncline, northeast of Relay Creek, on the Noaxe Creek map sheet.

The upper member of the Silverquick formation includes similar braided river deposits but the conglomerates are dominated by basic to intermediate volcanic clasts that vary from cobble to boulder size. Although many beds are composed exclusively of these lithologies, they are clearly interbedded with chert-rich conglomerates typical of the lower member. The upper member is only exposed in the Taylor Creek area on the Noaxe Creek map sheet, where it grades upward into volcanic breccia of the overlying Powell Creek formation. It is correlated with the dominantly volcaniclastic rocks of Unit 6a in the Warner Pass map area (Glover and Schiarizza, 1987).

THE POWELL CREEK FORMATION (UNIT 7)

This formation is equivalent to Units 6b and 6c, in the Warner Pass map area (Glover and Schiarizza, 1987); the proposed type section, northwest of Powell Creek, has a total thickness of 1550 metres, but the top is not exposed. It comprises dominantly volcanic breccia and lapilli tuff of andesitic to basaltic composition, intercalated with finer grained tuff, basaltic to andesitic flows and epiclastic sediments. It can be locally subdivided into a lower massive unit and an upper bedded unit; the latter is dominated by andesitic lahars and epiclastic sediments. These units are best exposed in the vicinity of Powell Creek and Battlement Ridge in the Warner Pass map area, but also occur northeast of Relay Creek on the Noaxe Creek map sheet. Elsewhere in the present study area the lower and upper parts of the Powell Creek formation are undifferentiated.

VOLCANIC ROCKS OF PROBABLE EOCENE AGE (UNIT 8)

This unit comprises predominantly andesites to rhyolites; it extends from Red Mountain to the northeastern corner of the map area, where it attains a thickness of about 800 metres. These rocks lie unconformably above conglomerates of the Jackass Mountain Group (Unit 3b). They comprise mainly reddish brown-weathering, platy to massive, aphyric andesitic to dacitic flows; they are locally vesicular and/or amygdaloidal and are columnar jointed in places. Flow breccias and/or brick-red regolith zones locally mark flow contacts. Massive andesite flows at the base of the succession are porphyritic, and contain phenocrysts of pyroxene, hornblende and plagioclase. Discontinuous units of light grey to white-weathering flow-banded rhyolite, commonly with phenocrysts of quartz and/or feldspar, occur at three different stratigraphic levels within the Red Mountain succession. The most extensive unit is locally more than 150 metres thick. The rhyolites include significant zones of flow breccia, vesicular glass and glassy breccia. Siliceous sinter (?) deposits displaying botryoidal growth structures occur locally.

Sedimentary rocks are uncommon in the Red Mountain succession. They comprise lenses of rusty brown and chalky white-weathering thin-bedded volcanic sandstone and siltstone which range up to several tens of metres thick. They occur along rhyolite-andesite contacts, or as lateral equivalents of rhyolite. Volcanic conglomerate outcrops at one locality, 2.5 kilometres northeast of Red Mountain summit, where it separates a rhyolite unit from underlying andesite. It comprises unsorted, angular dacitic to andesitic volcanic clasts, up to 80 centimetres in size, within a friable siltstone matrix. North-northeast-trending dykes of andesite and felsite are locally common. Dykes of the same orientation and plugs, composed of quartz-biotite-hornblende-feldspar porphyry, appear to grade into flow-banded rhyolite in places.

The Red Mountain volcanics are not dated. They are assigned an Eocene age on the basis of their unconformable relationship to underlying Jackass Mountain Group rocks, and their lithologic similarity to volcanic rocks to the north and northeast which have yielded several Eocene radiometric ages (Mathews and Rouse, 1984). These Eocene volcanics host the Blackdome epithermal gold deposit 10 kilometres to the north.

MIOCENE PLATEAU LAVAS (UNIT 9)

Flat-lying plateau basalts of Unit 9 unconformably overlie older rocks in the western part of the map area. The basalts occur as medium to dark grey, commonly rusty brown-weathering flows intercalated with minor amounts of volcanic breccia and volcanic conglomerate. They outcrop most extensively along the western edge of the map area, north of Relay Creek, where they overlap the Yalakom fault and adjacent rock units along an erosional surface with a shallow regional dip to the north. The unit is about 350 metres thick in this area. The basalts cap several ridges to the south, including Relay Mountain, where 300 to 350 metres of volcanic flows are exposed.

INTERMEDIATE TO FELSIC INTRUSIVE ROCKS

Porphyritic to equigranular intrusive rocks, ranging in composition from diorite to granodiorite, occur as small stocks, plugs and dyke swarms distributed sporadically through the map area. Most of these are Early Tertiary and (?) Late Cretaceous in age.

A small stock, composed of equigranular biotite-hornblende quartz diorite and granodiorite, occurs along the southern boundary of the map sheet, and outcrops mainly to the west and south of Eldorado Mountain. It intrudes the fault contact between the Taylor Creek Group on the east and Cadwallader Group on the west. An age of 63 Ma (Early Paleocene) has recently been obtained by potassium-argon dating of biotite from the stock (K.M. Dawson, personal communication, 1987).

Hornblende feldspar porphyry occurs as dyke swarms and small plugs within Units 5 and 7 between Relay Creek and the Yalakom fault. It comprises variable proportions of hornblende and feldspar phenocrysts, up to several millimetres in size, within a massive, grey aphanitic matrix. Carbonate and propylitic alteration is common within the porphyry and adjacent country rocks. These rocks are similar to hornblende feldspar porphyries which outcrop extensively in the Warner Pass map area (Unit A of Glover and Schiarizza, 1987). There, they were thought to be related to volcanics of the Powell Creek formation (Unit 7) of this report, and to be in part Early Tertiary in age. This will be tested by potassium-argon age determinations on samples collected from both Warner Pass and Noaxe Creek map areas during the past summer.

Hornblende feldspar porphyry also occurs in the southeastern corner of the map area, where it cuts ultramafic rocks of the Shulaps complex, mainly east and southeast of Big Dog Mountain. These porphyries locally contain biotite and grade into equigranular diorite and quartz diorite (Leech, 1953). Weakly sheared hornblende feldspar porphyry dykes, from which a sample was taken for radiometric dating, also occur locally within the Yalakom fault zone, east of Big Dog Mountain.

Light grey to white-weathering porphyritic bodies containing variable proportions of feldspar, hornblende, biotite and quartz phenocrysts intrude the Eocene (?) volcanic rocks at Red Mountain. Similar porphyries occur at Big Sheep Mountain, where they may be associated with felsic extrusive rocks (Leech, 1953), and as several stocks and plugs north of Tyaughton Creek. These porphyritic bodies are commonly carbonate altered, and locally contain zones of argillic alteration. They are probably Eocene in age, based on their close association with Eocene (?) volcanic rocks at Mount Sheba (Glover and Schiarizza, 1987) and at Red Mountain. Samples from these two areas, and of similar porphyries elsewhere in the map area, were collected for radiometric dating.

Intrusive rocks in the vicinity of Poison Mountain consist of hornblende feldspar porphyry and hornblende-biotite-feldspar porphyry. They occur as three separate stocks which outcrop south, southwest and west of the summit. A fourth stock, which is dominantly feldspar-phyric, occurs 3 kilometres to the east. Porphyry copper-gold mineralization occurs within and adjacent to the outer portion of the southwestern stock, where biotite partially replaces hornblende. Several potassium-argon dates obtained on biotite and hornblende from the mineralized stock give ages of 57 and 59 Ma (Late Paleocene to Early Eocene) (W.J. McMillan, personal communication, 1987).

STRUCTURE

OVERVIEW

The Yalakom fault divides the map into two parts. Northeast of the fault relatively widely spaced northwest and northeast-trending faults dominate the map pattern in an area mosty underlain by gently dipping sandstones and conglomerates of the Jackass Mountain Group. To the southwest, an intricate network of northwest-trending anastamosing faults, some of which merge with the Yalakom fault, separates most of the map units into relatively small, structurally discrete, lenticular blocks. Bedding attitudes are generally steep to vertical, especially close to high-angle faults, and their strikes are commonly to the northwest, but northeast trends occur locally in fault slices, probably due to rotation during strike-slip movement. Small-scale folds only occur in the less competent units and are generally disharmonic; fold axes vary in plunge but usually trend toward the northwest.

This map pattern, together with the nature and orientations of small-scale structures, kinematic indicators and the general lack of any penetrative deformation, indicate that Mesozoic rocks in the area underwent a protracted period of major dextral wrench faulting under brittle conditions at high crustal levels.

The mid-Cretaceous deformational event, documented by structures in rocks of the Taylor Creek Group and older units in the Warner Pass area (Glover and Schiarizza, 1987), is obscured by the later dextral wrench faulting in the present study area. However, there is some evidence for pre-middle Jurassic deformation in the older rocks of the Tyaughton Group, Cadwallader Group and Bridge River complex.

POST-MIDDLE CRETACEOUS STRUCTURES

THE YALAKOM FAULT

The Yalakom fault has a length of at least 230 kilometres; estimates of dextral strike-slip offset along the fault range from 80 to 190 kilometres (Tipper, 1969). Monger (1985) has correlated the Yalakom and Hozameen faults across the Fraser fault system, to which he attributed 70 to 90 kilometres of dextral strike-slip displacement that occurred during Late Cretaceous and/or Early Tertiary time. Potter (1983, 1986) proposed that the Yalakom and Fraser faults belong to the same system and suggested that significant dextral displacement occurs on both from 40 to 45 Ma.

In the map area the fault is poorly exposed, but its trace indicates that it is steeply dipping. For much of its length it is the locus of a narrow discontinuous zone of serpentinized peridotite. The most compelling evidence for transcurrent movement along the fault derives from the presence of contrasting mid-Cretaceous successions on either side, a feature that was pointed out by previous workers (for example, Kleinspehn, 1982, 1985). Kinematic indicators such as fibrous mineral growth and slickensides along and adjacent to the fault, northeast of Mud Creek, indicate that at least some of this movement was right lateral in nature.

Volcanic rocks of the Powell Creek formation, truncated by the fault in the northern part of the area, provide a probable upper limit of Cenomanian (earliest Late Cretaceous) for transcurrent movement along the fault. Plateau basalts of probable Miocene age, which truncate the fault in the Dash Creek area, currently provide the only lower constraint in the Noaxe Creek map area. However, forthcoming potassium-argon radiometric dates of hornblende from porphyry dykes, emplaced along the fault zone southwest of the Yalakom River, may provide a minimum age for the early history of movement.

STRUCTURES NORTHEAST OF THE YALAKOM FAULT

In this area, the structural pattern is dominated by northwest and northeast-trending faults and by east-trending folds which are probably related to dextral movement along the Yalakom fault system. Around Red Mountain faults that trend north-northwest to east-northeast may be younger structures related to Eocene and/or later dextral movement along the Fraser fault system.

Several northeast-trending faults were mapped in the southeastern part of the belt, where they are inferred on the basis of abrupt truncations of lithologic units or changes in facing direction. Faults of this group were also observed in outcrops along Churn Creek, in the north-central part of the area. The orientation of these faults is that expected for antithetic left-lateral strike-slip faults related to right-lateral displacement along the Yalakom fault. Left-lateral movement was demonstrated locally along minor faults of this orientation northeast of the Yalakom River.

An east-trending syncline occurs within the Jackass Mountain Group north of the Shulaps ultramafic complex, where it is outlined by exposures of Unit 3ak turbidites along the Yalakom River; this fold is apparently truncated to the west by the Yalakom fault. An easterly trending syncline is inferred from opposing dip and facing directions within Unit 3ak on either side of Dash Creek. Its probable extension to the east of a northwest-trending fault was mapped in rocks of Unit 3f along Churn and Lone Valley creeks. These folds may comprise part of a right-handed fold set (Campbell, 1958; Wilcox *et al.*, 1973) related to dextral movement along the Yalakom fault.

Rocks of Units 3 and 8 are bounded to the west by the north-northwest-trending Red Mountain fault. This fault apparently truncates or offsets a number of northeast-trending faults. One of these earlier faults, which separates Units 3cg and 3ak, north of Poison Mountain, can be matched with a similar fault on the opposite side of the Red Mountain fault, east of the upper Yalakom River. If this correlation is valid then the Red Mountain fault may have 4 kilometres of apparent right-lateral displacement along it.

Bedding attitudes in the volcanic succession of Unit 8 at Red Mountain are generally shallow dipping. The structure within these rocks is dominated by north-northeast-trending extensional faults and fractures that are probably Eocene and/or younger in age (Figure 1-9-5). These may have developed in conjunction with dextral wrench fault along the Fraser fault system (Mathews and Rouse, 1984; Price *et al.*, 1985).

North of Red Mountain an easterly trending fault is inferred separating sandstones of Unit 3 from volcanic rocks of Unit 8 which outcrop along the northern edge of the map area. This probably represents a vertical displacement of a few hundred metres, but the fault is not exposed and its dip is unknown. This fault was interpreted as part of the Hungry Valley thrust by Tipper (1978), and was inferred to extend to the west, across Churn and Dash creeks. Here, a northwest-trending fault that separates the Jackass Mountain Group from the Powell Creek formation is closely constrained by outcrops along these creeks; highly fractured rocks of Unit 3 are cut by northwest-striking, predominantly steeply dipping fault surfaces which locally display shallowly plunging slickensides. These features indicate strike-slip movement along this fault zone rather than thrusting, as proposed by Tipper.

STRUCTURES SOUTHWEST OF THE YALAKOM FAULT

Three major northwest-trending faults of probable regional extent that occur southwest of the Yalakom fault can be traced across the map area: the Relay Creek fault, the Castle Pass fault and the Tyaughton Creek fault. To the northwest these faults strike subparallel to the Yalakom fault but all swing sharply to the south at about the latitude of the Shulaps ultramafic complex. There is evidence that these are wrench faults; a minimum right-lateral offset of 8 kilometres along two of them is proposed.

The Relay Creek Fault

The Relay Creek fault has been traced along Relay Creek from east of Big Creek on the Warner Pass map sheet (Glover *et al.*, 1987), to the southeast, across the present study area, from where it probably merges with the Marshall Creek fault (Roddick and Hutchison, 1973; Woodsworth, 1977; Potter, 1983, 1986). If this correlation is valid, it would give the Relay Creek – Marshall Creek fault system a total length of at least 145 kilometres to its truncation by the Fraser fault system, south of Lillooet (Potter, 1986). In the northwest part of the Noaxe Creek map area the Relay Creek fault separates steeply dipping to vertical, northeast-facing strata of the Taylor Creek Group on the northeast from older, generally southwest-facing strata of the Relay Mountain Group on the southwest.

A minimum estimate of 8 kilometres right-lateral offset is obtained by using the truncation of the Upper Jurassic Relay Mountain Group along the fault from Noaxe Creek to Relay Creek (Figure 1-9-6). The timing of movement along this fault is poorly constrained, but the Marshall Creek fault, its correlative in the Bridge River area, displaces probable Eocene volcanic rocks and is itself truncated by the Mission Ridge pluton (Potter, 1983), biotite from which has yielded a potassium-argon date of 44 Ma (Woodsworth, 1977). Thus, this part of the fault system was active in the Middle Eocene.

The Castle Pass Fault

This fault was traced from near Graveyard Creek, in the Warner Pass map area (Glover *et al.*, 1987), to the southeast, into the Noaxe Creek map area, where it forms the northeast boundary of the principal exposures of Tyaughton Group rocks. South of Tyaughton Creek it truncates rocks of the Cadwallader Group on the west; east of the fault a 5-kilometre-wide, overturned, easterly dipping panel, comprising rocks of the Taylor Creek and Battlement Ridge groups, provides evidence for post-Cenomanian large-scale folding of rocks in this area. A recent potassium-argon radiometric age determination of 63 Ma (Paleocene) on biotite from the Eldorado stock (K.M. Dawson, personal communication, 1987), which truncates the Castle Pass fault along the southern margin of the map area, provides a lower age limit for movement along the fault.

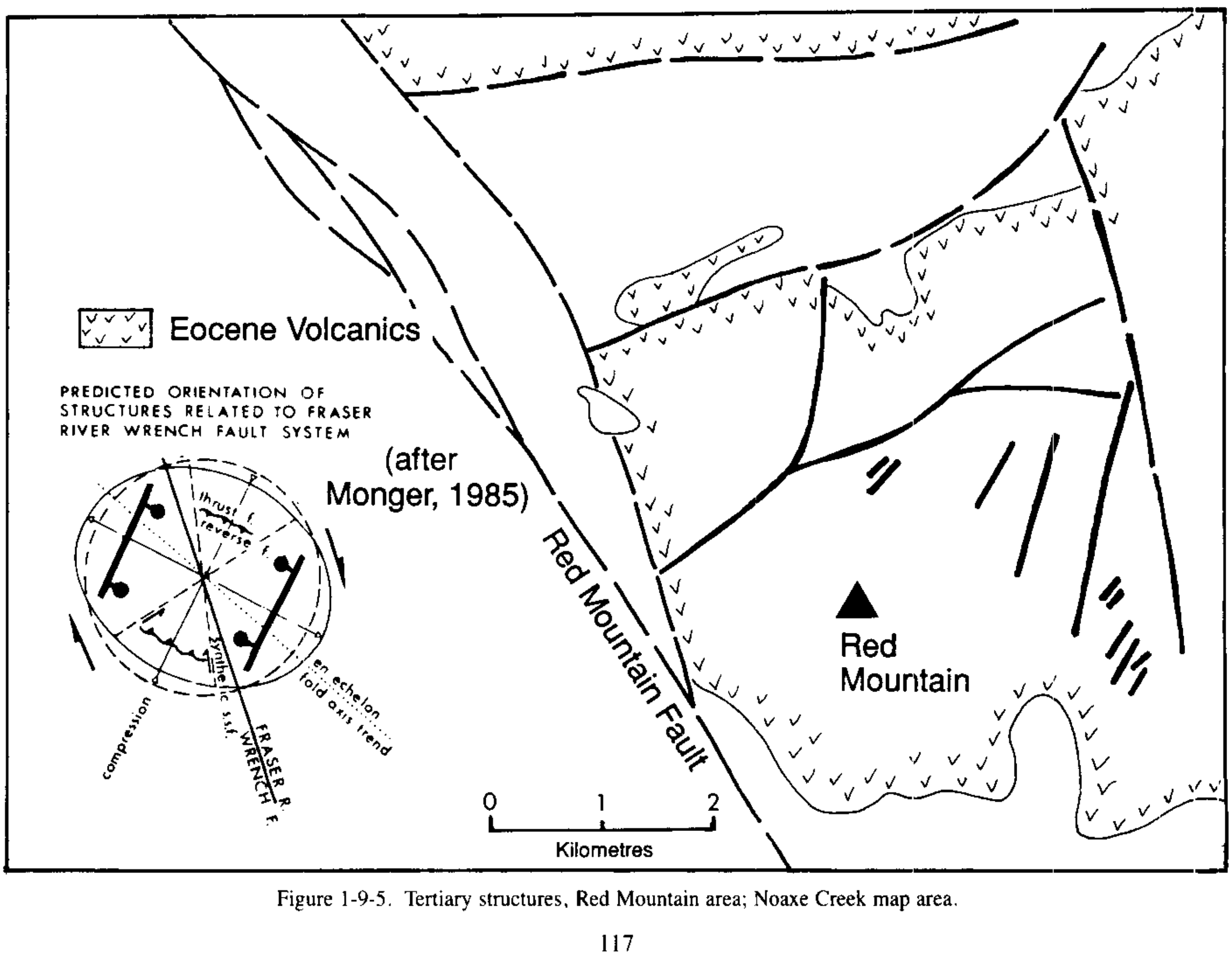


Figure 1-9-5. Tertiary structures, Red Mountain area; Noaxe Creek map area.

A complex array of upwardly fanning high-angle reverse faults, similar to that described by Wilcox *et al.* (1973), is rooted along the Castle Pass fault in the western part of the map area (Umhoefer and Garver, 1987, in preparation) and provides evidence for transcurrent movement along the major fault. However, the magnitude of displacement is unknown.

The Tyaughton Creek Fault

This fault is poorly exposed for most of its length from east of Lorna Lake, in the Warner Pass map area (Glover *et al.*, 1987) to Spruce Lake in the southwest part of the Noaxe Creek map area, from where it apparently swings to the south (Cairnes, 1943; Tipper, 1978). The Tyaughton Group occurs mostly on the northeast side of the fault, but an isolated klippe of rocks attributed to this unit south of the fault near Lorna Lake (Glover and Schiarizza, 1987) indicates a right-lateral offset in the order of 10 kilometres (B to B′, Figure 1-9-6); supporting evidence is provided by matching the truncations of an older, northeast-trending fault on the Warner Pass map sheet, which gives a right-lateral offset of 8 kilometres (C to C′, Figure 1-9-6).

The timing of movement along this fault is unknown, but possible transcurrent offset of the Powell Creek formation along its western extension in the Warner Pass map area, suggests a post-Cenomanian age. This is contrary to our previous interpretation of largely vertical movement along this section of the fault, and further work is required in order to test these hypotheses.

Other Post-middle Cretaceous Structures Southwest of the Yalakom Fault

North-northwest-trending faults of shorter strike length merge with or are truncated by the major faults and are distributed throughout the intervening panels. In general, these faults juxtapose progressively younger rocks to the west. Their orientation relative to the major faults matches that of early-formed synthetic dextral strike-slip faults (Wilcox *et al.*, 1973) which is, in general, supported by measurements of fibrous mineral growth and slickenside orientations along them. However, many of these faults show evidence of late dip-slip movement.

In the panel northeast of the Relay Creek fault, bedding attitudes outline a complex, northwest-trending, doubly plunging syncline in rocks of the Silverquick formation (Unit 6), which are surrounded by and in fault contact with rocks of the Powell Creek formation (Unit 7). This contact is defined by northwest-trending faults that are subparallel to the Yalakom and Relay Creek faults on the northeast and southwest limbs of the fold. However, along the northwestern

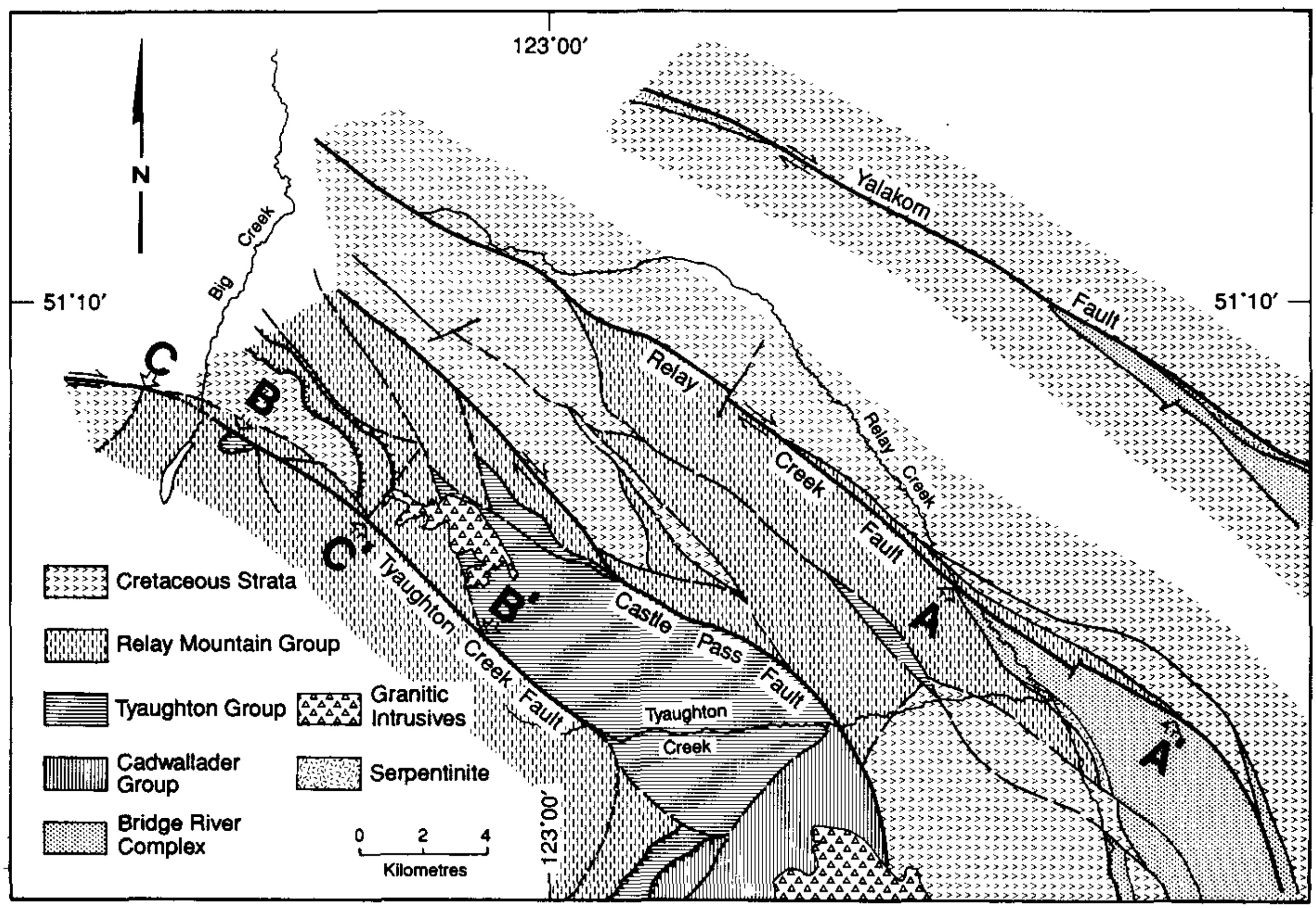


Figure 1-9-6. Probable piercing points and resulting right-lateral offsets along the Relay Creek and Tyaughton Creek fault zones, Noaxe Creek and Warner Pass map areas.

closure of the syncline, where rocks of Unit 7 apparently structurally underlie rocks of Unit 6, their contact may represent an early thrust that was subsequently folded. The outline of this syncline is reflected on a broader scale by stratigraphic and structural facing in the older rocks of the Taylor Creek Group to the northeast and southwest. This fold probably formed before or during the early stages of strike-slip faulting.

PRE-MIDDLE CRETACEOUS STRUCTURES

In the southwest part of the map area, excellent exposures and the well-defined internal stratigraphy of the Tyaughton Group permit detailed mapping of thrust faults, which are folded about axes with quite variable orientations; these folds are, in turn, truncated by north-northwest-trending high-angle faults, some of which have dextral strike-slip along them (P.J. Umhoefer, personal communication, 1987). The complex structural pattern that results implies polyphase deformation. Rusmore (1987) concluded that two phases of folding existed in rocks of the Cadwallader Group to the south. Similarly, Potter (1986), working to the southeast, found evidence for two phases of deformation in rocks of the Bridge River complex. These workers propose that these older rocks underwent a major deformational event in mid-Jurassic time (Umhoefer *et al.*, 1987). Small-scale north-easterly directed thrust faults observed in the Bridge River complex at the confluence of Noaxe and Tyaughton creeks may also belong to this phase of deformation. However, the complexity of structures typically associated with zones of major strike-slip faulting, which the Noaxe Creek map area undoubtedly represents, precludes this conclusion at this point in our study.

MINERAL OCCURRENCES

Mineral occurrences in the Noaxe Creek map area fall into two distinct groups: (1) generally low-grade gold and base metal occurrences with pyrite, minor arsenopyrite and/or pyrrhotite, associated with granitic intrusive rocks; and (2) minor cinnabar, stibnite and/or scheelite occurrences, associated with fault zones.

LOW-GRADE GOLD AND BASE METAL OCCURRENCES

Nearly all these occurrences appear to be small, with the exception of Poison Mountain, where significant chalcopyrite and molybdenite mineralization, with associated low gold values, occurs in a porphyry setting. Many of these prospects are hosted by carbonate and locally argillic-altered granitic stocks and dykes that are generally porphyritic. Some of the larger stocks exhibit chlorite-epidote alteration. Many of the dykes are structurally controlled by northwesterly trending faults. These mineral occurrences appear to range from an epithermal setting, for example, Big Sheep Mountain, to a porphyry setting, such as Poison Mountain. The associated intrusive rocks are probably Tertiary in age. The Blue Creek occurrences, Big Sheep Mountain and showings near Eldorado Mountain appear to be of this type (Cairnes, 1943; Dawson, 1982) but fall within the southern part of the map sheet, not covered during the 1987 field season. The principal occurrences of this type elsewhere on the map sheet are the upper Relay Creek claims and the Poison Mountain deposit, described below.

UPPER RELAY CREEK

Alteration and mineralization along upper Relay Creek are associated with a swarm of sills, dykes and small plugs which intrude volcanic and sedimentary rocks of Units 5 and 7. Interest in the area dates back to 1970 when it was explored for porphyry copper-molybdenum mineralization. More recent exploration by Consolidated Barrier Reef Resources Ltd. (now MFC Mining Finance Corporation) and by Esso Minerals Canada, the present operator, has concentrated on the area's gold potential. Carbonate alteration is widespread within both intrusive and country rocks; it is locally accompanied by chlorite-epidote alteration, silicification and minor clay alteration. Disseminated pyrite and/or pyrrhotite are common within and adjacent to the porphyries, and are locally accompanied by minor amounts of chalcopyrite, molybdenite, arsenopyrite and sphalerite. More intense pyritization is commonly associated with zones of silicification. Present interest is focused on the northwestern end of the altered belt, where gold values of 1 to 10 grams per tonne have been obtained from narrow quartz-carbonate and chalcedony veins which occur in association with broader zones of elevated gold values in the range of 50 to 300 parts per billion, and anomalously high values of arsenic (Dawson, 1981, Assessment Reports 9876, 11037). The narrow zones of higher grade mineralization reported to date are of limited extent.

POISON MOUNTAIN

The Poison Mountain copper-molybdenum-gold porphyry deposit occurs on the southwest slopes of Poison Mountain, 3 kilometres northeast of the Yalakom fault. The first lode claims were staked in 1935, after placer gold had been discovered along Poisonmount Creek in 1932 (Minister of Mines Annual Reports, 1933, pages A186 to A191; 1946, pages A101 to A102). Diamond drilling and trenching, carried out by various companies between 1956 and 1971, delineated a mineral inventory in the order of 175 million tonnes averaging 0.33 per cent copper, 0.015 per cent molybdenum and 0.3 gram per tonne gold (Seraphim and Rainboth, 1976). Additional drilling was carried out by Long Lac Mineral Exploration Ltd. in 1979 and 1980 (Brown, 1981, Assessment Report 8874), but no updated reserves were published.

Mineralization at Poison Mountain is associated with two granodiorite to quartz diorite stocks which intrude Jackass Mountain Group sedimentary rocks of Unit 3ak. The stocks comprise relatively unaltered cores of hornblende plagioclase porphyry which grade outwards into biotite plagioclase porphyry in which the biotite is an alteration product of hornblende. The highest grade mineralization occurs within the biotite-altered border phases and adjacent biotite hornfels. It consists mainly of pyrite, chalcopyrite, molybdenite and bornite, which occur as disseminations and fracture fillings, and in veins associated with quartz (Seraphim and Rainboth, 1976). Calcite and gypsum also occur as hydrothermal minerals, and pyrite, together with magnetite and hematite, forms an irregular halo around the mineralized zone. Chlorite-epidote alteration occurs sporadically within Jackass Mountain Group rocks for several kilometres around the deposit, but is not distinctly concentrated around the mineralized porphyries. Intrusion, potassic alteration and mineralization at Poison Mountain is about 58 Ma in age (Paleocene) as indicated by potassium-argon dating of hornblendes and biotites from the mineralized system (W.J. McMillan, personal communication, 1987).

MERCURY, ANTIMONY AND TUNGSTEN OCCURRENCES

Cinnabar, stibnite and/or scheelite mineralization is found associated with some of the major fault zones in the area. Most showings are hosted by orange to rusty weathering carbonatized and silicified serpentinite that locally contains up to 5 per cent green fuchsitic mica, mainly between Noaxe and Mud creeks (Figure 1-9-7). They are located along or close to a north-northwest-trending fault zone that forms the western margin of a panel of serpentinized peridotite and variable lithologies of the Bridge River complex. Narrow, carbonate-altered feldspar porphyry dykes, that occur locally along the fault zone, may be related to these mineral occurrences. These prospects include the Tungsten King and Tungsten Queen, where scheelite was discovered in 1939 and which produced a small tonnage of high-grade ore over the following two years (Cairnes, 1943). The property was intermittently explored for tungsten and antimony up to 1984. The showings comprise scheelite and stibnite in a stockwork of quartz and calcite veins that cut a carbonate alteration zone containing mariposite. Previous workers have thought that the protolith was limestone within lenses in the Bridge River complex. However, the mineralized zone is on strike with partially carbonatized serpentinite, and, although limestone lenses do occur nearby, there is no indication of skarn development. Apex, a mercury showing in a similar setting, occurs northeast of Quartz Mountain, and is hosted by carbonatized and silicified serpentinite within the Yalakom fault

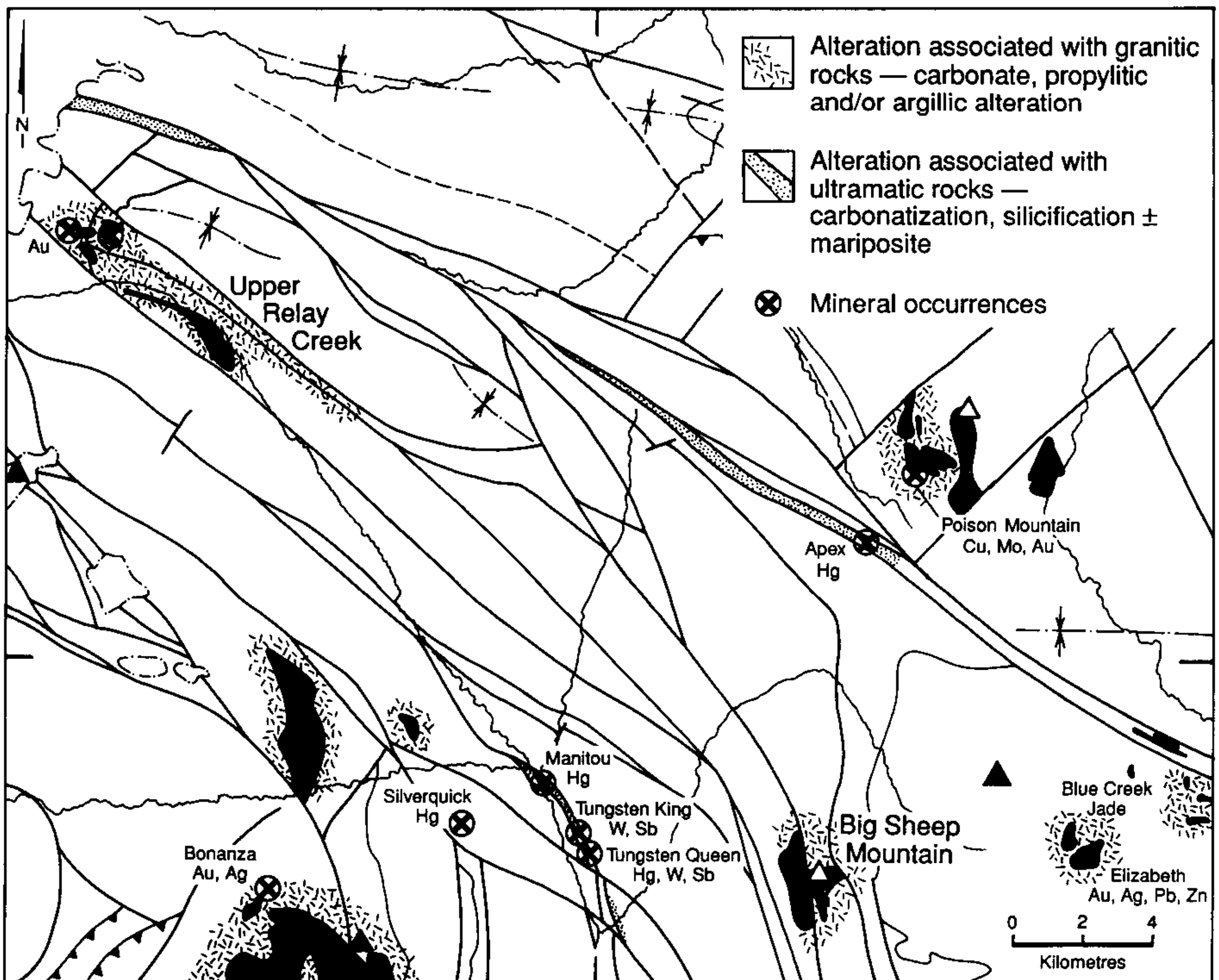


Figure 1-9-7. Mineral occurrences and alteration zones, Noaxe Creek map area.

zone. There are no gold values known to be associated with these showings.

The Manitou or Empire Mercury mine is located at the confluence of Mud Creek with Tyaughton and Relay creeks (Figure 1-9-7). The earliest record of underground workings is 1931; up to the end of 1940, twenty flasks of mercury had been produced (Cairnes, 1943). A substantial program involving refurbishing of some underground workings and a 7000-metre percussion drilling program was completed by Empire Mercury Corporation Ltd. in 1966 (Minister of Mines Annual Report, 1966). This property was not visited, but cinnabar was reported by Cairnes to occur along north-northwest and east-trending shear zones in volcanic rocks of the Bridge River complex. The Silverquick mercury showing (Minister of Mines, Annual Report, 1964) south of Tyaughton Creek occurs along a northwest-trending shear zone in conglomerates of the Silverquick formation. No gold values have been reported from these mercury, antimony and tungsten showings.

TECTONIC IMPLICATIONS

Much of the Noaxe Creek map area is underlain by rocks of Cretaceous age; this report documents the character and distribution of lithologic units in this succession, and, in part establishes their internal and external structural and stratigraphic relationships. The tectonic implications of this study are summarized as follows:

(1) The thick sequence of Taylor Creek Group sediments represents a period of major tectonic activity during the Albian (110 to 100 Ma). The chert-pebble conglomerates with minor ultramafic clasts and detrital chromite clearly record uplift of the Bridge River complex and Shulaps ultramafic complex close to the Tyaughton trough. Basin-wide events such as rapid deepening and shallowing suggest that the entire basin responded to tectonic events simultaneously. Lack of basin asymmetry, local fault-derived breccias and irregular paleocurrents suggest that strike-slip faulting was not important during deposition of the Taylor Creek Group.

(2) Sedimentary and epiclastic rocks of the Silverquick formation and overlying andesitic volcanic strata of the Powell Creek formation represent the inception and establishment of a continental volcanic arc that succeeded a period of major mid-Cretaceous compressional tectonics in the southwestern part of the Canadian Cordillera.

(3) Mesozoic rocks in the Noaxe Creek map area have undergone late Cretaceous and/or early Tertiary brittle deformation and displacements within a wide zone of dextral wrench faulting which can be related to two stress regimes: an early one associated with a north-south compressional axis that produced major northwest-trending dextral faults such as the Yalakom, Relay – Marshall Creek, Castle Pass and Tyaughton fault systems, together with northwesterly trending synthetic dextral faults and northeast-trending antithetic sinistral faults, and a later stress regime, defined by a north-northeast compressional axis and related to dextral movement along the Fraser fault system. In the north-eastern part of the map area, this later regime produced the north-northwest-trending Red Mountain fault and north-northeast-trending-tensional faults and fractures, together with minor faults that match the orientations expected for synthetic and antithetic strike-slip faults.

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GEOLOGY OF THE MOUNT SHEBA IGNEOUS COMPLEX* (92O/03)

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KEYWORDS: Regional geology, Mount Sheba, Chilcotin Range, subvolcanic system, felsic volcanic rocks, basalt flows, feldspar biotite porphyry.

INTRODUCTION

The Mount Sheba volcanic complex is located within the Chilcotin Range on the eastern margin of the Coast Mountains. The map area is located between 123°00′ and 123°07′ east longitude, and 51°00′ and 51°04′ north latitude, on the southeast corner of the Warner Pass map sheet (92O/03).

The Mount Sheba area was remapped at a scale of 1:15 000, providing detail not found in pre-existing maps (Glover and Schiarizza, 1986; Tipper, 1978). Particular attention was paid to outcrops of Tertiary volcanic and plutonic rocks. This study addresses the nature of the volcanic assemblage and the Mount Sheba intrusive bodies, as well as the relationship between these two suites. The Mount Sheba complex is well exposed and the volcanic rocks are well preserved, providing a rare opportunity to observe the roots of a subvolcanic system, as well as part of the overlying volcanic stratigraphy. This research establishes stratigraphic relationships between the Tertiary units, and documents the petrologic variations in these rocks.

At this point in the project, a preliminary description of the stratigraphic section and the distribution of lithologies are complete. The age relationships between the units of the Mount Sheba complex are established, together with the nature of the contacts between the units. Absolute ages of the plutonic suite are currently being determined by D. Archibald at Queen's University. Future work will expand the present field map around Mount Sheba and concentrate on the rock and mineral chemistry of the volcanic-plutonic suite.

GENERAL GEOLOGY

The regional geology of the Warner Pass map sheet (Figure 1-10-1) involves Mesozoic sedimentary and volcanic rocks which are overlain and intruded by Tertiary volcanic and plutonic rocks. The Mesozoic strata record the change in sedimentation in the northwest-trending Tyaughton basin from marine to nonmarine conditions. This change accompanied the uplift of the Coast plutonic complex in mid-Cretaceous time (Kleinspehn, 1985). The dominant northwest structural trend in these rocks is manifest in numerous strike-slip faults which are related primarily to the post-Albian northwest-trending Yalakom–Hozameen fault system, and also to the later Fraser–Straight Creek right-lateral strike-slip fault, believed to be late Cretaceous to early Tertiary in age (Monger, 1985).

Tertiary rocks in the region are primarily volcanic, volcaniclastic, or shallow intrusive, and unconformably overlie or intrude the Early Cretaceous Taylor Creek sedimentary rocks, Late Cretaceous Battlement Ridge volcanic rocks, and a Late Cretaceous to Early Eocene sedimentary unit. Felsic volcanic flows and volcaniclastic deposits of probable Eocene age (Glover and Schiarizza, 1986) are unconformably overlain by Miocene plateau basalts. Several groups of intrusive rocks occur throughout the area and exhibit contact relationships which suggest ages from possibly mid-Cretaceous to Eocene. In the Mount Sheba area, a feldspar biotite porphyry, ubiquitous throughout the field area, intrudes all of the units.

Locally sinuous faults offset the Eocene volcanic assemblage, for instance the Chita Creek fault. Although they are not well defined in the Mount Sheba area, it is suggested that these structures control the distribution of the Eocene rocks in the region (Glover and Schiarizza, 1986). The Miocene basalts often cover fault traces, implying that there has been little post-Miocene structural movement.

GEOLOGY OF MOUNT SHEBA

Three lithologic units dominate the Mount Sheba map area (Figures 1-10-2; 1-10-3): a series of felsic to intermediate flows and pyroclastic deposits; a sequence of mafic volcanic flows; and a subvolcanic highly porphyritic intrusion or series of intrusions, intermediate in composition. There are four other distinct lithologies in the study area, three of which comprise underlying Mesozoic strata, and the fourth a suite of late dykes, sills or stocks which form a mappable unit.

LITHOLOGIC DESCRIPTIONS

TAYLOR CREEK GROUP (UNIT 1)

Early Cretaceous Taylor Creek sediments are predominantly comprised of dark shales, medium to thickly bedded siltstones and sandstones and poorly bedded chert-pebble conglomerate, with sedimentary features indicative of deposition by turbidity currents in a marine environment (Glover and Schiarizza, 1986). In the Mount Sheba area, this unit is characterized by siltstones with tabular crosslaminations, mud-draping, and some soft-sediment deformation. One section has thin coal beds (approximately 5 to 10 centimetres

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

thick) intercalated with siltstones and shales. A debris flow consisting of poorly sorted lithic and volcanic clasts with a very fine-grained to sandy matrix is found near the upper contact between this unit and the unconformably overlying Unit 4, along the northern boundary of the map area.

BATTLEMENT RIDGE GROUP (UNIT 2)

The Battlement Ridge Group, formerly the Kingsvale Group (Glover and Schiarizza, 1986; Tipper, 1978), comprises primarily volcanic and volcaniclastic rocks of Middle to Late Cretaceous age. In the Mount Sheba area it is generally a massive, purple-weathering volcanic feldspar porphyry which forms large cliffs. In some areas volcanic flows are interbedded with coarse flow breccias comprised of angular lapilli-sized feldspar porphyry clasts and a matrix of the same composition. In less massive sections, flow banding is defined by alignment of feldspar phenocrysts. Locally the unit is altered to the extent that primary mineralogy is completely replaced, and the rock weathers a

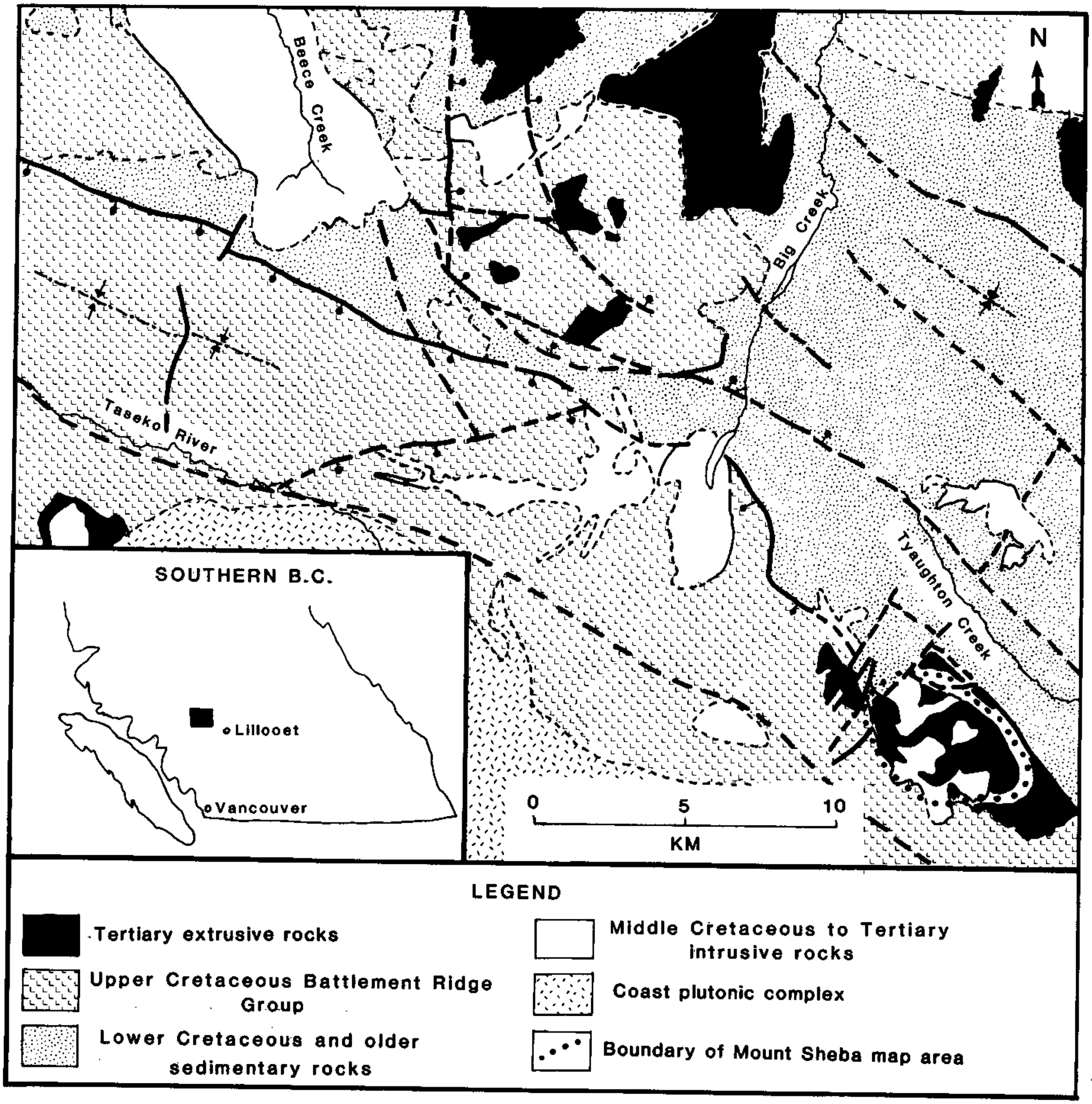

Figure 1-10-1. Location map, southern British Columbia, and generalized geology of the Warner Pass map sheet (modified from Glover and Schiarizza, 1986).

rusty colour. The Battlement Ridge Group is unconformably overlain by boulder conglomerates and arkosic sandstones of Unit 3 and intruded by the plagioclase biotite porphyry of Unit 7.

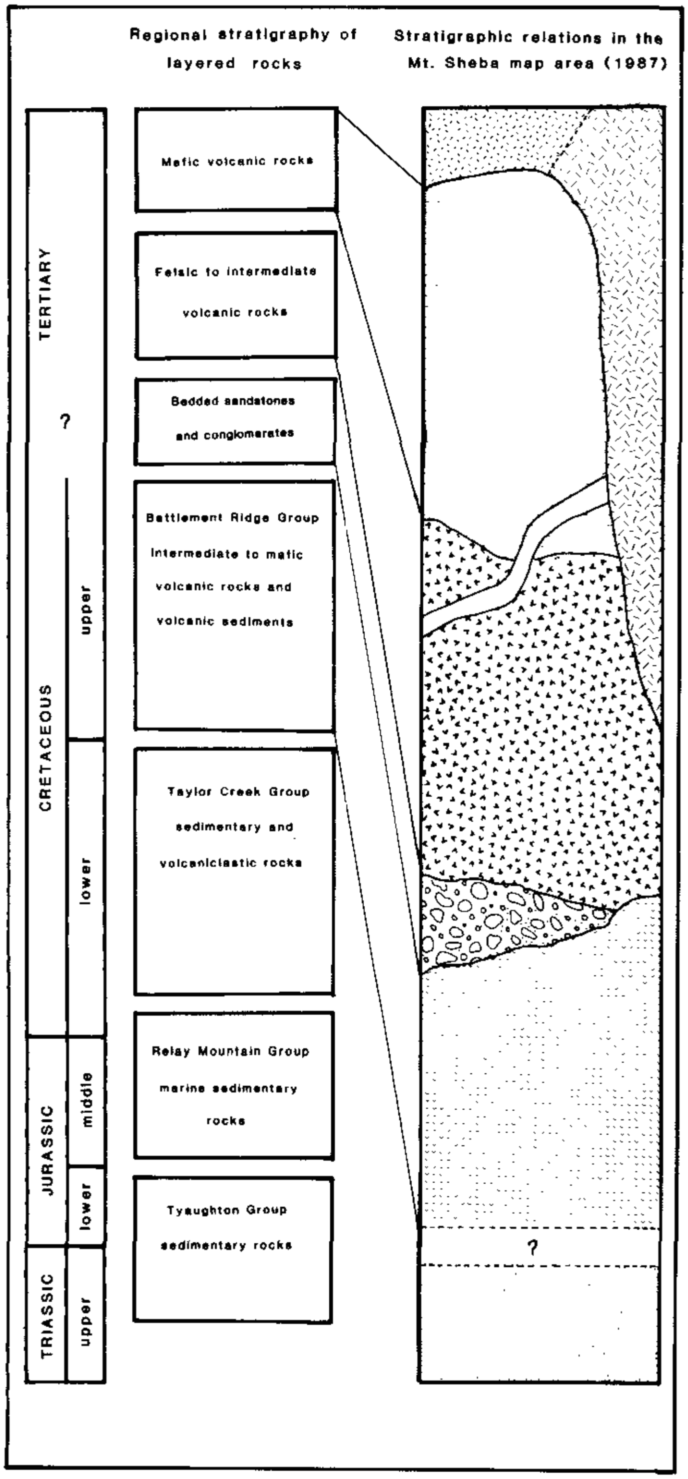

Figure 1-10-2. Regional stratigraphy of layered rocks and stratigraphic relationships in the Mount Sheba map area.

Arkosic Sandstones and Conglomerates (Unit 3)

Unit 3 is a discontinuous package of interbedded epiclastic conglomerates and sandstones which varies in thickness across the map sheet. Clasts vary in size from pebbles to boulders, are generally very well rounded and poorly sorted, and are predominantly lithic and granitic in composition. The sandstones are often lenticular and normally graded. This unit is limited to the immediate vicinity of the western part of the Mount Sheba map sheet, and is not well exposed. Locally the clastic unit pinches out. Unit 3 unconformably overlies the Battlement Ridge volcanic rocks and is overlain by Unit 4 felsic volcanic rocks, and therefore is inferred to be post-Late Cretaceous to Early Eocene in age.

Eocene Felsic Volcanic Rocks (Unit 4)

Felsic volcanic rocks are ubiquitous throughout the study area. They generally comprise felsic aphanitic flows and pyroclastic deposits. These rocks have a distinct appearance in the field, characterized by well-defined flow banding. The flow banding is on a scale of 5 to 50 millimetres and ranges from highly contorted to parallel bands. The unit weathers light green or purple and alters to a rusty or buff colour. The felsic volcanic rocks can be subdivided into three mappable subunits: light green-weathering fissile volcanic flows (Subunit 4a); massive purple-weathering volcanic flows (Subunit 4b); and a pyroclastic unit (Subunit 4c). The age of this unit is thought to be Eocene (Glover and Schiarizza, 1986).

Subunit 4a is comprised of massive cliff-forming purple-weathering volcanic flows, sometimes flow banded and often brecciated. These flow breccias are porphyritic and contain lapilli-sized fragments with feldspar phenocrysts. The breccias do not appear to delineate bedding or flow surfaces. This subunit is restricted to the central part of the field area.

Subunit 4b is light green weathering, fissile, and has prominent fine flow banding defined by thin bands of variable composition. In general this lithology is aphanitic, but some sections are porphyritic with small phenocrysts of amphibole, feldspar and quartz. At the margins of flows, particularly toward the top of the unit, flow breccias are quite common. These are characterized by angular lapilli-sized purple-weathering clasts within a green-weathering matrix on the flow surface. This subunit outcrops in the central part of the map area and stratigraphically overlies the more massive volcanic flows of Subunit 4a.

Subunit 4c is a pyroclastic deposit recognized at only one locality in the northwestern part of the map area, and its field relationships to other subunits of the Eocene volcanic rocks are uncertain. The unit is purple weathering and glassy with moderately well-developed fiammé and is generally quite weathered. Parts of the outcrop contain small biotite, amphibole and plagioclase crystals, as well as lapilli-sized pumice fragments in a glassy groundmass. It is interpreted as a welded crystal-lapilli ash flow tuff.

Layered Basalt Flows (Unit 5)

Basalt flows of Unit 5 are comprised of interbedded, fine-grained massive flows and flow breccias, 1 to 2 metres thick.

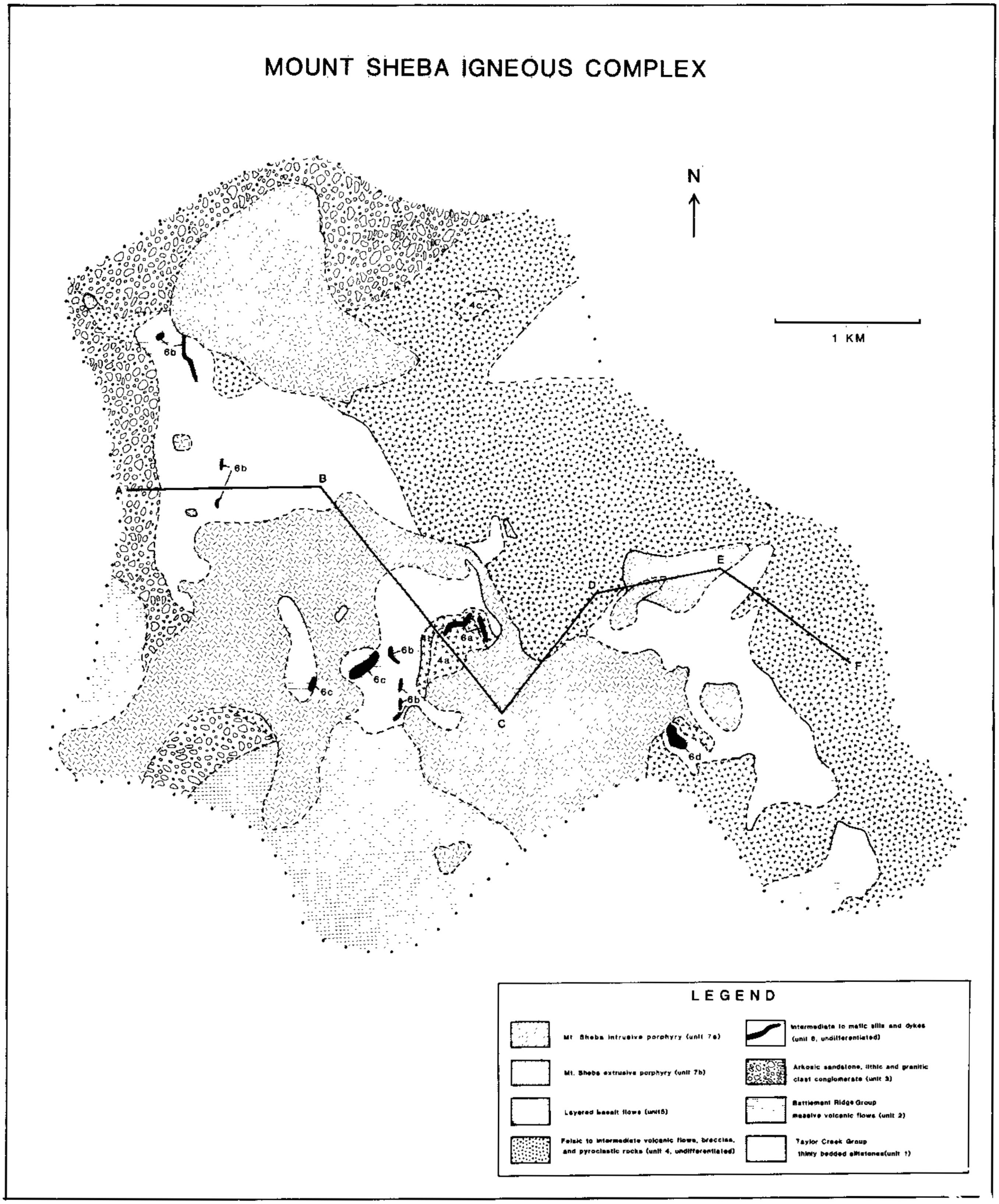

Figure 1-10-3. Geology of the Mount Sheba igneous complex.

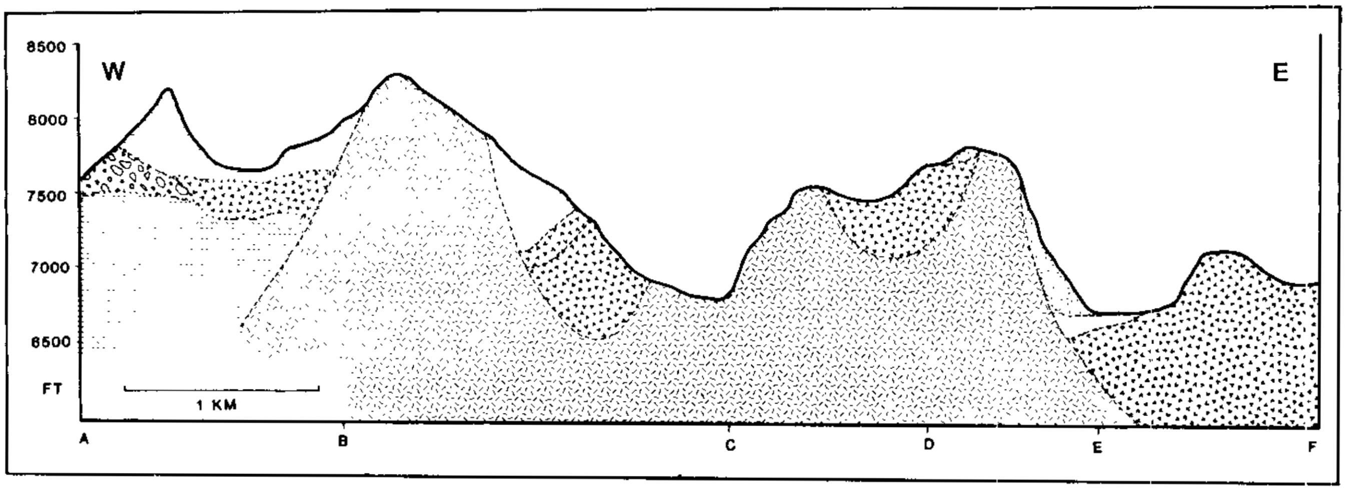

Figure 1-10-4. Cross-section A-B-C-D-E-F through the Mount Sheba map area. (*See* Figure 1-10-3 for legend.)

The massive flows are vesicular or amygdaloidal with calcite, chlorite and quartz amygdules. Interlayered flow breccias are fine grained, strongly oxidized and weather a bright red colour. The clasts appear to be of the same composition as the groundmass. Rocks of this unit are commonly cut by intermediate to mafic dykes, sills and stocks of Unit 6.

In general, the basalt flows and breccias are unfolded and dip gently westward. Close to intrusive bodies, bedding may steepen. The total thickness of the basalt flows varies across the map sheet. In several locations there are significant accumulations of flows, giving a "layer cake" appearance, while in other areas the basalts form a thin veneer covering underlying units. The thicker accumulations of layered flows appear to fill paleotopographic lows in Unit 4 rocks. Unit 5 may also occur as pendants within the Mount Sheba intrusion. It is superficially similar in outcrop appearance to other basalt units in the region dated as probable Miocene (Glover and Schiarizza, 1986). However the correlation between Miocene basalts and Unit 5 is uncertain. Unit 5 occurs throughout the map area, and unconformably overlies the Eocene felsic volcanic rocks and the arkosic sandstones and conglomerates of Unit 3.

Intermediate to Mafic Intrusive Rocks (Unit 6)

Intrusive rocks of intermediate to mafic composition occur as sills, dykes or stocks. Subunits 6a, 6b and 6c may be related to each other, whereas Subunit 6d is quite different. The intrusive subunits have been grouped together because all intrude Unit 4 or Unit 5 and in one location are truncated by Unit 7.

Subunit 6a is composed of intermediate to mafic porphyry dykes. Typically the unit has a greenish grey mesocratic aphanitic groundmass with green amphibole and feldspar phenocrysts. The dykes are 3 to 5 metres thick and cut flow banding in the Eocene volcanic rocks and the contact between Subunits 4a and 4b, but do not extend into nearby overlying layered basalts.

Subunit 6b is comprised of amphibole porphyry sills and dykes, 3 to 5 metres thick, which intrude layered basalt flows. They generally have a light grey-weathering aphanitic groundmass with small green amphibole phenocrysts and occasional feldspar phenocrysts. There is some flow banding and vesiculation at the margins of these intrusions.

Subunit 6c is comprised of amphibole porphyry stocks intruding layered basalt flows. It has a greyish green aphanitic groundmass with green amphibole phenocrysts. It is flow banded and vesicular or amygdaloidal near the margins and is similar in appearance to sills and dykes of Subunit 6b, except that it occurs as a large irregular body cutting well-layered basalt flows. Its proximity to outcrops of Subunit 6a also suggests that it may be related, perhaps as a feeder stock to the sills and dykes.

Subunit 6d intrudes the layered basalt flows only, and is different mineralogically from other intermediate to mafic intrusions. It is an altered medium-grained equigranular rock containing primarily biotite, plagioclase feldspar and secondary chlorite. It is cut by small dykes of porphyritic rock, 3 to 10 centimetres thick, with a leucocratic aphanitic groundmass and euhedral green amphibole and anhedral biotite phenocrysts.

Mount Sheba Plutonic Porphyry (Unit 7)

The Mount Sheba plutonic porphyry intrudes all of the other units in the map area and is therefore interpreted to be the youngest rock unit. It is generally a plagioclase biotite porphyry, with some amphibole and quartz phenocrysts, and has a light-coloured aphanitic groundmass. The Mount Sheba porphyry has been divided into subunits, based upon the nature of emplacement. Subunit 7a, the dominant unit, is comprised of flow-banded, generally crystalline plagioclase biotite porphyry. Subunit 7b is also a plagioclase biotite porphyry, but is more glassy in appearance and also includes breccias and possibly pyroclastic deposits.

Subunit 7a is porphyritic with plagioclase, biotite, hornblende and quartz phenocrysts in a leucocratic grey groundmass. Plagioclase phenocrysts are always present, are usually euhedral to subhedral, and are sometimes zoned. Biotite phenocrysts are common and usually occur as euhedral hexagonal prisms. Tiny (less than 2 millimetres) acicular, black amphibole phenocrysts are sometimes present. Quartz is the least common phenocryst; it occurs as small (approximately 5 millimetres) subrounded grains. The groundmass is generally aphanitic and is more crystalline toward the interior of the pluton and increasingly fine grained near the margins. Petrologically, this rock is a diorite.

A predominant physical characteristic of the unit is the presence of well-defined flow banding at the margins of the pluton. The flow banding parallels the intrusive contact and, in some cases, remains distinct well into the interior of the body. The intrusive bodies have well-defined chilled margins, indicated by decreasing phenocryst size and abundance, by a more glassy groundmass, and by xenoliths of the surrounding country rock. Autobreccias, probably due to internal magma flow, occur in a few locations. This unit also contains roof pendants of the surrounding country rock. The irregular nature of the intrusive contact is reflected in the map pattern as well as in small apophyses of this unit visible through the country rock.

The Mount Sheba diorite has an extrusive phase (Subunit 7b) which occurs in a single location in the eastern part of the field area, adjacent and partially surrounding a small body of the intrusive porphyry. The extrusive unit is a purplish weathering porphyry, similar in appearance to the intrusive unit, with plagioclase, biotite, and sometimes amphibole phenocrysts, set in glassy groundmass. Several types of breccia occur in this unit. A basal flow breccia is subparallel to flow banding and the clasts and matrix are of the same composition. Some breccias contain angular lapilli-sized pumice and tuff fragments. Other breccias are characterized by flattened glass fragments in the matrix. These features, together with the geometry, suggest that this unit is the extrusive equivalent of the intrusive Subunit 7a. There is also a tectonic breccia which is discordant to flow banding and is heterolithic with a buff-coloured grainy matrix.

FIELD RELATIONSHIPS

Field relationships do not indicate conclusively that the Mount Sheba intrusive porphyry is the source for the Eocene felsic to intermediate volcanic deposits. The layered basalt flows stratigraphically overlie the Eocene volcanic rocks and both are intruded by the porphyry. There must have been some time interval between the deposition of the Eocene volcanic rocks and the intrusion of the porphyry during which the basalt flows were deposited. Therefore, unless the felsic volcanic rocks, the basalts, and the Mount Sheba porphyry were all emplaced coevally, it is unlikely that the Mount Sheba porphyry is the direct source for the felsic volcanic rocks. Previous work on the Mount Sheba igneous assemblage suggests that perhaps the Mount Sheba porphyry is a volcanic centre for the Eocene felsic to intermediate volcanic rocks (Glover and Schiarizza, 1986). This hypothesis requires that the felsic volcanic rocks and basalts of Unit 5 be approximately coeval. If such is the case, then the felsic volcanic rocks and the basalt flows might be complementary units of a bimodal volcanic suite with separate but related eruptive centres. An alternative to the Glover-Schiarizza hypothesis is that the deposition of the felsic volcanic unit and the basalt unit, and the intrusion of the Mount Sheba porphyry, are all separate events. However, the close spatial association and similarities in composition and mineralogy argue that they may be related.

Field relationships suggest that the basalts and the felsic volcanic rocks are not coeval. The orientations of flow banding in the felsic volcanic rocks and flow tops in the basalts are usually discordant. In some locations the geometry of the units suggests that the basalt flows were deposited on an uneven paleosurface of the felsic volcanic rocks. For instance, the contact between these two units can be steeply dipping, while the basalt flows are subhorizontal and undisturbed, with no evidence of a fault contact. This suggests an interval of inactivity and erosion, and possibly structural tilting, between deposition of the felsic volcanic rocks and deposition of the basalts.

CONCLUSIONS

This study permits conclusive statements to be made on several aspects of the Mount Sheba igneous complex. The project has thus far produced a detailed stratigraphic section and a field map, and has elucidated the nature of the contacts and relative ages of the mappable units. Based on the observations to date, the Mount Sheba igneous complex comprises three distinct phases of plutonic and volcanic activity.

However, several important questions remain unanswered. At this point absolute ages of members of the complex are unknown. Relative ages are known from field relationships, but the timing of igneous events is uncertain. Several regional age relationships and the chemical and mineralogical character of the Mount Sheba igneous complex remain to be determined.

Planned future work includes petrographic and chemical analyses of rocks from the Mount Sheba igneous complex. Potentially, this will determine whether or not members of the Mount Sheba igneous complex are related. Also the petrography and chemistry of the Mount Sheba porphyry, both Subunits 7a and 7b, may provide information about the genesis and emplacement of a high-level pluton and its extrusive equivalents.

ACKNOWLEDGMENTS

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QUESNEL MINERAL BELT–THE CENTRAL VOLCANIC AXIS BETWEEN HORSEFLY AND QUESNEL LAKES* (93A/05E, 06W)

By Andre Panteleyev

KEYWORDS: Regional mapping, Quesnel terrane, Horsefly, Quesnel Lake, volcanic arc, placer gold, porphyry copper-gold deposits, propylitic alteration.

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 (*see* Figure 1-11-1). Results of ministry mapping in 1986 and previous work are summarized in Geological Fieldwork, 1986, by Panteleyev (1987) and Bloodgood (1987).

In 1987 enhanced provincial funding enabled an expanded project to be undertaken, with field mapping in four areas. The individual field studies are summarized in this report and by Bailey and Bloodgood elsewhere in this volume. Bailey's area adjoins this study to the northwest; Bloodgood's mapping is to the northeast. In addition, J. Lu conducted studies in the Cantin Creek area along Quesnel River in NTS area 93B/16. His study will be summarized in the ministry publication, Exploration in British Columbia, 1987.

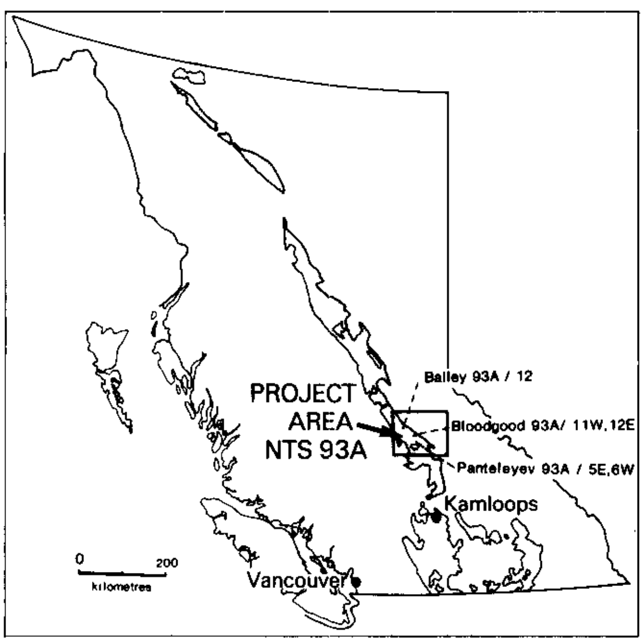

Figure 1-11-1. Location of mapping studies described in this volume. The Quesnel mineral belt project area within the Quesnel Terrane (shaded area) is shown.

This report outlines results of 1:20 000-scale mapping in a 480-square-kilometre area between Horsefly and Quesnel lakes, mainly to the west of the Horsefly River. Outcrop is scarce, it occurs in approximately 0.01 per cent of the map area. Bedrock is exposed mainly where the generally shallow overburden has been disrupted by industrial activity, most commonly logging and road building. Less frequently outcrop can be found in a few 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 made even more difficult by the similarity of the predominantly pyroxene-phyric lithologies and abundant block faulting. However, a few breccia units and flows containing analcite phenocrysts and feldspar laths provide distinctive, readily identifiable map units. Considerable assistance in map interpretation is provided by federal/provincial 1:63 360 (1 inch to 1 mile) aeromagnetic maps 5239G (93A/06) and 1532G (93A/05).

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 olivine and/or analcite phenocrysts. These mafic rocks overlie a basal sequence of basaltic-source sandstone and siltstone and are overlain, in turn, by more felsic polylithic alkalic volcanic-clast breccia and an upper unit of amygdaloidal analcite-bearing olivine basalt flows. Locally, remnants of Tertiary subaerial flows and ash flows of intermediate composition overlie the mafic rocks. Miocene or younger plateau basalts overlap the southwestern part of the map area and the south-central portion along the Horsefly River (*see* Figures 1-11-2, 1-11-3).

The area shown on Figure 1-11-2 is underlain by eleven major lithological units. These map units are identical to those of Bailey (this volume) and based on his earlier studies (Bailey, 1976, 1978), except for Unit 9 and the map units numbered with subscripts (for example, $2B_1$, $2D_2$, etc.) which are unique to this area. They simplify the 17 stratigraphic subdivisions described previously (Panteleyev,

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

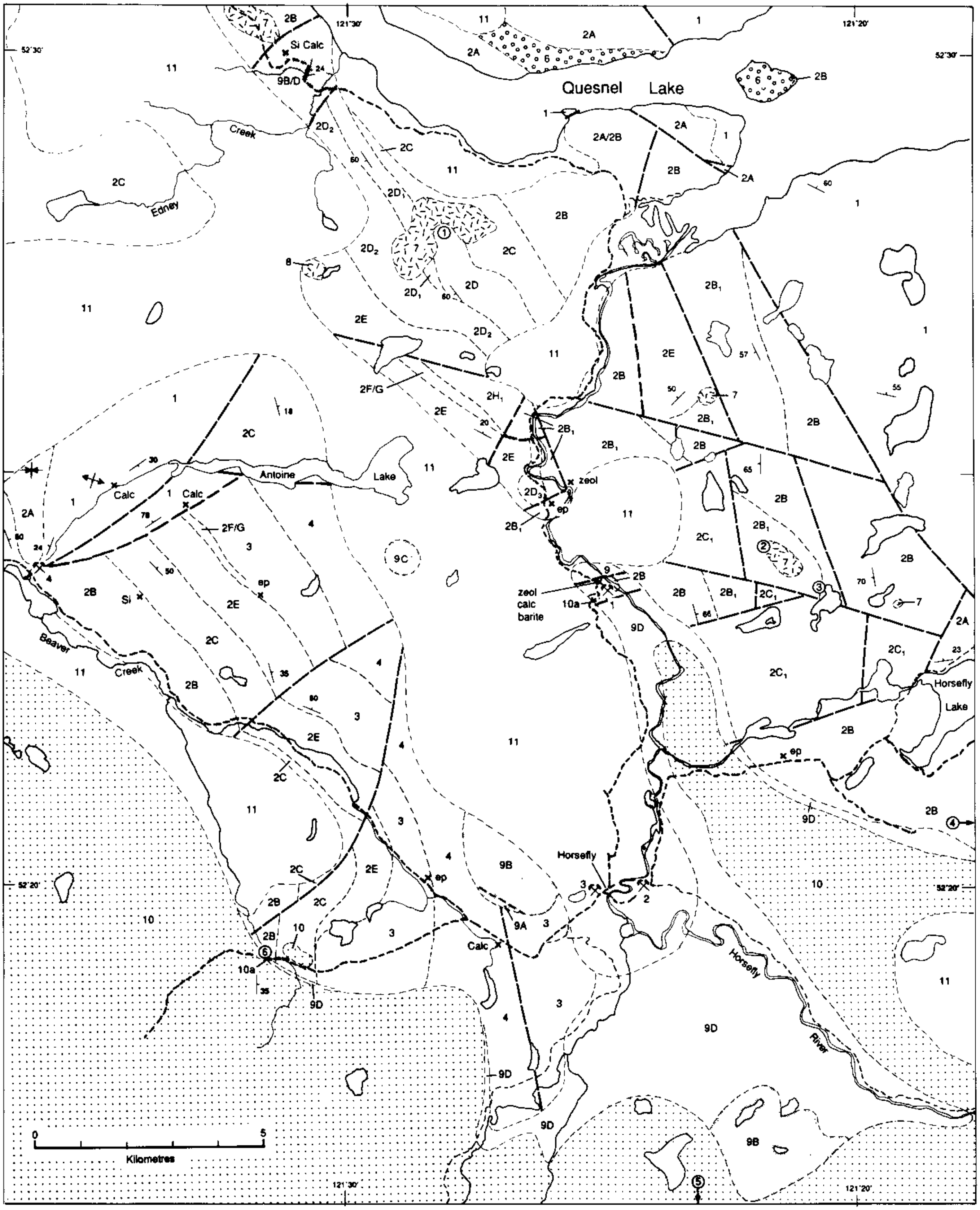

Figure 1-11-2. Geology of the central Quesnel terrane between Horsefly and Quesnel lakes.

LEGEND (also see Bailey, this volume)

QUATERNARY

PLEISTOCENE AND RECENT

11 Glacial and fluvial deposits; alluvium

TERTIARY

MIOCENE

10 Grey to black plateau basalt (alkali olivine basalt); 10a – basal white quartz-cobble conglomerate and gravel

EOCENE

9D Grey, pale mauve, olive and tan flows, sandstone and conglomerate. Includes 9A – hornblende andesite, 9B

9A/B/C – plagioclase crystal ash tuff, 9C – biotite latite, 9D – lacustrine siltstone, sandstone and conglomerate (see Figure 1-11-3)

JURASSIC

PLIENSBACHIAN?

6 Cobble conglomerate: clasts of chert, quartzite, limestone, sandstone; carbonaceous shale and sandstone

SINEMURIAN

4 Maroon and grey vesicular, zeolitized, amygdaloidal alkali olivine basalt, may contain analcite

3 Maroon and grey polylithic breccias; clasts of mafic and intermediate composition including latite and other feldspathic rocks; rare monzonite clasts. Locally feldspathic sandstone, limestone lenses and limestone-matrix breccia

TRIASSIC

NORIAN

$2H_1$ Feldspar-lath, pyroxene-phyric basalt; locally breccia with limestone matrix

2F/G Dark grey to brown, fetid mafic sandstone and siltstone, calcareous siltstone, limestone breccia

2E Analcite-bearing maroon and green-grey alkali basalt, locally feldspathic; minor crystal lithic ash tuff

2D Plagioclase and pyroxene-phyrix basalt, in part autobrecciated. Contains alkalic and intermediate composition clast breccia. Includes $2D_1$ – fine-grained sandstone, siltstone; $2D_2$ – pyroxene-phyric basalt flows and breccia, mafic polylithic breccia; $2D_3$ – sparse pyroxene-phyric aphanitic basalt

2C Polylithic grey, grey-green and purple mafic breccia, pyroxene-rich greywacke, minor feldspathic clasts. Includes $2C_1$ – monzonite and latite clast-bearing breccia, possibly equivalent to Unit 3

2B Dark green and maroon pyroxene-phyric alkali basalt, commonly vesicular-amygdaloidal; locally breccia, pillow breccia with limestone lenses and mafic wacke. Includes $2B_1$ – plagioclase microlite-bearing basalt

2A Green and dark grey pyroxene-phyric alkali olivine basalt and alkali basalt, flows, pillow lava and pillow breccia

CARNIAN AND (?) YOUNGER

1 Grey to dark brown silstone and sandstone, volcaniclastic towards top of unit, rare thin chert beds and limestone lenses

8 Grey hornblende quartz diorite and granodiorite

7 Grey and pink fine to medium-grained diorite, monzodiorite, syenodiorite, monzonite and syenite, hornblende porphyry dykes

SYMBOLS

Map unit contact

Fault – mapped and inferred

Major road

Bedding attitude 60

Fold axis

Historic placer workings

Hobsons hydraulic mine		1
Wards Horsefly mine		2
Miocene shaft		3
Antoine Creek		4
Mineral prospects		O
Shiko L.	Au, Cu	1
Kwun L.	Au, Cu	2
Beekeeper	Au, Hg	3
Lemon L.	Au, Cu	4
Megabuck	Au, Cu	5
Old adit	Au, Cu, Ag	6
Alteration zones sampled		×
Propylitic-epidote, calcite, chlorite, garnet, pyrite, chalcopyrite, tremolite		Ep
Zeolite and calcite		Zeol
Calcite and quartz		Calc
Silicification		Si

1987) in the eastern part of the map area and completely revise the stratigraphy described in the same area by Morton (1976).

The following map units represent a sequence that is approximately 5 kilometres thick shown on Figure 1-11-2.

UNIT 1: Dark brown and grey mafic volcanic-source sandstone and siltstone, minor chert and rare thin limestone lenses. A thinly bedded sequence containing turbidite units; beds near the top of the succession contain abundant pyroxene grains and limestone clasts.

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.

UNIT 2B: Dark green and maroon pyroxene-phyric alkalic basalt flows and flow breccia, locally pillow breccia. Mafic wacke interbeds are common; limestone forms small lenses and breccia matrix. Many flows are amygdaloidal and zeolitized. **$2B_1$** — Flow units contain fine to medium-grained plagioclase laths.

UNIT 2C: Breccia, grey, grey-green and purple polylithic mafic breccia derived from lahar or debris flow deposits. **$2C_1$** — Contains some feldspathic monzonitic clasts and is possibly equivalent to Unit 3.

UNIT 2D: Porphyritic plagioclase pyroxene basalt with interbedded alkalic breccia and sedimentary units. Mainly grey and grey-green coarse plagioclase lath and pyroxene-phyric basalt flows and autobrecciated flows. Includes thick lenses or wedges of grey, pink-weathering, epidotized polylithic breccia with abundant monzodiorite clasts. Minor mafic wacke beds. **$2D_1$** — Fine-grained sandstone and siltstone; contains carbonaceous wood debris and fragments of ammonites, bivalves, corals and gastropods. **$2D_2$** — Pyroxene-phyric basalt flows and breccia, mafic wacke. **$2D_3$** — Dark grey microcrystalline basalt with sparse fine to medium-grained pyroxene, possibly intrusive.

UNIT 2E: Grey-green and maroon 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.

UNIT 2F/G: Dark grey to brown sandstone and siltstone derived from mafic volcanics. Silty limestone or calcareous siltstone are common; limestone-clast breccia occurs locally. The rocks are fetid and contain fine sulphide grains. A benthonic bivalve faunal assemblage is relatively common.

UNIT 2H: Grey feldspar and 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. Flow rocks resemble feldspar-phyric rocks of Unit 2D.

UNIT 3: Breccia; maroon, lavender, purple 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.

UNIT 4: Dark grey, grey-green to maroon pyroxene-phyric basalt, generally zeolitized and amygdaloidal. Fine-grained analcite is present in some flows, which distinguishes this map unit from Unit 2B.

UNIT 6: Conglomerate with clast-supported cobbles of chert, limestone, siltstone, sandstone and rare greenstone. The sandy matrix contains ferruginous carbonate cement that commonly weathers rusty orange. Note Bailey's Unit 5 has not been recognized in this map area.

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.

UNIT 8: Grey fine-grained quartz diorite; weathers granular, rusty coloured. This unit is equivalent to Bailey's Cretaceous(?) Unit 9.

UNIT 9: Tertiary volcanic flow remnants and sedimentary basin deposits. **9A** — Grey to olive hornblende porphyry. **9B** — Grey to pale violet plagioclase crystal ash tuff; ash flows with chloritized, hematite-altered mafic minerals. **9C** — Grey, platy biotite-phyric latite. **9D** — Pale grey to buff and yellow, thin-bedded and varved lacustrine siltstone and sandstones with floral debris and rare fish imprints. Contains polymictic cobble conglomerate containing Unit 9B and C detritus and rare granitic clasts. The unit contains some tuffaceous interbeds.

UNIT 10: Plateau basalt; dark grey to black alkali-olivine basalt. **10A** — River channel gravel deposits with distinctive abundant white quartz detritus; locally calcite-cemented conglomerate above basal contact.

UNIT 11: Quaternary glacial and fluvioglacial deposits and alluvium. Thick valley fill in the upper reaches of the Horsefly River, between Horsefly River and Antoine Lake, and to the northwest of Antoine Lake. Elsewhere a relatively thin but persistent veneer on gently rolling hills. 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 (1978; 1988, this volume) gives faunal evidence for a Norian age for rocks of Unit 2; a Sinemurian age for Unit 3 and a Pleinsbachian age for Units 5 and 6 (*see* Bailey, Figure 1-11-4). The few fossils collected by this writer and examined by the Geological Survey of Canada have yielded equivocal information. The ammonites in map Subunit 2D cannot be positively identified and the taxonomy and biostratigraphy of the bivalves including *Lima* sp. in Subunit F/G have not been resolved (T.P. Poulton, personal communication, 1987). At best, a Late Triassic to possibly Late Hettangian range is indicated (H.W. Tipper, personal communication, 1987).

Radiometric data from diorite-monzonite plutons intruding Unit 2 basaltic rocks range from 192 to 201 Ma (Panteleyev, 1987). A new potassium-argon date of 185 Ma was obtained from the Kwun Lake stock (*see* Table 1-11-1). This

1-11-1). This somewhat younger date corresponds to the 184 Ma radiometric age of the mineralized Cariboo-Bell stock (Hodgson *et al.*, 1976).

TABLE 1-11-1
POTASSIUM-ARGON DATA, KWUN LAKE STOCK

Sample Number	Location (UTM)	Lithology	Material Analysed	%K	Ar^{40*} 10^{-40} (moles/gm)	Ar^{40*} Total Ar^{40}	Apparent Age (Ma)
86AP-20/6-64	611250E, 5806000N	Kwun stock	Biotite	5.00	16.932	89.8	185±6

Rocks of Unit 9 are considered to be Tertiary, probably Early and Middle Eocene. The lacustrine varved sediments and interbedded tuffs of Subunit 9D contain Middle Eocene fossil fish, which were found in 1898 and studied by the National Museum of Canada (Wilson, 1976, 1977). Two samples from the Horsefly River near the old Hobson minesite were submitted to Glenn E. Rouse, The University of British Columbia, for palynological examination. The samples yielded a large number of palynomorphs that confirm a Middle Eocene age of between 48 and 52 Ma for the basal beds of this lacustrine unit. The samples contained 17 species of angiosperm pollen, 7 species of conifer pollen, 5 species of fungal spores and fern glochidia. The most diagnostic palynomorphs are *Pistillipollenites mcgregorii*, *Sabal granopollenites*, *Ailanthipites berryi*, *Granatisporites cotalus*, *Pluricellaesporites psilatus*, *Multicellaesporites* -6, *Tetracellaesporites* sp., *Diporisporites* sp., and glochidia of the water fern *Azolla*.

Rocks of Subunits 9A to C are assumed to be Early to Middle Eocene or older, because they form isolated erosion remnants of volcanic deposits that appear to unconformably overlie basaltic rocks. Rocks of Subunit 9C provide coarse detritus for the basal conglomerate in Subunit 9D immediately downstream from the old Hobson hydraulic mine. Similarly, clasts of Subunit 9B are found in conglomerate overlying lacustrine beds of Subunit 9D near Quesnel Lake. Plateau basalt of Unit 10 is Miocene or Pliocene (Campbell, 1978). It locally overlies Miocene(?) river channel deposits of white quartz-cobble gravel (Subunit 10A) that rest on lacustrine sediments of Subunit 9D or the Triassic-Jurassic basaltic rocks.

STRUCTURE

The region is folded into a broad, northwesterly trending, extensively block-faulted syncline. In the northwestern part the fractured but unfoliated, poorly stratified volcanic flows and flow breccia form rotated panels that dip steeply to the southwest; in the southwest, moderate to shallow-dipping flows and debris flow or laharic breccia face northeasterly. The basal sedimentary rocks of Unit 1 crop out in the extreme east and west parts of the map area and, together with the intervening 15 to 20-kilometre-wide volcanic-arc deposits, define a broad structural depression, truly a "Quesnel trough".

The structural style is identical to that further along the volcanic belt to the northwest as described by Bailey (this volume). Notable differences are: (1) stratigraphic units in the southern part of the map area trend north to north-northeast rather than northwesterly; (2) the Early Jurassic plutons (Lemon Lake, Kwun Lake, Shiko Lake and two smaller unnamed stocks) intrude the older basaltic rocks of Unit 2 along the northeastern limb of the syncline rather than the younger, more felsic volcanic units in the core of the volcanic arc; and (3) the area is generally more fragmented by block faulting and has less stratigraphic continuity.

Three main sets of faults are recognized. The earliest faults are major north to northwesterly trending structural breaks. These are cut by northeast-trending faults. The youngest northerly trending faults, and possibly some reactivated northeasterly trending structures, control the distribution of the inliers of Tertiary flows and ash flows of Unit 9 (Figure 1-11-3). They outline a north to northwesterly trending broad, shallow graben along the Horsefly River–Edney Creek axis. This zone remained as a depression during the Middle Eocene and was the site of sedimentation and tuff deposition in a broad, shallow lake. The area now occupied by the Horsefly River valley east of Horsefly village remained as a (fault-bounded ?) depression into the Late Tertiary when it was flooded by Miocene to Pliocene plateau 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 and 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 production was achieved from underground and hydraulic workings at the Hobson and Ward's Horsefly mines and from the Miocene shaft in the village of Horsefly (*see* Figure 1-11-2). Placer activity has also been recorded on a number of other creeks including Antoine, Beaver Lake, China Cabin and Moffat creeks. Placer gold from the Big Bar Creek, about 9 kilometres west of the map area, is noted to have a fineness of 980 parts per thousand, the highest of any placer gold in the province (Holland, 1950).

Bedrock sources of the placer gold remain unknown. Much of the Horsefly River gold is derived from Miocene (?) river channels containing white quartz gravels of Subunit 10A. 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 area to the southeast (93A/07) or even further east. A metasedimentary source would be consistent with the two samples of pan concentrate taken from these gravels. They are notably lacking in black sand and contain considerable garnet; the light fraction contains abundant white micas. Other placer deposits, such as those on Antoine and Beaver Lake creeks, probably have a more proximal source in basaltic volcanic rocks or alkalic intrusions. These placers are reported in a number of Minister of Mines Annual Reports (for example, 1927, pages C181, C182) to contain abundant black sand and some platinum.

Exploration for lode gold and copper-gold deposits has concentrated on intrusion-related alteration zones within and peripheral to the Early Jurassic alkalic intrusions. Exploration targets are auriferous porphyry copper mineralization such as at the Cariboo-Bell deposit (Hodgson *et al.*, 1976) and gold in propylite alteration zones in basalts such as at the

QR deposit (Fox *et al.*, 1987; Melling, this volume). The Lemon, Shiko and Kwun Lake stocks are being examined for these types of deposits. In addition, cinnabar has been noted in quartz-carbonate veinlets associated with hornblende porphyry dykes near Kwun Lake (Bill Morton, personal communication, 1986). Similar but probably younger auriferous porphyry copper mineralization is associated with quartz-bearing intrusions (part of the Takomkane stock ?) in suspected Tertiary rocks at the Megabuck prospect, 8 to 12 kilometres to the southeast of Horsefly.

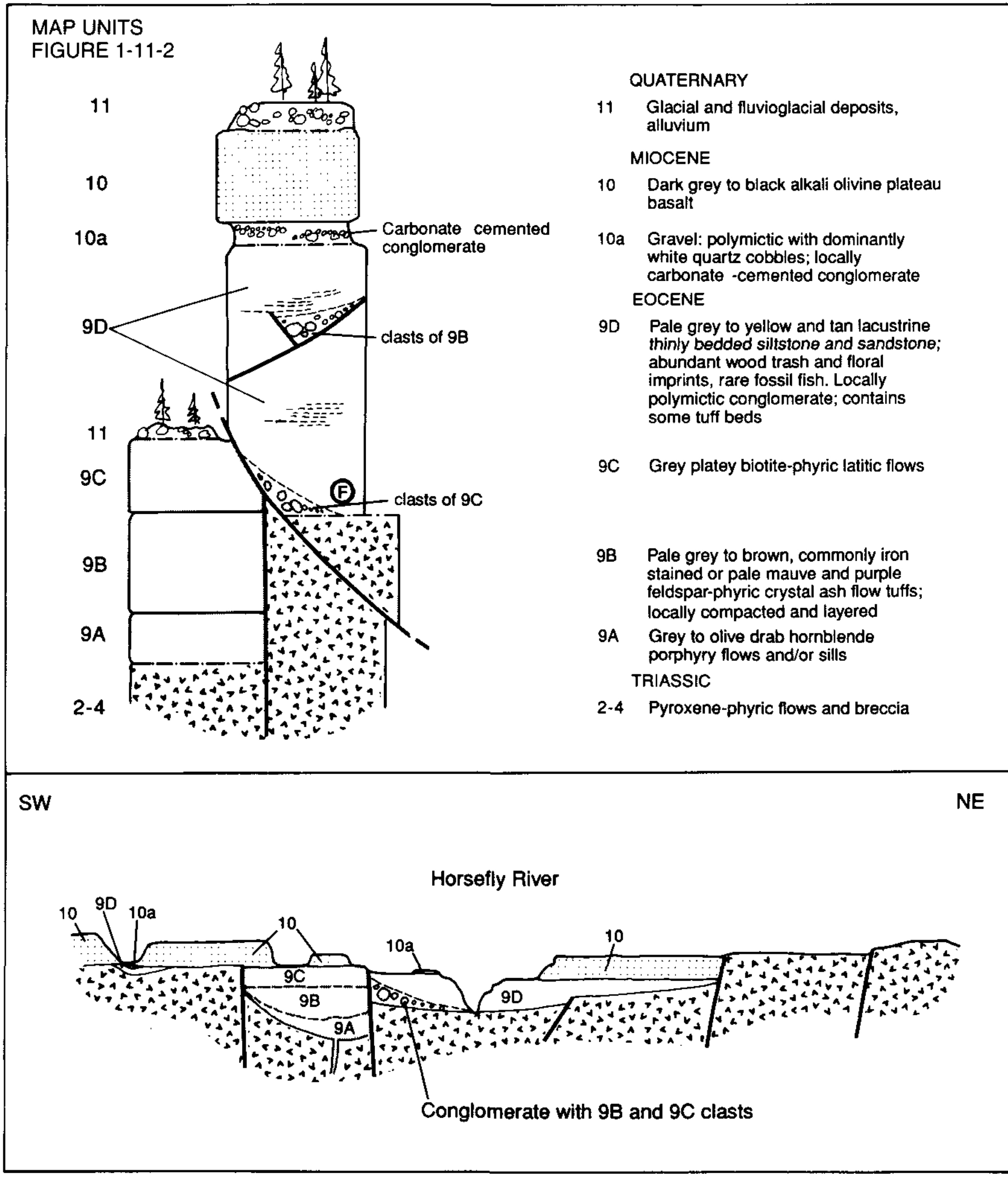

Figure 1-11-3. Schematic stratigraphic column of Tertiary map units and southwest-northeast cross-section from Beaver Creek to Horsefly Lake depicting Tertiary volcanic and sedimentary deposits infilling the northwesterly trending graben.

Elsewhere in the map area there are widespread indications of low-temperature fracture-controlled and fault-zone-related hydrothermal activity. Most commonly the fractured rocks contain zeolite and calcite veinlets and fracture coatings. Locally vein systems with calcite and calcite-quartz veinlets are developed. Propylitic alteration is evident with disseminated epidote, tremolite-actinolite, chlorite, rare garnet, pyrite and calcite veinlets in a few pervasive alteration zones in basaltic rocks. The extensively zeolitized window of basaltic rocks on the Horsefly River near the Hobson mine also contains a number of calcite-quartz veinlets, some with barite and pyrite and/or marcasite. Two areas with silicification were noted. One occurs as a pervasive to vuggy and banded pale grey chalcedonic quartz and dolomitic carbonate zone along the apparent contact of Subunits 2B and 2C about 1 to 2 kilometres north of Beaver Creek. The other is near the mouth of Edney Creek near Quesnel Lake, where chalcedonic epithermal-type vuggy quartz and calcite veins and breccia matrix are noted in the fault-bounded block of Subunit 9B/D rocks.

The association of broad propylitic alteration zones in the overall zeolite facies, subgreenschist-grade basaltic rocks, and the widespread fracture and fault-related zeolite-calcite-quartz vein systems, occasional sulphide-bearing quartz-carbonate, vuggy quartz veins and rare quartz-carbonate veins with barite or cinnabar, imply that large, low-temperature hydrothermal fluid systems were established in the map area. Veinlets and alteration are evident in almost all the Triassic and Jurassic rocks as well as some of the Eocene volcanic rocks. Thus, hydrothermal activity took place in the Tertiary as well as during the Jurassic following emplacement of the alkalic stocks. These indications are compatible with low-temperature gold deposits or peripheral zones of mesothermal gold mineralization and, therefore, provide some encouragement for further exploration.

ACKNOWLEDGMENTS

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GEOLOGY OF THE QUESNEL TERRANE IN THE SPANISH LAKE AREA, CENTRAL BRITISH COLUMBIA* (93A/11)

By Mary Anne Bloodgood

KEYWORDS: Regional geology, Quesnel terrane, Likely, Triassic black phyllites, structural geology, stratigraphy.

INTRODUCTION

The following paper summarizes the preliminary results of detailed mapping in the Spanish Lake area, Likely, central British Columbia. Fieldwork during the 1987 season was conducted in conjunction with mapping by A. Panteleyev and D.G. Bailey (this volume) to the south and west respectively. Regional mapping was initiated in 1986 (Panteleyev, 1987; Bloodgood, 1987b) to focus on the details of structure, stratigraphy and mineralization within the sedimentary and volcanic assemblages comprising the Quesnel belt within map sheet 93A. Fieldwork during the 1987 season extended mapping further to the north along the northwesterly trend of the Quesnel belt (Figure 1-12-1). The intent of this study is to elucidate the details of structure and stratigraphy within the Triassic metasedimentary sequence in the Spanish Lake area, and to determine possible controls on mineralization. The 1987 field studies focused on detailed structural and stratigraphic examination of the Triassic black phyllites. Regional correlations of the stratigraphic variations recognized within the black phyllite package were based upon previous work to the south, in the Eureka Peak area (Bloodgood, 1987a, 1987b), and recent work in the Quesnel Lake area by Struik (1983), Rees (1981) and Rees and Ferri (1983).

GEOLOGIC SETTING

The Spanish Lake area lies immediately east of Likely in central British Columbia. An area of approximately 400 square kilometres was examined, bounded to the south and west by the northern shore of Quesnel Lake; the eastern and northern map boundaries are defined by the trace of the Eureka thrust. The area lies within the Quesnel terrane (Struik, 1986) of the Intermontane Belt (Monger *et al.*, 1982) and is adjacent to the Omineca Belt–Intermontane Belt tectonic boundary (Figure 1-12-1). This tectonic boundary is believed to represent a convergent zone between the arc-related Quesnel terrane and the parautochthonous Barkerville terrane of the Omineca Belt to the east. The terrane boundary is defined by the Eureka thrust (Struik, 1986).

Underlying the area are middle Triassic to early Jurassic sedimentary and volcanic rocks, which historically have been correlated to the Quesnel River Group and Takla Group (Campbell, 1978; Rees, 1981; Tipper, 1978). More recently they have been informally correlated with the Nicola Group to the south, where rocks of equivalent age and lithology have been recognized within the Quesnel terrane. A mafic

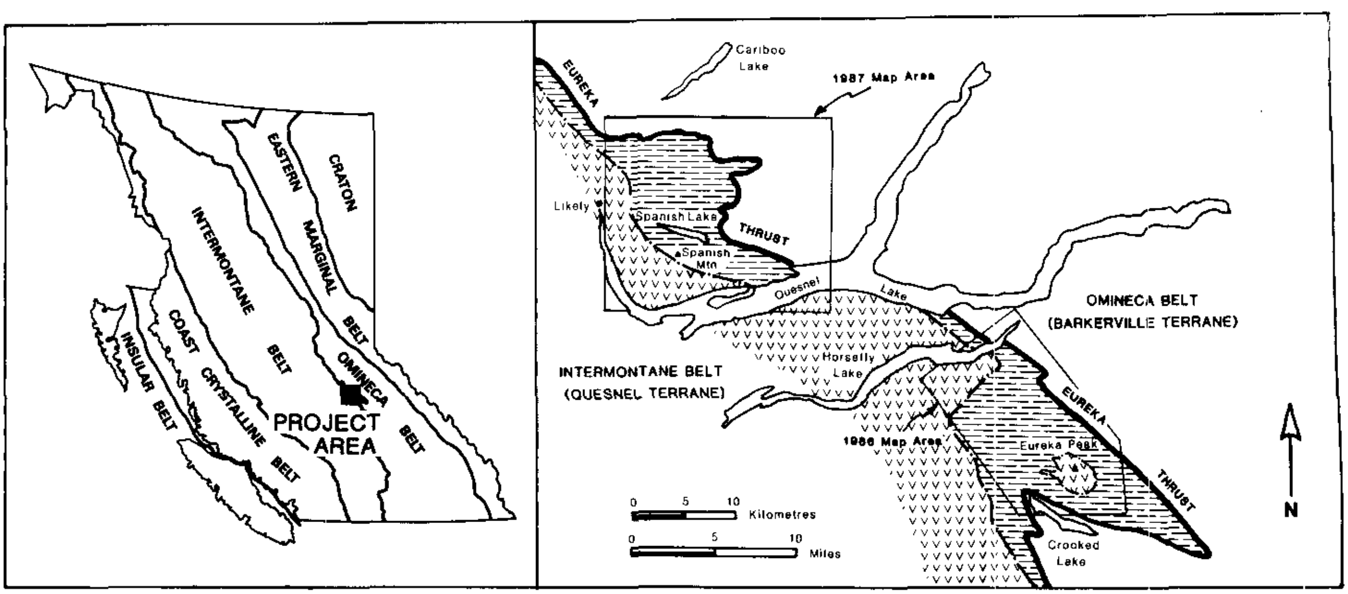

Figure 1-12-1. Location of the 1987 and 1986 map areas, with the configuration of the Omineca–Intermontane Belt tectonic boundary, defined by the Eureka thrust. The distribution of the Triassic metasediments is indicated by the stippled pattern; they are overlain by volcanics to the west.

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

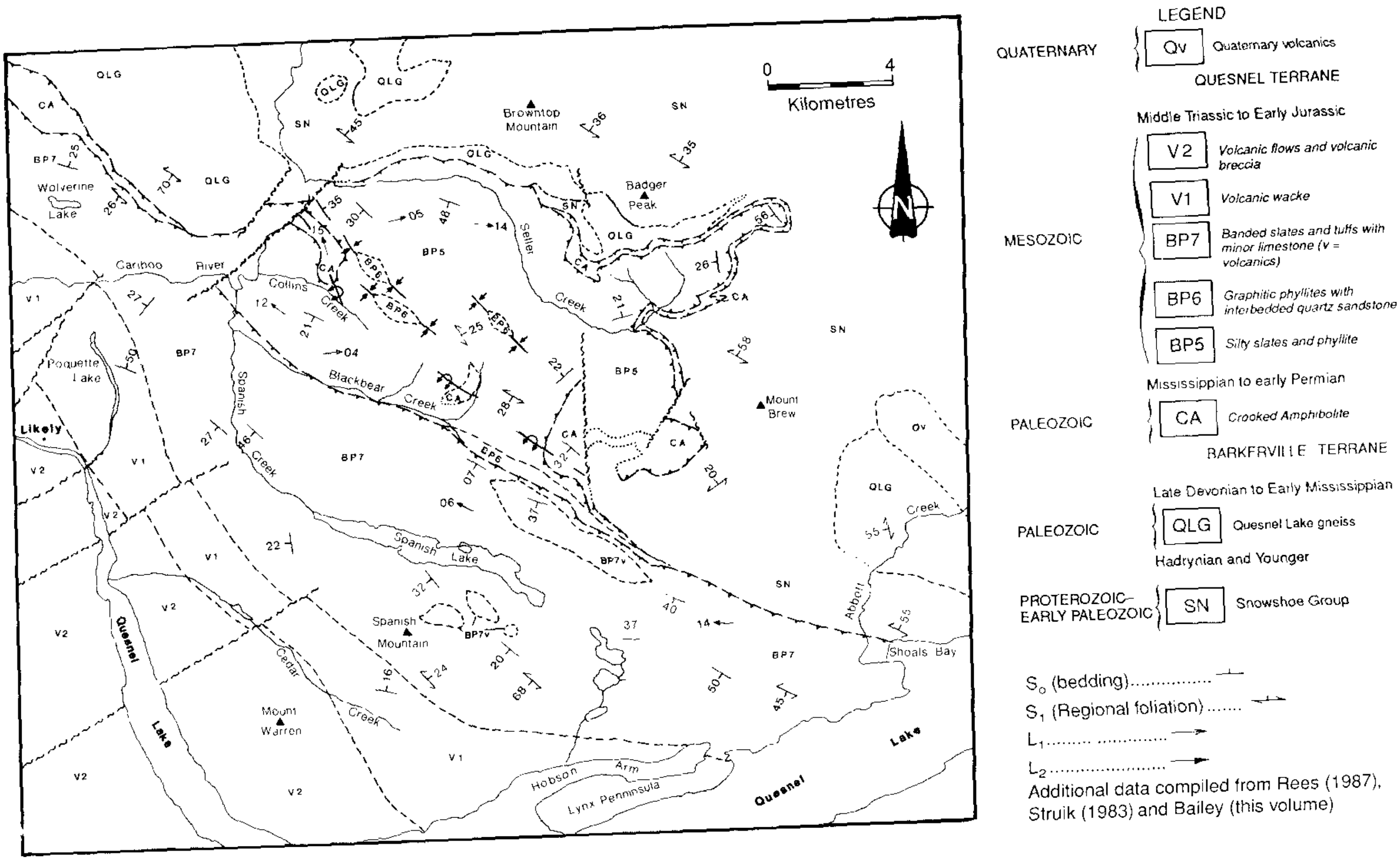

Figure 1-12-2. Generalized geologic map of the Spanish Lake area.

volcanic unit, the Crooked amphibolite, is the basal unit of the Quesnel terrane (Struik, 1986). It occurs discontinuously along the terrane boundary, and may be correlative to the Slide Mountain terrane exposed further to the north.

The Quesnel terrane overlies Hadrynian to early Paleozoic metasediments of the Snowshoe Group, and locally is in direct contact with the Quesnel Lake gneiss. These two units comprise the Barkerville terrane within the area.

STRATIGRAPHY

Field studies during the 1987 season concentrated upon establishing the finer stratigraphic details within the black phyllites. For a unified understanding of the regional geology, all of the major map units will be briefly described, with more detailed descriptions of the units identified within the phyllites. Figure 1-12-2 depicts place names, and areal distribution of the lithologies and structures in the discussion that follows.

BARKERVILLE TERRANE

SNOWSHOE GROUP

Rocks of the Snowshoe Group comprise the oldest lithologies observed within the area. They are well exposed in the northern part of the map area, to the north of Seller Creek. The Snowshoe Group consists of interbedded, dark grey to olive, pelitic and semipelitic schist, laminated micaceous quartzite, siliceous dark grey phyllite and metasiltite, with subordinate dark micritic limestone, grit, wackestone and amphibolite. Detailed mapping by Struik (1983) has delineated finer subdivisions within this map unit.

QUESNEL LAKE GNEISS

The Quesnel Lake gneiss occurs as a large intrusive body within the Snowshoe Group metasediments. Megacrystic quartz-feldspar augen gneiss of granitic composition comprises the unit within the map area. The Quesnel Lake gneiss is well exposed north of the Cariboo River where it occurs as a large body adjacent to the tectonic boundary. Along this contact, the gneiss contains a mylonitic fabric and is mechanically intercalated with the Crooked amphibolite which structurally overlies it (Plate 1-12-1). To the north of Seller Creek, the gneiss appears to be structurally overlain by the Triassic metasediments of the Quesnel terrane. Unfortunately the contact between the two is not exposed. Uranium-lead dating of the Quesnel Lake orthogneiss further to the south has constrained the age of emplacement as Late Devonian to Middle Mississippian (Mortensen *et al.*, 1987).

Plate 1-12-1. Mechanical intercalation of Quesnel Lake gneiss and the Crooked amphibolite along the Eureka thrust.

QUESNEL TERRANE

CROOKED AMPHIBOLITE

The Crooked amphibolite defines the basal unit of the Quesnel terrane. It overlies both the Quesnel Lake gneiss and the Snowshoe Group. It is well exposed north and west of the Cariboo River, where it overlies the Quesnel Lake gneiss, and it occurs discontinuously along the eastern trace of the boundary. The base of the Crooked amphibolite defines the Eureka thrust along which mechanical intercalation of the amphibolite with adjacent units is observed everywhere that the contact is exposed.

Medium to dark green, well-foliated talc chlorite schist, amphibolite, serpentinite and ultramafic rocks comprise the Crooked amphibolite within the map area. Compositional layering within the chlorite schists and amphibolites is defined by alternating plagioclase and hornblende-rich layers, 2 to 5 centimetres thick. The ultramafics occur as large, rusty weathering, lensoid bodies of serpentinized harzburgite near the tectonic boundary, and as smaller lenses (up to 2 metres) within individual exposures.

TRIASSIC BLACK PHYLLITE

Four mappable units have been defined in the Spanish Lake area. Differentiation of each unit and correlation with units recognized in the Eureka Peak area are based solely upon field observations of lithologic variations.

SILTY SLATES AND PHYLLITES (UNIT 5)

The basal member of the sedimentary succession is presently correlated with "Unit 5" of the Eureka Peak area (Bloodgood, 1987a, 1987b), and consists of reddish brown-weathering, dark to medium grey phyllites. Bedding is defined by fine compositional laminations and grey siltstone beds, 1 to 10 centimetres thick. Rusty to sandy weathering schistose tuffs occur locally, with an average thickness of 1 metre. Cleavage is always well developed; the unit is characterized by a planar slaty to phyllitic foliation. Carbonaceous material is commonly concentrated on cleavage planes.

The unit is well exposed along the roadcuts immediately south of Seller Creek, and comprises the bulk of the metasediments exposed to the north of Blackbear Creek.

GREY PHYLLITES AND INTERBEDDED SANDSTONES (UNIT 6)

This unit outcrops less extensively than Unit 5, and is generally confined to the core region of small synformal folds north of Spanish Lake. The basal contact with Unit 5 is gradational over a distance of several metres. Bedding is defined by pale grey, parallel-laminated siltstone beds, generally less than 2 centimetres thick (Plate 1-12-2). The consistently well-bedded, thin, light-coloured siltstone beds are characteristic of this unit, and distinguish it from the monotonously grey silty phyllites of Unit 5. Based on lithologic similarities, this unit is correlated with "Unit 6" in the Eureka Peak area (Bloodgood, 1987a, 1987b).

Tuffs, Slates and Phyllites (Unit 7)

Stratigraphically and structurally upsection, a package of mixed volcanics and sediments is recognized, and is in thrust contact with the underlying sequences along its entire strike length. It is well exposed south of Blackbear Creek, underlying the Spanish Lake and Spanish Mountain areas. It is lithologically distinguished from the underlying phyllitic sequence due to the incorporation of a distinct volcanic component in the sediments. Lithologically, it appears to be equivalent to "Unit 7" of the Eureka Peak area (Bloodgood, 1987a, 1987b).

Very black, rusty weathering, slaty to phyllitic metasediments comprise the sedimentary component of this unit. Individual finely laminated beds range from 3 to 50 centimetres thick. Minor pale silt and sand horizons are observed near the base of the unit and range in thickness from 1 to 4 centimetres. Colour laminations are common within the individual beds. Dark brown to black-weathering, grey limestones occur throughout the unit. Conodonts obtained from these limestones range in age from Anisian to Ladinian, and indicate possible imbrication within the unit (L.C. Struik, personal communication, 1987).

The volcanic component of the sequence increases progressively upsection, and consists of banded tuffs, volcanic conglomerate, flow breccias and local pillow lavas. Pale green, rusty weathering tuffs are interbedded with black slates and range in thickness from 2 centimetres to 1.5 metres. Locally, white-weathering, pale green tuffs dominate the succession. They are characteristically very siliceous and well banded; bedding varies from 2 to 5 centimetres thick. Despite the siliceous nature of this unit, a penetrative planar

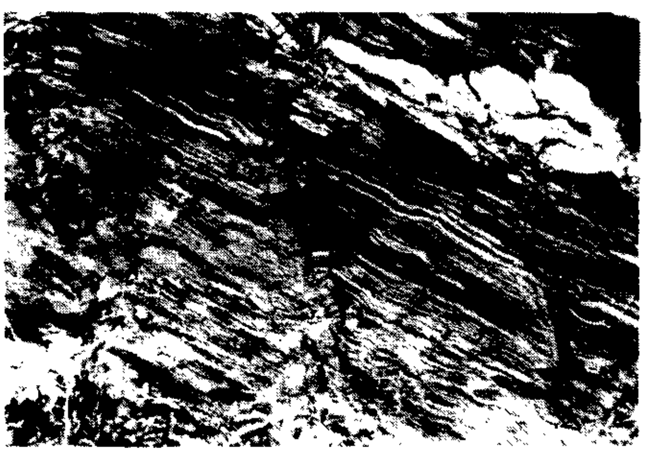

Plate 1-12-2. Thinly bedded, light-coloured siltstones characterize the bedding within "Unit 6". A barren quartz vein is observed shallowly truncating bedding in the upper right.

cleavage is usually well developed. Locally overlying the banded tuffs is a discontinuous volcanic conglomerate containing clasts of the underlying tuffs. Occurring as discontinuous lenses are volcanic flow breccias and pillow lavas which are well exposed on several prominent knobs east of Spanish Mountain. Compositionally and texturally, the flow breccias appear equivalent to the augite-bearing porphyritic flows which occur at the base of the volcanic sequence farther to the west (Bailey, this volume), and to the south in the Eureka Peak area (Bloodgood, 1987a). Dykes of the same composition occur locally, and are believed to represent feeders to the overlying volcanic sequence.

Volcanic Wackes

Coarse-grained, green volcanic sandstones and wackes comprise the uppermost unit of the sedimentary package. It is well exposed along the main road north of Likely, and to the south of Spanish Mountain. Interbedding of siltstones and sandstones and minor black argillaceous sediments defines bedding, which is generally obscure in this unit. Schistosity is poorly developed and is only present locally. No lithologically equivalent units are recognized in the Eureka Peak area.

Volcanics

Volcanic rocks of Triassic to Jurassic age immediately overlie the sediments described above. The contact between the sediments and volcanics is not exposed, but must occur in the Cedar Creek valley. The basal member of the volcanic sequence consists of augite-bearing flows and local pillow lavas. These are well exposed on Mount Warren, south of Cedar Creek. Equivalent lithologies are recognized in the Eureka Peak area, marking the base of the volcanic sequence. The remainder of the overlying volcanic sequence has been examined by Bailey (this volume).

STRUCTURE

FOLDING

Overprinting relationships of structural elements (bedding, cleavage, lineations) indicate that two phases of deformation involving folding have occurred.

Phase 1 Deformation

First phase structures (F_1) are recognized throughout the area and are represented by "mostly northeast-verging" folds of bedding (S_0). A penetrative slaty to phyllitic foliation (S_1), dipping shallowly to moderately to the southwest, is well developed axial planar to F_1 folds. The intersection of bedding and cleavage defines an intersection lineation parallel to the F_1 minor fold axes. A mineral elongation lineation is observed locally. First phase linear structures plunge gently to the northwest and southeast, in the azimuth range of 320 to 350 degrees.

First phase structures are developed at all scales throughout the area. Small-scale isoclinal folds of bedding are pervasively developed, and there is evidence for larger scale overturned to recumbent folds. The structural vergence observed on mesoscopic F_1 folds, and the map pattern outlined by the exposures of Crooked amphibolite south of the Cariboo River, indicate a large antiformal culmination in this area, which is interpreted as a large, easterly verging Phase 1 nappe structure.

PHASE 2 DEFORMATION

Phase 2 structures (F_2) overprint and refold F_1 structures throughout the area. Structural elements associated with F_2 are a well-developed nonpenetrative cleavage (S_2), manifest as a crenulation cleavage, or a spaced cleavage, or locally a fracture cleavage (Plate 1-12-3). A prominent lineation is defined by the intersection of S_0/S_2 or S_1/S_2. The intersection lineation is parallel to the fold axis of mesoscopic F_2 folds, and S_2 is developed axial planar to F_2 mesoscopic structures.

F_2 folds occur as open, buckle folds and conjugate kink-type folds. The axial surfaces of F_2 structures are present as conjugate sets dipping moderately to the northeast and southwest. Linear structures associated with F_2 are curvilinear along the trace of the F_2 hingeline (Plate 1-12-4), and plunge gently to the northwest and southeast. Within the hinge region of mesoscopic F_1 folds, the S_2 surface approaches into near parallelism with the S_1 surface. This geometric relationship characterizes the area north of Spanish Lake where an F_1 nappe is postulated.

The overprinting of F_1 structures by F_2 deformation, at a slightly oblique angle, is responsible for the development of a series of antiformal culminations and synformal depressions recognized throughout the area. This fold interference geometry is further enhanced by the doubly plunging nature of both the F_1 and F_2 fold axes. The map pattern of "Unit 6", which is restricted to lozenge-shaped synformal depressions, is attributed to this geometric relationship. This structural geometry, characterized by an arching in the hinge region, has resulted in the exposure of deeper structural levels within the core region of the F_1 structure.

PHASE 3 DEFORMATION

Phase 3 deformation is ubiquitous throughout the area as a spaced cleavage and fracture set. The fractures dip steeply to the north and south. Fracture spacing varies according to

Plate 1-12-3. A spaced fracture cleavage is developed in the hinge region of this open F_2 fold within the black phyllites.

Plate 1-12-4. Plan view of a slaty cleavage (S_1) surface which has been folded by F_2. The plunge of the F_2 fold axis changes along the trace of the F_2 hingeline (parallel to the eraser), giving rise to doubly plunging structures. The first phase lineation (L_1) defined by the intersection of bedding (S_0) on the slaty cleavage surface (S_1) can be seen in the lower right.

lithology, and ranges from about 1 centimetre to 1 metre. No macroscopic folds are associated with this structural event which overprints all previously developed fold forms.

FAULTING

THRUST FAULTS

Three major thrust faults are recognized in the area: the Eureka thrust; a thrust at the base of the metasedimentary package; and a thrust at the base of the tuff-phyllite unit.

Thrust faults are believed to be synchronous to F_1 deformation and are overprinted and deformed by F_2 structures.

The Eureka thrust is a low-angle, southwesterly dipping fault at the base of the Quesnel terrane. The Crooked amphibolite occurs discontinuously along the terrane boundary, and where it is absent, the Triassic metasediments immediately overlie the fault. Mechanical intercalation of the Crooked amphibolite with Quesnel Lake gneiss is well exposed on the large, logged knobs north of the Cariboo River.

A second thrust occurs at the base of the metasedimentary package. Near Collins Creek, imbrication of Crooked amphibolite with the overlying phyllites is well exposed. Plate 1-12-5 illustrates the faulted contact between these two units and also shows a well-developed S_2 fabric overprinting the fault zone. This fault is inferred from topographic features and confirmed by stratigraphic correlations to the Eureka Peak area, which indicate that the lower portion of the sedimentary stratigraphy recognized in that area is absent in the Spanish Lake area. It is believed that thrusting along the tectonic boundary affected higher structural levels, resulting in the removal of lower stratigraphic units.

A thrust contact is observed at the base of Unit 7 which discordantly overlies the Crooked amphibolite north of Cariboo Lake. In this area, mechanical intercalation resulting from thrusting is evident along the contact. North of Spanish Lake, Unit 7 directly overlies Units 5 and 6 of the black phyllite stratigraphy and, further to the east, metasediments and volcanics of Unit 7 overlie the Snowshoe Group. Ages of

Plate 1-12-5. Imbrication along the contact between the Crooked amphibolite and the Triassic metasediments. An imbricate slice of Triassic sediments lies in the hangingwall of this fault. Quartz-filled fractures are prominent close to the fault zone, which is overprinted by F_2 southwesterly dipping crenulations.

conodonts obtained from this unit indicate that it may also be internally imbricated (L.C. Struik, personal communication, 1987).

NORMAL FAULTS

Numerous steeply dipping, northeast-trending normal faults have been recognized within the volcanic sequences to the west of the study area (Bailey, this volume). These faults post-date the regional folding. High-angle faults are recognized in the metasediments and may be related to the Phase 3 spaced fractures which are well developed in the mapped area. Recognition of major throughgoing faults within the sediments is hindered by the subtlety of the stratigraphic variations.

Plate 1-12-6. Small quartz-filled fractures outlining rootless isoclines. The penetrative slaty cleavage is axial planar to these small folds which developed early in the deformational history.

MINERALIZATION

Gold mineralization within the metasedimentary sequences throughout the Quesnel gold belt is intimately associated with quartz-filled fractures. A detailed study was undertaken as part of this project, in order to document the association of mineralization with vein geometry, mineralogy, stratigraphic interval and structural position. It suggests mineralization may be related to the migration of fluids along major detachment surfaces recognized within the Quesnel terrane.

Veins are observed on all scales within the Spanish Lake area. Extension fractures are generally filled by quartz, or less commonly quartz-carbonate. The fibrous nature of the quartz filling is often evident in smaller fractures; larger fractures are characterized by a much blockier quartz filling. The veins range in size from small incipient quartz-filled veinlets which outline rootless isoclines (Plate 1-12-6) to much larger veins, up to 2 metres in thickness. Deformed and undeformed quartz veins occur on all scales, along the limbs of mesoscopic folds and localized in the hinge region of mesoscopic folds. This geometric relationship of the filled fractures to the mesoscopic structures indicates that fracturing began early, and continued throughout the deformational history, resulting in some fractures which are intensely deformed, while others remain unaffected by deformation.

In the Eureka Peak area, mineralization occurring as gold-pyrite-quartz veins is most prominent in the hinge region of second phase folds at a specific stratigraphic horizon. In contrast, preliminary observations in the Spanish Lake area suggest that gold mineralization may be concentrated near the intersection of merging fault zones. More detailed analysis of the data collected during the summer will be needed to substantiate this hypothesis.

CONCLUSIONS

(1) The stratigraphy within the metasedimentary sequence has been documented within the Spanish Lake area, and can be correlated with that defined in the Eureka Peak area, farther to the south. Correlation of units of similar lithology suggests that a large section of the basal portion of the stratigraphy is absent in the Spanish Lake area.

(2) Correlation of the morphological characteristics of structural elements associated with the major deformational events indicates that they are equivalent to

those documented in the Eureka Peak area. The geometry of the two major fold phases differs between the areas, and probably reflects differences in strain geometry and magnitude along the terrane boundary during and following initial plate convergence between terranes. The recognition of a regional F_1 structure contrasts with the Eureka Peak area, where no F_1 structures of regional extent have been identified (Ross *et al.*, 1985).

(3) Formation of thrust faults, that are frequently controlled by bedding contacts, occurred early in the deformational history. Both the Eureka thrust and the thrust at the base of Unit 7 are recognizable in both the Spanish Lake and Eureka Peak areas. These faults are overprinted by F_2 folds. Thrusting along bedding surfaces probably occurred in response to accumulated strain along contacts between rocks of differing composition and thus rheology. Internal imbrication of Unit 7 has been suggested by Struik (personal communication, 1987) based on ages obtained from conodonts extracted from this unit.

(4) Stratigraphic and structural evidence indicates a deformational history involving the development of regional easterly verging fold structures accompanied by easterly directed thrusting during the initial stages of accretion of the Quesnel terrane to North America. Due to the strong evidence supporting deformation by thrusting within the area, it is possible to interpret the geology in terms of an F_1 eastward verging nappe, which formed during Phase 1 deformation. With progressive deformation, detachment surfaces developed along zones of higher strain, resulting in the shearing out of the lower limb of the nappe. Only the upper limb is preserved, and hence, only the upper portion of the metasedimentary stratigraphy. North of the Cariboo River, only Unit 7 is preserved along the boundary. This same relationship is observed farther north in the Dragon Lake area (Struik, 1984). It is believed that internal imbrication within the Quesnel terrane resulted in the preservation of progressively higher stratigraphic "slices" of the metasedimentary package from south to north, as observed along the terrane boundary.

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GEOLOGY OF THE CENTRAL QUESNEL BELT, HYDRAULIC, SOUTH-CENTRAL BRITISH COLUMBIA (93A/12)

By D. G. Bailey

KEYWORDS: Regional geology, Quesnel belt, Hydraulic map area, Nicola Group, alkaline volcanic rocks, alkalic intrusions, copper-gold mineralization, QR deposit, propylitic alteration.

INTRODUCTION

An ongoing project to remap and re-interpret the central Quesnel belt was begun in 1986. During the 1987 field season the author mapped an area extending from south of latitude 52°30′ to about latitude 52°45′, covering the central volcanic part of the belt, at a scale of 1:50 000 (Figure 1-13-1). This work was carried out in conjunction with mapping by Panteleyev in the Horsefly area to the south (Panteleyev, 1987; 1988) and by Bloodgood (1987; 1988) to the east. This work is a revision and extension of Preliminary Map 20 (Bailey, 1976), undertaken to update knowledge of the geology of the belt following the discovery of the significant Quesnel River (QR) gold deposit by Dome Exploration (Canada) Limited.

From the south to north the Quesnel belt, formerly known as the Quesnel trough, includes volcanic and sedimentary rocks of the Rossland, Nicola, Takla and Stuhini groups of Middle Triassic to Early Jurassic age. In the central Quesnel belt these Mesozoic strata are included in the Nicola Group as defined in southern British Columbia, and comprise a basal assemblage of generally fine-grained sedimentary rocks overlain by a dominantly volcanic assemblage. The lower sedimentary rocks are in thrust contact with the Precambrian to Lower Paleozoic Snowshoe Group to the east (Struik, 1986). In the west, although the contact of the Quesnel belt with the Cache Creek Group is not exposed, it is considered to be a fault. This fault is probably the southern extension of the Pinchi fault which separates the equivalent Mesozoic Takla Group from the Cache Creek Group north of Prince George.

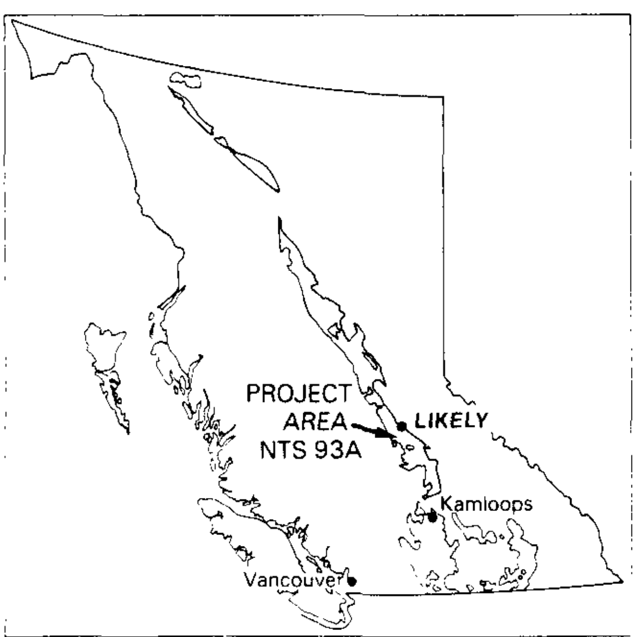


Figure 1-13-1. Location of the project area in Quesnel terrane (outlined area).

Basal sedimentary rocks of the central Quesnel belt range in age from probably Middle Triassic to Late Triassic. Overlying volcanic and associated rocks are Norian (Upper Triassic) to Sinemurian (Lower Jurassic). An essentially non-volcanic successor basin assemblage of late Lower Jurassic to Middle Jurassic (Pliensbachian to Bajocian) sedimentary rocks overlies the volcanic sequence. The regional Mesozoic geology of the central Quesnel belt and the distribution of major rock types are shown in Figure 1-13-2.

PREVIOUS WORK

The volcanic nature and Mesozoic age of rocks in the map area were first recognized by Amos Bowman in 1887 who named the upper part of the volcano-sedimentary sequence the "Quesnel River Beds". Cockfield and Walker (1934) re-examined Bowman's area and supported his conclusion that the Mesozoic rocks unconformably overlie Paleozoic rocks. Cockfield and Walker also implied that the volcanic rocks of Bowman's Quesnel River Beds were similar to those in the southern part of the Quesnel belt. The area was remapped and mapping extended to the east by Campbell (1961, 1963) and to the south by Campbell and Tipper (1970). These workers considered the Mesozoic volcanic rocks of the central Quesnel belt to be related to the Nicola Group of southern British Columbia (Schau, 1971; Preto, 1979). Subsequently Campbell (1978) renamed the volcanic rocks of the Quesnel River area the Quesnel River Group after Bowman's original name (Bowman, 1887). In this report, however, the name Nicola Group is applied to the Mesozoic strata of the central Quesnel belt.

The alkaline composition of most of the volcanic rocks of the central Quesnel belt was documented first by Fox (1975) and later detailed by Morton (1976) and Bailey (1978). Barr *et al.* (1976) described the distribution of the volcanic rocks and discussed the relationships between copper mineralization and alkalic plutonism within the belt. These authors

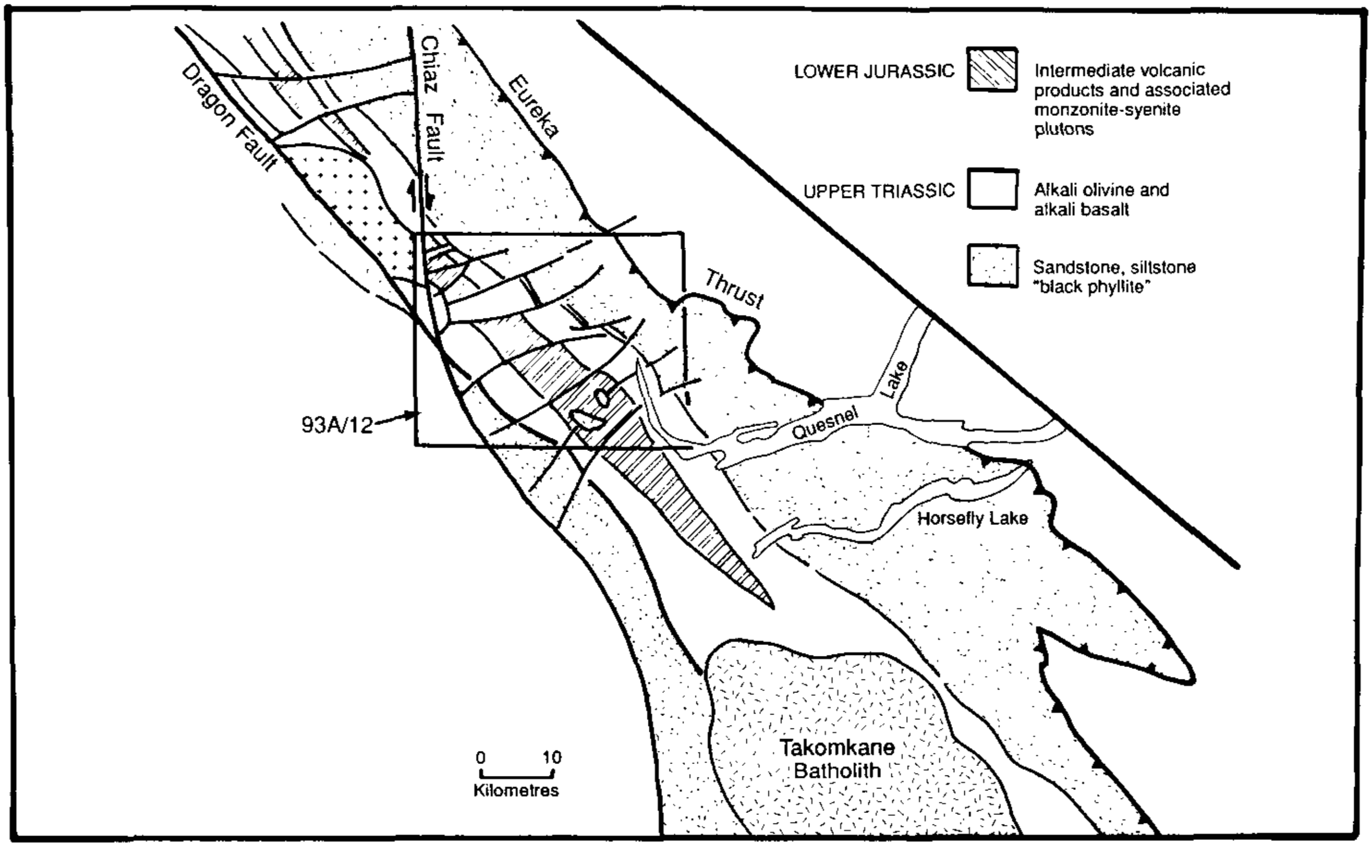


Figure 1-13-2. Simplified Mesozoic geology of the central Quesnel Belt.

argued that plutonism and volcanism were essentially comagmatic and coeval and that copper mineralization was both spatially and temporally related to these events, a conclusion supported by Bailey and Hodgson (1979) and Bailes (1977). The Cariboo-Bell porphyry copper deposit is an example of mineralization associated with alkaline intrusive and extrusive rocks; it occurs in the centre of the map area. This deposit has been described by Hodgson *et al.* (1976) and Bailes (1977). The recently defined QR deposit, a gold-copper deposit associated with an alkaline stock (Fox *et al.*, 1986), lies to the north of the Quesnel River.

STRATIGRAPHY

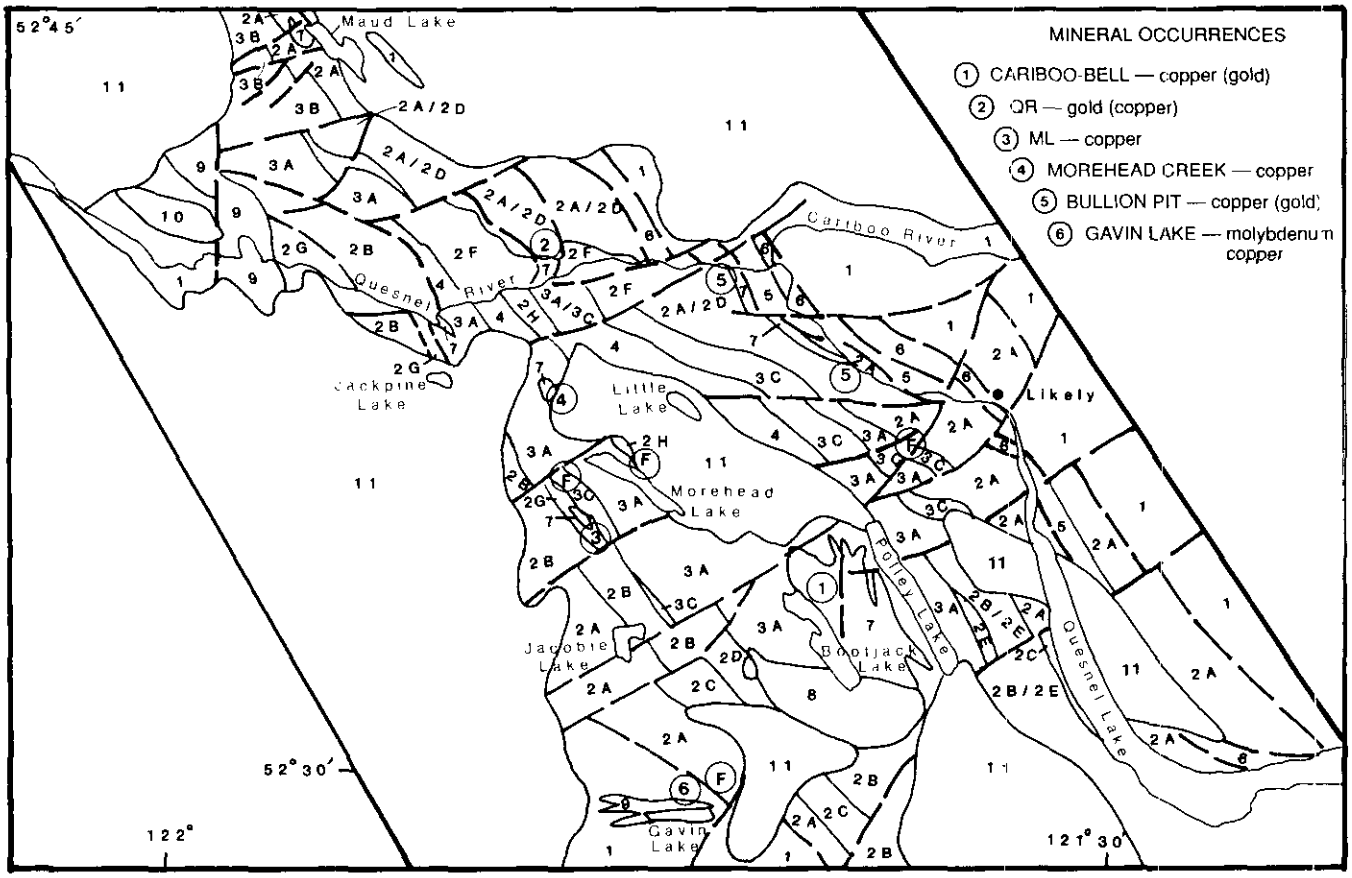
In contrast to the generally faulted and fragmented stratigraphic pattern of the southern part of the Horsefly map area (Panteleyev, 1987; 1988), the stratigraphic units of the Hydraulic map area (Figure 1-13-3) exhibit a bisymmetric, generally regular distribution which varies only in detail along the belt.

SEDIMENTARY AND VOLCANIC ROCKS

UNIT 1: The basal strata of the Mesozoic assemblage, both in the eastern and western parts of the belt, are fine-grained epiclastic sedimentary rocks. The eastern sedimentary assemblage is described by Bloodgood (this volume) and comprises her Unit 7. In the west this basal sedimentary unit is poorly exposed. Where observed it consists of phyllite, grading up into much less deformed siltstone, minor limestone, sandstone and greywacke. Toward the top of the unit mafic volcanic debris becomes common within the sedimentary rocks. This volcanic detritus is similar in composition to that of the overlying basaltic rocks, suggesting that early mafic volcanism and late sedimentation were essentially contemporaneous. Mafic dykes, interpreted to be feeders to the overlying volcanic rocks, cut the upper sedimentary sequence.

The age of Unit 1 in the eastern part of the belt has been determined from conodonts to range from Middle Triassic to Late Triassic (Struik, 1986). To the west, a Carnian fauna was collected from limestone within Unit 1 south of Gavin Lake (R.B. Campbell, personal communication, 1976) while *Monotis* sp. was collected from rocks immediately overlying Unit 1 near Gavin Lake (Bailey, 1978). Thus both the eastern and western sedimentary rocks exhibit a similar stratigraphic succession and are the same age. Therefore, it is concluded that the basal sedimentary rocks underlie the Quesnel belt and form the lowermost part of the Mesozoic volcano-sedimentary assemblage.

UNIT 2: Unit 2 comprises the products of mafic volcanism. It consists of green-grey pyroxene-phyric pillow lava, pillow breccia and autobrecciated flows, all of alkali olivine-basalt composition, at the base (2a), overlain by maroon to grey alkali basalt flows and breccia (2b). These two subunits comprise the bulk of Unit 2. In addition, mafic polylithic breccias, considered to have formed by laharic activity (2c), crop out in the central part of the map area.



LEGEND

SEDIMENTARY AND VOLCANIC ROCKS

PLEISTOCENE	11	*Glacial, fluvioglacial material*
MIOCENE	10	*Alkali olivine plateau basalt*
JURASSIC — PLIENSBACHIAN	6	*Chert, limestone and sandstone cobble conglomerate, shale, sandstone*
	5	*Interbedded sandstone, siltstone*
JURASSIC — SINEMURIAN	4	*Maroon alkali olivine basalt – analcite bearing*
	3C	*Feldspathic sandstone, siltstone*
	3B	*Monolithic latite tuff and breccia*
	3A	*Polylithic breccia with feldspathic clasts*
	2H	—
TRIASSIC — NORIAN	2G	*Massive grey limestone and calcareous sandstone*
	2F	*Interbedded mafic siltstone and sandstone*
	2E	*Analcite-bearing maroon and grey basalt*
	2D	*Hornblende-bearing pyroxene basalt*
	2C	*Polylithic mafic breccia*
	2B	*Maroon alkali basalt*
	2A	*Green and grey alkali and alkali olivine basalt*
	1	*Dark grey and green siltstone, sandstone, mafic tuff, minor conglomerate*

INTRUSIVE ROCKS

CRETACEOUS	9	*Granodiorite, quartz monzonite*
	8	*Nepheline syenite*
	7	*Monzonite, monzodiorite, syenite*

SYMBOLS

Fault

Geological contact

① Significant mineral occurrence

Ⓕ Fossil locality

Figure 1-13-3. Geology of Hydraulic area.

Hornblende-bearing pyroxene-phyric alkali basalt (2d) and analcite-bearing pyroxene-phyric alkali basalt that commonly contains plagioclase phenocrysts (2e) occur locally within rocks of Subunit 2a, that is, toward the base of Unit 2. A thick unit of siltstone and minor sandstone overlies and is interbedded with pyroxene basalt of Subunit 2a adjacent to the QR deposit.

Unit 2 is probably entirely of Late Triassic age (Norian). A thin red sandstone at the top of the unit in the Horsefly area contains a Norian fauna (R.B. Campbell, personal communication, 1976) and a limestone lens immediately overlying maroon basalt on the Morehead Lake–Beaver Valley road, 2.5 kilometres southwest of Morehead Lake resort, contains a Norian conodont fauna (H.W. Tipper, personal communication, 1987). *Monotis* sp. has been collected from a sedimentary lens within basalt at the base of Unit 2.

UNIT 3: Most of this unit consists of polylithic breccias (3a). These apparently formed by submarine slumping down oversteepened slopes during a second phase of volcanism. The compositions of rocks of this second phase of volcanic activity are mainly latite, trachyandesite and trachyte; breccias formed during this period of volcanism contain numerous clasts of these rocks. Where the breccias are proximal to volcanic centres, they contain more feldspar-rich clasts. Monolithic breccias, commonly of latitic composition (3b), with accompaying tuff, lie close to vent areas, now represented by syenite-monzonite plutons which formed within the volcanic edifices.

In the northern part of the map area monolithic latite breccia and immature tuffaceous sandstone predominate over polylithic breccias of 3a, while the polylithic breccias predominate in the southern and central parts of the map area.

Reasonably extensive feldspathic volcaniclastic and epiclastic siltstone deposits are poorly to well bedded and probably represent reworked tuffs (3c). These rocks are interpreted to be distal deposits related to major volcanic centres. The stratigraphic position of Subunit 3c is probably similar to that of 3a; Subunits 3a and 3c appear to lie on the uppermost basalt of Unit 2.

Unit 3 is probably Sinemurian in age. Strata deposited in a local sedimentary basin (2h), which appears to be partially covered by the volcanic products of Unit 3, are exposed in Morehead Creek and at Morehead Lake. Lower sediments in this basin contain Late Triassic fauna and they are overlain with apparent conformity by beds containing the Early Sinemurian index fossil *Badouxia canadense* (Frebold). These beds contain abundant mafic volcanic detritus suggesting a source in Unit 2, but no felsic volcanic detritus has been recognized in sediments of this basin. This suggests that felsic volcanism was later than Early Sinemurian and indicates a hiatus in volcanic activity of at least 4 to 5 million years duration. While spanning the stratigraphic gap between Unit 2 and Unit 3, sediments of this basin are included with Unit 2 because of the mafic composition and Norian age of the lower beds.

Thin discontinous sedimentary lenses occur within Unit 3 elsewhere in the map area. These sedimentary lenses are commonly calcareous and in places fossiliferous, but fossils obtained from them indicate only a general early Jurassic age (Bailey, 1978).

UNIT 4: This unit, which occurs only in the central part of the map area, consists of maroon alkali olivine basalt with characteristic small pink analcite grains present both as phenocrysts and as a matrix mineral. Generally highly amygdaloidal, the unit was probably erupted subaerially and represents the last stage of Nicola volcanism in the central Quesnel belt.

Unit 4 is younger than Subunit 3a on which it appears to sit unconformably and, thus, is probably younger than early Sinemurian.

UNIT 5: This unit, and overlying sedimentary rocks of Unit 6, represent a successor basin sedimentary assemblage which was deposited after late Triassic–early Jurassic volcanism had ceased. It comprises a sequence of dark to medium grey, commonly calcareous sandstone and siltstone which, although feldspathic, does not appear to contain detritus which can be directly attributed to a volcanic origin. In places these rocks are difficult to distinguish from rocks of Unit 1; their depositional environments appear to have been similar and they appear to occupy a similar structural position with respect to Unit 2. However, a Pliensbachian ammonite (*Arieticeras* sp.) has been collected from Unit 5 (R.B. Campbell, personal communication, 1976), demonstrating the younger age of these strata.

UNIT 6: Rocks of Unit 6 form a semi-continuous belt extending from near Horsefly Peninsula in the south (Panteleyev, 1987) to north of Quesnel River where the Mesozoic rocks of the belt become hidden by Pleistocene cover. Along the eastern margin of the Mesozoic volcanic belt, this unit is characterized by mature, generally clast-supported conglomerate. Clasts comprise dark grey chert, limestone, argillite, sandstone and, in places, greenstone presumed to be of basaltic composition. The Cache Creek Group which lies west of the Quesnel belt contains similar lithologies and represents the most likely source of the conglomerate beds. Fining-upward sequences of conglomerate, sandstone and carbonaceous shale are well developed within the unit.

The age of Unit 6 is probably Pliensbachian but there is no direct evidence for this. It appears to be in fault contact with Unit 5 and almost certainly with Units 1 and 2.

A generalized stratigraphic section of the sedimentary and volcanic rocks of the Hydraulic map area is given in Figure 1-13-4.

INTRUSIVE ROCKS

UNIT 7: This unit comprises varying amounts of syenite, monzonite, syenodiorite and monzodiorite and includes the Mount Polley, Bullion Pit, QR and Maud Lake stocks as well as a number of smaller plugs and dykes. Stratigraphic evidence (Bailey, 1978; Bailey and Hodgson, 1979) suggests that the Polley stock was coeval and comagmatic with the products of early Jurassic volcanism. However, radiometric data (Panteleyev, 1987), (Figure 1-13-5) and the observation that hydrothermal alteration associated with the Bullion Pit has affected Pliensbachian rocks indicate that plutonism continued after volcanism had ceased and may have extended into middle Jurassic time.

UNIT 8: Unit 8 consists of a single pluton, the Bootjack stock, which is composed mainly of nepheline syenite. Several textural types occur within this stock but the most distinctive is an orbicular nepheline syenite in which the orbicules are pseudoleucite. A whole-rock potassium-argon date obtained from a chilled margin of the stock is 111 ± 4 Ma suggesting that the stock is Cretaceous in age (Bailey, 1978). However, the material analysed was not very suitable for dating so this age must be treated with caution. Intrusive and stratigraphic relationships of the Bootjack and Polley stocks indicate that the nepheline syenite is younger than late Early Jurassic.

UNIT 9: Unlike all other rock types in the area this unit is characterized by the presence of modal quartz. It consists of quartz monzonite, granodiorite and granite and crops out as a faulted stock in the northwestern part of the map area and as the Gavin stock in the south. Small dykes of leuco-adamellite to leucogranite occur infrequently in the southern part of the map area, notably nepheline syenite of the Bootjack stock.

Unit 9 is probably also Cretaceous. Dykes of Unit 9 are younger than the Bootjack stock but Unit 9 granodiorite in the northwestern part of the area appears to be overlain by Miocene basalt.

Other intrusive rocks occur throughout the map area. Small bosses of hornblende syenite and hornblende monzonite, often surrounded by small alteration envelopes, are interpreted as part of Unit 7. These rocks intrude strata as young as Pliensbachian.

Pyroxene and pyroxene-hornblende-porphyritic mafic dykes, interpreted as feeders for the overlying mafic rocks, intrude Unit 1. Plagioclase-porphyritic mafic or intermediate dykes near the top of Unit 2 have only been seen in the northeastern part of the map area.

The youngest rocks in the map area, unrelated to the Quesnel belt, are plateau basalt flows of Miocene age (Unit 10). A large part of the area is covered by glacial and fluvioglacial deposits of Pleistocene age (Unit 11). Direction of transport of these deposits was toward the northwest (305 degrees).

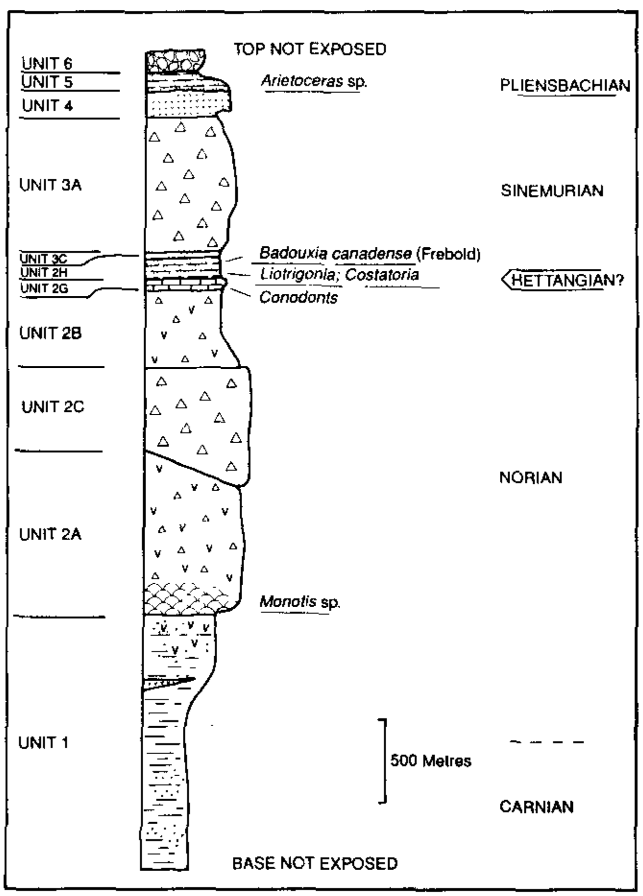


Figure 1-13-4. Generalized stratigraphic section, Hydraulic map area.

STRUCTURAL GEOLOGY

The central Quesnel belt has been folded into a broad open syncline of regional extent and cut by at least three generations of faults. In the area described in this report the geology exhibits two contrasting structural styles, one reflecting deformation caused by emplacement of Quesnellia onto the western margin of North America, and the second a later period of extensional tectonism.

The earliest deformation of the rocks is recorded in Unit 1, both to the east and the west of the volcanic belt. In the lower part of the sedimentary sequence, metapelites are deformed into east-verging recumbent folds with a well-developed axial planar fabric (*see also* Bloodgood, 1988). These folds have been refolded, giving rise to northeasterly lineations. No strong penetrative fabric is associated with this second period of folding although a crenulation cleavage is well

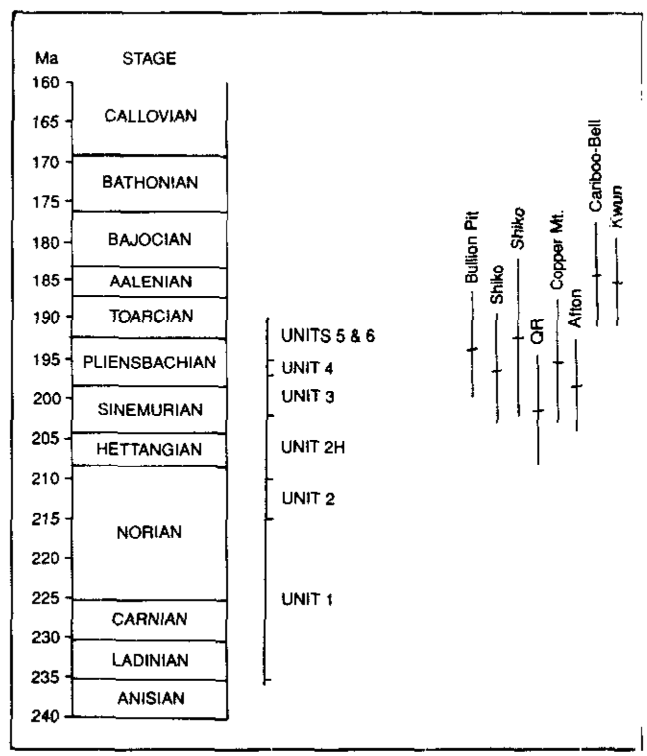


Figure 1-13-5. K/Ar radiometric ages of alkalic stocks of the Quesnel belt and their relationships to the stratigraphy of the central Quesnel belt.

developed in places. Higher in the Unit 1 stratigraphy deformation becomes less intense and, in the west, the coarser grained sedimentary rocks at the top of Unit 1 have not been penetratively deformed at all. Similarly, the coarse clastic and volcanic rocks of Units 2, 3 and 4 have behaved as a competent block and, although tilted and warped into a broad synform, are not penetratively deformed.

At least two periods of faulting have occurred within the map area. Early faults strike northwest. They appear to have been low-angle reverse faults which were subsequently steepened by tilting during later faulting. These reverse faults are seen only in the eastern part of the map area and are probably related to collision of Quesnellia with the Omineca terrane. Later faults strike dominantly to the northeast and the distribution of rock units suggests mainly sinistral displacement. A third fault set, mainly north striking, is probably related to the Pinchi fault system; these faults cut northeasterly striking faults. A north-striking dextral fault, informally named the Chiaz Creek fault, has displaced the central Quesnel belt and a pluton of probable Cretaceous age by a distance of about 7 kilometres.

The time of deformation of the central Quesnel belt was no earlier than late Early Jurassic, as Phase 1 thrust faults developed along incompetent siltstone beds within the conglomerate unit of probable Pliensbachian age. During this phase of deformation, which was probably the time of the first phase of folding in the lower sedimentary rocks, Norian volcanic rocks were apparently thrust eastwards over the Pliensbachian strata that are now exposed along the Quesnel River north of Likely.

Northeasterly striking faults appear to cut and, therefore, postdate low-angle reverse faults. Northeasterly faults are interpreted to cut the Polley stock, dated at about 185 Ma, but do not cut the Bootjack stock dated 111 Ma. Therefore, northeasterly faulting had ceased by Albian times (assuming the age of the Bootjack stock is correct).

North-striking faults which are related to the Pinchi fault system form the western boundary of the central Quesnel belt and may have been active into Tertiary time.

METAMORPHISM

With the exception of the lower sedimentary unit, the rocks of the central Quesnel belt are not significantly metamorphosed. Primary textures and fabrics are preserved except where the rocks have been affected by faulting or hydrothermal alteration. Most of the volcanic rocks record effects of zeolite facies regional metamorphism, due to burial.

In the underlying sedimentary rocks metamorphic grade is higher than zeolite facies but probably still subgreenschist.

MINERALIZATION

Alkalic stocks of the central Quesnel belt, such as the Polley stock, commonly host porphyry copper deposits which have a strong copper-gold association. Extensive propylitic alteration zones around these deposits are characterized by chlorite, epidote, calcite, pyrite and zeolites. Cariboo-Bell is the largest of the known alkalic porphyry deposits in the map area; reserves are about 116 million tonnes, grading 0.41 per cent copper and 0.025 gram per tonne gold.

The QR deposit to the north of the Quesnel River, with reserves of about 1.1 tonnes grading 7.2 grams per tonne gold, is also associated with an alkalic stock. Mineralization occurs within a zone of intense propylitization to the north and west of the stock but not within the intrusive body. Copper is closely associated with gold in the QR deposit which, although lower in the stratigraphy than the Cariboo-Bell porphyry deposit, probably formed at a much higher structural level.

Most of the syenite-monzonite stocks of similar age within the map area (for example, Morehead Creek, Morehead Lake, Bullion Pit) have propylitic alteration haloes. East of the Bullion Pit stock, alteration has affected rocks as young as Pliensbachian, which is in accord with the radiometric age of 193±7 Ma determined for the Bullion Pit stock (Panteleyev, 1987).

A number of monzonite-syenite stocks (for example, Maud Lake, QR, Bullion Pit and several smaller stocks) are distributed along or near the base of Subunit 2a in the easternpart of the map area. This distribution along a major facies boundary, at the base of the volcanic sequence and immediately above the lower sedimentary sequence, may reflect an early northwest-striking fault or fault zone which controlled the locii of mafic volcanism and stock emplacement. Similarly, the alignment of the Polley, Shiko, Lemon Lake and several other stocks suggests the presence of another linear structural feature controlling stock emplacement in the central part of the belt.

Hydrothermal calcite veins are associated with a hornblende monzonite intrusion to the east of the QR stock on the north bank of the Quesnel River. The veins occupy small extension fractures or faults within pyritic and chloritic basalt of Unit 2a which has been intruded by the monzonite.

The Gavin Lake stock hosts mineralization unrelated to Triassic-Jurassic volcanism and plutonism. The Gavin Lake stock consists of quartz monzonite and granodiorite which have intruded sedimentary rocks of Unit 1. These sedimentary rocks have been variably hornfelsed and metasomatized adjacent to intrusive contacts. Chlorite-pyrite alteration is prominent in places. Chalcopyrite-molybdenite mineralization is associated with quartz monzonite of the complex, mainly in the northern part. Exploration carried out in the 1970s failed to define economic mineralization and since that time no further exploration has been carried out in this area.

A granodiorite to quartz monzonite stock in the northwestern part of the map area, and which is presumed to belong to the same suite of intrusions as the Gavin Lake stock, has been variably propylitized around its margins and contains minor copper-molybdenum mineralization. The stock and its environs are at present being re-examined for possible gold mineralization.

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STRATIGRAPHY AND MINERAL OCCURRENCES OF CHIKAMIN MOUNTAIN AND WHITESAIL REACH MAP AREAS* (93E/06, 10)

By L. J. Diakow and V. Koyanagi

KEYWORDS: Regional geology, Chikamin Mountain, Whitesail Reach, Coast Complex, Intermontane Belt, Hazelton, Bowser Lake, Skeena, Kasalka, Ootsa Lake, Endako, quartz vein mineralization, porphyry copper-molybdenum, gold, silver-lead-zinc.

INTRODUCTION

The Whitesail project is a 3-year regional 1:50 000-scale mapping program that was begun in 1986. The project area, centred on Whitesail Lake, encompasses map sheets 93E/06, 10 and 11E.

The area is underlain by Mesozoic and Cenozoic volcanic and plutonic rocks that host epithermal and mesothermal vein deposits. The project objectives are twofold:

- Refine mapping of Mesozoic and Cenozoic stratigraphy and structures.
- Determine the geologic setting of known mineral occurrences.

During 1986, fieldwork was restricted to the Whitesail Range and Whitesail Reach areas. The results of this work are published as Open File 1987-4 and supplemented by a report in Geological Fieldwork, 1986 (Diakow and Mihalynuk, 1987b). In 1987, map coverage was expanded to the east and southwest to cover an additional 900 square kilometres (Figure 1-14-1). This report describes the lithostratigraphic divisions and structure of the area and the geological setting of several notable mineralized areas. The Whitesail project is funded under the Canada/British Columbia Mineral Development Agreement.

PREVIOUS WORK

The earliest reports of geological work in the study area cite results of reconnaissance shoreline mapping and document the development of mineral prospects in the Chikamin Range (Galloway, 1917, 1920; Brock, 1920; Marshall, 1924, 1925). Duffell (1959) published the first regional synthesis of geology in the Whitesail Lake map area. The same area was later remapped and the results published in a preliminary map (Woodsworth, 1980). This map, in addition to mapping immediately west of the project area by MacIntyre (1976, 1985) and van der Heyden (1982), are sources frequently referred to in the present study.

PHYSIOGRAPHY

The study area encompasses portions of the Coast Mountains and the Nechako Plateau. The Coast Mountains are a northwest-trending series of ranges made up of granitic and metamorphic rocks. The mountains commonly rise above 1800 metres elevation and typically have steep dissected slopes. The Nechako Plateau, which extends easterly from the Coast Mountains, is underlain by volcanic and sedimentary rocks. The transition between physiographic divisions is marked by Chikamin Range and Whitesail Range, which project northeastward from the Coast Mountains. These ranges have peaks in excess of 2200 metres elevation; relief gradually diminishes northeastwards to hilly topography, above 900 metres elevation, characteristic of the Nechako Plateau. The Quanchus intrusion forms the core of the Quanchus Range, an uplifted area rising more than 1100 metres above the valley bottom along the eastern margin of the study area.

The drainage in the area is split at a divide roughly coincident with the east boundary of the Coast Mountains. A northeastly drainage originates through a system of creeks and small lakes connected with Whitesail and Eutsuk lakes. This system provides access to lower slopes of the Whitesail and Chikamin ranges. A southwesterly drainage comprises a dendritic pattern of smaller tributaries connecting with larger streams flowing to the Pacific at Gardner Canal.

The effects of a major glacial epoch are evident throughout the map area. Striations on bedrock indicate a general northeasterly ice flow, roughly following the axis of Whitesail Lake. Ice-flow direction deviates easterly in northern Whitesail Range and north-central Chikamin Range, possibly indicating lobes deflected around areas of high relief. In the valleys, low amplitude glacial ridges and rounded topography, in places mantled with glacial deposits as thick as 75 metres, attest to widespread glaciation. Icefields and cirque glaciers are restricted to alpine areas above 1500 metres elevation in the mountain ranges.

GENERAL GEOLOGY

The study area, for the most part, is within the Intermontane Belt although the Coast plutonic complex underlies the southwestern sector. The boundary between these tectonic divisions is characterized by northeast-directed thrust faults, overprinted in places by younger high-angle faults (Woodsworth, 1978; van der Heyden, 1982).

The Coast Complex comprises polydeformed amphibolite and greenschist facies metamorphic rocks and synkinematic plutons that form a series of northeast-directed thrust sheets in the western Whitesail Lake map area. The protolith is interpreted as pre-Lower Jurassic volcanic and sedimentary rocks mostly of island arc affinity (van der Heyden, 1982). The deformed rocks reflect a Late Cretaceous to Early Terti-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

British Columbia Geological Survey
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ary tectonic event which resulted from the collision of allochthonous terrane with the western plate margin of North America (Monger *et al.*, 1982; Crawford *et al.*, 1987). Late Cretaceous and Early Tertiary post-orogenic plutons cut both the metamorphic rocks and thrust faults.

The Intermontane Belt is represented by a discrete series of volcanic and sedimentary rocks that accumulated in depositional basins which evolved in response to regional tectonic events. Unconformities separate the successive lithostratigraphic successions. The successions pertinent to this study, in order of decreasing age, are: Hazelton Group, Bowser Lake Group, Skeena Group, Kasalka Group, Ootsa Lake Group and Endako Group. The first three groups correspond with lower and middle Jurassic island arc volcanic and sedimentary rocks deposited in the Hazelton trough; middle and upper Jurassic marine and terrestrial sediments accumulated within the Bowser and Nechako successor basins; and mid-Cretaceous transgressive marine sediments deposited on older strata. The Kasalka Group unconformably overlies the Skeena Group. It is an upper Cretaceous volcanic succession erupted in a continental margin arc setting. In turn, Tertiary volcanic rocks of the Ootsa Lake Group and younger Endako Group succeed the Kasalka Group. The Tertiary successions represent widespread effusive flows erupted in a transtensional continental setting.

LOCAL STRATIGRAPHY

The stratigraphy in the study area is dominated by lava flows and pyroclastic rocks; sedimentary beds are not widespread. Plutons cut and in places metamorphose layered strata. These rocks are divided on the basis of general outcrop appearance, lithology and stratigraphic relationships. The age of sedimentary strata is determined by fossil fauna, whereas the age of crystalline rocks will be defined more accurately by isotopic dating techniques. The stratigraphic divisions proposed in this paper build upon the observations of previous workers within and outside the study area. The distribution of stratigraphic units is shown in Figure 1-14-2.

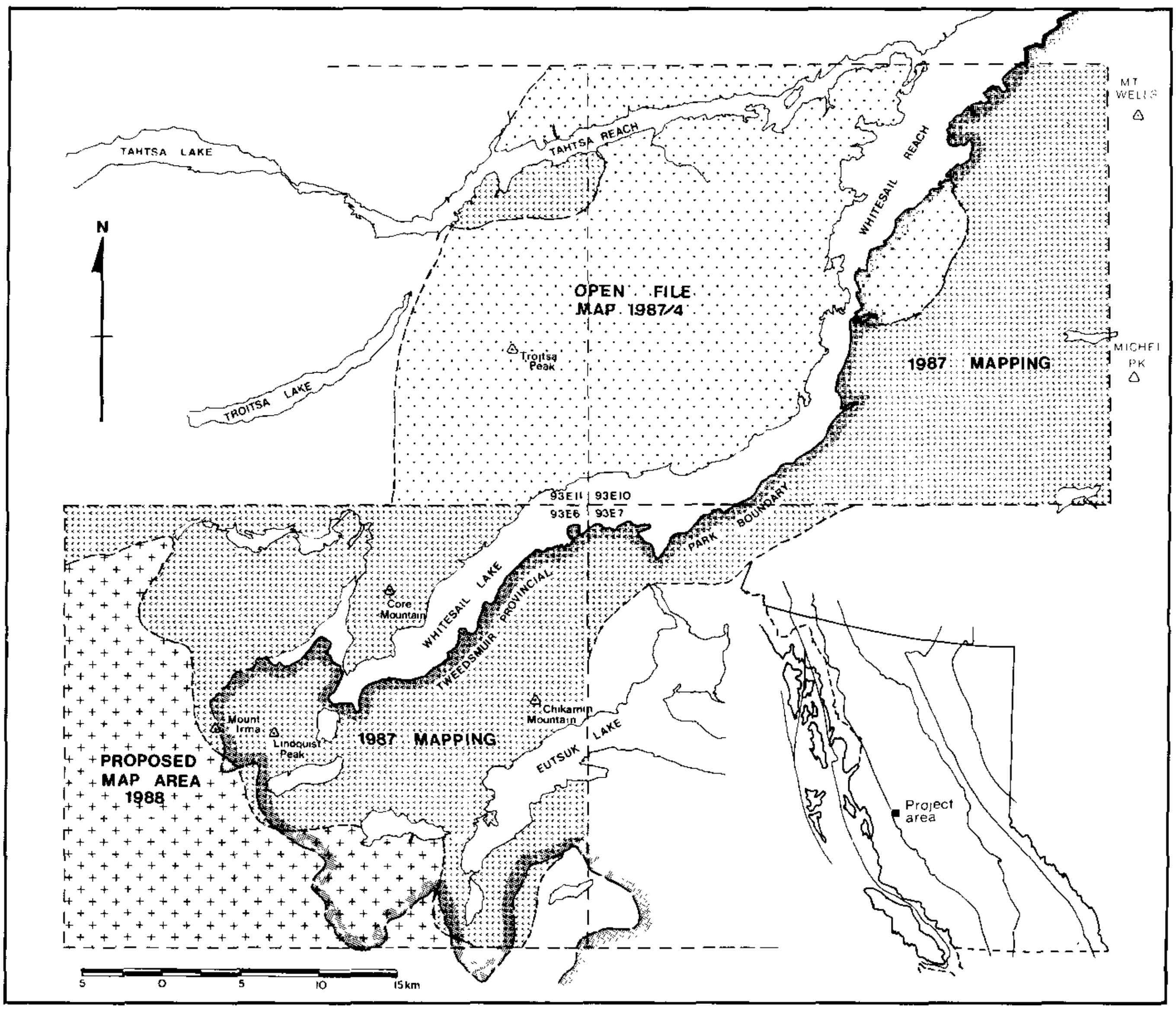

Figure 1-14-1. Location of Whitesail Project area.

PRE-JURASSIC ROCKS–GAMSBY GROUP (MG)

The Gamsby group is an informal name for metavolcanic and metasedimentary rocks exposed near the eastern margin of the Coast plutonic complex in Whitesail Lake map area (Woodsworth, 1978). In the present study area these rocks are confined to a narrow belt south and west of Lindquist Lake, where they structurally overlie the Skeena Group or are intruded by Coast intrusions. They comprise a succession of intermediate and mafic tuffs, flows and schists associated with a dioritic pluton. The diorite is found at the lowest structural level of the succession. It passes topographically upwards into a mixed assemblage of dark green lapilli tuffs, flows and phyllitic tuffs. The strata have been regionally metamorphosed to greenschist grade, a feature indicated by ubiquitous albite, chlorite and epidote. In places epidote lines fractures and is commonly found with quartz in irregular clots and discontinuous veins. The contact between diorite and metavolcanic rocks is not exposed, but is thought to be a fault.

Deformation is defined by a pronounced penetrative foliation with a moderately steep southerly dip in the metavolcanic rocks. The style of deformation varies between beds, from prolate fragments to mylonitic structure. The foliation in dioritic rocks appears to be related to the same deformational event that affected the metavolcanic rocks. It becomes more pronounced, changing the rock into mylonite, at a major thrust fault separating the diorite from younger rocks.

The protolith of the Gamsby group is a tholeiitic and calcalkaline series of volcanic rocks representative of a mature island arc setting (van der Heyden, 1982). The age of these strata is at least upper Triassic, but may be as old as upper Paleozoic (van der Heyden, 1982).

LOWER AND MIDDLE JURASSIC–HAZELTON GROUP

The Hazelton Group (Leach, 1910) is most recently redefined in north-central British Columbia by Tipper and Richards (1976), who propose a threefold division. The strata include, in order of decreasing age: the Telkwa Formation, Nilkitkwa Formation and Smithers Formation. They collectively represent widespread volcanic and sedimentary deposits accumulated within the Hazelton trough from Sinemurian to Early Callovian time. These strata, excluding the Nilkitkwa Formation, are well represented in the study area.

TELKWA FORMATION

The Telkwa Formation is exclusively comprised of volcanic rocks that can be arbitrarily subdivided into two map units: layered maroon volcanics (lJT_1) and foliated green volcanics (lJT_2).

Layered Maroon Volcanics (lJT_1)

Map unit lJT_1 is best exposed between Little Whitesail and Coles lakes, at Core Mountain and on north and east-facing slopes of Chikamin Mountain. South of Coles Lake an apparently unfaulted north-dipping monocline is at least 3000 metres thick. Neither the top nor bottom contact were found. These rocks are characterized by distinctly bedded maroon, brick red, and lesser green pyroclastic rocks and volumetrically subordinate flows. Intravolcanic epiclastic rocks are negligible or absent.

The pyroclastic rocks include, in order of relative abundance: crystal-lapilli tuff, ash tuff, and uncommon accumulations of lapilli block tuff and lahar. The pyroclasts mainly consist of aphanitic maroon and red subangular fragments that rarely exceed 3 centimetres in diameter. The matrix is dominated by indurated ash which supports plagioclase and sparse quartz phenocrysts. Thick beds exhibit graded pyroclasts, and parallel-laminated ash tuff with and without accretionary lapilli.

Lava flows form resistant layers interspersed within thick pyroclastic successions. The composition of flows ranges from basalt, through andesite to rhyolite, and they have amygdaloidal, porphyritic, aphyric and rarely flow-laminated textures. Most lava flows form uniformly thick beds between 2 and 12 metres thick; exceptions are the felsic flows which have large lateral variation in thickness. This variation probably reflects local eruptions of viscous lava.

The well-layered maroon pyroclastic and flow rocks represent subaerial eruptions probably related to composite volcanic centres. Successive eruptions of tephra and lava constructed a low-gradient plain relatively distant from any major centre.

Foliated Green Volcanic Rocks (lJT_2)

Lava flows and lesser tuff, and tuffaceous sediments, typically dark green with or without a penetrative foliation, characterize map unit lJT_2. They underlie a discontinuous northwest-trending zone straddling the northern half of Little Whitesail Lake and north Coles Lake. Similar rocks also underlie a 12-square-kilometre area west of Michel Lake. Their contacts with lJT_1 are generally presumed to be faulted. In the Michel Lake area, these rocks have an estimated minimum thickness of 2000 metres and a conformable upper contact with Middle Jurassic sedimentary rocks.

No type area exists for map unit lJT_2, instead it comprises variable proportions of flows and pyroclastic rocks. The Michel Lake succession is composed of aphyric and porphyritic basalt and andesite lava flows that are intimately interlayered with lapilli and ash tuff and local sedimentary rocks. The pyroclastic beds are commonly graded, laminated and rarely crosslaminated. Some of these finer grained layers suggest reworking of volcanic detritus within a shallow-marine environment. In places, indeterminate pelecypods have been recovered from volcanic-derived sandstone layers. Marlstone and pebble conglomerate interlayered with tuffs and flows occupy a panel thrust northwesterly over middle Jurassic strata about 3.5 kilometres west of Michel Lake. The marlstone, at least 35 metres thick, is characterized by a differentially weathered surface resembling the appearance of Swiss cheese. These rocks, unlike any observed from the Telkwa Formation elsewhere in the map area, indicate shallow-marine sedimentation prevailed locally during periods of relative volcanic quiescence.

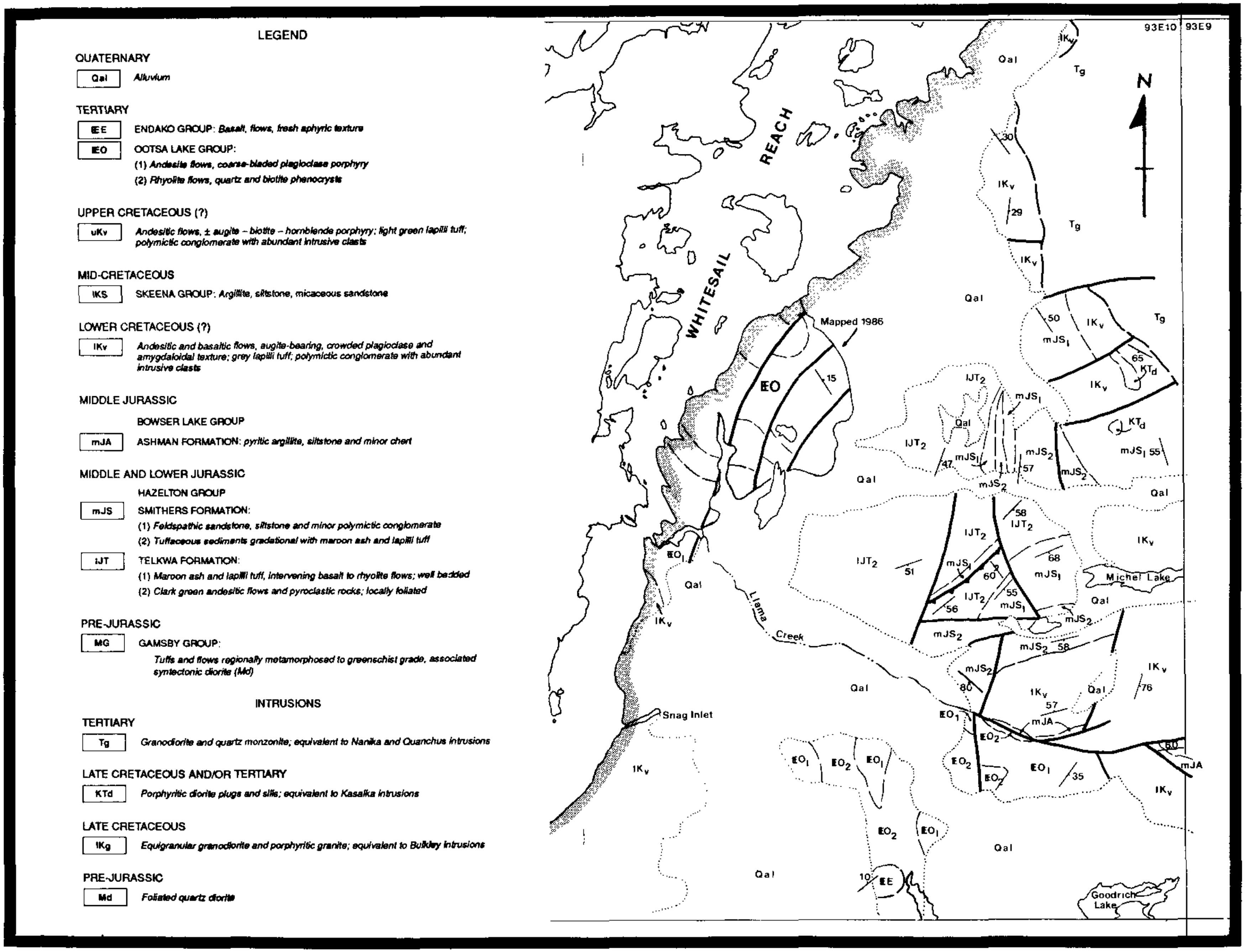

Figure 1-14-2A. Geology of the East Half of Whitesail Reach map sheet, NTS 93E/10.

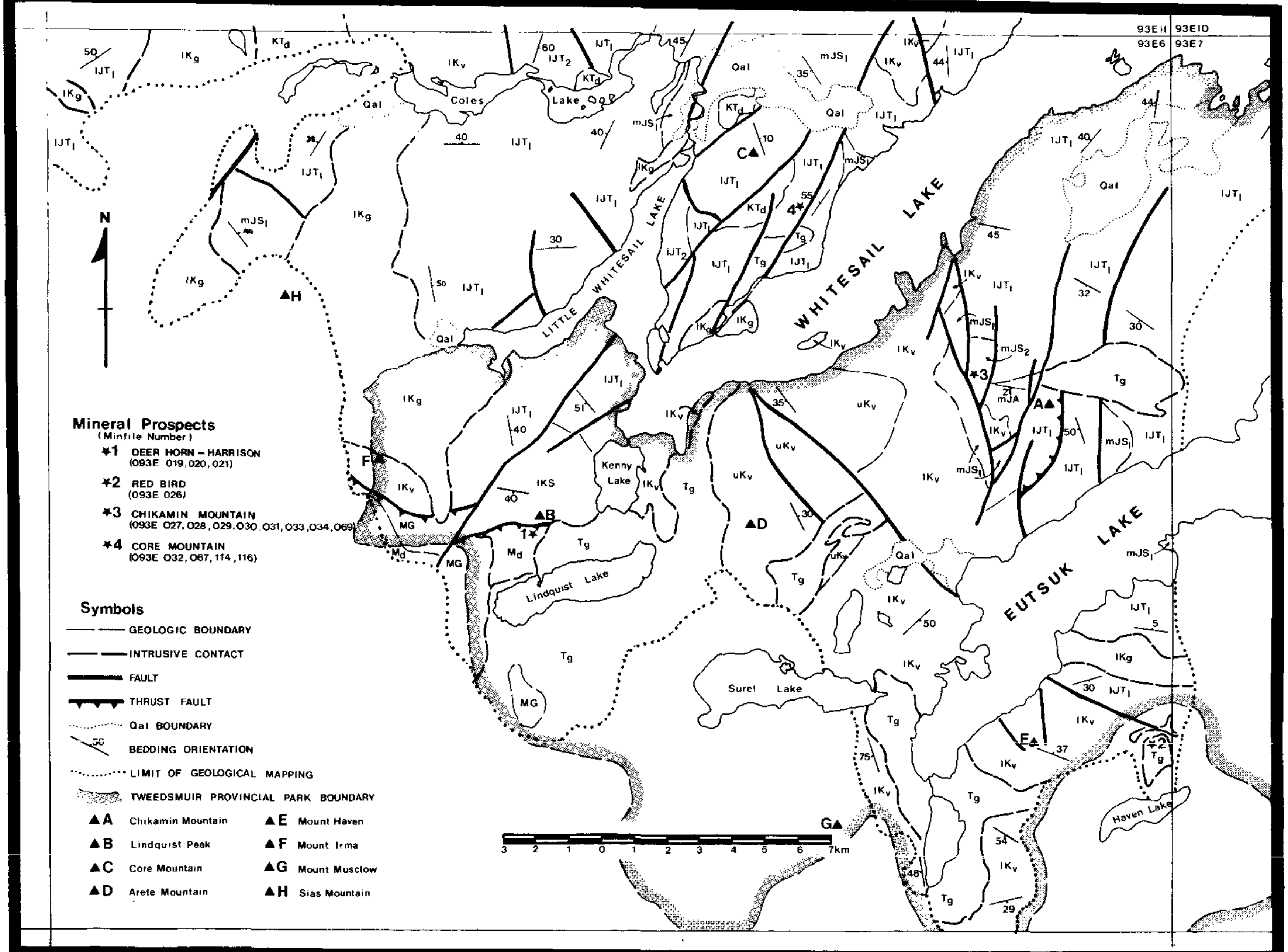

Figure 1-14-2B. Geology of Chikamin Mountain map sheets, NTS 93E/6.

The dark green colour and a locally prominent foliation are characteristic of these rocks. They probably indicate greenschist grade metamorphism, however, this feature is enigmatic in that related rocks of map unit lJT_1 are unaffected. Ubiquitous chlorite and epidote, in addition to irregular quartz veins, are widespread within the mafic flows.

On the basis of lithologic similarity, the maroon volcanic rock (map unit lJT_1) is correlated with the Howson subaerial facies of the Telkwa Formation. The metamorphosed volcanic and lesser sedimentary strata of map unit lJT_2 are most similar in appearance to pre-Jurassic Gamsby group, however, their spatial association within map unit lJT_1 and younger rocks, and their less intense deformation preclude this correlation. Lower Jurassic fossil fauna were recovered from intravolcanic sedimentary rocks in Michel Lake area (H.W. Tipper, personal communication, 1987).

SMITHERS FORMATION (mJS)

The Smithers Formation in the Whitesail Range is subdivided into a lower marine sedimentary division that grades into an upper division of subaerial pyroclastic rocks (Diakow and Mihalynuk, 1987a and b). The sedimentary division is widely exposed in the study area. In its absence, however, the pyroclastic division is indistinguishable from nearby deposits comprising map unit lJT_1 of the Telkwa Formation.

The sedimentary division (mJS_1) underlies mountain ridges and valley bottoms throughout the map area. It mainly comprises grey-green siltstone, sandstone, arkosic wacke and minor granule-pebble conglomerate; limestone and chert beds are uncommon. Most exposures are well bedded with average beds ranging between 10 and 40 centimetres thick. Internally, parallel laminations and grading are widespread within otherwise structureless beds. In several places, calcareous concretions, with recessed elliptical shapes up to 30 centimetres in diameter, are found in the siltstone beds.

The pyroclastic division (mJS_2) comprises tuffs and less common flows that are bound by, and rest upon, marine sedimentary rocks. These rocks are prevalent at Core Mountain, Chikamin Mountain and west of Michel Lake. On the north slope of Core Mountain thickly bedded sedimentary strata pass stratigraphically up-section through alternating immature volcanic sediments and maroon lapilli tuff. On the northwest slope of Chikamin Mountain, a poorly exposed succession at least 150 metres thick comprises accretionary tuff and lapilli tuff beds that are interlayered with fossiliferous clastic rocks. West of Michel Lake, sedimentary strata containing Aalenian ammonite fauna are periodically interrupted by discrete sections, as much as 75 metres thick, comprised of thinly laminated maroon ash tuff and rare accretionary lapilli tuff beds. The sedimentary division strata are eventually overlain by an undetermined thickness of alternating maroon and green ash tuff and lapilli tuff. Thin parallel-laminated and graded tuff is diagnostic of this section; planar crosslaminae are rarely observed. These rocks appear to underlie massive augite-bearing flows thought to be early Cretaceous in age.

The contact between marine sediments and tuffaceous rocks is most often interfingered. This contrasts with a gradational contact in western Whitesail Range. The pyroclastic rocks appear to become finer grained to the east and southeast of the Whitesail Range. These features indicate a local lateral facies gradation from subaerial to shallow-marine deposition of volcanic rocks during middle Jurassic time.

Strata of the Smithers Formation were initially deposited in a shallow-marine environment. The high proportion of angular feldspar in sandstone beds indicates rapid sedimentation and a nearby source. Telkwa Formation tuffaceous rocks are a probable source for the arkosic wacke, however, many of the feldspar-rich beds may be primary waterlain crystal tuff. Volcanic activity occurred contemporaneously with marine sedimentation in the eastern part of the study area. In the Whitesail Range the marine sedimentary division is supplanted by dominantly thickly bedded subaerially erupted pyroclastic rocks.

The age of the marine sedimentary rocks is inferred from abundant fossils, particularly ammonite fauna. Fossils tentatively identified to date by T.P. Poulton, H.W. Tipper and R.L. Hall (personal communications, 1986, 1987) indicate the oldest beds of Aalenian age underlie much of the Whitesail Range and occur west of Michel Lake. Early Bajocian fauna have widespread distribution in Chikamin Range and are found at Tahtsa Reach. At Cumins Creek in the eastern Whitesail Range (93E/10), a fault-bounded sedimentary succession has yielded an Early and Late Bajocian fauna (T.P. Poulton, personal communication, 1987). The irregular regional distribution of similar fauna may reflect local erosional disconformities within the middle Jurassic section.

MIDDLE AND UPPER JURASSIC–BOWSER LAKE GROUP

The Hazelton trough was effectively divided into two successor basins by uplift, defined by a northeast-trending locus of Early Jurassic Topley intrusions along the Skeena arch. The Bowser basin and its southern analogue, the Nechako basin, are sites of early widespread marine sedimentation. These deposits, called the Ashman Formation, constitute the lower division of the Bowser Lake Group. They were deposited between Upper Bajocian and Lower Oxfordian time (Tipper and Richards, 1976).

ASHMAN FORMATION (mJA)

The Ashman Formation is represented by more than 300 metres of interbedded fine-grained clastic and chemical sedimentary rocks capping the prominent peak 2 kilometres west of Chikamin Mountain. The contact with Smithers Formation rocks underlying the lower portion of the mountain is concealed by talus. The upper contact is conformable with Lower Cretaceous (?) lava flows northeast of Goodrich Lake. Bedded sedimentary rocks containing Upper Bathonian and Lower Callovian fauna (H.W. Tipper, personal communication, 1986) appear to conformably overlie similar Smithers sediments in a tributary of Cumins Creek in the eastern Whitesail Range (Diakow and Mihalynuk, 1987b).

The dominant lithologies of the Ashman Formation include black and grey argillite and siltstone. Feldspathic sandstone, arenaceous sandstone, chert and rare coralline limestone lenticles are found locally. Accretionary lapilli tuff is a rare occurrence in argillite at Chikamin Mountain. Rusty orange weathering of argillite is due to local concentrations of oxidized finely disseminated pyrite. Bedding in the Ashman Formation is generally thinner and more uniformly spaced than in Smithers strata and fossil fauna are less prolific.

The Ashman Formation, at least locally, appears to represent a continuation of marine deposits representative of the Smithers Formation. No major hiatus separating these successions is recognized in the study area. The succession exposed near Chikamin Mountain closely resembles regularly layered deep marine deposits.

LOWER CRETACEOUS (?) VOLCANIC ROCKS (lKv)

Map unit lKv is a heterogeneous succession of interlayered lava flows, tuffs and minor sedimentary rocks. The diagnostic presence of subvitreous augite phenocrysts in flows of andesitic to basaltic composition, and their stratigraphic position above middle Jurassic successions, distinguishes these rocks from the Telkwa Formation. The following section briefly describes the lithologic variability of this map unit starting near Michel Lake in the north and working toward Mount Haven in the south.

Southwest of Michel Lake, augite-phyric andesite flows comprise a resistant cap overlying map units mJS_2 and mJA. The flows exhibit "crowded" porphyritic texture imparted by roughly 60 volume per cent plagioclase, averaging 1 to 1.5 millimetres long, and up to 3 volume per cent variably chloritized augite. Similar rocks, noted between Chikamin Bay and Snag Inlet on Whitesail Lake, are associated with flows ranging in composition from basalt to rhyolite. The mafic flows contain platy plagioclase phenocrysts and amygdules, whereas felsic flows display laminations and spherulitic texture. Distinctly laminated pink and green spherulitic rhyolite is interbedded with lapilli-block tuff on the east shoreline of Whitesail Lake. This breccia contains angular fragments of rhyolite and porphyritic andesite as large as 40 centimetres in diameter. Identical rocks were found directly opposite on the west shore of Whitesail Lake.

Volcanic rocks and sporadic exposures of conglomerate extend from Zinc Bay on Whitesail Lake to Maroon Island on Eutsuk Lake. Augite-phyric andesitic flows form a resistant bench apparently overlying Ashman rocks on the south slope of the prominent peak west of Chikamin Mountain. Basaltic flows characterized by platy plagioclase phenocrysts between 4 and 13 millimetres long are prominent. They commonly exhibit amygdaloidal, trachytic and crowded medium-grained plagioclase-porphyritic texture. Rhyolite is uncommon in the pass between the lakes; it forms a dome-like body which contains rock fragments stoped from the Smithers Formation. Conglomerate deposits in excess of 75 metres thick generally consist of rounded cobble and boulder-size clasts with a volcanic provenance; rare argillite clasts also occur.

Mount Haven is underlain by gently inclined, very thick beds comprised of lapilli tuff separated by about 200 metres of augite-phyric andesite flows. The tuff is well exposed within a section in excess of 450 metres thick. It consists dominantly of siliceous lapilli, less than 1 centimetre in diameter, set within a resistant greyish green ash matrix. Lapilli-block tuff associated with parallel-laminated ash tuff were observed in several places. These deposits continue across the south end of Eutsuk Lake; a similar succession is found along the western contact of the Quanchus intrusion in the extreme north part of the mapped area.

East of the confluence of Troitsa Creek with Coles Creek, a conglomerate deposit as thick as 150 metres underlies a 4-square-kilometre area. These rocks appear to overlie the Telkwa Formation, and are in turn overlain locally by tuff interlayered with augite-phyric andesite flows. The conglomerate is characterized by a high proportion of intrusive clasts, upwards of 70 per cent in places. The framework clasts are generally poorly sorted rounded cobbles and boulders up to 30 centimetres in diameter. Sorted cobbles are found locally grading into granule and coarse sand interbeds up to 40 centimetres thick. Andesitic clasts with porphyritic and aphyric texture predominate. The intrusive clasts include quartz monzonite, biotite granite and biotite hornblende diorite. A fluvial origin is interpreted for the conglomerate.

The depositional environment for Lower Cretaceous volcanic rocks in the area is subaerial, indicated by the absence of marine intravolcanic sedimentary deposits. The regional environment was dominated by erupted flows and pyroclastic rocks building stratovolcanos. Periodic cessation of volcanic activity resulted in fluvial deposits in which the clastic detritus were shed from uplifted Jurassic volcanic and comagmatic plutonic rocks.

A porphyritic quartz biotite rhyodacite body is disconformable with volcanic rocks at Mount Haven. A potassium-argon determination on biotite from this rock will infer a minimum age for these volcanics. Tentative Lower Cretaceous rocks in the map area are similar to several lithologies of a succession reported by van der Heyden (1982). The reported succession includes augite-bearing andesite flows and polymictic conglomerate containing intrusive clasts. They form part of a more extensive volcanic-sedimentary succession tentatively assigned a Hauterivian age.

LOWER CRETACEOUS – SKEENA GROUP (lKS)

The Skeena Group (Leach, 1910) is a name applied to interlayered marine and nonmarine sedimentary and volcanic rocks deposited during Hauterivian to Albian time (Tipper and Richards, 1976). The lower contact, which separates it from Jurassic successions, is an unconformity identified by the presence of boulder conglomerate overlying Hazelton Group volcanics in the Tahtsa Lake area (MacIntyre, 1985). The Skeena Group is not present in the Whitesail Range area.

Sedimentary rocks of the Skeena Group are confined to a prominent salient in the northeast margin of Coast intrusive rocks near Lindquist Peak. Neither the top nor the bottom contact are exposed in a 400-metre-thick section.

Skeena strata consist of alternating grey and black sandstone, siltstone and argillite beds. Sandstone beds vary between 1 and 7 metres thick, and are resistant in appearance. Detrital muscovite, a diagnostic constituent, is often concentrated along parting planes within massive structureless beds. In places limy concretions up to 50 centimetres in diameter occur as solitary features aligned along a common plane in sandstone. Flute casts are rarely observed at the sharp base of some sandstone beds. Siltstone-dominated sections commonly display regular parallel laminae that are often internally graded or crosslaminated. Flaser structures and load casts become prevalent in siltstone beds containing a high proportion of mud. Siltstone commonly grades into featureless argillites that may locally contain finely disseminated pyrite. These rocks have features common to proximal turbidites.

A penetrative foliation is pronounced in argillaceous beds. Bedding and cleavage relationships indicate local overturned bedding defining limbs of tightly appressed folds. Further work is required to determine the significance of deformed rocks. The contact of Skeena strata west of Lindquist Peak is a steep, north-trending fault. The fault trace is delineated by rusty weathering polymictic conglomerate. The conglomerate marks the top of an unfoliated well-layered succession of tuff and lahar from map unit lJT_1, juxtaposed with foliated argillite. Quartz veinlets cutting the conglomerate contain sparse copper minerals. Southern and southeastern exposures of sedimentary rocks are truncated by a southerly inclined thrust fault. The hangingwall above the décollement is metamorphosed plutonic and volcanic rocks of the Gamsby group. The northeastern contact is concealed, however argillite contains andalusite crystals suggesting these rocks are likely in contact with an intrusion which is widely exposed in Lindquist Lake area.

UPPER CRETACEOUS–KASALKA GROUP (uK_v)

The Kasalka Group is an informal name proposed by MacIntyre (1976) for an Upper Cretaceous volcanic succession that unconformably overlies the Skeena Group in the Tahtsa Lake area. This succession varies from early silicic to late mafic eruptions that collectively represent a cauldron-forming eruptive cycle. The Kasalka group signifies a tectonically active episode in a continental margin arc setting during late Cretaceous time in west-central British Columbia.

Upper Cretaceous strata attain an estimated minimum thickness of 600 metres within a 26-square-kilometre area centred on Arete Mountain. Neither the top nor bottom contacts of the succession are exposed. It comprises a central tuff and epiclastic division which separates mainly flows comprising the lower and upper divisions. Contacts between divisions are transitional, marked by interfingered tuff and flow rocks. All strata are inclined gently westward, although beds deviate from this trend across steep faults.

The lower division is characterized by lava flows and relatively few tuff and epiclastic interbeds. The flows weather to cliffs that display local columnar joints at Arete Mountain. Green-grey and brown flow rocks typically contain vitreous phenocrysts of plagioclase averaging 3 or 4 millimetres, several per cent biotite and hornblende and trace augite. Plagioclase laths, up to 1.5 centimetres long, were observed in flows at Arete Mountain. Sparse intravolcanic rudite beds, generally less than 2 metres thick, are dominated by plutonic clasts. Lapilli tuff and thin parallel-laminated ash tuff comprise local thin units interspersed between flows.

The middle division is a poorly stratified and diverse assemblage composed of tuff and epiclastic rocks about 200 metres thick. Tuff beds dominate the lower and upper parts of the section. They are made up of subrounded green and maroon lapilli and few blocks, some as large as 1 metre in diameter. The fragments include, in order of abundance, aphyric and porphyritic andesite, flow-laminated dacite, plutonic rocks, laminated ash tuff, white rhyodacite and coarse platy plagioclase basalt. The matrix is composed of broken lithic fragments and crystals supported by light green and cream-coloured ash.

Conglomerate characterized by plutonic clasts is diagnostic of the crudely layered middle division. The plutonic clasts occur with heterolithic volcanic debris in tuffite beds or comprise discrete polymictic orthoconglomerate beds separated by lapilli tuff. Framework clasts in conglomerate are subrounded and rounded poorly sorted cobbles, ranging to boulders as large as 1 metre diameter. The composition of plutonic clasts includes coarse-grained biotite hornblende granodiorite, quartz monzonite and foliated quartz diorite. Coarse conglomerate and lapilli-block tuff rest directly on lower division flows on the 2000-metre summit along the west spur of Arete Mountain. The contact is sharp, and chilling of the upper flow contact indicates a brief time interval separates these deposits. A 25-metre section of dark grey siltstone and sandstone containing argillaceous partings, located at about 1650 metres elevation 4.0 kilometres northwest of Arete Mountain, apparently rests on lapilli tuff. Parallel laminations and flaser bedding are common in the finer grained beds.

Partially welded pyroclastic flows characterize the upper division. The lower contact is recognized by increasing induration and a corresponding decrease in the size and abundance of lithic fragments as middle division lapilli tuff grades upwards into flows. These flows are distinguished from the lower division by their brown to lavender colour, ubiquitous fragments and fluidal flow laminae. The pyroclasts include roughly 15 per cent phenocrysts and less than 10 per cent accidental fragments. Plagioclase, the most abundant phenocryst, is accompanied by 1 per cent variably chloritized biotite. The fragments, generally of lapilli-size, are typically subangular and have aphanitic texture. Exceptional plutonic and coarse platy plagioclase basalt fragments are also present.

The layered succession in the Arete Mountain area is interpreted as deposits built up on the flank of a composite volcano. The divisions suggest an eruptive history that began with passive effusion of flows, succeeded and partly synchronous with deposition of conglomerates and subaerial pyroclastic rocks, and culminating in pyroclastic flow eruptions. A general trend of increasing tectonic activity and increasing magnitude of eruptions is reflected by the lithologies of succeeding divisions. The conglomeratic deposits attest to rapid uplift and unroofing of a nearby intrusion. The Coast intrusions, southwest of Arete Mountain, may be comagmatic with volcanic rocks of this succession.

A Late Cretaceous age is tentatively inferred for volcanic and sedimentary rocks near Arete Mountain. This age is implied by the overall fresh appearance of rocks, vitreous mafic minerals, and widely dispersed plutonic fragments which resemble nearby Coast intrusions. Lower division flows were sampled at two localities for potassium-argon dates. The lower and middle divisions have lithologic and stratigraphic similarities with MacIntyre's (1985) porphyritic andesite unit and lahar unit, respectively. The upper division has no direct analog in Tahtsa Lake area.

TERTIARY VOLCANIC ROCKS– OOTSA LAKE GROUP (EO)

The Ootsa Lake Group (Duffell, 1959) is a succession of continental calcalkaline volcanic rocks and less abundant sedimentary rocks. They unconformably overlie Jurassic strata in the Whitesail Range and Whitesail Reach areas, where six lithologic divisions are recognized (Diakow and Mihalynuk, 1987a and b). The volcanic rocks are mainly lava flows ranging in composition from basalt to rhyodacite. The age of this volcanic succession is established by four new potassium-argon dates.

Tertiary strata are confined to the Whitesail Reach map sheet (93E/10). In this report they constitute basaltic and rhyolitic flows that underlie a plateau in the Goodrich Lake area. The plateau extends northward to a pronounced escarpment above Llama Creek.

Basalt comprises flat-lying flows with massive appearance and uncommon columnar joints. Deeply weathered exposures produce popcorn-size rubble and brownish orange soil. Relatively fresh lava flows are typified by evenly distributed platy plagioclase phenocrysts, between 4 and 12 millimetres long, set in a matrix that is dark green, reddish maroon and aphanitic. Amygdules infilled by opalescent silica are present, but uncommon. Celadonite, an earthy green mineral, is widespread in these rocks and can be easily confused with secondary copper. Rhyolitic rocks constitute a series of isolated knolls rising in excess of 40 metres above the basalt. They also underlie areas faulted against basalt. The rhyolite has a porphyritic texture imparted by 2 to 5 per cent plagioclase, several per cent vitreous biotite and 1 per cent or less quartz. These minerals rarely exceed 3 millimetres in diameter within a pink, grey or cream-coloured matrix that may be thinly laminated and have a spherulitic texture.

The lower contact is not exposed near Goodrich Lake. Lower Cretaceous (?) volcanic rocks exposed to the west presumably extend eastward, directly underlying the basaltic flows. Near Llama Creek, the basalt and rhyolite appear to abut Middle Jurassic sedimentary rocks. The contact, defined roughly by the creek, may be a steep fault or a buttress unconformity.

AGES OF OOTSA LAKE GROUP STRATA

Four new numeric ages constrain the timing of volcanic eruptions represented by the Ootsa Lake Group in Whitesail Range and Whitesail Reach areas.

The first three ages reported are from a well-layered succession of differentiated lava flows about 400 metres thick exposed approximately 7.0 kilometres northeast of Troitsa Peak. The fourth is for the uppermost volcanic member of the Ootsa Lake Group which is confined to an area adjacent to central Whitesail Reach. The results of potassium-argon age determinations are presented in Table 1-14-1.

Biotite-bearing dacitic lava, presumed to occur near the bottom of the Ootsa Lake Group in the Whitesail Range, yielded an age of 49.9 Ma. A synchronous age of 49.9 Ma for the overlying conformable section of platy plagioclase basaltic flows is inferred from a crystal ash tuff interbed low in the section. Rhyodacite lava flows generally rest conformably on platy basalt, although in places they are separated by a succession of vitrophyre interlayered with laharic deposits. Rhyodacite lava yields an age of 49.1 Ma close to its lower contact with platy basalt. To the east, at Whitesail Reach, an identical succession of basalt and rhyodacite is in turn overlain by vitrophyric andesite lava flows. An age of 50.0 Ma is determined for these vitrophyric flows. The age of the stratigraphically lowest and highest members increases. This variability is not, however, sufficient to preclude more or less continuous volcanic activity over a period of about 1 million years during Eocene time. Conglomerate, containing clasts derived from underlying rhyodacite and vitrophyric flows, marks the top of the Ootsa Lake succession at Whitesail Reach. Polynomorphs, extracted from amber, indicate a tentative Eocene or younger age for this deposit (J.M. White, personal communication, 1986).

Undivided volcanic rocks, thought to be part of the Ootsa Lake Group, underlie the area between Ootsa and Francois lakes. A date of 55.6 ± 2.5 Ma from dacite immediately north of Ootsa Lake is reported (Woodsworth, 1982). North of Francois Lake, the Goosly Lake and Buck Creek volcanic rocks are dated at 48.0 ± 1.8 Ma and 47.3 ± 1.6 Ma respectively (Church, 1972). These rocks correlate on the basis of

TABLE 1-14-1
POTASSIUM-ARGON DETERMINATIONS OF ENDAKO GROUP AND OOTSA LAKE GROUP VOLCANIC ROCKS, WHITESAIL REACH AND TROITSA LAKE MAP AREAS

Sample No.	UTM Location Easting Zone 09	Northing	Mineral	K_2O %	^{40}Ar 10^{-10} mole/gm	^{40}Ar* %	Apparent Age (Ma)	Formation (Group)	Map Unit 1987-4 (Diakow)	This Report
86-LD-19-1	644071	5955865	Whole rock	1.64 ± 0.01	0.899	27.6	31.3 ± 1.2	Endako	7c	EE
86-LD-32-4	630884	5942976	Whole rock	0.938 ± 0.017	0.686	86.9	41.7 ± 1.5	Endako	7c	
86-LD-5-0	647000	5947250	Biotite	6.87 ± 0.07	6.044	84.7	50.0 ± 1.7	Ootsa Lake	10	
86-LD-33-1	630807	5942805	Biotite	6.33 ± 0.02	5.467	87.7	49.1 ± 1.7	Ootsa Lake	9	EO_2
86-LD-22-3	639720	5945923	Biotite	6.65 ± 0.07	5.820	89.1	49.8 ± 1.7	Ootsa Lake	7b	EO_1
86-LD-31-1	632390	5943584	Biotite	6.13 ± 0.07	5.367	86.3	49.8 ± 1.7	Ootsa Lake	6a	

* radiogenic Ar.
Constants: $\lambda^{40}K_e = 0.581 \times 10^{-10}$ yr^{-1}; $\lambda^{40}K_b = 4.96 \times 10^{-10}$ yr^{-1}; $^{40}K/K = 1.167 \times 10^{-4}$.
%K determined by the Analytical Laboratory, British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria.
Ar determination and age calculation by J.E. Harakal, The University of British Columbia.

age with Eocene strata in the study area; the volcanic rocks dated at Ootsa Lake are slightly older.

ENDAKO GROUP

The Endako Group (Armstrong, 1949) is comprised of fresh basaltic flows in the map area. These rocks were previously included by the writer as a member of the Ootsa Lake Group. In this report they have been separated in light of two new potassium-argon dates.

The Endako Group underlies Mosquito Hills at Tahtsa Reach. These rocks also form isolated remnants overlying platy plagioclase basaltic flows of the Ootsa Lake Group in the Whitesail Range and northwest of Goodrich Lake. The dominant lithology is basalt which weathers to massive exposures that locally display columnar joints. The flows are characteristically black and aphyric, but the texture may vary from sparsely porphyritic to crowded platy plagioclase porphyry. The latter is indistinguishable from platy plagioclase andesitic rocks prevalent in the Ootsa Lake Group. The aphyric flows may exhibit thin parallel laminae which result from pilotaxitic texture of microscopic plagioclase. Interflow breccia and crudely stratified lahar are locally associated with the flows at Tahtsa Reach.

The results of two potassium-argon determinations on whole rock samples of Endako Group flows are presented in Table 1-14-1. The older date of 41 Ma is for a remnant of columar jointed aphyric lava in the Whitesail Range. These rocks overlie platy plagioclase basalt and crystal ash tuff dated at 49 Ma. Aphyric lava flows at Tahtsa Reach have an age of 31 Ma. This date is discordant with a 38.7 ± 3.1 Ma date derived from nearby flows (Woodsworth, 1982), and the 41 Ma date from the Whitesail Range, however, the latter two dates correlate.

INTRUSIVE ROCKS

Intrusions in west-central British Columbia are divided into discrete belts based on their composition and texture, isotopic age and associated metallic deposits (Carter, 1981). Two intrusive divisions applicable to this study include Eocene Nanika intrusions (Tg) and Late Cretaceous Bulkley intrusions (lKg). Late Cretaceous–Tertiary fine-grained porphyritic diorite (KTd) and pre-Lower Jurassic foliated quartz diorite (Md) also occur. The two former divisions are regionally distributed, whereas the latter have only local prominence. These intrusive rocks are manifested as plugs and stocks that display considerable variability in composition and texture. The following section describes intrusions in order of decreasing age.

Foliated quartz diorite (Md) is found exclusively in the Lindquist Lake area, where it is spatially associated with pre-Jurassic metamorphic rocks. This rock is typically medium grained, and contains as much as 35 per cent chlorite. The sole of a major north-directed thrust fault detaches the diorite and places it atop Skeena Group rocks near Lindquist Peak. The diorite hosts mineralized quartz veins in several localities at or near the décollement. At the Deerhorn mine, mineralized veins are found in sericite-altered diorite. A bulk sample of sericitized diorite has been collected for a potassium-argon age determination. This diorite body is centrally positioned relative to sedimentary rocks to the west and fresh granodiorite to the southeast. Dykes related to granodiorite cut the foliated diorite.

The Bulkley intrusions (lKg) include porphyritic granodiorite and quartz monzonite stocks dated at 70 to 84 Ma (Carter, 1981). A large body underlying the area between Coles Lake and Mount Irma is an example of such intrusions. It consists of unfoliated, equigranular medium and coarse-grained granodiorite and quartz monzonite. Biotite and hornblende, variably pseudomorphed by chlorite and epidote, are present in amounts ranging between 5 and 10 per cent of the rock. Between Coles Lake and Sias Mountain the inclination of lower Jurassic strata steepens approaching the intrusive contact, suggesting forceful intrusion.

Granitic contacts are varied in appearance and often characterized by increased concentration of mafic minerals, including actinolite adjacent to hornfelsed middle Jurassic sedimentary rocks. Chlorite enrichment marginal to the contact is observed at one locality where intermediate volcanic rocks have been assimilated. Andesitic dykes with a northwest trend and steep dips are found west of Sias Mountain. Similar intrusions also parallel and crosscut the contact in the same area. Elsewhere granitic dykes project outwards from the main intrusive body into the country rocks. A wedge-shaped pendant of Skeena Group argillite, enclosed by granodiorite, suggests a post-mid-Cretaceous emplacement for this intrusion.

The Nanika intrusions (Tg), described by Carter (1981), were originally named for quartz monzonite and granite plutons near Nanika Lake. They range in age from 47 to 56 Ma. In the map area these intrusions occur as stocks and batholiths in the vicinity of Lindquist, Surel and Musclow lakes, at Red Bird Mountain and in the Quanchus Range. The intrusion near Lindquist Lake is a coarse-grained granodiorite containing as much as 10 per cent vitreous biotite. Dioritic phases containing roughly 25 per cent combined hornblende and biotite are associated with granodiorite immediately west of Musclow Lake. The texture of these rocks varies from equigranular to porphyritic. The plutons intrude and metamorphose pelitic rocks to andalusite slate near Lindquist Peak and also hornfels upper Cretaceous volcanics near Arete Mountain. Dykes related to the main granodiorite body, southeast of Lindquist Lake, cut pre-Jurassic foliated quartz diorite and metavolcanic rocks. In this general area the granodiorite is dated at 58.8 ± 1.8 Ma (Woodsworth, 1979). Two additional age determinations from granodiorite near the northwest end of Lindquist Lake and at the head of Eutsuk Lake will be undertaken during this study.

The Quanchus batholith, named by Marshall (1925), occupies the core of the Quanchus Range which extends from Ootsa Lake to Eutsuk Lake. This intrusion occupies much of the eastern boundary of the study area on Whitesail Reach map sheet. The composition is mainly granite and quartz monzonite with equigranular and porphyritic texture. The batholith is characterized by a broad flat top and gently sloping flanks. Metamorphosed screens of country rock found near the margin, and small satellite plutons peripheral to the main intrusive body, suggest that the Quanchus batholith was emplaced at a high level in the crust and is barely exhumed. The intrusion is dated at 51.4 ± 2.2 Ma from porphyritic granite near Grizzly Hill (Woodsworth, 1982).

The Red Bird intrusion, located north of Haven Lake on Red Bird Mountain, is a quartz monzonite porphyry with phenocrysts of euhedral quartz, zoned plagioclase, orthoclase and biotite. This pluton is host to concentrically zoned molybdenum mineralization and is dated at 49.5 ± 3 and 49.0 ± 2 Ma (Carter, 1981).

Fine-grained porphyritic diorite (KTd) plugs and sills cap topographically high areas on Core Mountain. Elsewhere small isolated bodies occur west of Little Whitesail Lake and at Coles Lake. Dykes of the same lithology crosscut Late Cretaceous porphyritic granite on the southeast side of Core Mountain. These hypabyssal intrusions contain diagnostic chloritized pyroxene phenocrysts rarely exceeding 3 millimetres in diameter and felty textured plagioclase. The matrix is typically dark green and a high proportion of epidote is not uncommon. In the Tahtsa Lake area, MacIntyre (1985) describes these intrusive rocks as microdiorites that intrude Upper Cretaceous Kasalka Group strata.

STRUCTURE

Structural features in stratified rocks divide the study area into two domains. The western domain consists of penetratively deformed metavolcanic and metaplutonic rocks of the Gamsby group that are disrupted by thrust faults. The eastern domain is characterized by relatively undeformed but extensively block-faulted Mesozoic and Cenozoic strata. Foliated volcanic rocks have local prominence in the eastern domain. The boundary separating the domains is a northwest-trending thrust fault west of Lindquist Lake.

The Gamsby group underlies a thrust panel that structurally overlies strata of the Skeena Group. This décollement is traceable from the southwest ridge of Lindquist Peak, for about 2 kilometres to the west across Lindquist Pass to Mount Irma. The fault trace, concealed by talus on the southwest-facing slope of Lindquist Peak, is projected obliquely downslope, passing through the workings at the Deerhorn mine. The detachment plane dips at 20 degrees south, subparallel to bedding, increasing to about 50 degrees south at the Deerhorn mine. Several excellent exposures of the décollement are characterized by mylonitic structure which grades symmetrically over several metres into undeformed bedded sedimentary rocks in the footwall and variably foliated quartz diorite in the hangingwall.

Similar structural features are documented in Gamsby group strata, immediately west of this study area by van der Heyden (1982). There the rocks have been subject to multiple phases of ductile deformation and are imbricated by northeast-directed compression. The most easterly of these thrust faults roughly coincides with the boundary separating the Coast Complex from the Intermontane Belt. Conceivably the same boundary relationship is indicated by the stratigraphic setting of the thrust fault near Lindquist Peak. The timing of thrust-related compression in the Lindquist area postdates Lower Cretaceous Skeena Group sedimentary rocks. Cessation of movement is constrained by a mariolitic monzonite stock, dated at 48.9 ± 2.3 Ma (Woodsworth, 1979), which intrudes and truncates a thrust straddling the Gamsby River valley. A large body of granodiorite at Lindquist Lake appears to truncate hangingwall rocks and the thrust fault at the most easterly locality. A potassium-argon age determination for this body is in progress. The same pluton, 4 kilometres southwest of the west end of Lindquist Lake, is dated at 58.8 ± 1.8 Ma (Woodsworth, 1979).

High-angle gravity faults are the principal structures in the eastern domain. These structures are inferred by abrupt changes in lithology and variations in bedding attitudes. Some faults correspond with topographic depressions evident as prominent airphoto linears. In many areas, absence of stratigraphic markers makes it difficult to recognize faults in monotonous volcanic successions.

Core Mountain is transected by an array of northeast and a few northwest-trending faults. Displacement along individual structures is presumed small, inferred from brittle shear entirely within Jurassic strata. Slickensides on fault planes commonly have steep rake, indicating that many of the faults are extensional features with oblique slip movement. A pronounced north-trending fault controls the northwest shoreline of Whitesail Lake at Core Mountain. This structure is delineated for at least 5 kilometres by an incised drainage and offset plutons. A steep northwest-trending biotite-phyric dyke, offset by the fault, indicates sinistral movement of about 750 metres. The faults at Core Mountain are difficult to trace with certainty into bordering areas, but nevertheless comply with the dominant trend of faults mapped regionally in Whitesail Range and Whitesail Reach areas where northeast-trending faults juxtapose Eocene against lower Jurassic strata. Steep faults with variable orientation disrupt stratified rocks on the margin of intrusions occupying the core of Quanchus Range, Chikamin Range and on the ridge east of Eutsuk Lake. These faults place locally hornfelsed and altered rocks against unaltered, inclined sedimentary and volcanic strata.

Several northwest-directed thrust faults are documented at Chikamin Mountain in Open File Map 708 (Woodsworth, 1980). No compelling evidence was found to confirm these structures, instead gentle warping of strata in this area may be related to a northeast-directed thrust fault. About 1 kilometre west of Chikamin Mountain summit, a steeply dipping northerly trending fault separates gently inclined Ashman strata to the west from open-folded Telkwa maroon tuff. Smithers strata are tilted to a near-vertical position adjacent to this fault.

A penetrative foliation is locally developed in volcanic rocks of map unit lJT_2 of the Telkwa Formation. These rocks occur intermittently between Little Whitesail and Coles lakes, and they underlie a large area west of Michel Lake. At the former area, a steeply dipping foliation is evident within zones, tens of metres wide, that grade into unfoliated rock. This fabric is explained in terms of fault movement. In contrast, the latter area is characterized by a pervasive foliation akin to regional deformation. The widespread occurrence of greenschist facies minerals, and local folds indicated by bedding and cleavage relationships, support the idea of regional deformation. The proximity of foliated strata close to the Quanchus intrusion suggests this deformation is related to emplacement of plutons.

MINERAL PROSPECTS

Mineral showings and developed prospects are concentrated at Lindquist Peak, Chikamin Mountain, Core Mountain and Red Bird Mountain. They can be categorized as follows:

(1) Gold-bearing quartz veins associated with thrust faults.

(2) Silver-lead-zinc quartz veins in extensional fractures.

(3) Porphyry copper-molybdenum deposits associated with quartz monzonite intrusions.

LINDQUIST PEAK AREA– GOLD-BEARING QUARTZ VEINS

The original Harrison claim group (Holland, 1945, 1946) were staked in 1943, following the discovery of scheelite in talus about 1 kilometre southeast of Lindquist Peak. Subsequent interest in the property focused on gold and silver-bearing quartz veins. Pioneer Gold Mines Ltd. conducted surface trenching and diamond drilling on quartz veins in 1944 and continued exploration work until 1946 when its option lapsed. In 1950, title of the original claims was acquired by Deer Horn Mines Ltd. which actively developed the property in 1954 and 1955. Development included construction of a road connecting the property with Whitesail Lake, and extensive underground and surface work (Bacon, 1956). No further work was recorded after 1967, when Granby Mining Company Ltd. undertook a program of bulldozer trenching and geological mapping.

The Harrison quartz veins occur mainly within foliated diorite and associated metavolcanic rocks assigned to the pre-Lower Jurassic Gamsby group. These rocks are in sharp contact with a succession of black argillite, flaser siltstone and sandstone that underlies Lindquist Peak. The sedimentary rocks are representative of the Lower Cretaceous Skeena Group. The contact between diorite and sedimentary rocks strikes westerly and dips south. Increased shearing in diorite resting structurally above younger sediments indicates the contact is a thrust fault. A large granodiorite stock and dykes of Nanika intrusions cut the diorite and locally metamorphose pelitic rocks to andalusite slate.

The quartz vein system consists of two mineralized zones that coalesce downdip on the main vein. The zones include a main vein striking west and dipping south that is traceable for 370 metres, and a subsurface zone of quartz stringers in quartz-sericite-altered diorite adjacent to the contact with sedimentary rocks. Gold is found in native form and with silver in tellurides within the quartz vein system. Minor quantities of arsenopyrite, galena, sphalerite, chalcopyrite and scheelite have also been identified (Papezik, 1957). Underground work has defined a 330-metre section of the main vein averaging 7.7 grams per tonne gold and 216 grams per tonne silver over a vein width of 2.9 metres. A section of the contact zone 221 metres long averages 13.9 grams gold and 420 grams silver per tonne over 2.7 metres (Buckles, 1954).

CORE MOUNTAIN AREA

Activity in the Core Mountain area began in 1944 with staking of the Core and Shirley groups of claims to cover numerous vein-type mineral occurrences along strong northeast-trending fault structures. Telkwa Formation volcanics and Smithers Formation sediments dominate the geology of Core Mountain; younger diorite and granite bodies, possibly related to the Coast and Bulkley intrusions, intrude the older rocks. Limited soil, rock and stream geochemical surveys, as well as a magnetometer survey, were conducted from 1980 to 1983, revealing mineralization in quartz-filled fracture zones and shear zones carrying erratic geochemically anomalous gold and silver values. Disseminated pyrite and chalcopyrite constitute sporadic mineral prospects adjacent to the major fault structure bounding the northwest shore of Whitesail Lake.

CHIKAMIN MOUNTAIN AREA– SILVER-LEAD-ZINC VEINS

Claims in Chikamin Mountain area were initially staked in 1916 on silver-lead occurrences at Zinc Bay on Whitesail Lake. Subsequent work until 1924 outlined a number of similar vein occurrences traversing the northwest slope of Chikamin Mountain. Trenches and several adits outlined these mineralized zones, and in the 1940s some diamond drilling was done.

The mineralized area is underlain by tuffaceous sedimentary rocks of the Smithers and Ashman formations. Mineralization consists of sulphides in quartz-calcite veins that infill extensional fractures, joints and shear fractures. The veins host typically massive pyrite, galena, chalcopyrite, sphalerite and sporadic arsenopyrite and tetrahedrite. Gold is, for the most part, negligible although spotty anomalous assays are reported from grab samples. The structures hosting the veins appear to be related to a poorly defined system of extensional faults that delimit Middle Jurassic sedimentary rocks at Chikamin Mountain. They consistently trend in a southeasterly direction and veining is generally steeply dipping.

RED BIRD MOUNTAIN– PORPHYRY COPPER-MOLYBDENUM

The Red Bird group of claims, located on the northeastern side of Red Bird Mountain, was staked in 1929 and restaked as the Old Glory group in 1944. From 1960 to 1967, Phelps Dodge Corporation of Canada conducted surface trenching, geophysical surveys and diamond drilling totalling over 20 000 metres. In 1966, a 762-metre airstrip was built near the outlet of Bone Creek on Eutsuk Lake. It is connected to the property by a 17.6-kilometre road. During 1979 and 1980, Craigmont Mines Limited completed close to 20 000 metres of diamond drilling.

The area is mainly underlain by bedded pyroclastic rocks of the Telkwa Formation. A quartz monzonite porphyry intrudes the volcanics and hosts molybdenum mineralization. The mineralization is found within a concentrically zoned pluton but extends into hornfelsed wallrock. Quartz stockwork veins are found near the contact and occur for over 300 metres into the country rock, but decrease sharply beyond the pluton. Disseminated pyrite and chalcopyrite are common within the quartz veins. A gossanous zone outlines pyrite-rich rocks extending for up to 1.5 kilometres beyond the pluton and is reported to contain pyrite, galena, sphalerite and molybdenite mineralization.

CONCLUSIONS

This study establishes a stratigraphy and describes the setting of several mineral occurrence types in the map area. The conclusions of this work are:

(1) *The stratigraphic succession is principally comprised* of volcanic and lesser sedimentary strata. The volcanics include Lower Jurassic, Cretaceous and Tertiary lava flows and pyroclastic rocks. Middle Jurassic and mid-Cretaceous marine deposits dominate the sedimentary successions. The Middle Jurassic sedimentary section separates visually similar maroon pyroclastic rocks. These pyroclastic successions are difficult to distinguish in the absence of the sedimentary marker.

(2) Pre-Jurassic metavolcanic and metaplutonic rocks constitute the oldest strata. They form a thrust panel structurally overlying mid-Cretaceous sedimentary rocks at Lindquist Peak.

(3) Easterly directed thrust movement is a post mid-Cretaceous and pre-Eocene tectonic event, which presumably resulted from collision of allochthonous Wrangellia with the previously accreted Stikine terrane. Auriferous quartz veins at Deerhorn mine occur in thrust-faulted metamorphic rocks west of Lindquist Lake. *Similar vein occurrences, localized in meta*plutonic rocks intermittently along the thrust fault west of the minesite, suggest that these strata and structures have regional exploration significance.

(4) Northeast and northwest-trending high-angle gravity faults disrupt Mesozoic and Cenozoic strata. These structures displace volcanic rocks dated at 50 Ma in Whitesail Range. At Chikamin Mountain, narrow quartz veins contain silver-lead-zinc minerals in steep northwest-trending fractures. Sparse pyrite and copper minerals occur adjacent to northeast faults at Core Mountain.

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MANSON CREEK MAPPING PROJECT (93N/09)

By Filippo Ferri and David M. Melville

KEYWORDS: Regional geology, Manson Creek, Intermontane Belt, Omineca Belt, Slide Mountain Group, Ingenika Group, Wolverine Complex, precious metal veins.

INTRODUCTION

The Manson Creek mapping project was initiated by the British Columbia Ministry of Energy, Mines and Petroleum Resources to provide a detailed geological base map at a scale of 1:50 000 for the Manson Lakes (93N/09) map sheet. In addition an inventory of the mineral occurrences will be compiled, with emphasis placed on the lode gold occurrences. The project is in the first year of a proposed 6-year program.

PHYSIOGRAPHY AND ACCESS

The Manson Lakes map sheet is located in east-central British Columbia approximately 200 kilometres northwest of Prince George (Figure 1-15-1). Primary access is via an all-season gravel road north from Fort St. James which follows the Manson River – Manson Lakes drainage system and diagonally divides the map sheet. The northeastern part of the map area is occupied by the Wolverine Range of the Omineca Mountains with eastern slopes falling off into the Rocky Mountain Trench. Approximately three quarters of the area is accessible by logging roads, the remaining parts are reached by helicopter.

REGIONAL GEOLOGY

The project area straddles the boundary between the Intermontane and Omineca belts of the Canadian Cordillera. This boundary places allochthonous and para-allochthonous oceanic rocks of the Slide Mountain Group to the west, against miogeoclinal Proterozoic rocks of the North American craton to the east (Monger and Price, 1979).

Within the map area the contact between the two terranes is a west-side-down normal fault which increases in displacement to the southeast (Figure 1-15-2) and probably also has a dextral strike-slip component of motion. This normal fault has obscured the overthrust relationships seen elsewhere along this contact (Nelson and Bradford, 1987; Struik, 1986; Rees and Ferri, 1983).

The Slide Mountain Group is Late Paleozoic in age and is composed of a suite of oceanic rocks. These have been intruded by the Early Cretaceous Germansen batholith (Garnett, 1978) and in places covered by Tertiary (?) felsic volcanics (Armstrong, 1949).

The Omineca crystalline belt is represented by a thick sequence of predominantly siliciclastic sediments with minor carbonates and mafic rocks. These have been assigned to the Ingenika Group and are Late Proterozoic in age (Mansy and Gabrielse, 1978). These sediments have been highly metamorphosed within the Wolverine Range and subsequently intruded by granodioritic bodies and associated pegmatites

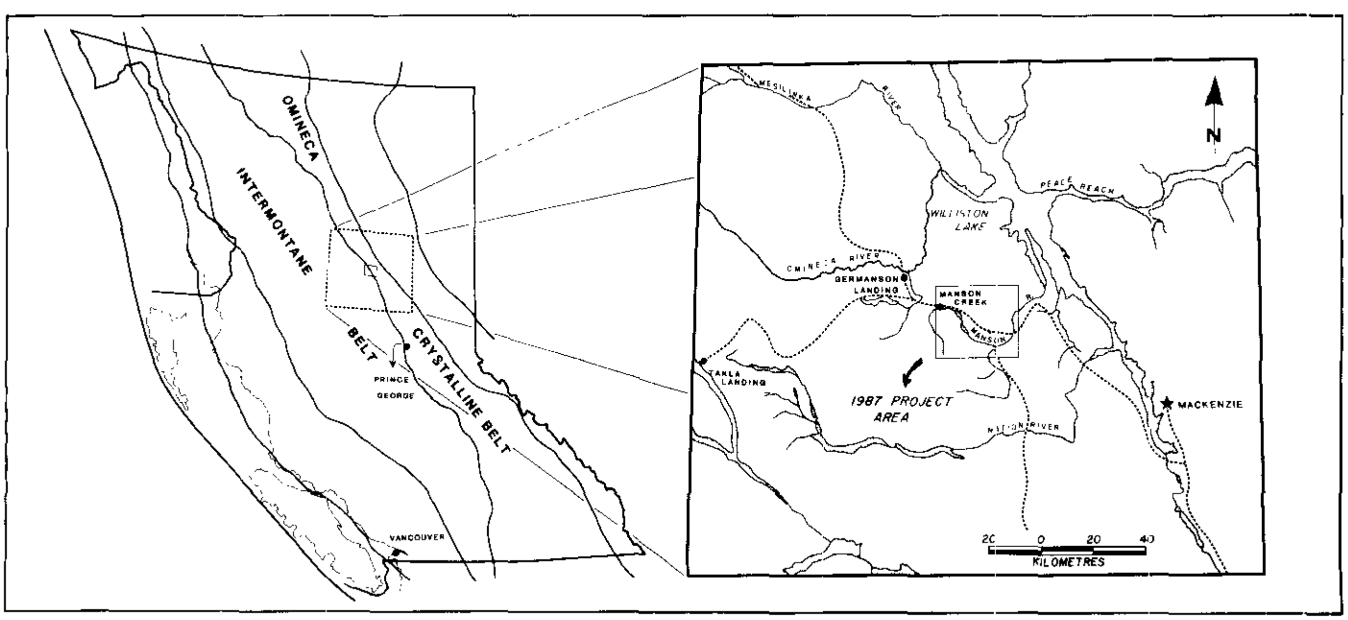

Figure 1-15-1. Location of the project area within the framework of the Canadian Cordillera.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

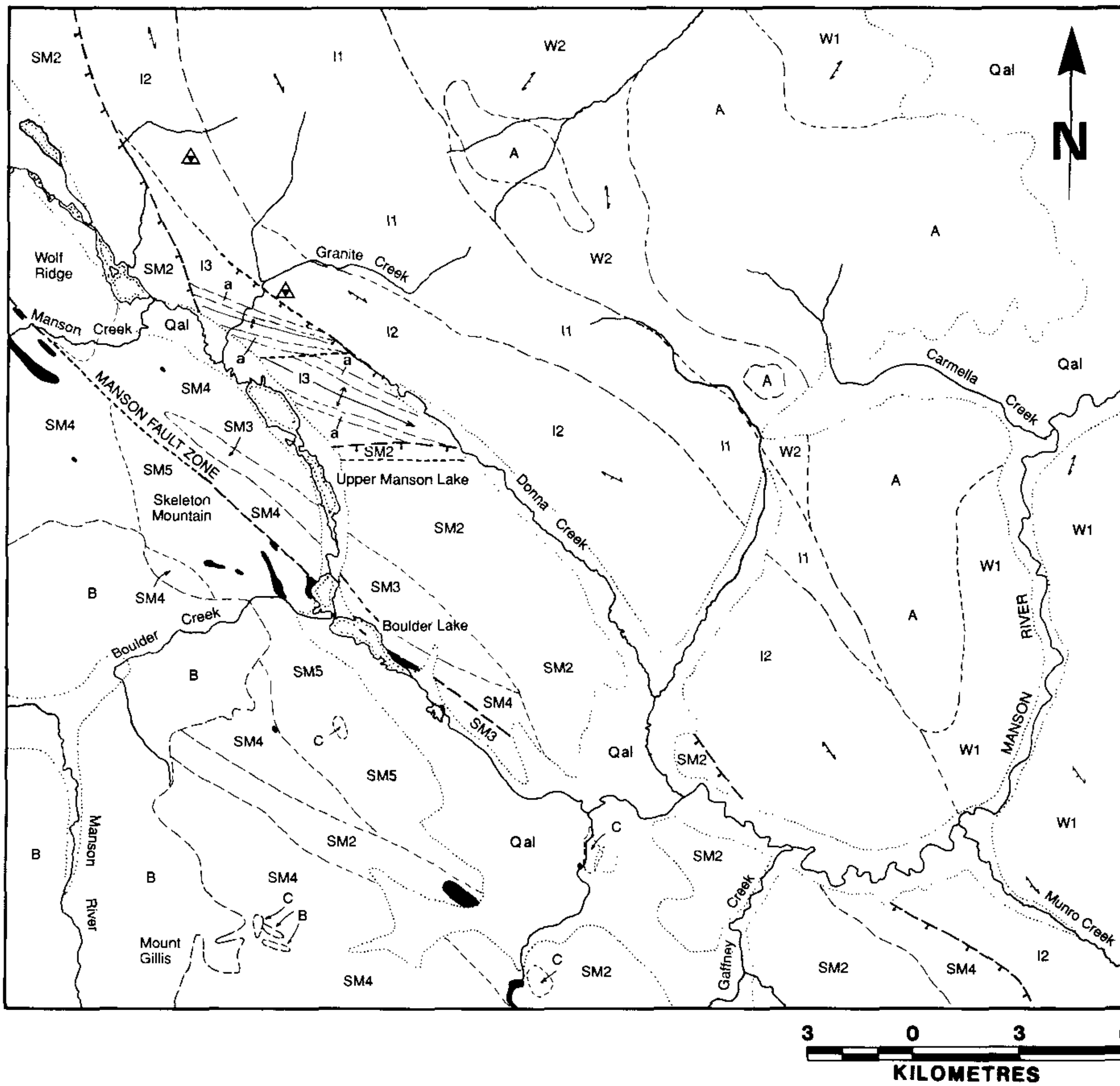

Figure 1-15-2. Geological map of the project area.

which are possibly early Cretaceous (Parrish, 1976). Where deformation, metamorphism and related intrusions have deformed the sedimentary sequence to levels where original lithological determinations are impossible or tenuous, the Wolverine complex has been applied.

INTERMONTANE BELT LITHOLOGIES

SLIDE MOUNTAIN GROUP

Within the project area the Slide Mountain Group was initially mapped as Cache Creek Group by Armstrong (1949). Similar rocks were also mapped as Cache Creek Group in the Aiken Lake map area by Roots (1954) and within the McLeod Lake map area by Armstrong *et al.* (1969). During initial work within the Paleozoic sequences of the Omineca Mountains to the north, Monger (1973) realized that these rocks were correlative with the Slide Mountain Group and Sylvester Group found elsewhere along this segment of the Canadian Cordillera.

The Slide Mountain Group, as seen in the project area, is composed of black phyllite and argillite, mafic and intermediate flows and tuffs, greywackes to gritty phyllites, diorite and gabbro sills and dykes, ultramafic rocks and cherts together with minor carbonates and ribbon cherts. Unit thicknesses in the following paragraphs are rough estimates produced from cross-sections as no continuous section of any one unit was seen in the project area.

LEGEND

QUATERNARY

- Qal — *Glacial till and alluvium*

TERTIARY (?)

- C — *Intermediate to felsic flows and dykes*

UPPER CRETACEOUS

- B — *Germansen batholith: granite and minor granodiorite*

UPPER PALEOZOIC AND YOUNGER

SLIDE MOUNTAIN GROUP

- SM5 — *Argillaceous sandstone, phyllite, gritty phyllite*
- SM4 — *Phyllite, argillite, argillaceous limestone*
- SM3 — *Gabbro*
- SM2 — *Mafic to intermediate volcanics, tuff, siltstone, minor argillite, chert, and gabbro*
- SM1 — *Ultramafics: serpentine, talc-serpentine, and talc-ankerite schists*

UPPER DEVONIAN/LOWER MISSISSIPPIAN

- ▲ — *Syenite and carbonatite*

PROTEROZOIC

INGENIKA GROUP

- I3 — *Upper: Phyllite and lesser quartzite and argillaceous quartzite. a – Middle carbonate member*
- I2 — *Middle: Quartzite, argillaceous quartzite, and schist*
- I1 — *Lower: Meta-arkose, meta-grey wacke, schist, quartz-feldspar gneiss and minor calc-silicate and amphibolite gneiss*

WOLVERINE COMPLEX

- W2 — *Schist and quartz-feldspar gneiss intruded by granodiorite and related pegmatite**
- W1 — *Amphibolite and calc silicate gneiss, schist and quartz-feldspar gneiss intruded by granodiorite and pegmatite**
- A — *Foliated granodiorite and pegmatite**

*Intrusive probably Cretaceous

Figure 1-15-2a. Legend for Figure 1-15-2.

The internal contact and stratigraphic relationships within the Slide Mountain Group are tenuous due to the sparse outcrop. The stratigraphic succession implied in the legend in Figure 1-15-2a is based more on typical oceanic stratigraphy than on field observations.

Unit SM1 (Ultramafics)

Two linear belts containing bodies of ultramafic rock, the largest of which probably has an areal extent of 1.5 square kilometres, trend through the map area. One belt extends from the town of Manson Creek southeast to the mouth of Boulder Creek and along Boulder Lake to the point where Gaffney Creek leaves the map sheet. The second group of ultramafics is found within the belt of predominantly mafic volcanic rocks (Unit SM2, Figure 1-15-2) found immediately northeast of Mount Gillis. Good exposures of this unit can be found on the banks of the Manson River immediately west of Manson Creek and on the main road near Boulder Lake.

Three ultramafic rock types are present: serpentinite bodies, talc-serpentine bodies and talc-ankerite-serpentine schists. Where contact relationships are visible, these bodies are typically found in fault contact with the surrounding rocks.

The serpentinite bodies are almost pure serpentine with minor amounts of disseminated talc, ankerite and epidote alteration accompanying quartz veining. The serpentine is dark green to brown weathering, generally magnetic and may contain thin veins of chrysotile.

Talc is found as either disseminated grains or fine-grained masses 0.5 to 1 centimetre across to radiating crystal masses a few centimetres in diameter, and may comprise more than 50 per cent of the rock. A weak foliation may be developed within the more talc-rich bodies.

Bodies of mariposite-magnetite-quartz-serpentine-talc-ankerite schist are found in some localities. They are composed essentially of talc and ankerite with lesser amounts of the remaining minerals. They are grey-green to brownish weathering and commonly coarsely crystalline with large (up to 1 centimetre) porphyroblasts of ankerite. Mariposite is common and magnetite can be found as finely disseminated crystals which may make up to 2 per cent of the rock.

Unit SM2 (Volcanic and Volcaniclastic Rocks)

This unit is highly variable and is composed of numerous members including: massive to pillowed basalts, intermediate volcanics, tuffs, siltstones, cherts, argillites, conglomerate and minor ribbon chert. These rocks have been intruded by fine to medium-grained gabbro sills and dykes. The best exposures are on the ridge immediately southwest of Donna Creek and in the Gaffney Creek area. The thickness of this unit is at least 1 kilometre.

The basalts are grey-green to green in colour with occasional very finely crystalline feldspar phenocrysts and rare olivine. Some of the more massive flows (especially in the Donna Creek area) appear to be more intermediate in composition and contain medium-grained feldspar and pyroxene phenocrysts. These volcanics are usually highly fractured, chloritized and may be cut by quartz-calcite-epidote veining. The basaltic flows are generally massive but pillow selvages are sometimes seen. The best exposures of basalt flows are on a ridge leading off an unnamed peak north of Mount Gillis.

Associated with the basalts and intermediate flows are predominantly fine-grained tuffs (?) and siltstones of probable volcanic derivation. These rocks are grey-green to olive-green weathering with a dark grey fresh surface. They generally appear massive but faint bedding can be seen occasionally. The siltstone is often quite siliceous. Thick (10-metre) layers of conglomerate and breccia made up of siliceous siltstone, chert and tuffaceous clasts are occasionally present within these tuffs and siltstones.

Grey, green and cream to white chert and siliceous argillite are found as pods within the volcanics or as thin to massively bedded intervals up to 5 metres thick. The cherts are sometimes ribboned.

Dyke or sill-like gabbro bodies ranging from a few metres to tens of metres across, are green to grey-green in colour, very fine to finely crystalline and may contain phenocrysts of feldspar.

Unit SM3 (Gabbro)

Gabbro is found as three lenticular bodies which trend northwesterly across the map area. This rock type is found underlying Wolf Ridge, south of the Upper Manson Lake and north of Boulder Lake; the best exposure is on Wolf Ridge.

The rock is green to dark green in colour and light brown to rusty brown weathering. It ranges in composition from 40 to 60 per cent plagioclase with the remainder of the rock being pyroxene, hornblende and minor biotite. It is typically fine to medium grained, but pegmatitic phases can be seen on Wolf Ridge. Phenocrysts of pyroxene and plagioclase up to 5 millimetres in length may be present.

Most exposures of this unit contain a weak mineral lineation with an accompanying very weak planar fabric. This weak fabric grades into zones of mylonite. These zones are a few metres across and deformation is not uniform throughout any outcrop. Their distribution is sporadic but they are generally found toward the periphery of gabbro bodies.

The contact between the gabbro and the surrounding rocks is not well exposed but a decrease in grain size toward the edge of these bodies may represent chilled margins. This relationship is seen on Wolf Ridge. Nearby, at the Fairview showing, serpentinized ultramafics appear to be in fault contact with this unit and faulted contacts are suspected elsewhere in the map area.

Unit SM4 (Phyllite/Argillite)

This unit underlies the greater part of the map area. Its areal extent, together with structural measurements, suggests it may be at least 2 kilometres thick.

The phyllites are grey to black and are thin to moderately bedded (1 to 5 centimetres). Cleavage is commonly the dominant planar fabric with bedding being impossible or difficult to distinguish. Phyllites are quite lustrous and typically graphitic. They grade into dark grey to black graphitic argillites which are moderately to thickly bedded and may be fairly siliceous. These argillites tend to have a spaced cleavage and, in these horizons, bedding is the dominant planar feature.

The phyllites can become quite calcareous and grade into graphitic, dark grey to black, thin-bedded argillaceous limestones. Small lenses of buff to cream-weathering, thin to moderately bedded recrystallized limestones are observed in the Boulder Creek area and are best exposed along the main road and along the creek flowing southeast into Boulder Lake.

Ribbon chert was seen in a few localities within the argillaceous member. It is characterized by grey to beige chert bands 1 to 3 centimetres thick, alternating with dark grey argillite layers of similar thickness.

Layers of argillaceous sandstone or feldspathic wackes a few metres thick are a minor constituent of this unit. They are grey to light brown weathering and massively bedded.

Unit SM5 (Argillaceous Sandstone – Gritty Phyllite)

This unit is typified by phyllites, silty phyllites and siltstones which are grey-green to green in colour and thin to moderately bedded. Thin to moderately bedded, grey to beige beds of very fine to fine-grained argillaceous sandstone, feldspathic sandstone or quartzite occur in some localities (for example, on Skeleton Mountain). These sandstones are typically interlayered with very thinly bedded grey-green phyllite to siltstone. This predominantly sandstone sequence is approximately 100 metres thick. Small exposures of argillaceous sandstone or quartzite a few metres thick are also found within the phyllite/argillite unit. A minor constituent of Unit SM5 is a buff to dark grey-weathering, thinly bedded, finely crystalline limestone similar to that seen within Unit SM4.

The phyllite and silty phyllites of Unit SM5 can be traced east and north from Skeleton Mountain and grade into the darker and cleaner phyllites of the black phyllite/argillite unit. The southern extent of this unit is obscured by a thick covering of Quaternary material. To the west it has a fairly sharp contact with the underlying argillites.

Unit SM5 is best exposed on Skeleton Mountain and on the ridge immediately south of Boulder Lake. Its thickness is difficult to estimate but is believed to range from 500 to 1000 metres.

Toward the contact with the Germansen batholith, these phyllites and silty phyllites were subjected to contact metamorphism, and porphyroblasts of chlorite, biotite, garnet and occasionally staurolite were formed. This relationship can be clearly seen across the ridge southwest of Boulder Lake. This zone of contact metamorphism is quite large but can be explained by the fact that the eastern contact of the Germansen batholith dips at a shallow angle below the surrounding sediments in the vicinity of Mount Gillis.

Unit SM5 is problematic within the project area. The sandstones, wackes and gritty phyllites form a distinct package within the Slide Mountain Group. Other layered rocks tend to be grey to black in colour whereas the rocks of this unit have a distinct greenish hue and their gritty nature is not characteristic of an oceanic setting. The sandstones and wackes closely resemble the sandstones and argillaceous sandstones of the upper unit of the Ingenika Group elsewhere in the area and may represent a fault slice of Ingenika Group rocks.

The reasons for including this unit within the Slide Mountain Group are: the presence of thick beds of feldspathic wacke to arkose within the black phyllite unit; the apparent stratigraphic continuity of the phyllites of Unit SM5 into those of the Unit SM4; other workers (Schiarizza and Preto, in press; Nelson and Bradford, 1987) also see similar rocks within Slide Mountain Group equivalents. It should be reiterated here that the lack of outcrop in this area does not allow a definitive answer to this problem and both interpretations must be considered.

Germansen Batholith

The Germansen batholith is a Late Cretaceous two-mica granitic intrusion which occupies the southwestern portion of the project area. It is predominantly granite in composition though granodiorite and diorite phases are seen at its southeastern contact. It is white to grey in colour and weathers beige to pink. It is commonly coarsely crystalline and occasionally phenocrysts of potassic feldspar up to a few centimetres in length are seen. Accessories are primarily biotite and muscovite with lesser amounts of hornblende and, in some areas, chlorite after biotite. Granite pegmatite and aplite dykes, up to a metre in thickness, cut the batholith. The pegmatites are similar in composition to the intrusion but they commonly contain garnet and lesser beryl.

The batholith has been dated by Garnett (1978), using potassium-argon method, at 106 Ma and 86 Ma for hornblende and biotite respectively. These dates come from a sample collected just south of Germansen Lake, which is west of the project area.

Intermediate Volcanics

Small bodies (<1 square kilometre) of andesitic flows and dykes are found in several localities. They are beige to pinkish in colour, locally vesicular and typically contain phenocrysts of plagioclase, biotite and minor hornblende and quartz. The dykes are predominantly north-northwest trending and commonly recessive producing gullys. These rocks appear to be restricted to the Slide Mountain Group but rubble of this material is found within the Wolverine Range. The age of these rocks is not known but they are probably Tertiary (Armstrong, 1949).

OMINECA CRYSTALLINE BELT LITHOLOGIES

INGENIKA GROUP

Within the project area, Armstrong (1949) grouped the sequence of phyllites, siltstones, argillaceous sandstones, sandstones, quartzites, carbonates and their higher grade metamorphic equivalents (with associated granodiorite) into the Wolverine complex. To the north, Roots (1954), having better exposures of the lower grade equivalents of these rocks, was able to subdivide them into two broad groups. the upper Ingenika Group and the lower Tenakihi Group. He confined the Wolverine complex to areas where these rocks are so metamorphically and structurally altered that correlation with surrounding rocks is impossible.

Gabrielse (1975) and Mansy and Gabrielse (1978) found that Roots' divisions were not separately mappable units due to the similarity between the rock types. Mansy and Gabrielse (1978) suggested that the upper part of the Ingenika Group, which is of Early Cambrian age, be reassigned to the Atan Group (correlative of the Gog Group), the Tenakihi Group dropped, and the name Ingenika Group placed on all Proterozoic strata within the Omineca Mountains.

Mansy and Gabrielse (1978) divided the Ingenika Group into four formations, from base to top: the Swannell, Tsaydiz, Espee and Stelkuz formations. Where metamorphism and deformation have been too intense to allow positive lithological determination and stratigraphic positioning, the rocks have been assigned to the Wolverine complex.

Within the project area the relatively unmetamorphosed sediments within the Omineca Belt can be subdivided into three broad sequences: a lower section of feldspar-quartz schist, micaceous quartzite, meta-arkose and wacke; a middle sequence of interlayered micaceous quartzite, quartzite and quartz schist; and an upper sequence which is made up of phyllite, higher grade schist, metasiltstone, impure quartzite, metasandstone and carbonate. The units seen in the Omineca Belt conform to the subdivisions proposed by Mansy and Gabrielse. The lower division corresponds to the lower and middle parts of the Swannell Formation; the middle division to the upper member of the Swannell; and the upper division includes the Tsaydiz, Espee and Stelkuz formations. These rocks appear to be approximately 4 kilometres thick, but undoubtedly this has been significantly increased by faulting and folding.

Toward the centre of the Wolverine Range these rocks are intensely metamorphosed and deformed, and are intruded by granodiorite and related pegmatite. This area has been mapped as Wolverine complex.

To the southwest the sediments and metasediments can be traced into high-grade calc-silicate gneiss, amphibolite gneiss and granitic gneiss, also assigned to the Wolverine complex.

Lower Division

The lower division is composed predominantly of quartz-feldspar-mica schist or gneiss, micaceous quartzite and metamorphosed feldspathic wacke or feldspathic quartzite. Minor constituents are calc-silicate gneiss and amphibolite.

Volumetrically the quartz-feldspar-mica schists and gneisses are the most important, probably making up to 60 per cent or more of this unit. They are composed primarily of medium to coarse-grained muscovite and biotite with lesser amounts of chlorite, a product of retrograde metamorphism. Accessory minerals are commonly garnet and less frequently kyanite.

The metamorphosed feldspathic wackes and feldspathic quartzites are typically grey to grey-brown, medium to very coarsely crystalline and form beds 10 centimetres to 1 metre thick. They occur in intervals up to 10 metres thick and are typically interlayered with the quartz-feldspar-mica schists. They may contain up to 25 per cent potassic and calcic feldspar. The quartzites are similar but typically contain less than 5 per cent feldspar and mica.

Grey-green diopside-bearing calc-silicate gneisses are observed within this unit. These gneisses are massively layered, coarsely crystalline and may contain up to 50 per cent diopside.

Middle Division

The middle division comprises micaceous quartzite, quartzite, quartz-mica schist and minor amphibolite. This unit is not well exposed but is predominantly quartzose.

The quartzite is typically impure, grey-brown in colour and contains 5 to 10 per cent micaceous material (biotite and/or muscovite with chlorite in the lower grade areas or as a product of retrogression) and less than 5 per cent feldspar. It is fine to medium grained and is found in beds 10 to 50 centimetres thick in sequences up to 5 metres thick. These quartzites are typically interlayered with quartz-muscovite-biotite ± chlorite schists which are 10 centimetres to 1 metre thick and may form continuous intervals 2 to 5 metres thick. The schists are silver to greyish silver-brown and may contain considerable quartz. In general the upper part of this unit has thicker sequences of quartzites. These are particularly well exposed in the northern half of the Wolverine Range.

Upper Division

The upper division, characterized by grey-green slate, phyllite, schist, siltstone, impure quartzites and sandstones, has an estimated thickness of approximately 1000 metres. It contains a 200 to 300-metre-thick limestone unit, which serves as an excellent marker along the western flank of the Ingenika package. Thinner carbonate sequences are found in the rocks above and below the thick carbonate. The upper division is best exposed along Granite Creek.

The slates and phyllites of this unit are grey-green to green. They commonly contain abundant very fine-grained quartz. They occur over intervals of greater than 50 metres and are intercalated with minor thin-bedded siltstone layers. Toward the eastern contact, the phyllites begin to exhibit porphyroblasts of chlorite and biotite.

The quartzites and sandstones are grey to grey-brown and very fine grained. They are thin to massively bedded and are commonly interlayered with thin phyllite or slate beds. Intervals of up to 10 metres are exposed in creek beds. These quartzites and sandstones are more common within the upper part of this division.

The thick carbonate marker unit is white, cream or grey to blue-grey and is typically massive though occasionally wispy bedding is evident. It is commonly recrystallized, at times to a coarse-grained marble, and has a strong planar or linear fabric produced by the preferential alignment of calcite crystals. These planes are parallel to the cleavage in the surrounding phyllites. Most often it is these "cleavage" planes that are evident, and bedding is obscure. Where seen in less recrystallized sections, bedding is characterized by thin (1 to 5-centimetre) wavy beds of alternating light and dark grey limestone with the darker beds being somewhat coarser grained or recrystallized. The darker layers are at times stretched out into boudins parallel to bedding.

Pegmatite sills, dykes and minor related granodiorite intrude the Ingenika suite up to 4 kilometres from the contact of the Wolverine complex.

WOLVERINE COMPLEX

The name Wolverine complex is used here to describe a series of high-grade schists and gneisses which have been extensively intruded by pegmatites and large bodies of granodiorite. The grade of metamorphism is so high that accurate correlation of these units or determination of original protolith is impossible. Within the complex, the dominant exposed rock types are pegmatite and granodiorite, typically 70 per cent or more of total outcrop, but recessive metasediments may be under represented.

The margin of the Wolverine complex is marked by a series of steep northeast-facing slopes. Within the complex, the ridges are fairly straight and consistently trend northeasterly, parallel to the dominant foliation in the granodiorites and pegmatites. This supports the inference that much of the complex is underlain by these rock types. These relationships are most evident in the northern part of the complex.

Metasediments in the northern two-thirds of the complex are schists and quartz-feldspar gneisses with minor amphibolite and calc-silicate gneiss. The southern third (beginning at approximately the Manson River) of the complex is characterized by amphibolite gneiss, marble and calc-silicate gneiss in addition to the rocks above.

The schists and gneisses are very similar to those seen in the higher grade areas of the Ingenika Group. Dark brown, rusty weathering sillimanite-garnet-quartz-feldspar-muscovite-biotite schists are found in layers 1 to 100 centimetres thick. They are coarsely crystalline and may be slightly chloritized.

Dark grey to dark grey-brown garnet-muscovite-biotite-feldspar gneisses are interlayered with the schists in bands 1 to 200 centimetres thick. They tend to be quartz and feldspar rich (up to 80 per cent combined) and most likely derived from grits of the lowermost Ingenika Group.

Amphibolite gneiss is composed of garnet, quartz, biotite, amphibole and plagioclase. The amphibole content varies from 20 to almost 100 per cent. These gneisses are often thickly layered and coarsely to very coarsely crystalline. The hornblende shows low-grade retrogression to actinolite.

Marbles and calc-silicate gneisses are associated with the amphibolite gneisses in the southern third of the complex, generally at a higher structural level, as seen in outcrop immediately west of the Manson River. The marbles are grey to cream in colour, coarsely crystalline and contain phlogopite, garnet, diopside and calcite. They are found in bands 0.1 to 2 metres thick interlayered with calc-silicate rocks. The calc-silicate gneisses are predominantly diopside and plagioclase with lesser garnet and calcite. They are dark green to green and coarsely crystalline.

Pegmatite and granodiorite are the most extensive rock types within the complex. Contacts between them are generally gradational and crosscutting relationships, with pegmatite cutting granodiorite, are observed in only a few localities.

The pegmatite typically occurs as dykes and sills up to 5 metres thick and it is common to find large irregular outcrops of pegmatite up to 250 metres in diameter. These bodies are grey to white in colour and are made up of garnet, muscovite, biotite, quartz, potassium feldspar and plagioclase. The quartz is dark and smoky at times. Garnet may be an important accessory and comprises up to 10 per cent of the rock; it is often concentrated toward the contacts of the sill or dyke. Beryl is a rare accessory. Micas may make up to 20 per cent of the rocks with large books of mica, up to 10 centimetres across, present within some of the larger pegmatite bodies. The larger dykes or sills usually do not display any internal fabric except for a discontinuous fracture cleavage or closely spaced jointing. A weak foliation is present within the thinner sills and dykes and they are sometimes boudinaged; some of the thinner dykes and sills show complete dislocation.

The granodiorite is grey to beige in colour, medium to very coarsely crystalline and occurs as small stocks up to 50 square kilometres in area. Their composition is the same as that of the pegmatites and garnet is a very important accessory. The potassic feldspar is oligoclase and it is commonly perthitic. These rocks are very uniform in composition throughout the complex. North and west of Carmella Creek, granodiorite and pegmatite underlie an area of some 60 square kilometres. Bodies of similar size outcrop in the northern part of complex. These rocks display a weak to moderate foliation which is steeply dipping and trends northeasterly.

Parrish (1976) mapped pegmatite and related granodiorite within the Wolverine complex in the Aiken Lake map area and obtained an age of 79 Ma from rubidium-strontium analysis. These rocks are probably related to the same intrusive event, most likely anatexis of the continental crust. Parrish (1976) believes this age has been slightly reset indicating that these rocks are older, probably close to the age of metamorphism.

CARBONATITES

Several bodies of carbonatite and syenite outcrop at Granite Creek and immediately southeast of Treb Creek (Figures 1-15-1, 1-15-3; Table 1-15-1). These bodies are small, with the Granite Creek exposure being 50 metres wide and 500 metres long. They contain significant concentrations of rare earths, particularly niobium. They have been dated by Pell (1987), using uranium/lead ratios, as being Late Devonian to Early Mississippian. For a more detailed account of these bodies *see* Pell (1987).

STRUCTURE

The rocks of the Omineca and the Intermontane belts contain structural and metamorphic elements quite distinct from each other. In the project area the Slide Mountain Group rocks generally contain one phase of deformation (locally two) and metamorphism. The Ingenika Group has undergone polyphase deformation and metamorphism. The structural fabric present within these rocks was developed during the emplacement of oceanic Slide Mountain Group rocks over Ingenika Group rocks of the North American craton. This is thought to have occurred during the middle to late Jurassic, with the main period of metamorphism occurring shortly afterward (Monger and Price, 1979; Parrish, 1979). These rocks were subsequently affected by a lower grade metamorphic event sometime in the early Tertiary.

Within the map area structures trend northwest and, for the most part, are inclined to the northeast. The two belts are separated by a west-side-down normal fault along which displacement increases to the southeast. This is demonstrated by the change in metamorphic grade across the fault as it is traced southward. The change in grade across the upper Manson Lake is negligible, whereas in the southern part of the map area greenschist facies in the Slide Mountain Group are placed against middle amphibolite facies of the Ingenika Group.

INTERMONTANE BELT

Within the Slide Mountain Group, lack of a reliable marker horizon inhibits delineation of large-scale structures, and thrust fault repetition is difficult to document as the internal stratigraphy is poorly defined. However, the rocks are intensely folded and thrust repetitions are probably present, as elsewhere in this belt. On a smaller scale, folds seen within the phyllites, argillites and carbonate units are usually tight to isoclinal and sometimes limbless. A subvertical cleavage is the most dominant planar fabric. A weak to moderate crenulation (and rarely a weak crenulation cleavage) is developed locally in the sandstones, greywackes and gritty phyllites of Unit SM5.

The large bodies of gabbro commonly exhibit a strong south-plunging mineral lineation associated with a weaker planar fabric. This planar fabric may become quite strong and grade into northwest-trending mylonitic zones up to a few metres thick. These zones cannot be traced over any significant distance due to the lack of outcrop, but they are common within the two northern bodies of gabbro.

The Manson fault zone mapped by Armstrong (1949) extends from Gaffney Creek, through Boulder Lake, to the town of Manson Creek. Brecciated and silicified rocks of the Slide Mountain Group occur along it. Kinematic indicators, including subhorizontally stretched fault breccia clasts (Plate 1-15-1) and subhorizontal slickensides, indicate strike-slip motion. This fault zone is made up of a series of parallel faults.

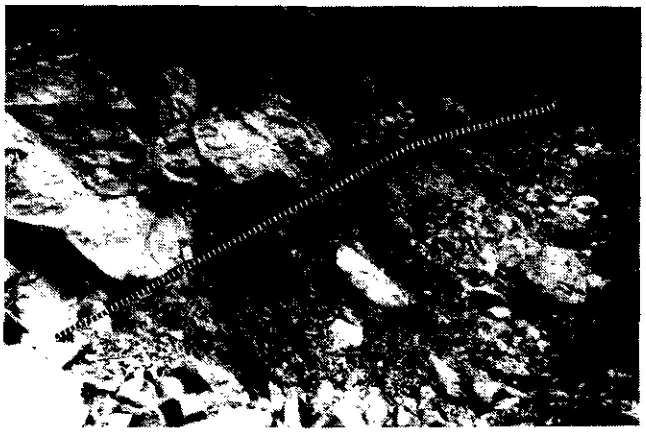

Plate 1-15-1. Talc-ankerite schist of Unit SM1 resting on sandstones and quartzites of unit SM5. Both units have a strong planar fabric which increases in intensity toward the contact (dashed line). Boulder Creek showing, the Bold Claims, near Boulder Lake.

Plate 1-15-2. Fault breccia found on an island in the central part of Boulder Lake. Matrix-supported quartzitic clasts up to 10 centimetres in length are contained within a sericite-quartz-carbonate matrix. Disseminated pyrite is also present. These clasts are stretched out into the viewing direction and produce a prominent lineation which trends 320°/17°. The internal fabric of the clasts indicates that the protolith to the clasts was highly strained prior to brecciation.

A number of small ultramafic bodies outcrop along the Manson fault zone. Typically they have steep contacts with their surrounding rocks and where seen, the contacts are tectonic with subhorizontal slickensides. In one locality, close to the mouth of Boulder Creek, an ultramafic body is found overlying sheared sandstones and quartzites of Unit SM5 (Plate 1-15-2).

OMINECA BELT

The rocks of the Omineca Belt have recorded quite a different structural history than those of the Slide Mountain Group, with at least four periods of deformation recorded within the Ingenika Group rocks.

The first period produced the strong, layer-parallel fabric present in these rocks and the south to southwest-trending limbless isoclinal folds associated with it. A weak to moderate mineral lineation, produced by synkinematic growth of metamorphic minerals, parallels the axes of these folds.

The second period of deformation is represented by south to southeast-trending, tight, parallel folds (within the more competent units) which fold and/or crenulate the layer-parallel schistosity in their cores. The axial planes of these folds are also parallel to layering.

The third phase is represented by a series of poorly developed subvertical northeasterly trending crenulations with a wavelength of 1 to 2 centimetres. These crenulations are roughly parallel to a foliation or strong parting found within the granodiorite and pegmatite, indicating that they may be genetically related.

The fourth phase of deformation warps the larger first phase structures into a broad anticlinorium which plunges gently to the southeast along the core of the Wolverine Range.

On the west flank of the Wolverine Range, the general strike of bedding or compositional layering changes from southerly in the northern part of the range to northwesterly further to the south. Large-scale structures within the lower and middle divisions of the Ingenika Group cannot be delineated due to lack of a suitable marker. Small-scale second phase structures indicate larger folds are present and have most likely thickened the package considerably.

The carbonate marker in the upper division of the Ingenika Group was most helpful in delineating larger structures at this level. Within this package, large-scale folds have a wavelength of approximately 1 kilometre and are upright to slightly west verging. This contrasts with the folds within the lower and middle divisions which are east verging with axial planes dipping moderately to the southwest. This difference most likely reflects the different structural levels at which each package was deformed.

METAMORPHISM

Metamorphism is lower greenschist facies within the Slide Mountain Group, as indicated by the presence of actinolite within some of the gabbro units and the persistent lack of biotite in the slates. Grade increases to lower amphibolite facies around the Germansen batholith where contact metamorphic garnet and staurolite are developed in the slates.

Within the Omineca Belt, metamorphism increases quickly from lower greenschist facies around Upper Manson Lake to middle to upper amphibolite facies within the Wolverine complex. The determination of metamorphic grade is often difficult due to the persistent lack of index minerals except garnet; kyanite or sillimanite are present in only a few localities.

The presence of chlorite around biotite and actinolite around hornblende within amphibolite gneisses, indicates overprinting by a low-grade metamorphic event. This has been observed throughout the southern part of Omineca Belt (Monger and Price, 1979) and is of early Tertiary age.

The recrystallized nature of the micas and other minerals in these rocks indicates that the main period of metamorphism was synkinematic with the first two phases of deformation and outlasted them. The presence of kinked micas in a few areas may reflect the affects of the last two phases of deformation. Microscopic examination of several samples of lower grade metasediments from the west flank of the Wolverine complex indicates the presence of mylonitic texture which is postmetamorphic and parallel to layering. The significance of these rocks is uncertain, but they may be related to the uplift of the complex.

MINERALIZATION

Mineral occurrences within the map area can be categorized as: (1) carbonatite, (2) ultramafic-hosted chromite, (3) sediment-hosted barite, (4) vein-hosted molybdenum and tungsten, (5) sulphide-bearing amphibolite gneisses and (6) vein-hosted precious and base metals. The last type is of widespread occurrence along the Manson fault zone, which appears to have localized mineralization in the area, and is presently of interest. Table 1-15-1 lists and describes the occurrences in the area; locations are shown on Figure 1-15-3.

Gold, in association with sulphide mineralization, is found in significant concentrations along the Manson fault zone which extends northwest of the study area. At present most significant gold showings are found immediately northwest of Manson Creek (for example, Farrell and Flagstaff showings). This mineralization occurs within quartz veins and

TABLE 1-15-1.

TABLE OF MINERAL OCCURRENCES (93N/09)

Map Type No.	MINFILE No.	Name	Economic Minerals	Description
1 Carbonatites (Nb, Ti, Ta, U, Th, V, Zr)	93N-174	Wolverine/Virgil	Columbite, pyrochlore ilmenorutile, zircon	Pure carbonate and syenitic carbonatite rocks containing disseminated columbite, pyrochlore, etc. Intruded within metasedimentary rocks of the Ingenika Group.
2 ,,	93N-190	Granite Creek	,,	,,
3 ,,	93N-012	Lonnie	,,	,,
4 Ultramafic-hosted chromite	93N-135	Manson Creek	Chromite	Mineralization is found disseminated in fault-bounded serpentinized bodies.
5 Sediment-hosted barite	93N-087	Omineca Queen	Barite, sphalerite, galena, tetrahedrite	Mineralization occurs stratabound in an argillaceous unit of the Slide Mountain Group. Minor amounts of galena, sphalerite and tetrahedrite are known to exist.
6 Vein-hosted molybdenum and tungsten	93N-118	Blackjack East	Molybdenite	Molybdenite is developed in small quartz veinlets in a fine-grained granodioritic phase of the Germansen batholith.
7 ,,	New	Jordi	Molybdenite	Molybdenite occurs in feldspar-quartz-muscovite veins near the contact of the Germansen batholith.
8 ,,	93N-119	Blackjack South and Central	Molybdenite ± chalcopyrite	Mineralization is hosted by quartz veins in hornfelsed sedimentary pendants within Germansen batholith.
9 ,,	93N-078	Tait Tungsten (Billy, Glo)	Scheelite	Scheelite is found in quartz stringers parallel to axia plane cleavage of folds within the Manson fault zone.
10 Vein-hosted precious and base metals	93N-030	Kathy (Joy, Troy)	Galena, tetrahedrite, sphalerite ± scheelite, bornite, chalcopyrite, gold, molybdenite	Mineralization occurs in quartz veins, fault breccia zones and hydrothermally altered rocks related to the Manson fault zone. Veins are hosted in limestones, argillites, ultramafics and chlorite schists of the Slide Mountain Group.
11 ,,	93N-027	ASP (Bold)	,,	,,
12 ,,	93N-137	Bold (Stroh)	,,	,,
13 ,,	93N-028	Berthold (Bold)	,,	,,
14 (Pb ± Ag, Au)	93N-117	Lost Creek	Galena ± silver, tetrahedrite, gold	Sulphide-bearing quartz veins in limestones, argillites, greenstones and cherts of the Slide Mountain Group within the Manson fault zone.
15 ,,	93N-136	Not named	,,	,,
16 ,,	93N-148	Blackjack Mountain	,,	,,
17 (Ag, Au)	93N-113	Not named	Silver, gold	Low-grade gold and silver mineralization in quartz veins within Ingenika Group rocks northeast of the Manson fault zone.
18 ,,	93N-134	,,	,,	,,
19 (Au, Ag, Cu, W)	93N-023	Fairview	Tetrahedrite, gold, azurite, malachite, chalcopyrite (?)	A 0.5-metre-wide quartz vein is found in a shear zone bounded by quartz-carbonate-altered ultramafics and gabbros. It is traced for approximately 50 metres.
20 Sulphide-rich mafics	New	Not named	Chalcopyrite	Disseminated pyrite and chalcopyrite of varying concentrations occur within amphibolite gneisses and amphibolites of the Wolverine complex.

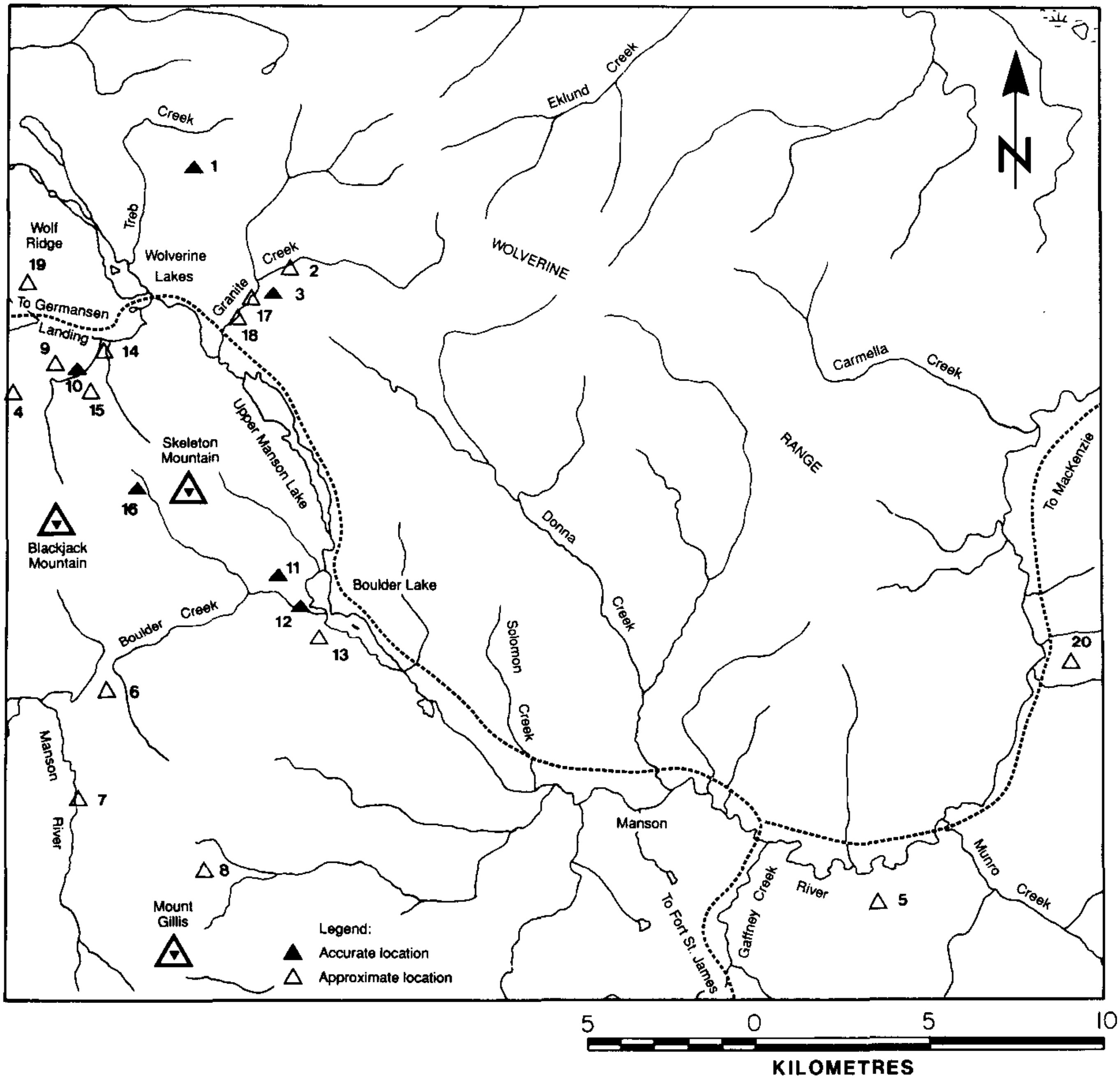

Figure 1-15-3. Location of known mineral occurrences within the project area. Numbers on the map correspond to listed occurrences in Table 1-15-1.

stockworks associated with quartz-ankerite-pyrite ± sericite ± mariposite alteration of the country rocks, and spatially related to silicified and carbonatized ultramafic bodies.

This alteration is characterized by the presence of disseminated and/or porphyroblastic ankerite and pyrite with accompanying sericitization and silicification of the host rocks. The ultramafic rocks exhibit the most intense alteration. These bodies are transformed to talc-ankerite-quartz ± mariposite ± magnetite assemblages that may also contain remnants of the original rock. Altered zones are typically buff weathering, are massive to slightly foliated, and are cream to grey on fresh surfaces.

Within the map sheet, significant gold concentrations are found at the Fairview showing (Figure 1-15-4). Pyrite and tetrahedrite mineralization is hosted by a quartz vein 1 metre wide and traceable for a strike length of approximately 50 metres. The vein occupies a silicified and slightly carbonatized fault zone between gabbro to the northeast and ultramafic rock to the southwest. Armstrong (1949) reported assays of 0.28 ounce per ton gold and 22.3 ounces per ton silver on a sample from the most strongly mineralized zone and 0.02 ounce per ton gold and 0.96 ounce per ton silver from a grab sample.

Sulphide-bearing quartz-carbonate veins (for example, Bold and Kathy showings) are found southeast of Manson

Creek, along the Manson fault zone. Some of these veins contain slightly anomalous gold values (Oddy, 1978; Melnyk, 1982). This mineralization is associated with carbonatized ultramafic rocks and to a lesser extent, sediments.

Two localities with pyritiferous quartz veins with reported anomalous gold values (*see* Table 1-15-1) are found on Granite Creek. These veins are hosted by phyllites and sandstones of the Ingenika Group, are less than 1 metre wide and are not extensive.

Several other zones of altered Slide Mountain Group rocks crop out along the Manson fault zone. Altered ultramafic rocks are exposed along the main road near Boulder Lake. They are cut by numerous quartz-calcite veins with mariposite developed within the ultramafic body. No alteration of the surrounding phyllites was seen.

Highly fractured, silicified and mariposite-bearing serpentinite crops out along the first major creek west of Gaffney Creek and running parallel to it. These exposures are on strike with the southern extension of the Manson fault zone. A large body of talc-ankerite-serpentine schist crops out upstream from this occurrence. Exposure is restricted to the creek valley and no other rock types are exposed. The outcrop exhibits the typical alteration present within ultramafics associated with gold occurrences.

CONCLUSIONS

(1) The Intermontane Belt in the project area is represented by the Slide Mountain Group which has been subdivided into five mappable units.

(2) Within the Omineca Belt, a threefold subdivision has been proposed for rocks outside the Wolverine complex which is correlative with the Ingenika Group to the north.

(3) The Ingenika Group has recorded at least three or possibly four periods of deformation.

(4) The Wolverine complex is composed predominantly of granodiorite and related pegmatite which have extensively intruded high-grade schists and gneisses of the Ingenika Group.

(5) The two tectonostratigraphic provinces are separated by a west-side-down normal fault.

(6) The Manson fault zone may have a strike-slip component of motion along it.

(7) Precious metal and sulphide mineralization is spatially related to the Manson fault zone and is associated with carbonate alteration and ultramafic bodies.

ACKNOWLEDGMENTS

We would like to thank Grant Malenalk and Neil Swift for cheerful and patient assistance in the field. As well we send our appreciation to those who helped in producing this paper.

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BABINE PROJECT*
(93L/15)

By D. G. MacIntyre and P. Desjardins

KEYWORDS: Regional geology, Babine Range, stratigraphy, Hazelton Group, Bowser Lake Group, Skeena Group, Kasalka Group, structural geology, mineral occurrences.

INTRODUCTION

The objective of the Babine project is to map the Babine Range at 1:50 000 scale and to develop metallogenic models for the mineral deposit-types present. The project began in 1984 and earlier work is summarized in two previous reports (MacIntyre, 1985a; MacIntyre *et al.*, 1987).

This report summarizes work completed during the 1987 field season. The area mapped to date is shown in Figure 1-16-1. The work was done from the town of Smithers using both four-wheel-drive vehicles and helicopters for transportation. A total of 444 geological stations were recorded within an area of approximately 196 square kilometers. The field data were coded and entered into a database file using a Compaq II microcomputer and are available to the public either as a printout or on a floppy diskette.

The major conclusions from the work completed in 1987 are:

(1) A thick pile of Late Cretaceous to Tertiary volcanic and sedimentary rocks and associated high-level intrusions is preserved in an arcuate belt of tilted and thrusted fault blocks in the vicinity of Mount Cronin. These rocks are probably related to a major eruptive centre and cauldron subsidence complex of Late Cretaceous age.

(2) The Cretaceous and Tertiary volcanic rocks are folded, thrust faulted and offset by northeast-striking shear zones, indicating a very young compressional tectonic event has affected rocks of the Babine Range. This tectonic event appears to be unique to the Babine Range and may be related to opposing transcurrent movement on bounding faults, that is, transpressional tectonics.

(3) Sericite-pyrite alteration zones and gold-silver-bearing quartz veins occur in zones of intense foliation or shearing within Tertiary, Late Cretaceous and older rocks. Many of these zones trend northeast. There is also a spatial association with rhyolite and diorite intrusions, especially along the eastern fault boundary of Late Cretaceous volcanic rocks. Dykes that parallel this contact may have been emplaced along ring fractures produced during the main episode of volcanic eruption and subsidence.

REGIONAL GEOLOGIC SETTING

West-central British Columbia is part of the Stikine terrane. This terrane includes: submarine calcalkaline to alkaline immature 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 downthrown fault blocks and grabens. Plutonic rocks of Jurassic, Cretaceous and Tertiary age are known and form distinct intrusive belts (Carter, 1981). 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.

GEOLOGY OF THE BABINE RANGE

The Babine Range is a northwest-trending horst of folded and faulted Jurassic and Cretaceous volcanic and sedimentary rocks. Younger Tertiary volcanic and sedimentary rocks crop out in the Bulkley Valley, which lies west of the range (Figure 1-16-1). The structural setting is similar to the Basin and Range province of the United States and is probably related to extensional tectonics induced by right lateral movement on major northwest-trending transcurrent faults.

The structural style of the Babine Range is characterized by asymmetric to overturned, southeast-plunging folds that are truncated by northeast-trending shear zones and northwest-striking high-angle reverse and normal faults. Downward stepping of tilted fault blocks occurs to the northwest, exposing progressively higher stratigraphic levels in this direction. Faults created during an early episode of block faulting were apparently reactivated during a Tertiary compressional event, resulting in squeezing of subsided blocks upward and over adjacent fault blocks.

GEOLOGY OF THE STUDY AREA

The preliminary geology of the study area, as determined by fieldwork completed in 1987, is shown in Figure 1-16-2. Relationships between the different map units are shown diagrammatically in Figure 1-16-3. Table 1-16-1 lists the map units as defined to date.

HAZELTON GROUP

The Hazelton Group (Leach, 1910) is a continental to island-arc calcalkaline assemblage that was deposited in the northwest-trending Hazelton trough in early to middle

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

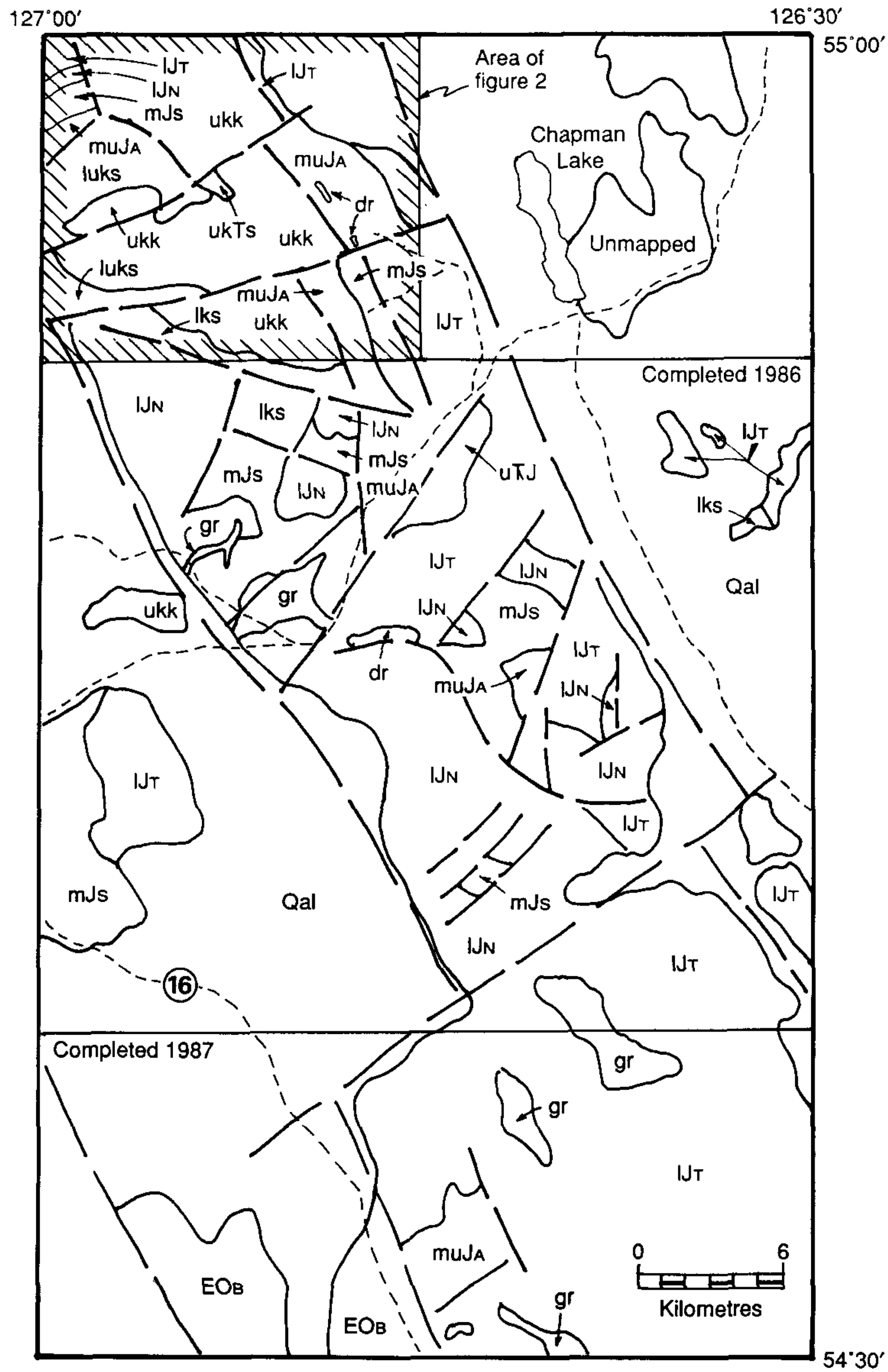

Figure 1-16-1. General geology of the Babine Range (93L/10, 93L/15). *See* Table 1-16-1 for description of map units.

TABLE 1-16-1
TABLE OF FORMATIONS

SEDIMENTARY AND VOLCANIC ROCKS

EPOCH	FORMATION	MAP UNIT	LITHOLOGY
Late Cretaceous and Early Tertiary		uKTs	Well-bedded, tuffaceous siltstones, argillites and chert. Lapilli tuff and tuffaceous siltstone at base.
		Unconformity	
Late Cretaceous	Kasalka Group	uKK2d	Maroon to grey hornblende feldspar porphyry intrusions.
		uKK2c	Maroon to grey hornblende feldspar porphyry flows, breccia.
		uKK2b	Crystal tuff, ash tuff, and minor mudstone.
		uKK2a	Volcanic breccias and lapilli tuffs; hornblende-biotite-feldspar-phyric clasts and a feldspathic crystal-rich matrix.
		unconformity	
		uKK1f	Siliceous maroon ash flow, crystal tuff, breccia, lapilli tuff.
		uKK1e	Bedded lahar, epiclastics, porphyry flows, breccia.
		uKK1d	Lapilli tuffs and volcanic breccias; maroon and green feldspar-phyric clasts.
		uKK1c	Augite basalt and andesite, amygdaloidal, vesicular and massive; local flow breccia.
		uKK1b	Tuffaceous siltstone, sandstone, and conglomerate.
		uKK1a	Poorly sorted heterolithic pebble conglomerate and siltstone.
		Unconformity	
Early to Late Cretaceous		luKS5	Siltstone, argillite, shale, matrix-supported pebble and boulder conglomerate.
		luKS4	Well-bedded siltstone, sandstone and pebble conglomerate.
		luKS3	Tuffaceous siltstone; flaser bedding; orange weathering.
		luKS2	Shale, siltstone; minor conglomerate beds.
		luKS1	Maroon and green phyllite.
		Disconformity?	
Early Cretaceous	Skeena Group	lKS	Polymictic pebble conglomerate; sandstone and shale. Micaceous with shale clasts and plant impressions.
		Unconformity	
Middle to Late Jurassic	Bowser Lake Group Ashman Formation	muJA	Argillite, shaly siltstone, quartzose wacke.
		Unconformity?	
Early to Middle Jurassic	Hazelton Group Smithers Formation	mJS	Feldspathic wacke, siltstone, glauconitic sandstone, conglomerate; fossiliferous.
		Unconformity	
Early Jurassic	Nilkitwa Formation	lJN	Amygdaloidal basalt, red epiclastic, phyllite, shale, siltstone, conglomerate.
		Unconformity	
	Telkwa Formation	lJT	Lapilli tuff, breccia.

INTRUSIVE ROCKS

gr quartz monzonite, granodiorite, quartz diorite
dr diorite, quartz diorite
rh rhyolite, quartz porphyry

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)

The Telkwa Formation, which is comprised of subaerial and submarine pyroclastic and flow rocks with lesser intercalated sedimentary rocks, is the thickest and most extensive formation of the Hazelton Group. The mixed subaerial to submarine Babine Shelf facies of the Telkwa Formation, which separates the subaerial Howson facies to the west from the submarine Kotsine facies to the east, underlies the Babine Range (Tipper and Richards, 1976).

The only outcrops of Telkwa Formation in the study area are located north of Reiseter Creek and south of Debenture Creek. Here the formation is comprised of maroon and green lapilli tuff and volcanic breccia with poorly defined interbeds of lithic, crystal and ash tuff. These rocks typically contain clasts of porphyritic andesite or crystal tuff in a fine-grained hematitic matrix of feldspar crystal and lithic fragments. In places the clasts are flattened and elongate parallel to bedding. These rocks are difficult to distinguish from lithologically similar Late Cretaceous volcanic rocks. Stratigraphic position and an older, more altered and weathered appearance are the criteria used in this study to distinguished Telkwa rocks from their younger counterparts.

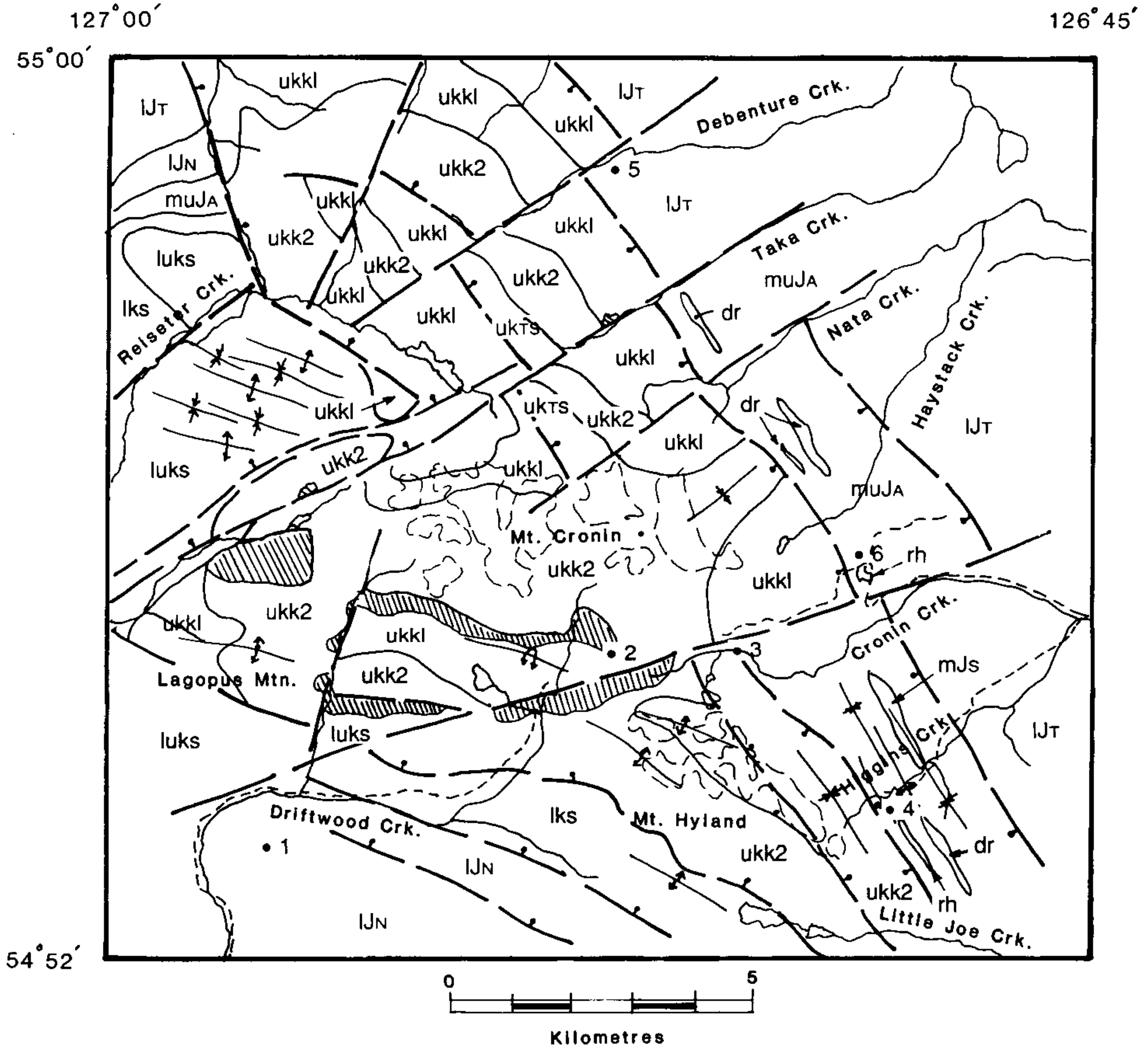

Figure 1-16-2. Geology of the Mount Cronin area (93L/15NW). *See* Table 1-16-1 for description of map units and Table 1-16-2 for list of mineral occurrences. Cross hatched areas are pyritic gossans.

NILKITKWA FORMATION (lJN)

The Nilkitkwa Formation conformably to disconformably overlies the Telkwa Formation and is an important host to mineral occurrences in the Babine Range (MacIntyre *et al.*, 1987). West of the Babine Range it is comprised of predominantly red epiclastic rocks; to the east it includes Early Pliensbachian to Middle Toarcian transgressive marine sedimentary rocks that overlie rhyolite and basalt flows and red epiclastic rocks. Units within the Nilkitkwa Formation were described in an earlier report (MacIntyre *et al.*, 1987).

In the study area, the Nilkitkwa Formation is predominantly green and maroon amygdaloidal flows with red-weathering phyllitic tuff and epiclastic interbeds. The sedimentary part of the formation is thin or absent. The amygdaloidal flows are best exposed in Little Joe Creek where they form the steep fault scarps along the south side of the valley. Similar, but much thinner, flows are also exposed in the extreme northwest corner of the study area, and in an anticlinal core north of the headwaters of Higgins Creek.

SMITHERS FORMATION (mJS)

In the northern part of the Babine Range, the Smithers Formation, which elsewhere is predominantly Bajocian in age, disconformably overlies the Nilkitkwa Formation. It is comprised of fossiliferous, green glauconitic sandstone and

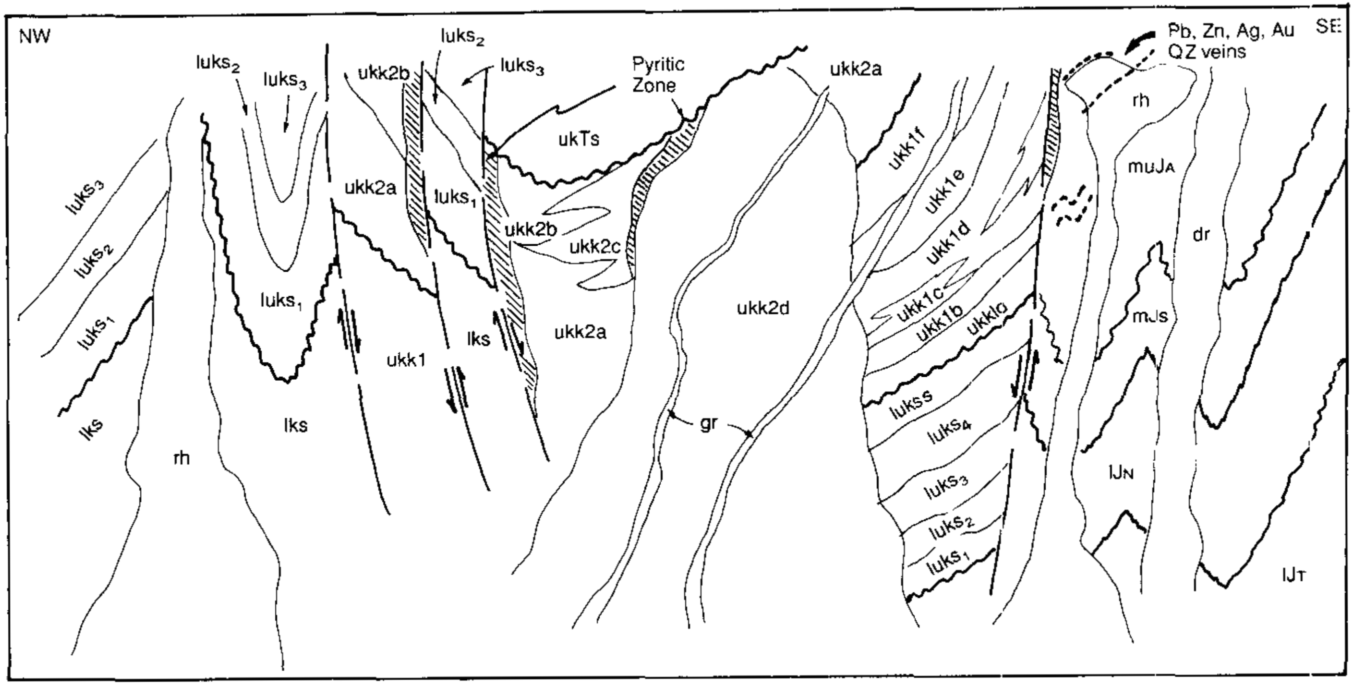

Figure 1-16-3. Diagrammatic sketch of relationships between map units in the Mount Cronin area. *See* Table 1-16-1 for description of map units.

siltstone, with lesser intercalated felsic tuff. These rocks were deposited during a marine regression.

To the south and west of the Babine Range, the Smithers Formation is either absent or rests directly on Telkwa Formation. In the current study area, the best exposures are located in the Higgins and Cronin Creek areas where fossiliferous, well-bedded shale, wacke and pebbly sandstone disconformably overlie amygdaloidal flows of the Nilkitkwa Formation. The Geological Survey of Canada has identified several fossil collections from this area as Middle Jurassic in age. None of the fossils collected could be assigned a more specific age.

BOWSER LAKE GROUP

Within the Hazelton trough, successor basin deposits of the Bowser Lake Group (Duffell and Souther, 1964) conformably overlie the Smithers Formation. These rocks range in age from Late Bajocian to Early Oxfordian. Only the lowermost Ashman Formation is believed to be present in the study area. It was deposited during a mid-Jurassic marine transgression that apparently advanced as far south as the Skeena arch (Tipper and Richards, 1976).

Ashman Formation (muJA)

In the northern Babine Range, phyllitic, tightly folded dark grey argillites and siltstones, with lesser intercalations of quartzose wacke and chert-pebble conglomerate, crop out along the eastern fault margin of Late Cretaceous volcanic rocks extending from Higgins Creek in the south to Debenture Creek in the north. These rocks are tentatively correlated with the Ashman Formation on the basis of stratigraphic position and lithology. A fossil collection from near the forestry lookout tower east of the Cronin mine yielded a possible Callovian age. The quartz and chert-bearing turbidite interbeds distinguish this unit from lithologically similar rocks of the Nilkitkwa Formation.

In the absence of fossils, the Ashman Formation is difficult to distinguish from the overlying Red Rose Formation of the Skeena Group which is also mapped as black shale and chert-pebble conglomerate. However, the coarse clastic beds of the Red Rose Formation often contain detrital mica and this has been used by other workers in the Babine Range to distinguish the two formations.

SKEENA GROUP

The Skeena Group (Leach, 1910) comprises interbedded marine and nonmarine sedimentary strata of an Early Cretaceous successor basin. West of Telkwa these rocks unconformably overlie the Telkwa Formation and contain important coal seams (Koo, 1984). The coal seams occur in upward-fining fluvial clastic sequences of conglomerate, sandstone, siltstone and mudstone.

Red Rose Formation (lKS)

The Geological Survey of Canada has mapped much of the area north of McKendrick Pass as the Red Rose Formation (Sutherland Brown, 1960) of the Skeena Group. It is uncertain what criteria have been used to establish the age of these rocks. Rocks that have been mapped as Red Rose Formation within the study area vary from well-bedded sandstone, mudstone and pebble conglomerate to graphitic black shale. They include well-bedded, strongly foliated dark grey, micaceous siltstone, argillite and mudstone with abundant wood and plant impressions (lKS1). These rocks grade upsection into a pebble conglomerate (lKS2) with tectonically

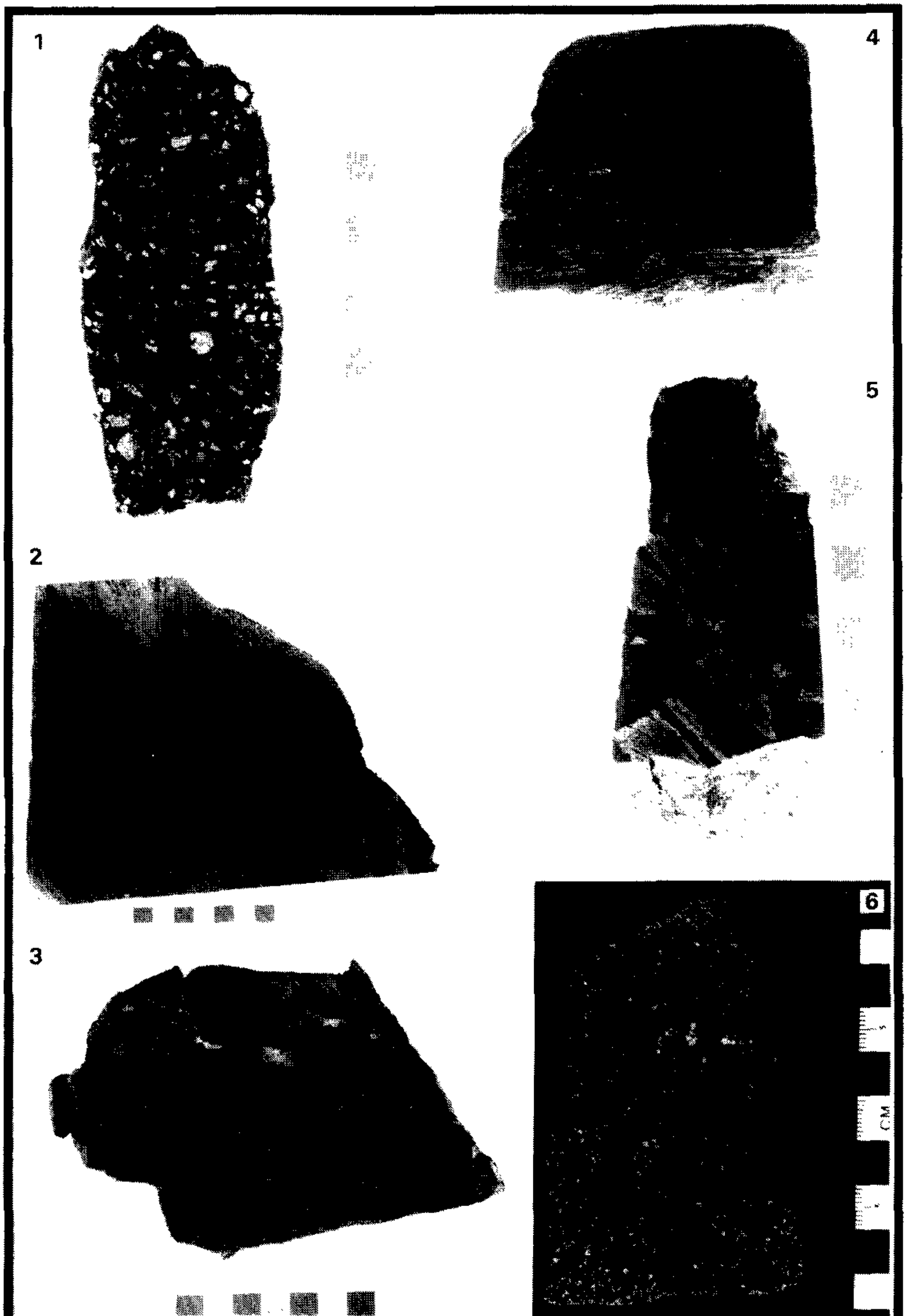

Plate 1-16-1. Bedded lapilli tuff and ash of lower division Kasalka Group. Sample from Silver King basin. Plate 1-16-2. Lapilli tuff with maroon and green clasts, lower division, Kasalka group. Sample from north of Mount Cronin. Plate 1-16-3. Banded siliceous maroon ash-flow tuff, lower division, Kasalka Group. Sample from north of Mount Cronin. Plate 1-16-4. Siliceous maroon volcanic breccia with angular clasts of banded ash-flow tuff, lower division, Kasalka Group. Sample from north of Mount Cronin. Plate 1-16-5. Crowded hornblende-feldspar-porphyritic andesite, upper division, Kasalka Group. Sample from Mount Hyland. Plate 1-16-6. Sparse maroon hornblende-feldspar porphyritic andesite, upper division, Kasalka Group. Sample from north of Mount Cronin.

flattened clasts of chert, quartz, granite, black argillite and orange-coloured siltstone. The best exposures of these rocks occur along the south side of Little Joe Creek valley and in the area northwest and southeast of Reiseter Creek.

EARLY TO LATE CRETACEOUS SEDIMENTARY ROCKS (luKs)

In the Tahtsa Lake area of west-central British Columbia, Late Cretaceous volcanic rocks rest with angular discordance on the Skeena Group (MacIntyre, 1985b). However, in the Babine Range there is a succession of predominantly sedimentary strata that separates rocks correlated with Skeena Group from rocks correlated with the Late Cretaceous Kasalka Group.

The Early to Late Cretaceous sedimentary succession, from base to top, includes a maroon and green phyllite (luKs1), dark grey argillaceous siltstone (luKs2), resistant orange-weathering, flaser-bedded, foliated dolomitic siltstone (luKs3), well-bedded grey siltstone, wacke, chert-pebble conglomerate, cherty and shaly mudstone (luKs4) and poorly bedded, intensely folded dark grey argillite (luKs5) with bands of matrix-supported volcanic and intrusive clasts. The most complete section is exposed along the crest of the ridge south of Reiseter Creek. The basal phyllite unit lies conformably to disconformably on pebble conglomerate of the Skeena Group. The unit is apparently overlain by a heterolithic pebble conglomerate that constitutes the basal member of the Late Cretaceous volcanic succession.

KASALKA GROUP (uKK)

The Kasalka Group (MacIntyre, 1985b) is a Late Cretaceous continental volcanic succession that is predominantly porphyritic andesite and associated volcaniclastic rocks. Sutherland Brown (1960) mapped similar rocks in the Rocher Déboulé Range north of Smithers as the Brian Boru Formation. Porphyritic volcanics in the vicinity of Mount Cronin were also mapped by the Geological Survey of Canada (Tipper and Richards, 1976) as Brian Boru Formation. These rocks are correlated with the Kasalka Group in this study.

In the current study area, the Kasalka Group has been subdivided into lower and upper divisions. The lower division (uKK1), which varies from 100 to 500 metres thick, includes heterolithic volcanic conglomerate and breccia (uKK1a), volcanic wacke and tuff (uKK1b), feldspar and augite-phyric amygdaloidal and vesicular flows (uKK1c), air-fall lapilli and crystal tuff and associated epiclastic rocks (uKK1d), and siliceous maroon ash flow, lapilli and crystal tuff with occasional conglomerate interbeds (uKK1e). The upper division (uKK2) is up to 1000 metres thick and is mainly hornblende feldspar porphyry and crystal tuff breccia (uKK2a), foliated hornblende feldspar crystal tuff (uKK2b), coarse-grained maroon to greenish grey hornblende feldspar porphyry flows and flow breccia (uKK2c) and hornblende feldspar porphyry subvolcanic intrusions (uKK2d).

The lower division represents explosive subaerial volcanism and possible cauldron subsidence; the upper division represents a period of lava eruption and construction of volcanic cones. Within the lower division there are several hematitic conglomerate beds that probably represent periods of erosion between volcanic events. The resistant Late Cretaceous volcanic rocks underlie the highest peaks in the area — Mount Hyland, Mount Cronin and Lagopus Mountain. The alpine plateau northeast of Reiseter Creek is also underlain by these rocks.

The contact between the Kasalka Group volcanic rocks and Ashman Formation argillites is exposed along the east margin of the Babine Range and appears to be a high-angle reverse fault with the Late Cretaceous rocks thrust upwards over the older strata. A similar relationship was observed south of Mount Hyland and Lagopus Mountain. However, south of Reiseter Creek the opposite situation is observed. Here, the older ocks have been thrust over the Late Cretaceous volcanic rocks.

LOWER DIVISION

Basal Conglomerate (uKK1a)

The basal member of the Kasalka Group is a maroon and green, heterolithic, poorly sorted pebble conglomerate that has rounded to subangular maroon and green tuff clasts. The conglomerates are interbedded with sandstone, siltstone and mudstone. Best exposures occur at the toe of several glaciers that occupy cirques on the north face of Mount Cronin. Here the conglomerates conformably overlie well-bedded argillites and siltstones (luKS4 and luKS5).

Bedded Tuffs and Epiclastics (uKK1b)

Grey, recessive, thin-bedded tuffs, epiclastics and tuffaceous siltstone, sandstone and conglomerate (Plate 1-16-1) crop out in Silver King basin. These rocks are overlain by mafic flows and are probably underlain by maroon and green conglomerates. Rocks of this unit are often strongly foliated. Best exposures are on the ridge east of Silver King basin and in the cirque east of Mount Lagopus. Black siltstone containing angular felsic fragments crops out on the west side of a southerly flowing creek that empties into Reiseter Creek, and may be part of the same unit.

Mafic Flows (uKK1c)

Overlying and interfingering with volcaniclastic rocks of the lower division are flows of augite-feldspar-phyric, green to maroon, vesicular and amygdaloidal basalt and andesite. These flows are most common in the eastern part of the study area, particularly from Mount Cronin to Debenture Creek. In one locality, north of Reiseter Creek, massive flows are exposed as a resistant knob that lies on a hematitic conglomerate bed. Underlying volcaniclastic rocks are orange to rust coloured and may have been oxidized or altered prior to eruption of the mafic flows.

Lapilli Tuff and Breccia (uKK1d)

A thick-bedded, massive, maroon and green, feldspathic lapilli tuff (Plate 1-16-2) and volcanic breccia overlies and is interfingered with green to maroon vesicular basalt. This unit has a feldspathic matrix and in places is very difficult to distinguish from lapilli tuff of the Telkwa Formation. Stratigraphic relationships are best exposed along the east slope of the Babine Range, from Mount Cronin to Debenture Creek. In this area bedding dips moderately to steeply to the southwest. The lapilli tuffs overlie or are in fault contact with orange-weathering volcaniclastic rocks which are exposed farther down slope.

Bedded Lahar, Epiclastics and Flows (uKK1e)

South of Debenture Creek, the lapilli tuff is overlain by green and maroon heterolithic conglomerate which grades up-section into a sequence of bedded rocks that include bedded epiclastic rocks, volcanic conglomerates and breccias, lahars and porphyry flows. North of Debenture Creek, the same section of lapilli tuffs apparently underlies an orange-weathering crystal tuff and overlies feldspar-phyric andesite. Similar lapilli tuffs also crop out on either side of the lake situated north of Mount Cronin and draining into Reiseter Creek, but the contacts in this area are probably high-angle normal or reverse faults and stratigraphic position is uncertain. In fact these lapilli tuffs may be part of the Lower Jurassic Telkwa Formation.

Siliceous Ash-Flow Tuff and Breccia (uKK1f)

Laminated to thick-bedded, siliceous, maroon and green ash-flow tuffs (Plate 1-16-3) and breccias (Plate 1-16-4) with interbeds of volcanic breccia, lapilli tuff, hematitic pebble conglomerate and feldspar-phyric flows crop out on the steep ridge just north of Taka Creek. These rocks dip moderately southwest and conformably overlie lapilli tuff and orange-weathering volcaniclastic rocks that comprise the lower part of the Kasalka stratigraphic succession. Farther up-slope the siliceous pyroclastic rocks are intruded by coarse-grained feldspar porphyry.

Upper Division

Volcanic Breccia (uKK2a)

A thick section of grey to greenish grey-weathering, poorly bedded volcanic breccia with interbeds of orange-weathering foliated tuff forms the core of Lagopus Mountain and Mount Hyland. These rocks contain hornblende feldspar crystal tuff and porphyritic andesite clasts. Clasts are angular and vary from matrix to clast supported. Some clasts have reaction rims and irregular ovoid shapes suggesting they may be bombs. The contact with underlying maroon volcaniclastic rocks of the lower division is not well exposed but is assumed to be conformable.

Crystal Tuff (uKK2b)

Volcanic breccias grade up-section into grey to greenish grey, poorly bedded to faintly laminated hornblende feldspar crystal (Plate 1-16-5) and ash tuffs with minor mudstone interbeds. These rocks are locally strongly foliated. This unit is well exposed on Mount Hyland and Lagopus Mountain, on the crest of the ridge south of Reiseter Creek, and in the Silver King basin. It has also been mapped in the Debenture Creek area.

Porphyritic Andesite (uKK2c)

Interbedded with, and in part overlying volcanic breccias and tuffs at the base of the lower division, are flows of coarse-grained hornblende feldspar porphyritic andesite. These flows have a fine-grained maroon matrix with euhedral feldspar phenocrysts up to 1 centimetre long (Plate 1-16-6). Hornblende phenocrysts are typically altered to chlorite or epidote. The flows are best exposed on Lagopus Mountain, on the east side of Mount Cronin and on Mount Hyland. It is difficult to determine if all of the feldspar-porphyritic rocks are flows; some may be intrusive.

Subvolcanic Intrusions (uKK2d)

The jagged peaks of Mount Cronin are comprised of sheet-jointed, massive, grey to maroon hornblende feldspar porphyritic andesite. These rocks are interpreted to be the subvolcanic intrusive core of a major stratovolcano. A belt of similar, coarsely porphyritic maroon andesite extends north from Mount Cronin and cuts volcaniclastic rocks of the lower division at a high angle. The contact is irregular, with fingers of porphyry extending outward into the adjacent wallrock. No contact metamorphism was observed. Hematitic streaks are common within the porphyry.

LATE CRETACEOUS TO TERTIARY SEDIMENTARY ROCKS (uKTs)

Northeast of Mount Cronin, a gentle syncline of well-bedded tuffaceous and argillaceous sedimentary rocks lies on top of coarse-grained intrusive feldspar porphyry. Examination of the contact indicates the feldspar porphyry was weathered prior to deposition of the sedimentary strata. This suggests the contact is an erosion surface and the sedimentary rocks were deposited directly on the porphyry. These sedimentary rocks are probably latest Cretaceous or early Tertiary in age. Both the porphyry and overlying sedimentary rocks have been offset and truncated by northeast-trending shear zones.

The sedimentary succession begins with interbedded tuffaceous siltstone and crystal tuff and grades up-section into interbedded dark grey argillite, siltstone and wacke with occasional light grey cherty bands. Chert fragments are common in overlying pebble conglomerate and wacke. In general the sequence appears to coarsen up-section.

INTRUSIVE ROCKS

Within the study area, three major groups of intrusions have been identified. These are rhyolitic (rh), dioritic (dr) and granitic (gr). The rhyolitic and dioritic intrusions occur as dykes and plugs cutting rocks that parallel the northwestern and eastern boundaries of the area of Late Cretaceous volcanic rocks. Rhyolite dykes also cut strongly foliated Late Cretaceous volcanic rocks west of Mount Cronin and north of Lagopus Mountain. These dykes are not foliated and therefore must postdate Late Cretaceous to Tertiary folding and shearing.

A swarm of granitic dykes is exposed on the steep east-facing slope of Mount Cronin and can be followed south toward Mount Hyland. These dykes are most abundant within the Late Cretaceous volcanic pile and particularly within subvolcanic intrusions of porphyritic andesite. They may be emanating from a granitic core at depth.

STRUCTURE

Structural trends in the study area are shown in Figure 1-16-4. The trends shown include bedding (S_0), slaty cleavage (S_1), a crenulation or fracture cleavage (S_2) and a late cleavage (S_3) related to northeast shearing. Minor fold axes and dyke trends are also shown. In general there is a swing from easterly to southeasterly trends going from northwest to southeast.

Four deformational phases are recognized. The earliest phase is related to a regional compressional tectonic event in the late Early Cretaceous that was accompanied by folding and uplift of much of the Smithers area. This was followed in Late Cretaceous and Early Tertiary time by extensional tectonics accompanied by block faulting and associated volcanism. The Late Cretaceous and Tertiary volcanic event was followed by compression and folding with reactivation of earlier high-angle faults and thrusting of subsided blocks over adjacent rocks. The latest event appears to be development of northeast-trending shear zones and offsetting of earlier structural trends.

The arcuate belt of inward-tilting fault blocks in the northern part of the study area may have been produced by explosive eruption and evacuation of magma chambers during the early stages of Late Cretaceous volcanism. Radiating normal faults occur in the northwestern part of the map area and may be part of a radial fault system centred on the area of collapse. Dykes of diorite and rhyolite that parallel the eastern and northwestern fault boundaries of subsided blocks of Late Cretaceous volcanics may have been emplaced along ring fractures.

Post-volcanic compression and folding is probably Tertiary in age and related to opposing motion on northwest-trending transcurrent fauls bounding the Babine Range — a transpressional tectonic regime. Compression in the area

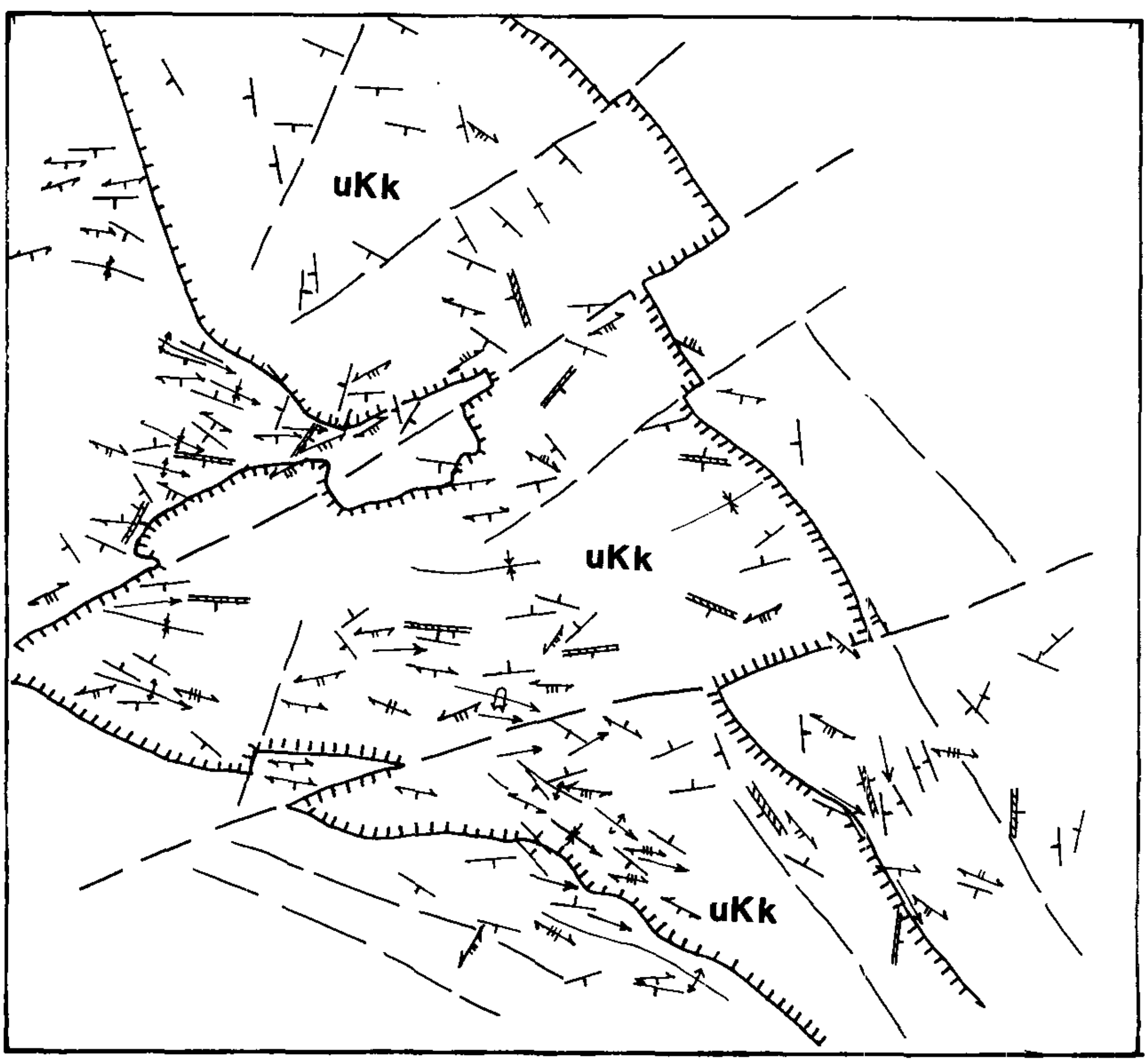

Figure 1-16-4. Structural trends in the Mount Cronin area. Hatched boundary is limit of Late Cretaceous volcanic rocks.

between the transcurrent faults resulted in squeezing upward of previously subsided fault blocks and thrusting of these fault blocks over adjacent areas. As folding and thrusting continued, northeast-trending shear zones were developed that offset the northwest-trending geology.

Incompetent sedimentary strata that are in fault contact with upward thrusted blocks of Cretaceous volcanic rocks are tightly folded with a well-developed penetrative cleavage Fold axes trend east to southeasterly with consistent plunges to the east or southeast. Change of fold axis trend appears to be related to movement and rotation along zones of northeast shearing. These folded rocks are cut by dykes that have not been deformed.

MINERAL DEPOSITS

Mineral deposits in the Babine Range can be subdivided into six groups. These are: (1) mesothermal gold-silver-bearing quartz veins; (2) copper-silver veins in mafic and felsic volcanic rocks; (3) copper-zinc-silver massive sulphide deposits associated with mafic flows; (4) polymetallic massive sulphide occurrences associated with rhyolitic volcanic rocks; (5) porphyry copper-molybdenum deposits associated with dioritic sills; and (6) porphyry copper-molybdenum deposits associated with quartz monzonite intrusions. Types 1 and 2 are present in the study area (Table 1-16-2).

COPPER-SILVER VEINS

RAINBOW (MINFILE 093L-132)

The Rainbow property is located between 1100 to 1400 metres elevation on the east side of Driftwood Creek, 8 kilometres northeast of Smithers. The Rainbow claims were first held by a Smithers syndicate of which G.R. Wright and H.J. Kelly were the principal members. Exploration and development work was reported in 1921. The Rainbow 1 and Rainbow 2 claims were optioned by F.H. Taylor of Smithers in 1925.

In 1987, Atna Resources Ltd. worked on the property. A crew set up a grid, soil sampled and did some geophysics. A trench exposing a quartz vein carrying chalcopyrite, tetrahedrite, azurite and malachite in amygdaloidal basalt of the Nilkitkwa Formation was visited. Adjacent to the quartz vein the basalt is a light green colour with stretched out chlorite blebs and limonite and epidote alteration. Chlorite occurs along fractures that have slickensides.

MESOTHERMAL QUARTZ VEINS

SILVER KING BASIN (MINFILE 093L-201)

The Silver King prospect is located at the head of Driftwood Creek in the Silver King basin. Prior to 1917, this prospect was owned by P.J. Higgins of Spokane. The property was optioned to the Goldfield Consolidated Co. in 1917. Workings at that time included a 30-metre adit. Drifting was continued in the 1920s and 1930s; 6.35 tonnes of sorted ore was shipped.

George Hanson first mapped the Silver King claim in 1924. Remapping by Tipper and Richards (1976) showed the area to be underlain by varicoloured porphyritic tuff, breccia and flows of the Brian Boru Formation (Kasalka Group). The mineralization is therefore Late Cretaceous or younger in age.

Mineralized quartz veins occur in shear zones within the Late Cretaceous volcanic succession. The shear zones strike easterly and dip 45 to 70 degrees north. The veins occur as discontinuous stringers and lenticular masses of shattered quartz ranging in width from 2.5 centimetres to 1.8 metres and containing variable amounts of galena, tetrahedrite, chalcopyrite, pyrite, sphalerite, and a little native copper and silver. Similar mineralization is found in two prospect adits about 370 metres southeast from the main workings.

Rocks within the mineralized area are altered to chlorite and carbonate and contain disseminated pyrite. Adjacent to the vein these rocks are silicified.

HYLAND BASIN (MINFILE 093L-128)

The property is located at the 1735-metre elevation at the head of Cronin Creek and is accessible by road from the Cronin mine.

Martin Cane and Tom King held the Hyland Basin claim group from about 1922. The property was optioned by a Mr. Duthie in the fall of 1923 and an adit was driven for 58 metres along the projected strike of the veins. Various owners did trenching on the property in the 1930s and 1940s. Two lots of sorted ore were shipped to the Department of Mines sample plant at Prince Rupert in 1940. American Yellowknife Gold Mines Ltd. did some mapping and trenching in 1951.

Near the showings, rhyolite dykes intrude argillite, argillaceous quartzite, limestone and tuffs of probable Jurassic age. Some dykes follow shearing of the country rock. Quartz veins are associated with the rhyolite dykes which strike easterly, parallel to shearing or slaty cleavage in the argillites.

TABLE 1-16-2
MINERAL OCCURRENCES

Map No.	Minfile	Occurrence	Commodities	Type of Deposit	Map Unit	Attitude	Comments
1	132	RAINBOW	Cu,Ag	VEIN	lJN	VARIES	Lenticular quartz veins
2	201	SILVER KING BASIN	Pb,Cu,Zn,Ag	QUARTZ VEINS	uKK2b	EAST/45°-70°N	Irregular in attitude
3	128	HYLAND BASIN	Pb,Cu,Zn,Ag	QUARTZ VEINS	uKK2a	EASTERLY	Lenticular quartz veins
4	126	LORRAINE	Pb,Zn,Cu,Ag	QUARTZ VEIN	muJA	SOUTH/70° W	Quartz stringers
5	140	DEBENTURE	Pb,Ag?	QUARTZ VEIN	lJT	120°/55°NE	Bands of galena
6	127	CRONIN	Ag,Pb,Zn,Cu	QUARTZ STOCKWORK	muJA	NE/NW	Fault zones carry mineral

The quartz veins vary from barren to well mineralized with galena, tetrahedrite and a little sphalerite and chalcopyrite. Grab samples were taken from these showings and are being analysed.

LORRAINE (VICTORIA) (MINFILE 093L-129)

The property is located at the 1550-metre elevation at the head of Higgins Creek, 27 kilometres northeast of Smithers. The Victoria claim was first owned by P.J. Higgins of Spokane. A 43-metre adit and three shafts were completed between 1916 to 1918. H.L. Messner optioned the property in 1926 and formed Lorraine Copper Silver Mines Limited to conduct underground exploration on the property.

B.F. Messner was the owner of the Lorraine Group in 1946. American Yellowknife Gold Mines Ltd. optioned the property in 1951 and carried out geologial mapping, stripping, sampling, and some diamond drilling. Native Mines Limited was incorporated in 1964 and acquired the property as the Silver Queen, New Strike and Extension group. It completed an electromagnetic survey, surface stripping, surface diamond drilling and 240 metres of underground development in 1965 and 1966.

Folded, dark grey to orange-weathering phyllite underlies the Lorraine property and is cut by rhyolite, diorite and andesite dykes. Quartz stringers parallel the slaty cleavage and have been folded and dismembered. An orange-weathering massive andesite dyke cuts the phyllite and is post-tectonic. "M"-style folding and undulating slaty cleavage are common in the phyllites. Orange-weathering siltstone and less foliated massive green fragmental tuff overlie the phyllites. Thick-bedded greenish grey-weathering ash-flow tuffs which contain flow-banded rhyolite overlie the orange-weathering siltstone.

The Main vein is a bedded quartz lode in contorted argillaceous phyllite. The lode pinches and swells irregularly and probably averages about 45 centimetres in width. It is sparsely mineralized with disseminated pyrite, galena, sphalerite, chalcopyrite and occasional grains of tetrahedrite. Grab samples from this area were sent to the Geological Survey Branch analytical laboratory for assay.

The West vein consists of two parallel quartz stringer zones separated by about 50 centimetres of sheared argillite and gouge. It strikes south and dips 70 degrees to the west. The hangingwall is a rhyolite dyke and the footwall is argillite. The quartz stringers contain sparsely disseminated pyrite and base metal sulphide.

DEBENTURE (MINFILE 093L-140)

The Debenture showing is located at the 1450-metre elevation on the south side of Debenture Creek, 29 kilometres northeast of Smithers. In 1916, Debenture Creek Mines Ltd. drove a crosscut adit 116 metres on the 1430-metre level and intersected the No. 2 vein at 99 metres. In 1964, Native Mines Limited acquired the Debenture property and drove a new adit about 30 metres. In 1966, Wanda Mines and Exploration Ltd. acquired the property and did some sampling.

A diorite sill or dyke, approximately 6 metres thick, is exposed about 61 metres below the adit. This intrusion cuts chlorite-epidote-altered lapilli tuffs of probable Late Cretaceous age that dip 40 to 45 degrees southwest. The main showing is a segmented, contorted quartz vein with variable amounts of galena, that strikes northwest and dips northeast. The vein occurs within a rusty zone of partly sericitized, silicified and sheared volcanic rock. Stringers of galena with minor pyrite occur in silicified andesite tuffs. Grab samples have been submitted to the Geological Survey Branch laboratory for assay.

CRONIN (MINFILE 093L-127)

The Cronin mine is on the east flanks of Mount Cronin, approximately 28 kilometres northeast of Smithers. The property is accessible by a rough road that connects with the Babine Lake road just east of McKendrick Pass.

The property was first staked in 1906. In 1909, James Cronin acquired the claims and completed 122 metres of underground workings prior to 1910. The mine reopened in 1914 and development work was carried on each summer until 1923. Between 1928 and 1931, Babine Bonanza Metals Limited completed additional crosscuts and raises. Cronin Babine Mines Ltd., incorporated in 1948, drilled on surface (five holes totalling 387 metres) and underground (11 holes totalling 407 metres). Nothing further was reported until 1951 when the workings were reopened and mill construction began. The 40 tonne-per-day mill was in operation in 1952 and from 1956 to 1957. From 1962 to 1972, Kindrat Mines Ltd. carried out small-scale intermittent mining on the property. Hallmark Resources Ltd. acquired Kindrat Mines in 1972 and completed 75 metres of drifting and raising, geological mapping and a geochemical soil survey. In 1974 drifting and stope preparation were carried out on No. 2 vein and the mill operated from July to August. Coca Minerals Ltd. optioned the property in 1975 and drilled 10 surface diamond-drill holes into the Wardell zone, identifying a small high-grade body of mineralization. Goldsil Mining and Milling Inc. optioned the property in 1983 and completed extensive underground sampling and some surface diamond drilling. This work confirmed and improved the previously known reserves. Drill-indicated reserves are 317 000 tonnes grading 1.7 grams per tonne gold, 354.4 grams per tonne silver, 8.0 per cent lead and 8.0 per cent zinc (as indicated in MINFILE). In 1987 Southern Gold Resources Ltd. acquired an option on the property and, with financial support from the FAME program, did geologic mapping and sampling over the main area of interest.

The Cronin showings occur within a northeast-trending zone that cuts through a rhyolite plug or dome into sericite schist, dark grey to black argillite, quartzose sandstone, greywacke and chert-pebble conglomerate of the Ashman Formation. These rocks are in fault contact with Late Cretaceous volcanic rocks of the Kasalka Group immediately west of the showings. Diorite dykes also outcrop in the vicinity of the showings and are probably members of a series of such dykes that parallel the Kasalka Group – Ashman Formation fault boundary. Rocks near the rhyolite bodies are intensely sericitized and foliated. Foliation may have been superimposed on these rocks by overthrusting of Late Cretaceous volcanics from the west and by movement along a major northeast-trending shear zone that trends up Cronin Creek and into Silver King basin. Northwest of the showings, the lower division of the Late Cretaceous volcanic succession strikes northeasterly and dips steeply to the northwest. It is comprised of varicoloured porphyritic tuffs, breccias and flows with unaltered feldspar phenocrysts. These rocks, like older Ashman rocks to the east near the main showings, are cut by rhyolite dykes, indicating the dykes must postdate Late Cretaceous volcanism. If the rhyolite plug hosting the mineralization at Cronin is the same age as these dykes, then mineralization must also be post-Late Cretaceous, perhaps Tertiary.

Schroeter (1975) distinguishes two phases of rhyolite intrusions at Cronin. One is a grey rhyolite porphyry that is massive, medium to fine grained with 20 to 40 per cent albite laths 1 to 3 millimetres in length in an aphanitic groundmass of quartz, calcite, sericite, zoisite and chloritoid. There is no appreciable chilled margin where this unit is in contact with the sedimentary rocks. A quartz stockwork cuts the rhyolite porphyry and has been truncated by a younger rhyolite porphyry phase. This younger phase is host to a second generation of quartz veins. Quartz veinlets average 4 to 20 millimetres in width and carry variable amounts of sphalerite and galena.

A strongly sericitized, white to pale yellow rhyolite cuts the early rhyolite porphyry phases (Schroeter, 1975). This intrusion is mostly aphanitic, but locally contains up to 15 per cent quartz phenocrysts. Very fine-grained quartz, "sericite" and calcite make up the bulk of the rock. Pyrite, sphalerite and galena occur on dry fractures rather than in a quartz stockwork (Schroeter, 1975). Both rhyolitic units have undergone low-grade regional metamorphism.

The main exploration targets at Cronin are massive sulphide and quartz veins that contain argentiferous galena and sphalerite with relatively minor pyrite and chalcopyrite. Boulangerite, freibergite and arsenopyrite have also been identified. The sulphide minerals also occur in breccia zones and as fracture fillings in the rhyolite with little quartz. Massive quartz veins are up to 0.6 metre thick, strike northeast and dip 45 to 65 degrees to the northwest. One major quartz vein containing pockets of massive high-grade mineralization has been traced over a length of 75 metres.

On surface the Wardell vein, a heavily mineralized breccia, crosscuts the dominant lithological trend at approximately 90 degrees. Numerous other quartz and quartz-sulphide veins are oriented in a variety of directions in a coarse stockwork pattern.

PYRITIC GOSSANS

Prominent gossans occur within the area of Late Cretaceous volcanic rocks, particularly west of the Silver King

TABLE 1-16-3
ASSAY DATA

Sample No.	Easting Northing	Location	Minerals	Au ppb	Ag ppm	Cu ppm	Pb ppm	Zn ppm	Ni ppm
DM87 52 1	634435 6093371	DEBENTURE CK.	gossan, diss py	<20	0.5	23	12	50	24
DM87 71 1	636271 6091672	EAST OF MT. CRONIN	quartz-carb exhalite	40	0.8	9	5	20	2
DM87 80 1	638332 6089968	EAST OF MT. CRONIN	malachite, azurite in quartz	650	420.0	2200	8	107	3
DM87 92 1	637657 6086782	HYLAND BASIN	rusty phyllite	<20	0.5	17	8	112	4
DM87 93 1	633948 6089968	EAST OF LAGOPUS MT.	bleached sericite py	<20	0.5	13	42	113	5
DM87 94 1	633934 6085553	EAST OF LAGOPUS MT.	gossan	<20	0.5	9	12	72	2
DM87 99 1	632735 6086206	EAST OF LAGOPUS MT.	gossan bleached	<20	0.5	2	8	4	2
PD87 270 1	637231 6084602	MT. HYLAND	malachite	80	0.4	210	7	10	7
PD87 277 1	636545 6083910	MT. HYLAND	altered andesite	<20	0.4	15	10	66	3
PD87 282 1	634821 6086702	NW OF DRIFTWOOD CK.	altered andesite	<20	0.4	27	13	17	0
PD87 284 1	634668 6086694	NW OF DRIFTWOOD CK.	gossan, diss py	50	0.4	13	17	24	4
PD87 287 1	634426 6087614	NW OF DRIFTWOOD CK.	gossan, diss py	<20	0.5	17	22	33	5
PD87 290 1	634238 6087860	NW OF DRIFTWOOD CK.	gossan, diss py	130	0.4	8	18	69	5
PD87 330 2	634254 6094783	WEST OF DEBENTURE CK.	gossan, diss py	<20	0.5	0	37	99	8
PD87 331 1	634317 6094816	WEST OF DEBENTURE CK.	altered andesite	90	0.5	28	56	85	19
PD87 353 1	635984 6094491	DEBENTURE SHOWING	quartz vein	200	33.0	27	12000	*	8
PD87 353 2	635984 6094491	DEBENTURE SHOWING	quartz vein	<20	100.0	217	*	*	4
PD87 353 3	635984 6094491	DEBENTURE SHOWING	quartz vein	<20	140.0	117	*	*	12
PD87 353 4	635984 6094491	DEBENTURE SHOWING	quartz vein	<20	0.5	34	45	210	18
PD87 353 6	635984 6094491	DEBENTURE SHOWING	quartz vein	<20	480.0	280	*	*	10
PD87 372 4	637084 6090317	NORTH OF MT. CRONIN	gossan	<20	0.5	32	13	150	28
PD87 372 6	637096 6090394	NORTH OF MT. CRONIN	gossan	<20	0.5	24	15	64	14
PD87 376 4	637379 6090773	NORTH OF MT. CRONIN	cp,py,malachite	<20	4.0	3600	758	557	420
PD87 383 2	637668 6088342	MT. CRONIN	limonitic qtz.	<20	0.6	8	13	62	9
PD87 385 1	638217 6088304	MT. CRONIN	rhyolite	<20	0.7	6	15	66	0
PD87 388 1	639065 6088218	MT. CRONIN	gossam sericitic	<20	3.0	106	123	335	42
PD87 388 2	639065 6088218	EAST OF LAGOPUS MT.	limonitic	90	0.5	3	8	32	2
PD87 392 1	639240 6088584	MT. CRONIN	malachite	370	420.0	2500	*	*	5
PD87 400 2	639779 6088227	MT. CRONIN	7% sulphides	520	310.0	70	*	107	2
PD87 401 1	640053 6088205	MT. CRONIN	quartz with gl.	2300	14.0	13	*	142	6
PD87 402 1	633715 6088009	EAST OF LAGOPUS MT.	gossan, diss py	<20	2.0	20	93	38	9
PD87 430 2	633936 6087795	EAST OF LAGOPUS MT.	altered ands. dis py	<20	0.8	13	62	47	26
PD87 403 3	633393 6087795	EAST OF LAGOPUS MT.	quartz	<20	0.5	2	12	12	7
PD87 404 1	633214 6083214	EAST OF LAGOPUS MT.	gossan, py	<20	0.6	15	33	63	63
PD87 405 2	633118 6087805	EAST OF LAGOPUS MT.	quartz	<20	0.5	2	10	3	2
PD87 409 1	632768 6087805	EAST OF LAGOPUS MT.	gossan, py	<20	0.5	9	10	90	44
PD87 410 1	632642 6087111	EAST OF LAGOPUS MT.	altered ands py	<20	0.5	20	12	112	34
PD87 411 1	632430 6086713	EAST OF LAGOPUS MT.	gossan	<20	0.5	15	12	22	6
PD87 412 1	632312 6086482	EAST OF LAGOPUS MT.	altered basalt	<20	0.5	11	15	56	5
PD87 413 1	632212 6086303	EAST OF LAGOPUS MT.	gossan, sericite	<20	0.5	10	12	214	30
PD87 413 2	632212 6086303	EAST OF LAGOPUS MT.	quartz	<20	0.5	10	12	214	30

* = very high grade

basin and in the valley north of Lagopus Mountain (Figure 1-16-2). Rocks within these gossan zones are typically strongly foliated, sericitized and bleached. Disseminated pyrite occurs throughout them; locally there is silicification, quartz veining and brecciation. All of the gossans in the map area were sampled (Table 1-16-3).

The gossans appear to be related to post-Late Cretaceous shear zones. One exception may be the gossan near the head of the cirque valley northwest of Silver King basin which appears to parallel the contact of a subvolcanic intrusion of porphyritic andesite.

A gossan with approximately 3 per cent disseminated chalcopyrite, pyrite and malachite in strongly foliated and sheared volcanics occurs in Taka Creek, approximately 2 kilometres north of Mount Cronin. Together with several others to the southeast, it occurs along a major northeast-trending shear zone that offsets Late Cretaceous to Tertiary volcanic and sedimentary rocks.

Quartz Veins

Barren quartz veins are common within the study area, particularly near major fault zones. These veins are both pre and post-shearing.

On the ridge west of Mount Hyland, a quartz vein 10 to 20 centimetres wide cuts sheared Late Cretaceous volcanic rocks. It pinches and swells within the shear zone and carries minor malachite and possibly tetrahedrite. A grab sample of vein material contained slightly anomalous (80 ppb) concentrations of gold.

On the ridge north of Lagopus Mountain, a rhyolite plug or dome cuts Cretaceous sedimentary rocks. Numerous subhorizontal barren quartz veins, some up to 2 metres thick, occur within the plug but do not appear to extend into adjacent wallrock. Only background gold concentrations were detected in samples submitted for assay.

A northwest-trending quartz vein cuts Late Cretaceous porphyritic andesite 2 kilometres northwest of the Cronin Mine. A sample of malachite-stained quartz from a small pit along the vein contained 600 ppb gold.

Siliceous Zones

A zone of silicified volcanic and sedimentary rocks extends for 4000 metres along the west slope of the plateau north of Mount Cronin. Strata in this area trend northwest and dip moderately southwest. East of the silicified zone are well-bedded Late Cretaceous to Tertiary sedimentary rocks (uKTs). West of the silicified zone are maroon lapilli tuffs which we believe are part of the lower division of the Kasalka Group. The apparent stratigraphic offset across the silicified zone suggests it follows a major fault zone. Samples of silicified rock have been submitted for assay but results are not yet available. There is little or no sulphide mineralization associated with the silicification but streaks of manganese oxide are common. If our interpretation is correct, this fault zone was the site of extensive hydrothermal activity and may be a favourable target for epithermal mineralization.

ACKNOWLEDGMENTS

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SUMMARY OF FIELDWORK IN THE INGENIKA RANGE, NORTH-CENTRAL BRITISH COLUMBIA (94D/09; 94C/12)

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KEYWORDS: Regional geology, stratigraphy, Ingenika Range, Takla Group, Savage Mountain Formation, Ingenika Group, Swannell Formation.

INTRODUCTION

This report summarizes field data collected during 1987 in the Ingenika Range, north-central British Columbia. Fieldwork was conducted in rocks of the Takla Group and Ingenika Group. Each will be discussed separately.

TAKLA GROUP

The study area for the Takla Group is northwest of Johanson Lake, in the southwestern corner of the Ingenika Range (94D/09, Johanson Lake). Rocks of this area belong to the Upper Triassic Takla Group (Monger, 1977). Monger examined Takla rocks in the area of McConnell Creek and published a map at a scale of 1:125 000.

GENERAL GEOLOGY

The general geology of the study area is shown in Figure 1-17-1. Exposure is excellent along most ridge faces. Contour lines (20-metre intervals) are omitted along ridge crests to allow for clearer representation of the geology. Correlation across valleys is difficult because of the absence of marker beds. Although the region is cut by several northwest-striking high-angle faults, bedding has broadly consistent attitudes throughout.

STRATIGRAPHY

Rocks of the Takla Group are volcaniclastic, sedimentary and volcanic. The stratigraphic succession consists of approximately 2300 metres of interlayered breccias, tuffs and siltstones. Demonstrable lava flows were not identified.

The conformable succession (Figure 1-17-2), although interlayered and repetitive, may be divided into several units

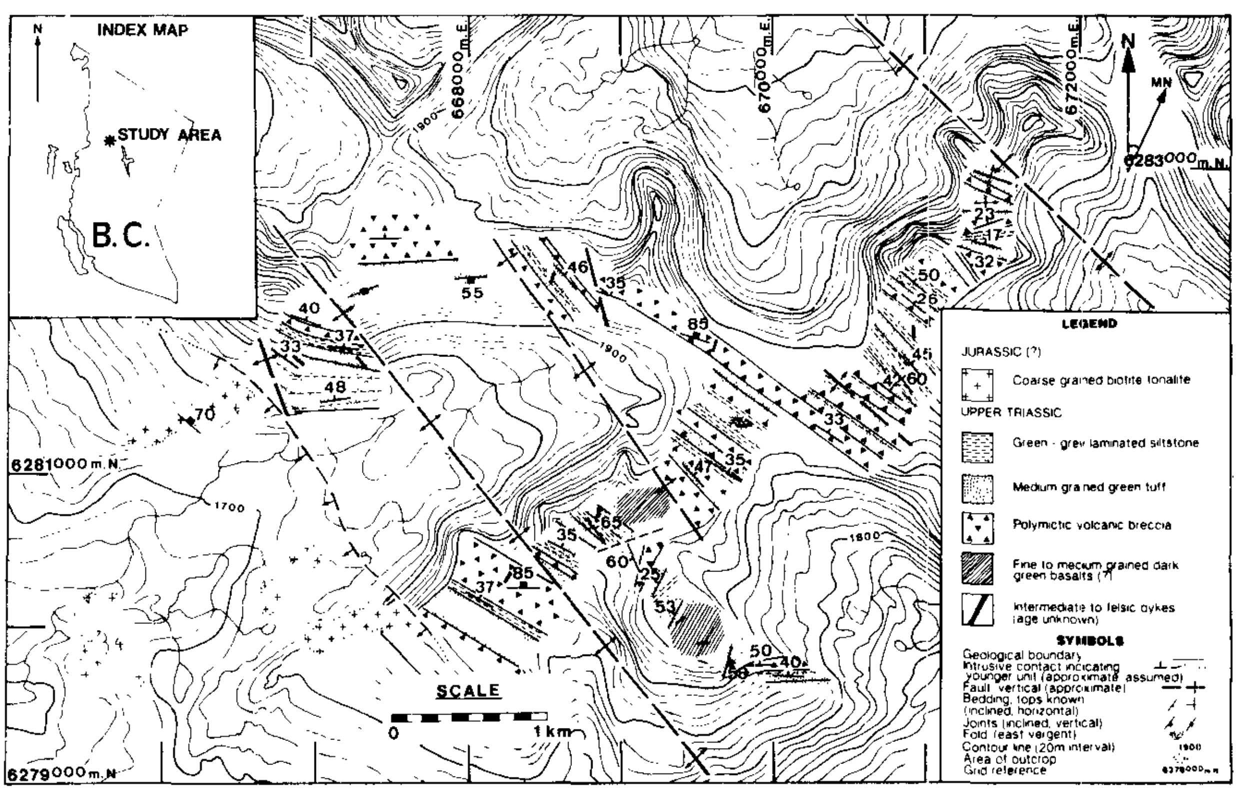

Figure 1-17-1. General geology of Takla Group rocks north of Johanson Lake.

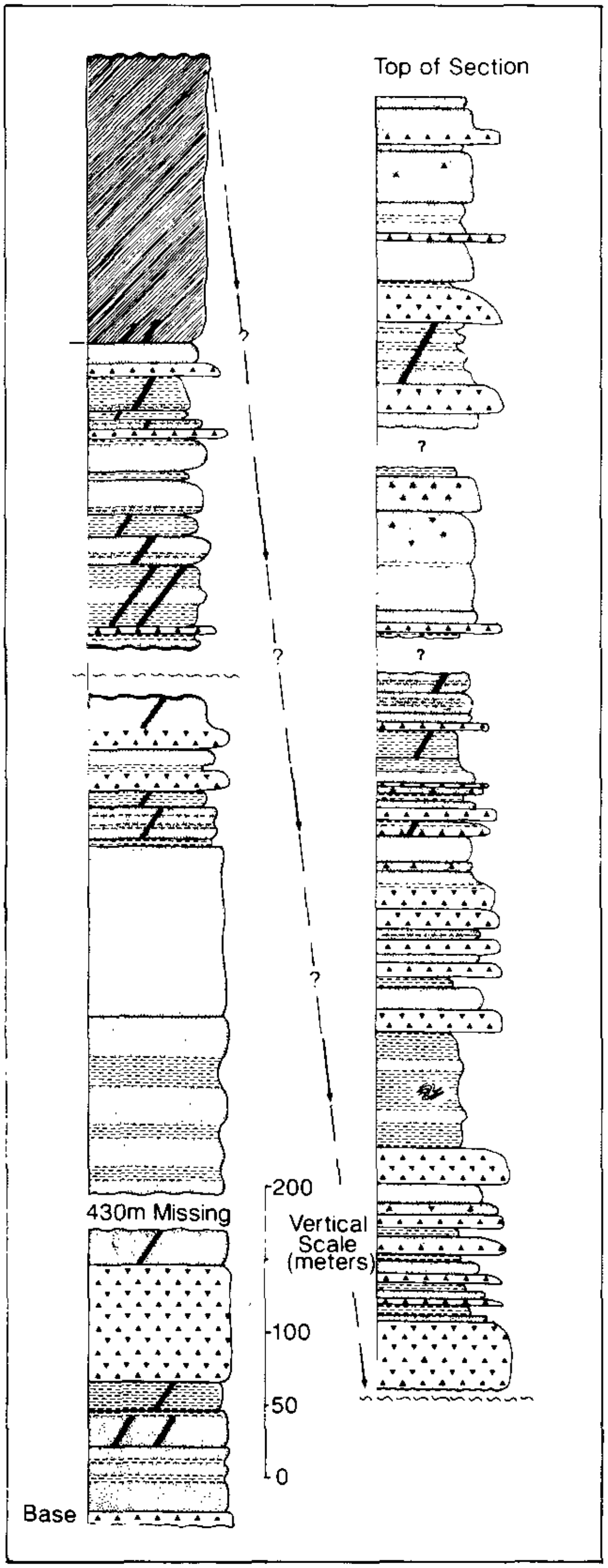

Figure 1-17-2. Generalized stratigraphic column of approximately 2300 metres of Takla rocks in a northeast transect across the area. The top of the section is bounded by a high-angle northwest-striking fault, while the base of the section is terminated by a tonalitic intrusion. Correlation across faults is highly speculative. Lithology symbols as in legend of Figure 1-17-1.

based on the occurrence of volcanic breccias and the fining upwards of sediments above them. A typical unit has a base of green volcanic breccia, of mafic to intermediate composition, that commonly contains phenocrysts of amphibole and plagioclase up to 2.5 centimetres long. Breccia fragments are subrounded to subangular and are both sedimentary and volcanic in origin. Sedimentary fragments include buff-coloured carbonate and fine-grained green siltstones that may be internally laminated. Volcanic fragments appear to be intermediate in composition. Many contain plagioclase phenocrysts up to 0.5 centimetre long and have a typical brown-green-weathered surface. Fragments of the fine-grained green volcanic matrix of the breccia are also present, indicating internal brecciation during flow. Fragment sizes range from a few centimetres to 45 centimetres in diameter, with the majority being less than 10 centimetres. The breccia units vary from 5 to 80 metres in thickness and although the breccias do not appear bedded, they frequently show rough grading from base to top.

The volcanic breccias commonly grade into sand-sized green tuffs, which display apparent igneous textures in outcrop. The tuffs may show excellent bedding with upward-facing graded beds, or they may exhibit little variation in grain size or be entirely devoid of phenocrysts. These tuffaceous layers range in thickness from several centimetres to 115 metres, and pass upwards into demonstrable clastic sediments with graded beds and sedimentary laminations.

The sedimentary units are dominated by very fine-grained, green, well-laminated siltstones with stratigraphic thicknesses of up to 30 metres. Minor carbonaceous sandstone beds, 1 to 30 centimetres thick, occur rarely with siltstone layers. The siltstones commonly exhibit rusty weathering due to the presence of pyrite, which in some areas defines bedding. Although sulphides are concentrated in sedimentary layers, minor pyrite is present in most of the rocks.

INTRUSIVE ROCKS

The strata are cut by abundant intermediate to felsic dykes and sills, typically 1 to 3 metres wide. Intermediate dykes are commonly green or grey amphibole and plagioclase porphyries. The grey to buff-coloured felsic dykes may contain amphibole needles, biotite blobs and quartz eyes. Dyke attitudes are highly variable, but there are several with the same attitude as a prominent fracture set.

Massive mafic igneous rocks in the middle of the stratigraphic section are green in colour, and contain small amphibole and plagioclase phenocrysts. Grain sizes increase from fine to medium grained away from the inferred contacts, which are faulted in several cases. Intrusive relationships are not apparent and there is no compelling evidence for flow origin. These mafic bodies may be fine-grained gabbroic sills or basaltic flows.

A coarse-grained, biotite-rich, tonalitic pluton outcrops in the westernmost part of the map area. Intrusive relationships are evident in local host rocks. However, the contact is highly fractured and epidote rich, indicating reactivation by fault movements. Jurassic to Tertiary granitic plutonism has been extensive in Takla rocks (Monger, 1977). It is likely that the tonalitic intrusion is of a similar age.

DEFORMATION

Rocks of the Takla Group are cut by several major northwest-striking vertical faults. Rocks in these fault zones are highly fractured, contain epidote and quartz veining, and sometimes have a vertical shear-fabric developed parallel to the fault. Lithology and bedding remain relatively consistent across these boundaries.

Fracturing is extensive. Although there is a wide range of attitudes, a fairly consistent set of fractures has an average orientation of 015°/55° southeast. Two small folds with easterly vergence are present in siltstone layers in the central part of the map area.

INTERPRETATION

The Takla assemblage in the study area is indicative of formation in a submarine environment. The green colour and pyroclastic nature of the rocks characterize them as Lower Takla Group (Lord, 1948). Monger and Church (1977) divided the Lower Takla into the lower Dewar Formation dominated by tuffs and volcaniclastic sediments, and the upper (and sometimes time equivalent) Savage Mountain Formation dominated by flows. The base of the Savage Mountain Formation is defined by the first appearance of volcanic breccia. The study rocks are assigned to the Savage Mountain Formation based on this criterion.

Monger (1977) suggests that a volcanic centre near Sustut Peak could account for the 3000 metres of Savage Mountain stratigraphy in which flows predominate over volcaniclastics. It is likely that the study rocks represent a distal facies of the Upper Triassic volcanism that occurred in this area.

The thick breccia-based units of the Savage Mountain Formation probably represent submarine flows containing phenocrysts, that underwent autobrecciation and incorporated other volcanic fragments from pyroclastic sources as they moved along the seafloor. The ambient sedimentation reflected in the tuffaceous and sedimentary horizons may have been predominantly epiclastic. The depositional environment of these rocks was clearly close to a major active volcanic region.

Follow-up work will include detailed microscopic examination to determine the exact character of the Takla rocks, as well as geochemical analysis of some of the flow units, tuffaceous units and dykes.

INGENIKA GROUP

Fieldwork in the Ingenika Group was conducted in the Ingenika Range 24 kilometres north of Aiken Lake, in the area of Cutbank Creek (94C/12, Orion Creek). Rocks in this region belong to the Upper Proterozic Swannell Formation (Mansy and Gabrielse, 1978). Although previous work has resulted in subdivision of the Swannell Formation into discrete units (Mansy, 1986), we have found subdivision in the area of Cutbank Creek to be difficult, as there are no marker beds. The Swannell Formation consists of monotonous sequences of mica schist (muscovite ± biotite), garnet mica schist (garnet + muscovite ± biotite), quartzose schist (quartz + muscovite ± garnet ± biotite) and metaquartzite (± muscovite ± biotite). These rock types are interbedded and have both gradational and sharp contacts. Graded quartzose beds consistently show upward-facing younging directions. Individual beds range in thickness from 50 centimetres to tens of metres.

DEFORMATION

The polyphase deformational history of the area begins with southwest-closing recumbent (F_1) folds with northwest-trending fold axes. These folds are recognized only in relatively competent quartzose units. Local facing data support southwesterly vergences for the folds. F_1 folds have an axial-planar schistosity and garnet growth was associated with D_1 deformation. The S_1 schistosity was later crenulated about northwest-trending axes. This crenulation event was associated with the growth of well-developed rolled garnets that show westerly vergence, and a strong crenulation lineation. Numerous late-stage southwest-vergent tight folds were observed folding the crenulated S_1 schistosity in quartzose units. West-directed thrusting associated with D_1 deformation is evident near Orion Creek.

Mesoscopic northeast-vergent F_2 folds have the same northwest axial attitudes as F_1 folds and crenulations. D_2 garnet was observed overgrowing mylonitic fabrics in a D thrust.

A later, regional-scale deformation has been documented by Mansy (1986) and involves the development of a metamorphic antiform around a northwest-trending axis. Schistosity and fracture data indicate cylindrical folding about this axis (Figure 1-17-3).

Subsequent research will involve detailed microscopic and microprobe examination to determine the complex rela-

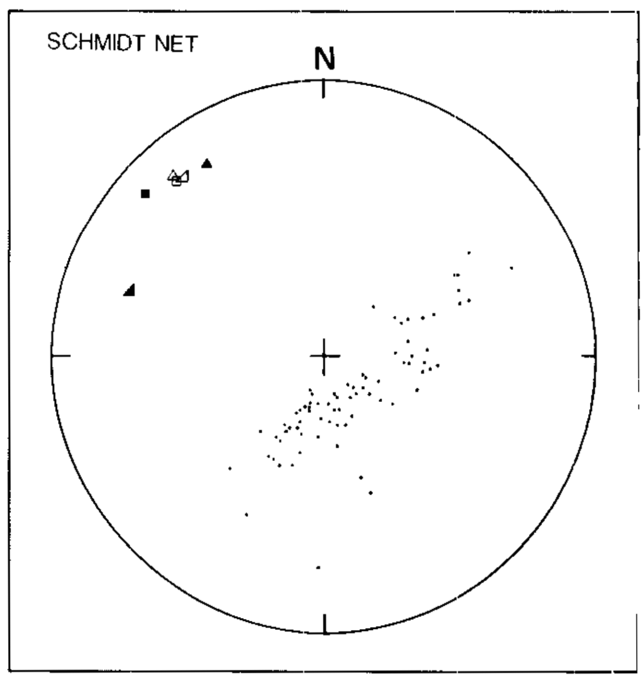

Figure 1-17-3. Stereonet plot of structural data from Swannell Formation. Symbols: □, average fold axis of southwest-vergent F_1 recumbent folds; •, poles to schistosities; ▲, average fold axis of tight southwest-vergent late F_1 folds; ◿, average crenulation lineation; ■, average fold axis of northeast-vergent F_2 folds; △, fold axis of major anticline; ◢, fold axis of fractures.

tionships between the deformation and metamorphism of the area.

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SULPHURETS MAP AREA (104A/05W, 12W; 104B/08E, 09E)

By J. M. Britton and D. J. Alldrick

KEYWORDS: Regional geology, Sulphurets, Hazelton Group, island arc, porphyry copper-molybdenum, epithermal veins, gold, silver, Stikinia.

INTRODUCTION

This paper summarizes preliminary results of the Sulphurets project based on fieldwork from July 23 to September 15, 1987. The Sulphurets map sheet covers 1000 square kilometres roughly centred on Brucejack Lake, 60 kilometres north-northwest of Stewart (Figure 1-18-1). The area is under active exploration for precious metals. New mine developments are underway at Brucejack Lake West zone (Newhawk Gold Mines Ltd.) and at the Goldwedge deposit (Catear Resources Ltd.). A 2-year mapping project begun this year has the following objectives:

- Produce 1:50 000 and 1:20 000-scale geology maps.
- Establish a regional stratigraphic column.
- Examine mineral deposits and major mineral occurrences.
- Expand and update the ministry's mineral inventory file (MINFILE).
- Collect samples for assay, platinum group element and whole-rock analyses, dating and fossil studies.

The project is part of a long-term study of the geology and mineral deposits of the Iskut district in the Southern Boundary Ranges. Ultimately mapping will cover 3500 square kilometres, extending from Bowser Valley west to Jekill River and from Iskut River south to the United States border (Figure 1-18-1). Sulphurets map sheet adjoins the recently released Salmon River sheet (Alldrick, 1987).

Access to the area is by helicopter from Stewart or the Tide Lake airstrip. A tractor road and barge link with Highway 37 is under construction (Figure 1-18-1).

EXPLORATION HISTORY

The Unuk River and its tributaries, including Sulphurets Creek, have been known as a source of placer gold since the 1880s (Wright, 1907). Placer gold was worked on Sulphurets Creek as early as 1895 but no production records are available. Modest work on gold-silver-lead veins was reported in the early 1900s but, from 1904 until the advent of helicopters in the 1950s, the area received scant attention. Prospectors penetrated this remote region to discover large gossans in the vicinity of Treaty Glacier in 1929, lead-zinc-copper deposits at Tom MacKay Lake in 1932, and broad areas of disseminated copper mineralization between Mitchell and Sulphurets creeks in 1935.

The discovery of the Granduc deposit in 1953 renewed interest in exploration for massive and disseminated base metal deposits. Regional geological, geophysical and geochemical surveys conducted by Granduc Mines Limited and Newmont Mines Ltd. from 1960 to 1975 resulted in the discovery of numerous copper, molybdenum, lead, zinc, gold and silver showings. The main copper-molybdenum prospects were tested by drilling. Exploration activity in the area peaked again during the molybdenum boom of the late 1970s. Since 1980 interest in precious metals has brought exploration activity to unprecedented levels resulting in discoveries of both low-grade, high-tonnage disseminated deposits and high-grade vein deposits of gold and silver.

PREVIOUS AND CURRENT WORK

Earliest geological coverage of part of the present map area was published by the Geological Survey of Canada in 1957 as part of "Operation Stikine" (1:250 000). R.V. Kirkham (1963) completed an M.Sc. thesis that included mapping the area between Brucejack Lake and Mitchell Glacier (1:12 000). E.W. Grove (1971, 1986) mapped the entire area (1:100 000) between 1964 and 1970, incorporating the regional geological mapping (1:25 000) conducted by Newmont Mines Ltd. between 1960 and 1964. More recent thesis studies in the area include work by Egan (1981), Simpson (1983) and Gunning (1986). Other sources of data include the ministry's annual reports, property file and assessment reports. A series of unpublished geological reports and detailed maps by Esso Minerals Canada Ltd. cover the area between Brucejack Lake and the Mitchell Glacier (Bridge *et al.*, 1981; Bridge and Melnyk, 1982, 1983; Britten, 1983; Lomenda, 1983; Melnyk, 1983).

Current research includes a lithogeochemical study of the large alteration zones within the Sulphurets map area by S.B. Ballantyne, D.C. Harris and R.V. Kirkham of the Geological Survey of Canada, Ottawa. The joint federal/provincial Regional Geochemical Survey sampling program completed coverage of NTS 104B this year. R.G. Anderson at the Geological Survey of Canada, Vancouver, is presently mapping the entire Iskut River map sheet (104B) at 1:250 000.

To the west of the Sulphurets map sheet, D.V. Lefebure and M.H. Gunning of the British Columbia Geological Survey Branch, Smithers, mapped 140 square kilometres in the Bronson Creek area (104B/10, 11) at 1:25 000 scale (Figure 1-18-1). Mineral properties within this map area include the Reg (Mount Johnny), Snip, Inel and Gossan prospects.

Traverse data for the Sulphurets project were recorded on 1:10 000 airphoto enlargements and then compiled on 1:20 000 and 1:50 000 base maps.

GEOLOGICAL SETTING

Sulphurets map area is situated in the rugged Boundary Ranges of the Coast Mountains physiographic belt. It lies

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

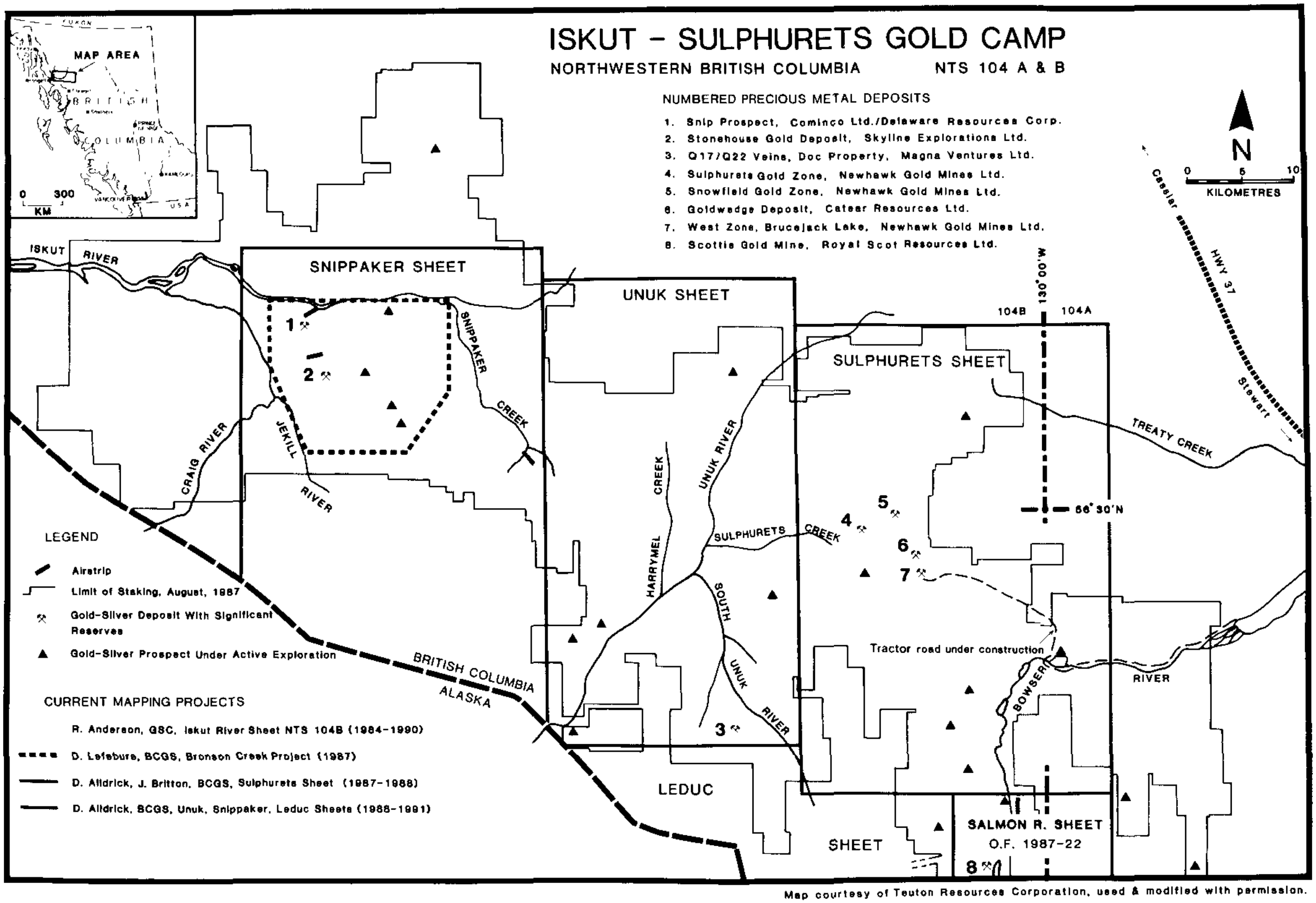
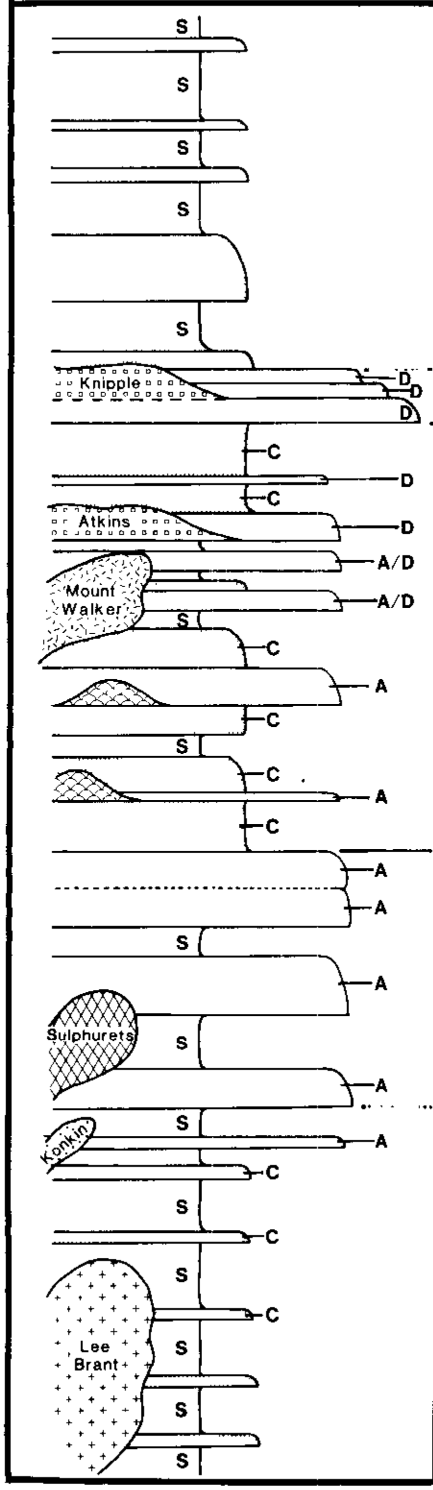


Figure 1-18-1. Iskut-Sulphurets gold camp; precious metal deposits and current mapping projects.



MAP UNIT, FORMATION, THICKNESS, and AGE	LITHOLOGIES * indicates diagnostic features	MINERAL OCCURRENCES
UNIT 4 SALMON RIVER FORMATION >1000 m Toarcian to Bajocian	*Black siltstones with lesser thick-bedded sandstones and minor limestone lenses. *Basal fossiliferous and pyritic wacke.	
UNIT 3: MOUNT DILWORTH FORMATION 75 m to 150 m Toarcian	*Felsic pyroclastics and flows. Tuff breccias, lapilli tuffs, ash tuffs, and dust tuffs. Local*welded ash flows and *agglomeratic tuff breccias. *Chalcedonic veins.	KNIP
UNIT 2 BETTY CREEK FORMATION 700 m to 1200 m Pliensbachian to Toarcian	Interbedded volcanic tuffs, flows, and *hematitic sedimentary rocks. *Purple to maroon conglomerates, wackes, siltstones and mudstones. Basaltic to dacitic tuffs and flows. *Pillow lavas, crystal and lithic tuffs. *Columnar jointed units. Minor black fossiliferous siltstone sequences.	TREATY ISLAND GOLD WEDGE SHORE, RED RIVER
UNIT 1B UPPER UNUK RIVER FORMATION 1000 m to 1500 m Hettangian to Pliensbachian	Volcanic strata with lesser black siltstone members *Two feldspar porphyry ±hornblende (Premier Porphyry), *hornblende porphyry, and *bedded airfall crystal tuff. Minor fossil occurrences.	GOSSAN HILL WEST IRON CAP SNOWFIELD SPINE, ELECTRUM, 367 4-J's
UNIT 1A LOWER UNUK RIVER FORMATION >1000 m Norian to Hettangian	Mixed sedimentary strata with minor tuff units. *Black siltstones, heterolithic pebble to cobble conglomerates and wackes. *Hornblende feldspar crystal tuffs. Minor fossil occurrences.	KERR KONKIN

Figure 1-18-2. Schematic stratigraphy, Sulphurets map area. A = andesitic volcanics; D = dacitic volcanics; S = siltstones; C = conglomerates; stipple = sandstones.

Figure 1-18-3. Geology and mineral deposits, Sulphurets map area.

LEGEND

INTRUSIVE ROCKS

Lee Brant Stock

Mount John Walker Porphyry

Mitchell-Sulphurets Intrusions: monzonite (M), syenite (S), and granite (G)

Potassium-feldspar-plagioclase-hornblende porphyry trachyandesite

VOLCANIC AND SEDIMENTARY ROCKS: Units 1-4

SYMBOLS

Phyllite belt

Gossan

Fault (U = up; D = down)

Contact

Syncline; anticline

Bedding; foliation

Mine under development

Prospect

Access road under construction

	MINERAL OCCURRENCES NAME	COMMODITY
A	Konkin	Au, Cu, Pb, Zn
B	Treaty	Gossan
C	Iron Cap	Cu, Au
D	Mitchell	Cu
E	Kirkham	Cu
F	Snowfield	Au, Mo
G	Sulphurets	Cu, Mo, Au
H	Hanging Glacier	Au, Ag
I	Kerr	Au, Cu
J	Goldwedge	Au, Ag
K	Red River	Au, Ag
L	Shore Zone	Au, Ag, Pb, Zn
M	West Zone	Au, Ag, Pb, Zn
N	Spine Zone	Au
O	Knip	Ag, Pb, Zn
P	Delta	Ag, Pb, Zn
Q	Tribe	Au
R	Gamma	Ag, Pb, Zn

along the western margin of the Intermontane tectonic belt and, according to terrane concepts, is entirely within Stikinia (Wheeler and McFeely, 1987). The area is underlain by Lower to Middle Jurassic Hazelton Group volcanic and sedimentary rocks (Grove, 1986) that have been folded, faulted and weakly metamorphosed, mainly during Cretaceous time (Alldrick *et al.*, 1987). Strata are cut by at least three intrusive episodes that produced small synvolcanic plutons, satellitic stocks of the Coast plutonic complex and minor dykes and sills. Intrusive activity spans Jurassic to Tertiary time.

The geology is typical of an island arc setting. Formations have characteristics that persist on a regional scale, but individual members show little lateral continuity due to rapid facies changes and the simultaneous operation of volcanic and sedimentary processes.

VOLCANIC AND SEDIMENTARY ROCKS

Hazelton Group volcanic and sedimentary rocks can be divided into four lithostratigraphic map units (Figures 1-18-2, 1-18-3). Informal names in current use (Grove, 1986; Alldrick, 1987) are given in parentheses for comparison with earlier work.

MAP UNIT 1 (UNUK RIVER FORMATION, ANDESITE SEQUENCE)

Unit 1 consists of a thick sequence of interbedded sedimentary and volcanic rocks. Sedimentary rocks include immature sandstones (wackes), fine-grained conglomerates, rhythmically bedded siltstones (turbidites) and mixed epiclastic-pyroclastic rocks (tuffites of Schmid, 1981); limestone and chert are absent. Most coarse clastic rocks are quartz-poor lithic or arkosic wackes. Lithic fragments are commonly volcanic. Grain size roughly correlates with the physical appearance of outcrop: coarse clastic rocks are dull, rusty buff-brown to grey and form rubbly, ribbed outcrops; siltstones form rusty, dark grey, smooth or scree-covered exposures. Sedimentary sequences tend to be recessive relative to volcanic rocks (Figure 1-18-2).

Volcanic rocks are intermediate pyroclastics: andesitic tuffs, lapilli tuffs and breccias with subordinate flows and bedded air-fall tuffs. Plagioclase phenocrysts are ubiquitous; hornblende occurs in more mafic rocks and pyroxene was seen only in tuff-breccia clasts in two outcrops. Near the top of Unit 1 potassium feldspar, plagioclase and minor hornblende occur as phenocrysts, both in tuffs and in apparently coeval hypabyssal intrusions. Potassium-feldspar-bearing units may be trachyandesite. Typical volcanic outcrops are medium green, massive and fairly resistant to weathering.

Unit 1 can be subdivided into a lower, predominantly sedimentary sequence, including tuffites, and an upper, predominantly volcanic sequence (Figure 1-18-2). Within the upper sequence, rhythmically bedded carbonaceous siltstones are the principal sedimentary component amid rather massive, poorly bedded, volcanic accumulations.

Thickness is not known but must exceed 2000 metres. No base was observed. Lower and upper sections appear to form one conformable depositional sequence although lacunae doubtless exist. The contact with overlying Unit 2 is exposed south of Brucejack Lake and is conformable on outcrop scale. Unit 1 is best exposed from Atkins Glacier south through the McTagg, Mitchell and Sulphurets drainages before passing beneath the Frank Mackie Icefield. Few fossils were found in Unit 1.

Map Unit 2 (Betty Creek Formation, Coarse Clastic Sequence)

Unit 2 consits of heterogeneous pyroclastic and epiclastic rocks, distinguished by brightly coloured red, green and purple units. Bedded sedimentary rocks are characteristically hematitic. Common rock types include crystal and lithic tuff, lapilli tuff, tuff breccia, tuffite, hematitic mudstone, siltstone and sandstone. Minor conglomerate, pillow lavas and flows occur locally. Generally this unit has well-developed compositional layering but, where it is massive, it can be distinguished from other volcanic units by the presence of hematitic mudstone seams. Massive volcaniclastic sequences tend to weather light green; massive sediments are light grey.

Volcaniclastic rocks are of intermediate to felsic composition; most are feldspar-phyric dacite. Air-fall lapilli tuffs are common. Clasts are subangular to subrounded and include variable amounts of accidental fragments. Sedimentary rocks are, on the whole, less abundant than pyroclastic rocks. They tend to be better sorted than sediments of Unit 1 and generally consist of fine-grained feldspathic wackes and siltstones.

Unit 2 is estimated to be from 700 to 1200 metres thick. Its lower and upper contacts are conformable and locally may be gradational. Widespread hematite implies that much of Unit 2 was deposited subaerially or else in shallow, oxygenated water. Typical sections occur in the Treaty Glacier area, on the flanks of Mount John Walker and in the Bowser Valley around Canoe Glacier. The few fossils found in Unit 2 include gastropods, molluscs and bivalves.

Map Unit 3 (Lower Salmon River Formation, Felsic Volcanic Sequence)

Unit 3 consists of light-weathering, predominantly felsic pyroclastic rocks, including welded tuffs. Sedimentary rocks are absent; flows are rare. Composition is dacitic to rhyodacitic. Rocks locally carry quartz phenocrysts in addition to the usual plagioclase. The unit forms a relatively thin but persistent marker throughout the map area. Locally, as at Knipple Lake and Treaty Glacier, the unit is strongly pyritic, giving rise to prominent gossans which have long drawn the attention of prospectors. Previously included as part of the lower Salmon River formation (Grove, 1986), this unit was identified as a mappable regional marker in the Stewart area by Alldrick (1987).

Unit 3 is from 75 to 150 metres thick. It conformably overlies Unit 2, but may paraconformably underlie Unit 4. It represents an interval of explosive felsic eruptions, perhaps a result of evolving magma compositions beneath the island arc complex.

Good exposures are found around the toe of Treaty Glacier, midway along Knipple Glacier and immediately north of Mitchell Glacier (Plate 1-18-1). No fossils were found in this unit.

Map Unit 4 (Salmon River Formation, Siltstone Sequence)

Unit 4 consists of dark grey siltstone and fine-grained sandstone. It is distinguished by lithologic uniformity, good bedding and complex disharmonic folding.

At its base the unit has coarse pyritic sandstone and fossil accumulations, overlain by rhythmically bedded (turbiditic) siltstone sequences that contain limy lenses, concretions and thin pyritic layers. The strata represent renewed marine sedimentation following subsidence of the arc complex at the end of volcanism.

Unit 4 is at least 1000 metres thick in the map area. In most exposures it conformably overlies Unit 3 except at Knipple Lake where there is a marked angular unconformity (Figure 1-18-2). The best exposures are in the northeast corner of the map area and in the Bowser Valley around Knipple Lake. Fossils found in the basal wackes include belemnites, bivalves and gastropods. Ammonites were seen in one exposure. R.G. Anderson (personal communication, 1987) considers the basal sediments to be of Toarcian age.

INTRUSIVE ROCKS

Intrusive rocks are not extensive within the map area but are important due to their apparent spatial or temporal association with the main mineral occurrences.

The largest intrusive is the Lee Brant stock located west of the Frank Mackie Icefield. The main mass of the pluton, which crops out over 40 square kilometres, lies just west of the map area. It is a fresh, coarse-grained, leucocratic, hornblende-biotite quartz monzonite, with large potassium-feldspar phenocrysts. Contacts with sedimentary country rocks are discordant, sharp but unchilled. Zones of low-grade hornfels occur along the contacts. Grove (1986) suggested a Tertiary age for this stock. On the basis of textural and mineralogical similarities to the Texas Creek batholith and the Summit Lake stock (Alldrick, 1986), it is probably Jurassic.

A wide variety of syn and post-volcanic hypabyssal stocks is concentrated in the vicinity of the Sulphurets and Mitchell glaciers. They range from monzodiorite to monzonite to quartz monzonite and granite. Typically they are quartz-poor and have alkaline affinities. Porphyritic textures are common with phenocrysts of plagioclase, potassium feldspar, hornblende and biotite set in an aphanitic to microcrystalline groundmass. Synvolcanic plutons tend to be compositionally and texturally similar to the extrusive rocks. A good example is potassium feldspar + plagioclase-phyric trachyandesite that forms small intrusive bodies cutting Unit 1 around the toe of Freegold Glacier. Compositionally this rock is the same as bedded air-fall tuffs exposed at the east end of Brucejack Lake. In other exposures, where crosscutting relationships are obscured, it is not possible to determine if the rock is intrusive or extrusive.

Post-volcanic intrusions tend to be more phaneritic. They clearly intrude their hosts and do not have compositions or textures equivalent to extrusive rocks. Examples are hornblende feldspar porphyry monzonite exposed along the east side of Sulphurets Glacier and leucomonzonite on Mitchell-Sulphurets ridge. Some of these are associated with disseminated copper and gold mineralization. Another post-volcanic stock underlies the head of Freegold Glacier, including the summit of Mount John Walker. It is a homogeneous, coarse, plagioclase-phyric rock with crowded porphyry texture and fine-grained phaneritic groundmass. A distinctive feature is the presence of numerous fine-grained dioritic (apparently cognate) xenoliths. The unit appears to cut host rocks at a very low angle and may be a sill. Contacts are sharp and unchilled. This intrusive does not appear to be associated with mineral occurrences.

Dykes, including diabase, andesite, biotite lamprophyre and keratophyre, also cut rocks in the Sulphurets – Mitchell Glacier area.

In addition to the Lee Brant stock, two rock types previously mapped as Tertiary intrusions by Grove (1986), have been reinterpreted. One, north of Atkins Glacier, consists of stratabound, hornblende feldspar porphyry, and is thought to be a Jurassic flow or crystal tuff ("Atkins" in Figure 1-18-2). The other, at Knipple Lake, consists of coarse, white, glomeroporphyritic plagioclase set in a dark grey dacitic groundmass ("Knipple" in Figure 1-18-2). Up to boulder-sized clasts of this rock occur in overlying conglomerates and wackes at the base of Unit 4, indicating a Jurassic age. No intrusive contacts were seen in this rock. Field examination did not resolve whether it is a flow or an unusual tuff.

STRUCTURE

FOLDS

Folds are best revealed in sedimentary rocks; most volcanic strata are too massive to give useful structural data. Unit 4 displays complex, tight, disharmonic folding; it appears crumpled against more rigid volcanic rocks. This is due to competency contrasts and the extreme planar anisotropy of the strata. Unit 1 sediments in McTagg drainage display less intense deformation with only moderate warping. Fold amplitudes are less than 100 metres and wavelengths are several hundred metres long. Crenulation folds were found only in phyllite and some foliated rocks in alteration zones. Primary folds and other soft-sediment deformation structures were seen in most siltstone sequences.

On a regional scale, the northern and northeastern part of the map area consists of a northeast-facing homocline. In the west, the Sulphurets syncline of Grove (1986) is now interpreted as a major anticline exposing the deepest members of Unit 1. Along the Bowser River on the east and southeast of the map area, major synclines preserve pockets of Unit 4. Fold axes strike roughly northwest. The southwest part of the sheet was not mapped.

FAULTS

Only one growth or syndepositional fault was observed (at Tim Williams nunatak) but this type of fault may be important in controlling the distribution of rock types within Units 1 and 2. Growth faults may account for some of the abrupt lithologic changes seen on Brucejack Plateau.

Northerly striking, steep normal faults with several hundred metres displacement were seen in the Bowser Valley and Mitchell Glacier areas. The Mitchell Glacier faults may be extensions of the prominent Brucejack lineament which extends from Sulphurets Icefield to Freegold Glacier. The Brucejack lineament is a subvertical structure, the trace of which is a narrow trough. Apparent displacement across this structure is rather small for such a pronounced feature, in the order of tens of metres. Other regional breaks include a northeast-striking reverse fault that extends from Mitchell Glacier to Treaty Glacier and a northwest-striking normal fault that parallels Knipple Glacier.

Minor thrust faults are fairly common in more deformed parts of Unit 4. West-dipping thrust faults with perhaps a few hundred metres displacement were seen between Sulphurets Creek and the north side of Mitchell Glacier (Plate 1-18-1). Thrust faults appear to predate at least some of the displacement along normal faults, but postdate mineralization and alteration.

Minor faults with only tens of metres displacement abound in the map area. These may be very important in the exploration and exploitation of ore deposits.

METAMORPHISM

Metamorphic grade throughout the area is, at most, lower greenschist. Metamorphism has produced typical propylitic assemblages: chloritized mafic minerals and saussuritized plagioclase. Mineralogical transformations are most evident in intermediate to mafic volcanic rocks. On the whole, textural changes are slight, amounting to minor recrystallization.

In the Sulphurets and Mitchell Glacier area, large zones of argillic and phyllic alteration have been subjected to moderate dynamic metamorphism. The resultant rock, commonly termed sericite (or talc) schist in mining reports, is in fact a foliated to schistose pyrite-quartz-sericite rock with variable amounts of carbonate. Relict textures such as lapilli and phenocrysts can be discerned in zones where alteration is weak to moderate. Dynamic metamorphic effects are not confined to altered rocks. Stretching, flattening and re-orientation of lapilli, creation of secondary foliations at all angles to primary layering, and incipient transposition of bedding are widespread on Brucejack Plateau.

Between upper Sulphurets Glacier and Ted Morris Glacier a band of true phyllites is locally developed from pelitic and tuffaceous protoliths. In this area transposition of bedding is all but complete. Small folds are tight to isoclinal. Gradations from unfoliated rocks to phyllites are quite rapid, in the order of a few tens of metres. The genesis and limits of this northerly trending belt of phyllitic rocks are not yet known.

Regional foliations strike north-northwest and dip steeply to the east. Near Freegold and Mitchell glaciers most strikes are easterly, with steep northward dips.

MINERAL DEPOSITS

Prior to this project only 13 mineral occurrences were listed for the Sulphurets map area in the ministry's mineral inventory file (MINFILE). Information on more than 60 additional occurrences has been collected from published

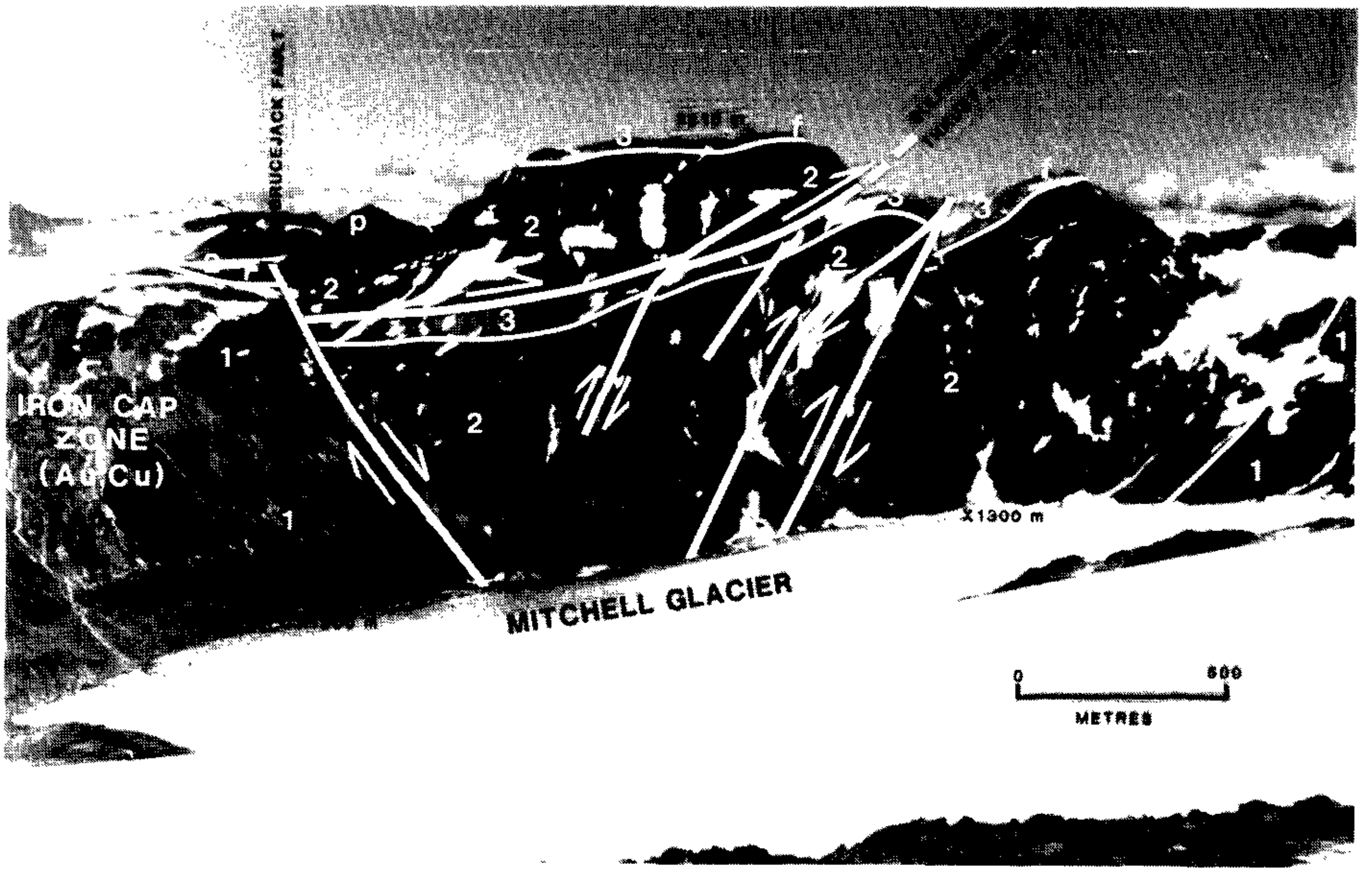


Plate 1-18-1. Stratigraphic and structural relationships, north side of Mitchell Glacier. (1, 2, 3 = Units 1, 2, 3; p = pillow lava; f = *fiammé in welded ash-flow tuff; F = fossil occurrence; thin lines = contacts; thick lines = faults with relative displacement indicated by* arrows; x = spot elevation in metres).

and unpublished reports and discussions with company geologists.

The map area is notable for major gossans ranging up to 20 square kilometres in size. Copper, molybdenum, gold and silver mineralization found within these gossans has affinities to both porphyry and meso to epithermal types of deposits. There appears to be overprinting of ore types and multiple generation of alteration and vein assemblages. Much work remains to be done before proposing a working hypothesis that accounts for the diversity of ore and gangue mineralogy, alteration types and structural characteristics.

Most mineral deposits occur in the upper members of Unit 1 or in the lower members of Unit 2. Using a simple, nongenetic scheme, mineral occurrences can be grouped into four main categories: veins, disseminations, intrusive contacts and stratabound.

VEINS

Six main types of veins occur in the map area. They can be classified on the basis of metal content and gangue mineralogy. Most exposed veins are thin (<1 metre) and short (<50 metres). In parts of intensely altered areas, veins may form more than 25 per cent of outcrop and may grade imperceptibly into strongly silicified host rocks.

The six vein types (with examples) are:

(1) Base metal quartz veins (Brucejack Plateau).
(2) Silver-rich base metal veins (Knip claim).
(3) Precious and base metal quartz veins (Brucejack Lake West zone).
(4) Precious metal quartz veins (Goldwedge deposit).
(5) Carbonate veins (Atkins Glacier).
(6) Barite veins (Brucejack Lake penninsula).

Base metal quartz veins consist of thin stringers of quartz ± carbonate which carry zones of disseminated to massive pyrite ± galena ± sphalerite. They are found locally around the Brucejack Plateau outside the main areas of alteration. Individual veins may be strongly gossanous.

TABLE 1-18-1
PUBLISHED RESERVES IN THE SULPHURETS GOLD CAMP

Mineral Deposit	*Reserve Category*	*Tonnes*	Gold *g/tonne*	Silver *g/tonne*
West Zone	Drill indicated	486 046	11.38	722.06
	Inferred	436 331	11.38	722.06
TOTAL WEST ZONE		922 377	11.38	722.06
Shore Zone	Inferred	489 685	9.02	933.69
Gossan Hill Zone	Inferred	25 074	66.51	120.34
TOTAL BRUCEJACK LAKE (Newhawk)		1 437 136	11.54	783.78
Snowfield Zone (Newhawk)	Inferred	7 000 000	2.57	
Goldwedge (Catear)	Inferred	69 854	18.17	138.52

Silver-rich base metal veins occur mainly in the southeastern quadrant of the map sheet. Locally they give spectacular assays in silver (>3000 grams per tonne) but virtually no gold (<1 gram per tonne). Pyrite, galena, sphalerite, tetrahedrite and minor chalcopyrite in quartz and calcite is a typical assemblage (Cremonese, 1985; Gallop, 1981).

Precious and base metal veins are polymetallic stockworks of thin veins and fracture fillings. Tension-gash structures are common. The veins show complex crosscutting relationships that indicate repeated fracturing and filling as the host rocks underwent brittle deformation. Precious metal mineralization may be confined to one particular episode of veining, and not necessarily the same episode as base metal mineralization. The best exposed example of this type of quartz ± calcite vein system is the West zone at Brucejack Lake which contains pyrite, ruby silver, tetrahedrite, electrum, argentite, galena and sphalerite as its main metallic minerals (Bridge *et al.*, 1983; Tribe, 1987).

Precious metal veins are essentially pyrite + electrum in quartz or quartz + calcite veins. Arsenopyrite may occur peripherally in the host rocks. Locally these veins give very high assays with generally low gold to silver ratios (roughly 1:1 to 1:5). A well-exposed example is the Goldwedge deposit (Kruchkowski, 1987).

Rusty weathering carbonate veins, weakly mineralized with pyrite, form thin discontinuous stringers in most parts of the map area, but near the toe of Atkins Glacier they are significantly thicker and more continuous. They are not known to carry precious metal values but sampling has been limited. They appear to be emplaced later than most quartz veins.

Barite veins were first discovered by Bruce and Jack Johnstone, prospectors from Ketchikan, Alaska (Minister of Mines Annual Report, 1935). They occur near the outflow of Brucejack Lake and appear restricted to that area. They consist of coarsely crystalline barite with minor quartz, carbonate and sulphides.

DISSEMINATIONS

Gossans

Gossans ranging up to 20 square kilometres in area have long drawn the attention of prospectors. They occur around Mitchell, Freegold, Sulphurets and Treaty glaciers, as well as Sulphurets Icefield and consist essentially of pyrite disseminated in argillic and phyllic alteration zones. Detailed prospecting in some of these has revealed copper, molybdenum, gold and silver mineralization (discussed below). The size of these zones, their tectonic fabric, intensity of alteration and coincidence of several mineral or metal associations make them attractive for exploration but difficult to interpret. All of these gossans are much larger than the hypabyssal plutons that may lie within them. None is centred on a major pluton. Most are a product of fault and fracture-controlled hydrothermal activity that has affected large volumes of rock over long periods of time. At the Treaty nunatak, the presence of native sulphur and alunite (R.M. Britten, personal communication, 1987) indicates that this zone is acid-sulphate alteration characteristic of high levels of epithermal systems. Plutons are not exposed at surface but may well exist at depth.

Copper-Molybdenum

Porphyry-type disseminated pyrite + chalcopyrite ± molybdenite mineralization occurs in volcanic and sedimentary rocks and within subalkaline porphyritic intrusions, including monzodiorite, monzonite, syenite and granite. Examples include the Kirkham zone, Mitchell zone and Sulphurets Copper zone located at the toe of Mitchell Glacier and on Mitchell-Sulphurets ridge. Mineralization consists of disseminations and fine quartz stringers carrying pyrite, chalcopyrite, magnetite and malachite. Grades of 1.5 per cent copper have been reported. Molybdenite occurs as thin coatings on foliation planes in pyrite-quartz-sericite rocks (Malcolm, 1962).

Gold

Gold (and silver)-bearing zones occur within large alteration areas. However, gold zones do not necessarily coincide with copper-molybdenum mineralization. An example is the Snowfield zone, located between Mitchell and Freegold glaciers, which is estimated to contain 7 million tonnes grading 2.57 grams per tonne gold (McLeod, 1986). The mineralization extends over an area of 240 by 120 metres. Molybdenite is found only in trace amounts and chalcopyrite is absent (Lomenda, 1983).

INTRUSIVE CONTACTS

A new discovery, the Konkin zone, was announced in early September by Teuton Resources Corporation (press release, September 10, 1987). Gold-bearing skarn mineralization (magnetite-hematite-chalcopyrite-pyrite-quartz-calcite veinlets in chlorite-diopside-garnet-bearing rock) occurs in Unit 1 strata intruded by a diorite stock. Native gold (electrum) occurs locally as coarse arborescent bands. Gold assays of chip and trench samples ranged up to 10 grams per tonne over 6 metres. The discovery chip sample assayed 960 grams per tonne gold over 1.3 metres.

Several minor occurrences of pyrrhotite and chalcopyrite are located around the margin of the Lee Brant pluton. These zones may be similar to gold-bearing pyrrhotite-pyrite veins that are emplaced peripheral to Jurassic plutons in the Stewart area (Alldrick, 1985, page 337). No assays are known for the Lee Brant mineralization.

STRATABOUND

Stratabound mineralization consists almost exclusively of pyritic zones, lenses and seams contained within a particular stratum or restricted set of strata. Typically they are confined to a single formation. Examples include: disseminated pyrite (up to 15 per cent) in Unit 3 felsic volcanic rocks exposed on the west side of Treaty Glacier; millimetre-thick seams of massive pyrite in bedded siltstones of the lowermost 50 metres of Unit 4 exposed in the Bowser Valley; and disseminated to massive pyrite in dacite porphyry and its overlying sediments located at the toe of Knipple Glacier. None of these stratabound pyrite occurrences is known to have associated precious metal values.

SUMMARY

The map area is underlain by lower to middle Jurassic volcano-sedimentary arc-complex lithologies, capped by middle Jurassic marine-basin turbidites. All rocks are members of the Hazelton Group. Syn to post-volcanic intrusions predate middle Jurassic turbidites. Tertiary plutons are few and of limited extent. The rocks record a protracted and complex history of fracturing, faulting and folding. A correct interpretation of this history may be critical in understanding the distribution and types of mineral deposits.

Strata of upper Unit 1 and lower Unit 2 contain most of the major vein and disseminated deposits. Although these deposits are epigenetic they appear to share the same geological history as their host rocks. Mineral and alteration zones are therefore probably middle Jurassic rather than Tertiary.

The area is heavily staked (Figure 1-18-1), but few companies are currently active. It warrants much more intensive prospecting and exploration. The potential for discovering bonanza-type and bulk-tonnage precious metal deposits is excellent.

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LOWER JURASSIC VOLCANISM OF THE STIKINE SUPER-TERRANE*

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KEYWORDS: Lithogeochemistry, Stikine super-terrane, Jurassic volcanism, Quesnellia, Stikinia, shoshonitic, calc-alkaline.

INTRODUCTION

The Stikine super-terrane formed by the "docking" of the Quesnel, Cache Creek and Stikine terranes in Late Triassic times. Triassic arc volcanism, subalkaline at first, became shoshonitic as the subduction zone was disturbed by the collision of these terranes, and ceased thereafter. The shoshonites and associated more sodic alkaline rocks form the greatest part of the Nicola, Takla and Stuhini arcs (Spence, 1985). Volcanism resumed during the Sinemurian, seemingly after a lull of at least 13 million years (Rhaetian and Hettangian). It was short lived on Quesnellia, generating the alkaline, mainly shoshonitic, Rossland and Horsefly groups during the Sinemurian. On Stikinia, volcanism was intense, widespread, long lived (Sinemurian to Bajocian) and of mainly calcalkaline character; it is represented by the Hazelton Group and "Toodoggone Volcanics".

The purpose of this paper is to re-examine the available chemical data for these Jurassic volcanic sequences and to redefine their magmatic trends more precisely. The volcanic sequences for which data are available include the Elise Formation and Tillicum Mountain basalts of the Rossland Group, the Horsefly Group, the Telkwa and Nilkitkwa formations of the Hazelton Group and the lower "Toodoggone Volcanics". This paper documents (1) the presence of shoshonites in the Horsefly Group and emphasizes the importance of shoshonitic volcanism in the Quesnel trough, and (2) the chemical distinction between two types of calcalkaline suites in the Hazelton and Toodoggone groups.

Magmatic trends were determined by extracting analyses of "unaltered" samples using the MgO versus CaO diagram and examining their patterns on several diagrams. These diagrams and a nomenclature based on a purely chemical classification scheme were presented previously (de Rosen-Spence, 1976; Spence, 1985; de Rosen-Spence and Sinclair, 1987). As a reminder, the term "calcalkaline" is used here for alkali content intermediate between calcic and alkaline, as determined on the alkali versus silica diagram; it is absolutely descriptive and does not presuppose an absence of iron enrichment, whereas the terms "iron rich" and "iron poor" refer to what is described elsewhere as tholeiitic and calcalkaline trends. Petrographic nomenclature of root names follows the recommendations of the I.U.G.S. Commission on Systematics in Petrology (Zanettin, 1984). Rocks of the shoshonitic suite were given their subroot names to distinguish them from other alkaline rocks because this suite is an important indicator of collisions. This peculiar suite is characterized by a subalkaline sodium content and very high to extremely high potassium content (VHK and EHK).

VOLCANISM ON QUESNELLIA

The lower Jurassic sequences analysed are all from the southern (Elise Formation, Tillicum Mountain basalts) and central (Horsefly Group) Quesnel trough and are thus submarine except for the upper Horsefly Group which emerged as an island.

ROSSLAND GROUP

ELISE FORMATION

The Elise Formation has been described in detail and analysed by Beddoe-Stephens (1982) who recognized its shoshonitic nature. It comprises a thick sequence of mainly brecciated and agglomeratic ankaramites, absarokites and shoshonites, as well as some high potassium basalts and basaltic andesites which commonly are associated with shoshonites (revised petrographic names). The Elise Formation has since been dated as Sinemurian by fossils (Tipper, 1984).

TILLICUM MOUNTAIN BASALTS

The Tillicum Mountain basalts have been described and analysed by Kwong (1985) and Ray (Ray and Spence, 1986). They are also shoshonitic, more precisely absarokites, and have been correlated on the basis of their composition with the Elise Formation only 60 kilometres to the south (Ray and Spence, 1986). No other volcanic rock types have been identified, but the Tillicum Mountain basalts are intruded by high potassium dioritic sills which probably are related to the same igneous episode. This basaltic belt continues northwestward through Vernon and beyond, but no data are available to characterize its composition.

HORSEFLY GROUP

The Horsefly Group was isolated from the Quesnel River Group by Morton (1976) who recognized its alkaline character, but not the presence of shoshonites, nor its arc setting (low titanium content). He identified three distinct

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volcanic cycles, each with its set of small intrusions following an episode of extensive alkaline basaltic volcanism.

The Horsefly Group is fairly well preserved overall and the plots of the "unaltered" samples show the first cycle to be clearly shoshonitic, and composed mainly of absarokites with a few shoshonites and latites. The second and third cycles, although mostly as potassic (very high potassium) as the first cycle, are also more sodic, and thus are defined here as "potasso-sodic"; they comprise alkali basalt, trachybasalt and basaltic trachyandesite. The association of shoshonitic and potasso-sodic suites is very common in the alkaline arcs of British Columbia. All three cycles show a low titanium content and iron-poor trend characteristic of an arc setting.

Analyses from a smaller area of the group reported by Panteleyev (1987) are mainly from ankaramites and thus difficult to attribute to the shoshonitic or potasso-sodic suites. Basaltic trachyandesites, mildly alkaline shoshonites and high potassium basalt are also present.

The age of the Horsefly Group is not well constrained because fossils are rare and outcrops sparse; it is considered lower Jurassic by Morton (1976), but mainly upper Triassic by Bailey (1978) who mapped an area further north than Morton. According to Panteleyev (1987), Sinemurian fossils, gathered by Tipper, occur in the middle of the sequence in a sedimentary unit intruded by the seemingly shoshonitic Shiko stock dated as Pliensbachian-Toarcian. Thus, at least a part if not all of the Horsefly Group is Sinemurian. It could, however, include some upper Triassic shoshonitic basalts at its base as it is situated at the junction of the northward extensions of the Nicola and Rossland belts.

DISCUSSION

The Nicola shoshonitic belt is associated on the west with a calcalkaline belt (Preto, 1979; Mortimer, 1986) and is therefore thought to be related to the destruction by collision of the then active Cache Creek subduction zone. The Rossland-Horsefly belt, on the other hand, shows no signs of normal subalkaline volcanism (its high potassium basalts are not part of a "normal" suite). It was formed **after** a period of quiescence (Rhaetian and Hettangian) following the destruction of the Cache Creek subduction zone and, in its southern end, it is situated 200 kilometres to the east of that zone. It cannot, therefore, be a direct continuation of the Nicola volcanism as has been suggested (Monger, 1985; Mortimer, 1986). A parallel to events in the eastern Mediterranean (Kolios *et al.*, 1980) is proposed here: that the Rossland-Horsefly shoshonitic volcanism was generated in a zone of local extensional stress (Quesnel trough) created by the continuing oblique pressure of Stikinia against Quesnellia after the destruction of the subduction zone and before the lateral northward slip of Stikinia relieved this stress. Although not the direct continuation of the Nicola, the Rossland-Horsefly volcanism can be considered to have been the last volcanic gasp of the tectonic cycle which generated the Nicola arc.

VOLCANISM ON STIKINIA

Volcanism on Stikina differs from that on Quesnellia in composition and duration. It is mainly calcalkaline, although alkaline suites are (or may be) present, and it spans the Sinemurian to Bajocian interval. Volcanic sequences are grouped in the Hazelton Group along the southern and western edges of the Bowser basin and in the "Toodoggone Volcanics" along the eastern and northeastern margin.

Plots of "unaltered" samples of the Hazelton Group and "Toodoggone Volcanics" are illustrated on Figures 1-19-1 to 1-19-4.

HAZELTON GROUP

TELKWA FORMATION

The Sinemurian Telkwa Formation at the base of the Hazelton Group is entirely volcanic. Tipper and Richards (1976) subdivided it into five facies which are, from west to east: subaerial Howson, shelf Babine, submarine Kotsine, subaerial Bear Lake and Sikanni. They provided analyses for the Howson, Kotsine and Bear Lake (Bait Range) and showed that the Bear Lake facies was more sodic and alkaline and less rich in iron and titanium than the Howson and Kotsine facies. Additional data for the Bear Lake (Two Lake Creek) and Sikanni facies are found in Monger (1977) and Church (1976).

Reinterpretation of the data confirms Tipper and Richards' findings. The use of different plots and consideration of only "unaltered" samples allow for more confidence, although widespread zeolitization clouds the determination of the original trends.

Howson Facies: This sequence is a bimodal association of basaltic flows and rhyolitic ash-flows and flows belonging to a moderately potassic (Figure 1-19-1), subalkaline (Figure 1-19-3), mildly calcic (?) and mildly iron rich (tholeiitic

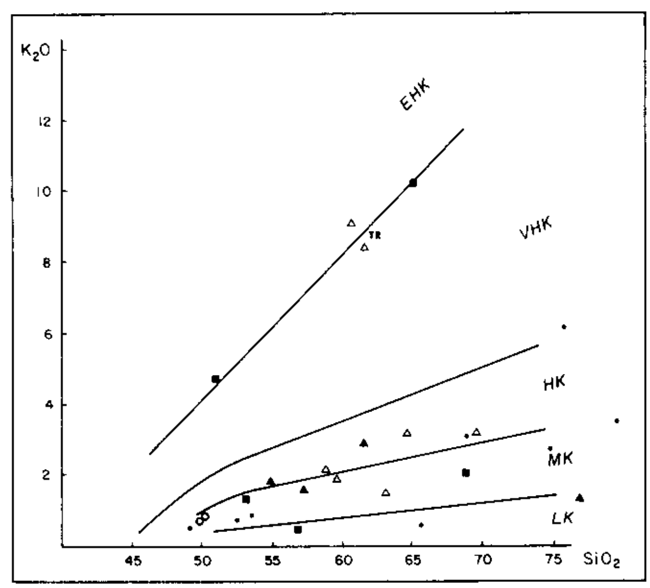

Figure 1-19-1. K_2O versus SiO_2 for the Hazelton Group: Howson (filled circles), Bear Lake (filled squares) and Sikanni (filled triangles) facies, Ankwell basalts (open circles); and for the lower "Toodoggone Volcanics" (open triangles, TR = Toodoggone trachyte (two samples)). Only "unaltered" samples plotted from analyses recalculated 100% dry. Data are from Church (1976), Tipper and Richards (1976), Monger (1977) and Foster (1984) and domains from de Rosen-Spence (1976).

trend) (Figure 1-19-4) suite. It may reflect conditions of extension in the arc, possibly in the arc tholeiitic zone, if the sequence is truly calcic.

Kotsine Facies: This facies consists of altered flows and tuffs of basalt and basaltic andesite composition and can be attributed to a subalkaline, moderately potassic, mildly iron rich suite similar to that of the Howson facies. Its submarine deposition and mafic character suggest a more prominent extension of the arc in that area.

Bear Lake Facies (Bait Range and Two Lake Creek Area): This is an altered succession of basalt, basaltic andesite, dacite and rhyolite flows and tuffs; some trachyte flows are also present. The sequence plots as mainly moderately potassic (Figure 1-19-1), alkaline (Figure 1-19-3), very sodic (Figure 1-19-2), iron poor (Figure 1-19-4), and is richer in aluminum and poorer in titanium than the Howson facies. Because of the extensive alteration involving the formation of calcite and exchanges between sodium and potassium, it is likely that samples classed as "unaltered" are actually also somewhat altered; it is not possible to classify this sequence with certainty as an alkaline sodic suite, only as a probable one.

Sikanni Facies: This is a succession of basalt, basaltic andesite, andesite, dacite and rhyolite flows and tuffs, apparently less altered than the Bear Lake facies. It can be considered a medium to high potassium (Figure 1-19-1), calcalkaline (Figure 1-19-3) suite, iron poor (Figure 1-19-4), and belonging to an arc of Type II (Figure 1-19-5) (de Rosen-Spence and Sinclair, 1987). It differs from the Howson facies by the complete petrographic range from basalt to rhyolite, lower iron and titanium, slightly higher potassium contents and the well-defined calcalkaline content, whereas the Howson facies seems to be more calcic and iron rich. The Sikanni facies is similar to the Pliensbachian Toodoggone sequence to the north.

Nilkitkwa Ash-fall Tuffs

The Nilkitkwa ash-fall tuffs are interbedded with sediments of Pliensbachian age; they are andesitic to rhyolitic and belong to a moderately potassic, subalkaline, mildly iron rich arc suite. Hence, they belong to a group chemically similar to the Howson facies, but their altered state prevents a more precise classification into calcic or calcalkaline.

Ankwell Basalts

The Ankwell basalts are submarine flows and aquagene tuffs of Toarcian age. They form the top member of the Nilkitkwa Formation in the Hazelton trough and are time equivalent with the subaerial rhyolitic Red Tuffs member on the southwestern edge of the trough. They plot as moderately potassic, calcalkaline high alumina basalts.

Hazelton Group in the Stewart Mining Camp

In the Stewart mining camp, the Hazelton Group is represented by a thick succession of waterlain andesitic tuffs. Data from Alldrick (1985) show them to be altered and commonly silicified. In spite of this they can be classed as subalkaline and mildly iron rich, similar to the Howson facies or the Nilkitkwa tuffs.

"TOODOGGONE VOLCANICS"

The "Toodoggone Volcanics" are a subaerial arc assemblage of Pliensbachian to Bajocian age (Gabrielse, 1978; Smith *et al.*, 1984) situated along the northeastern margin of the Hazelton trough. They are time equivalent with the mostly sedimentary Nilkitkwa and Smithers formations of the Hazelton Group. All data available (Schroeter, 1982; Foster, 1984; H. Gabrielse, personal communication, 1985) are from the Pliensbachian succession in the Toodoggone River area, that is, they represent the lower "Toodoggone". Only a few analyses from samples of uncertain age were available from the Cry Lake map area (Anderson, 1983). In the Toodoggone River area, some andesites have been as-

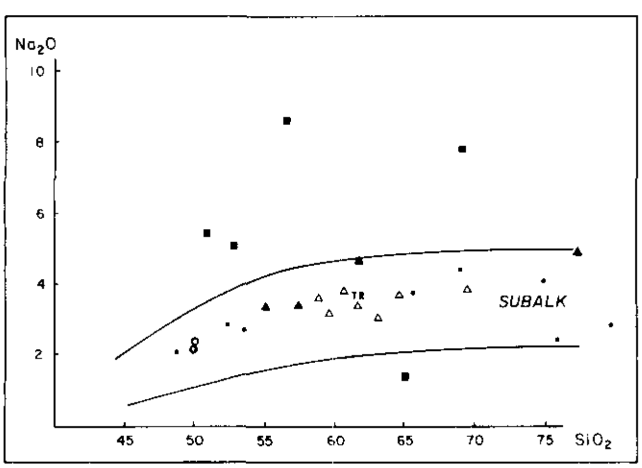

Figure 1-19-2. Na_2O versus SiO_2 for the Hazelton Group and "Toodoggone Volcanics". Legend as in Figure 1-19-1.

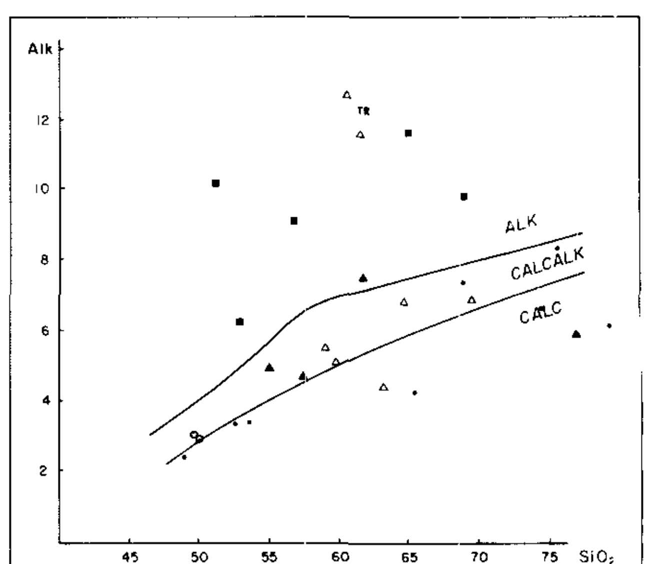

Figure 1-19-3. Alkali versus SiO_2 for the Hazelton Group and "Toodoggone Volcanics". Legend as in Figure 1-19-1.

signed to the Hazelton Group (Telkwa Formation), but have not been dated; they are treated with the "Toodoggone Volcanics".

Lower "Toodoggone Volcanics"

In the Toodoggone River area, the "Toodoggone Volcanics" of Pliensbachian age rest unconformably over the Upper Triassic Takla Group. According to Schroeter (1982), Panteleyev (1983) and Foster (1984), they consist mainly of a succession of andesitic flows and pyroclastic deposits followed by potassic trachyte, the whole being blanketed by extensive dacitic ash flows.

In spite of widespread and varied alteration related to gold mineralization, the andesitic and dacitic succession analysed by Foster (1984) can be interpreted as a medium to high potassium, calcalkaline and iron-poor suite of arc Type II (Figure 1-19-5). The trachyte is potassic (TR on Figures 1-19-1 to 4). In the set of samples analysed, the most prevalent alteration is silicification accompanied by loss of calcium and some gain of sodium in the dacitic ash flows; in addition, andesites modified by potassic alteration near mineralization mimic the composition of shoshonites. In the same area, the succession analysed by Schroeter (1982) comprises some high potassium andesites, apparently an absarokite and shoshonite, and altered shoshonitic trachyte tuffs.

Hazelton Group East of the "Toodoggone Volcanics"

A succession of andesitic pumice-breccia and flows situated to the northeast of the "Toodoggone Volcanics," and separated from them by a fault, has been assigned to the Hazelton Group on the basis of its similarity to the Sikanni facies of the Telkwa Formation. It also rests unconformably on the Takla Group. No fossils are known in the Sikanni or in this sequence of "Hazelton" to verify the correlation and their assigned Sinemurian age.

Data from Foster (1985) and Gabrielse (personal communication, 1987) show that the andesites have suffered from some sodium-potassium exchanges and thus are difficult to classify with certainty; they probably are high potassium subalkaline andesites but could include some mildly alkaline latites. They are similar to the Toodoggone high potassium andesites.

In the Toodoggone River area, the identification of bona fide shoshonites is hampered by alteration, mainly by the common exchange of sodium and potassium and the existence of demonstrated potassic alteration near mineralization. The zirconium content has been used to separate altered subalkaline and alkaline suites (Winchester and Floyd, 1976) because it is generally considered "immobile". Zirconium data from Foster (1984) give a subalkaline classification for all the "Toodoggone", including the potassic trachyte flow and the "Hazelton" samples. The only alkaline sample is a sodic trachyandesite. Whether zirconium is diagnostic in this case may be open to question because of the widespread addition of CO_2 and the suggestion by Hynes (1980) that zirconium is mobile during carbonatization.

DISCUSSION

Two main types of subalkaline suites can be recognized in the lower Jurassic arc volcanism of Stikinia. The first is a subalkaline, moderately potassic, mildly iron-rich suite, represented by the western Hazelton Group, excluding the Bear Lake and Sikanni facies. This type seems to have been deposited during extension of the arc. The second type is a subalkaline, medium to high potassium, iron-poor suite represented by the Sikanni facies of the Telkwa Formation, the "Toodoggone Volcanics" and the "Hazelton" Group in the Toodoggone area. Alkaline suites may be present and would be represented by the sodic Bear Lake facies of the Hazelton

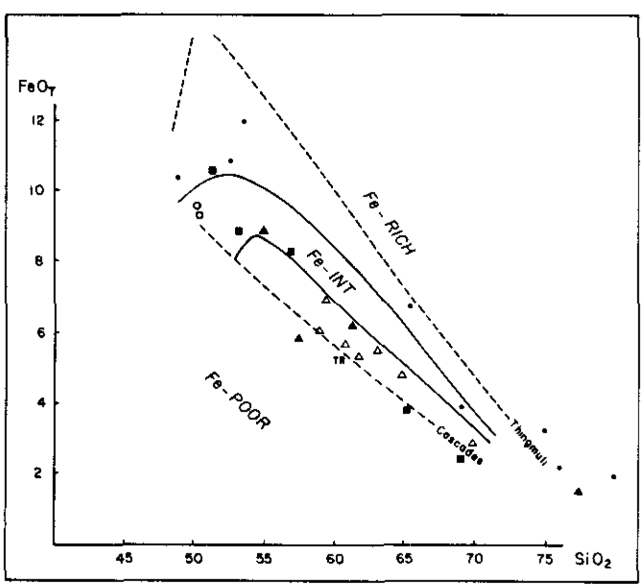

Figure 1-19-4. FeO_T versus SiO_2 for the Hazelton Group and "Toodoggone Volcanics". Legend as in Figure 1-19-1.

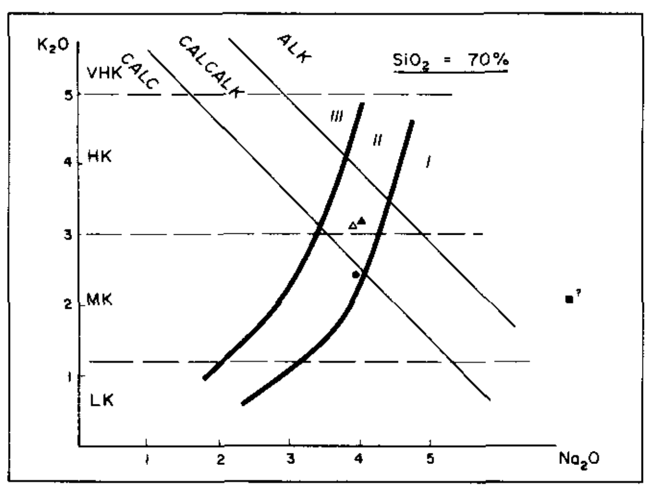

Figure 1-19-5. K_2O versus Na_2O for 70% SiO_2, showing the classification into arc types of the Howson, Bear Lake and Sikanni facies of the Hazelton Group and of the "Toodoggone Volcanics". Domains from de Rosen-Spence and Sinclair (1987) and legend as in Figure 1-19-1.

Group and the shoshonitic trachytes of the "Toodoggone Volcanics" if their alkalinity could be confirmed by additional petrographic and chemical data.

The arc is postulated to have been generated by the subduction of the Bridge River – Anyox(?) ocean in probably three episodes:

(1) During the Sinemurian, a new arc formed along the edge of Stikinia under extensional conditions, the Howson formed a western chain characterized by mildly iron-rich, probably calcic (arc tholeiitic) products. To the east an extensional trough developed and was filled by the Kotsine basalts, also iron-rich. An eastern chain composed of both the Bear Lake and Sikanni is difficult to reconcile because of their apparent difference in alkalinity. If the Sikanni is truly Sinemurian (it has no fossils) and the Bear Lake is truly alkaline, then the Bear Lake—which is a little older than the Kotsine—does not belong to the Hazelton cycle and its western subduction zone; instead it could be considered a last gasp of the Takla alkaline volcanism reactivated by the new tectonic conditions. If instead, the Sikanni is younger and part of the Toodoggone cycle (it has the same composition), then the Bear Lake can be an alkaline chain associated with the Howson chain. Alternatively, the Bear Lake is truly calcalkaline and associated with the Sikanni in a calcalkaline chain.

(2) The second episode, during the Pliensbachian and Toarcian, is marked by a shift of the main activity inland to form the calcalkaline Toodoggone chain, while much reduced episodic activity persisted to the west. The presence of shoshonitic trachytes, if confirmed, would indicate a disturbance of the subduction zone during the Pliensbachian.

(3) The third episode, during the lower Bajocian, is represented on the Stikine arch (Gabrielse, 1978) and in the Smithers Formation south of the Skeena arch, where it is deposited directly on the Telkwa Formation (Tipper, 1979).

CONCLUSION

The lower Jurassic volcanism on the Stikine super-terrane is different on Quesnellia and Stikinia and reflects two different tectonic environments. On Quesnellia, the shoshonitic volcanism is the last gasp of the upper Triassic arc magmatism; it was generated in a local zone of tension formed by continued pressure of Stikinia against Quesnellia, long after the Cache Creek subduction zone had been destroyed. On Stikinia, on the other hand, the subalkaline volcanism is the product of a new subduction, postulated to be that of the Bridge River ocean. Arc volcanism ended with the final collision against North America and intrusion of the mid-Jurassic plutons.

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PRELIMINARY GEOLOGY OF THE TUTSHI LAKE AREA, NORTHWESTERN BRITISH COLUMBIA (104M/15)

By M. G. Mihalynuk and J. N. Rouse

KEYWORDS: Regional geology, Tutshi Lake, Stikine terrane, Nisling terrane, Cache Creek terrane, Llewellyn fault, Laberge Group, Stuhini Group, Boundary Ranges metamorphics, mineral occurrences.

INTRODUCTION

Geological mapping at 1:25 000 scale (compiled at 1:50 000) and geochemical stream sediment sampling in the Tutshi Lake area were conducted by a four-man crew between mid-June and early September of 1987. The purpose of the program was to construct an accurate 1:50 000 geological map and to evaluate the involvement of ore-forming processes in the deposition and later deformation of rocks that range from Proterozoic(?) to Tertiary age within the Tutshi Lake area. Results of the geochemical program and 1:50 000-scale geological map are scheduled for release in open file format in February 1988. This study was undertaken, in accordance with Geological Survey Branch objectives, to create a high quality geological database to benefit industry and stimulate exploration activity in British Columbia.

The area is part of an anomalous antimony-arsenic province extending southward from the Venus mine to beyond the old Engineer mine (Figure 1-20-1) with sporadic, but commonly high gold and silver values (Schroeter, 1986). High antimony background values are likely an artifact of abundant stibnite-bearing veins which appear related to a late Cretaceous intrusive event.

Sheared quartz-carbonate alteration zones, locally hosting lead-zinc mineralization within Triassic volcanics, are associated with a major, long-lived, dextral oblique-slip fault system that bisects the map area. This structural setting is analogous to the Polaris Taku and Engineer mines to the south.

ACCESS AND PHYSIOGRAPHY

Access to the field area is via the Klondike Highway, 120 kilometres south of Whitehorse. An extensive lake system provides good boat access to most of the low-lying areas; the remainder is accessible by multi-day hikes or by helicopter.

The region is mountainous with approximately 1500 metres of relief produced by alpine glaciation; relatively small remnants of a once extensive ice cover still remain. Widespread glacial features occur at all elevations; an upland alluvial plateau at 1500 metres exists east of Bennett Lake, with eskers found on valley floors at 700 metres.

Snow covers much of the alpine areas (above 1200 metres) until early July, and flurries can be expected at higher elevations throughout the summer.

REGIONAL GEOLOGIC SETTING

Parts of three terranes are evident in the map area: Stikinia, Nisling and Cache Creek (Wheeler, 1987; *see* Figure 1-20-1). At this latitude, Stikinia is dominated by rocks of the Whitehorse trough. Within the study area the Llewellyn fault zone (Bultman, 1979; Schroeter, 1986), a major dextral transcurrent extension of the King Salmon fault, forms the western boundary of most of Stikinia and the eastern boundary of the Nisling terrane. Minor erosional remnants of Laberge Group and younger strata east of the Llewellyn fault rest on mainly pre-Permian metamorphic rocks here termed the "Boundary Ranges metamorphics" of the Nisling terrane. This metamorphic terrane is bounded on the west by hornblende-biotite granites[1] and granodiorites of the Coast crystalline complex. Within and adjacent to the map area, it underlies the eastern flank of the Boundary Ranges and marks the transition between the Coast and the Intermontane belts.

Strata of interpreted Cache Creek affinity are juxtaposed with the Upper Cretaceous Montana Mountain volcanic complex by a possible northern extension of the Nahlin fault with considerable west-side-down motion.

The oldest rocks within the area are strongly deformed pre-Permian schists and allochthonous Mississippian Cache Creek lithologies which contain an anomalous Verbeekinid fusulinid fauna of presumable Tethyan origin (Monger, 1975, 1977). Laberge trough strata overlie pre-Permian basement rocks with profound unconformity, and together have suffered extensive deformation sometime between middle or late Jurassic to late Cretaceous time. Montana Mountain volcanic rocks of probable Late Cretaceous age post-date folding, but are crosscut by a late Cretaceous to Tertiary quartz monzonite body (Figure 1-20-2; Table 1-20-1).

LAYERED ROCKS

"BOUNDARY RANGES METAMORPHICS" (PPM)

The Boundary Ranges metamorphics are exposed in a gently plunging, tight to open fold pair within a northwest-trending belt 4 kilometres wide (Domain II of Figure 1-20-3). These metamorphic rocks are identical to those described by Werner (1977, 1978) south of the Wann River (Figure 1-20-1), and may also correlate with deformed strata to the north, previously known as the Yukon Group (Cairnes, 1913; Christie, 1957, 1958) and later incorporated under the name "Yukon crystalline terrane" (Tempelman-Kluit, 1976). Tempelman-Kluit suggests that the name Yukon Group be abandoned in favour of names that more accurately

[1] IUGS modal classification scheme of Streckeisen (1973) is used throughout.

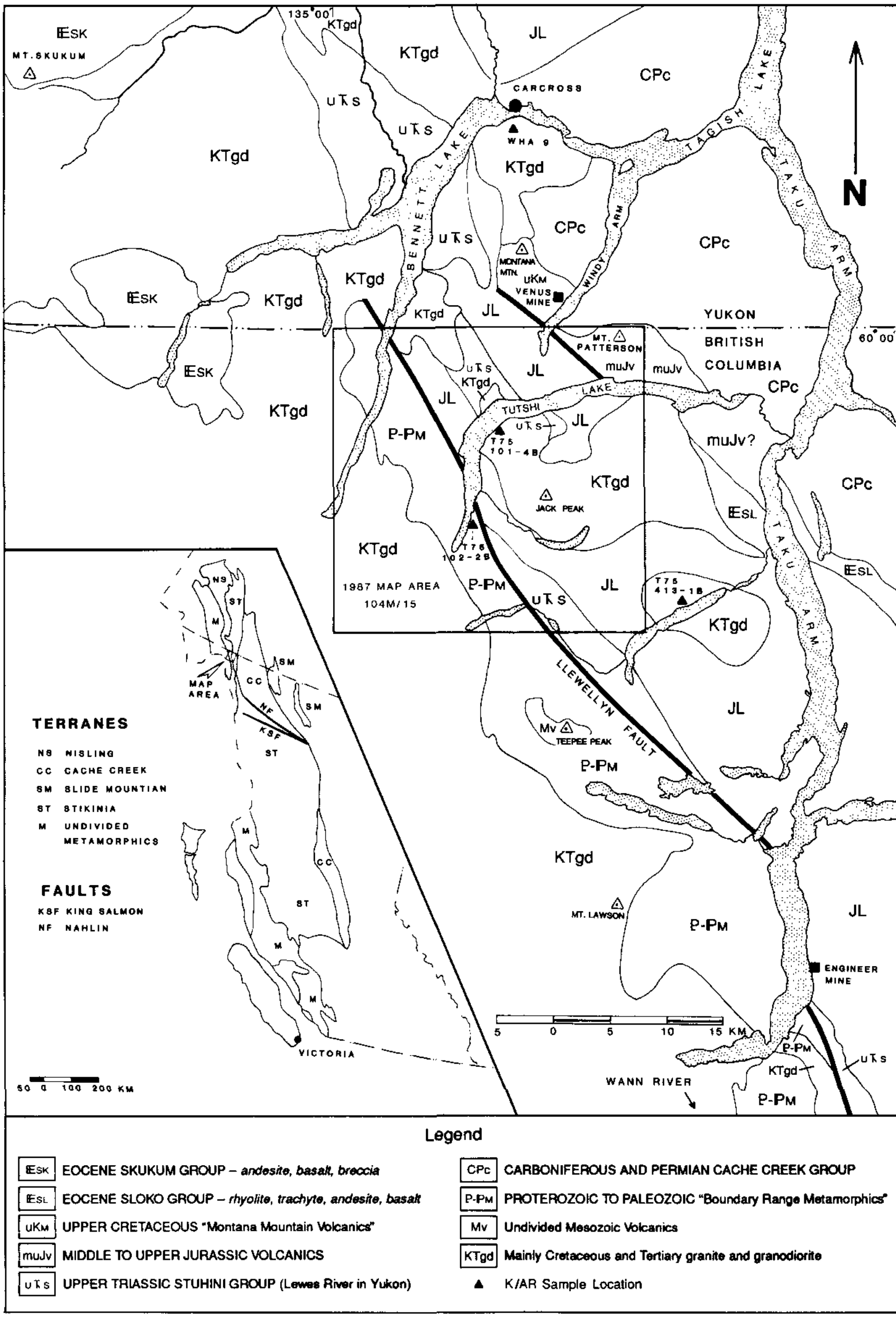

Figure 1-20-1. Regional geologic and tectonic setting of the Tutshi Lake map area (104M/15).

TABLE 1-20-1
ROCK FORMATIONS

Era	Period of Epoch	Formation	Lithology
Quaternary		Quaternary alluvium	Poorly sorted sands, gravels and till
Mesozoic	Upper Cretaceous?	Montana Mountain volcanics	Intermediate to felsic pyroclastics and flows; typically altered and orange weathering; crosscut by 64-Ma intrusive*
		Fault or intrusive contact**	
	Upper Cretaceous	Coast intrusions	K-feldspar megacrystalline granite varying to alkaline granite and granodiorite; dated at 77.9 and 89.5 Ma***
		Chilled intrusive contact	
		STIKINIA	
	Probable lower to mid-Jurassic	Volcanics	Dominantly variegated pyroclastic lapilli tuffs; rhyolitic tuffs; bladed-feldspar porphyry flows
		Unconformity and/or gradational	
	Lower Jurassic	Laberge Group, Inklin Formation	Siltstones, arenaceous wacks, argillites and conglomerates; rarely fossiliferous
		Erosional unconformity	
	Upper Triassic	Stuhini Group	Green pyroxene feldspar porphyry tuffs and breccias; variegated tuffs; minor tuffaceous sediments, limestone
		Erosional unconformity	
	Triassic?	Early intrusives	Polyphase granodiorite to alkali granite, typically sheared, foliated and/or altered
		Intrusive and/or faulted	
Paleozoic/ Proterozoic		**NISLING TERRANE**	
	pre-Permian (maximum age unknown)	"Boundary Ranges metamorphics"	Argillaceous siltstones, greywackes, lesser basalts, felsic pyroclastcis and carbonates; variably metamorphosed to upper greenschist grade
	Not observed — separate terranes assumed in fault contact, if at all		
		CACHE CREEK	
	Mississippian	Nakina Formation	Massive greenschist, altered basic flows and tuffaceous sediments

*Morrison *et al.* (1979)
**Observation of Roots (1980)
***Bultman (1979)

indicate the stratigraphic heterogeneity of this metamorphic package. Current nomenclature (Wheeler, 1987) includes the Boundary Ranges suite in the Nisling terrane.

Within 104M/15 these rocks are metamorphosed to upper greenschist facies although, in places, no secondary mineral development was observed in outcrop. Protoliths are variable but dominated by siltstone, lesser basalts and intermediate pyroclastic rocks and minor carbonates.

Insufficient petrographic work has been done to outline isograds or to fully characterize the secondary mineralogy. Extremely rapid changes in metamorphic mineralogy reflect not only varying protoliths, but also differing metamorphic grade. It appears that isogradic surfaces may be folded, or alternatively, faults subparallel to the Llewellyn fault may juxtapose metamorphic rocks of different grades.

The degree of deformation varies from locally nonexistent to more typically strong and pervasive. Schistosity or compositional banding may display polyphase, coaxial as well as disharmonic folding. Multiple phases of veining and microfaulting suggest a long metamorphic history (Plate 1-20-1; *see* also "Structure"). Some concordant quartz segregations and lesser discordant veins obtain thicknesses of 1 metre and may be boudined. These are generally barren, but just north of the Yukon border host pyrite, tellurides and free gold (Wheeler, 1961). Similarly, to the south, the Tonya (104M/9W) and Rupert (104M/8W) mineralized quartz vein showings have yielded assays of 23.31 grams per tonne gold and 237.6 grams per tonne silver respectively.

Plate 1-20-1. An outcrop of Boundary Ranges metamorphics on the ridges above and north of Skelly Lake. An earlier 290-degree fabric is paralleled by a 3-centimetre-thick quartz vein. The foliation displays the initial phases of transposition to the dominant regional structural trend of 340 degrees. Three-pound sledge hammer (38.5 centimetres long) for scale.

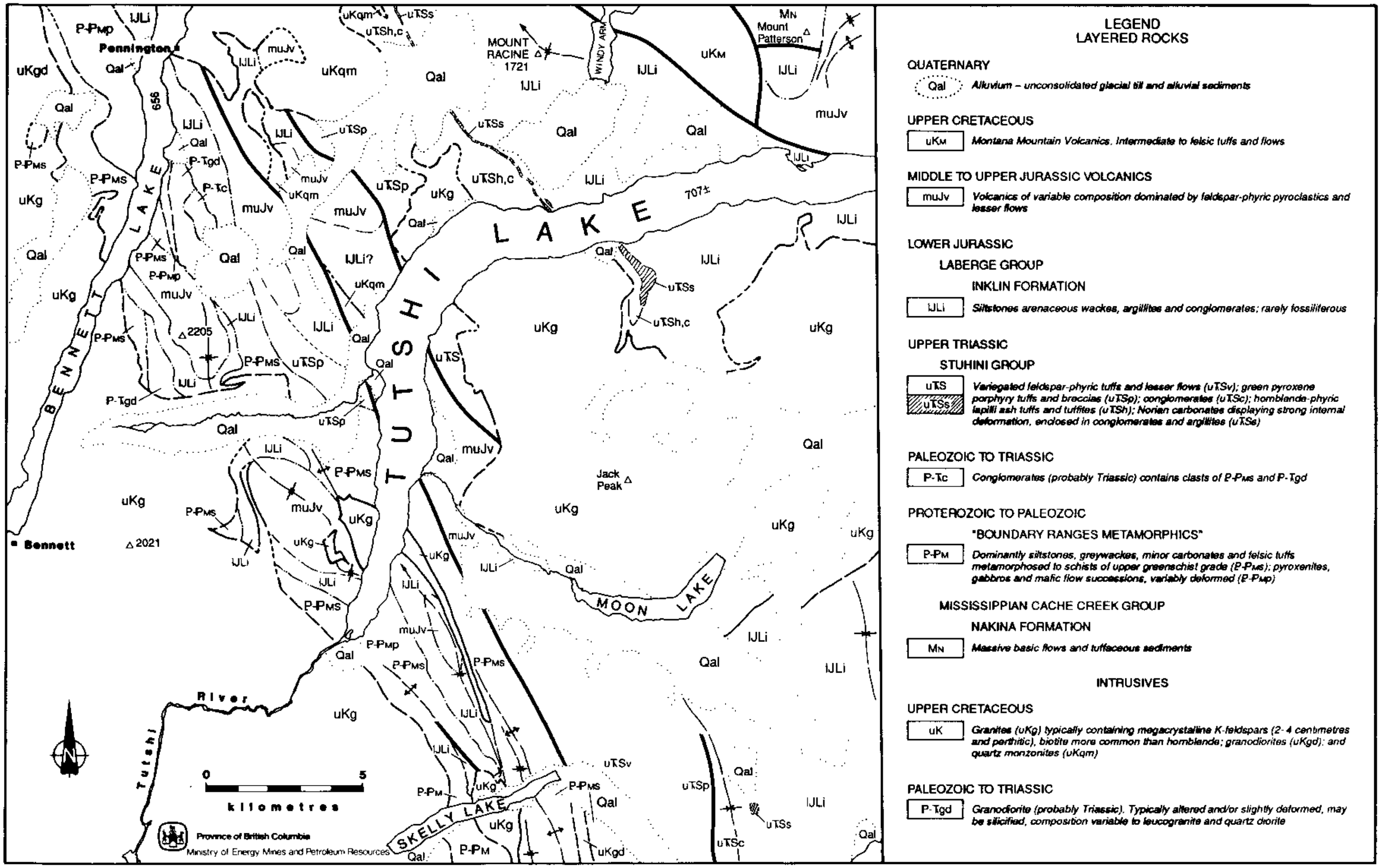

Figure 1-20-2. Preliminary simplified geology map of the Tutshi Lake area (104M/15).

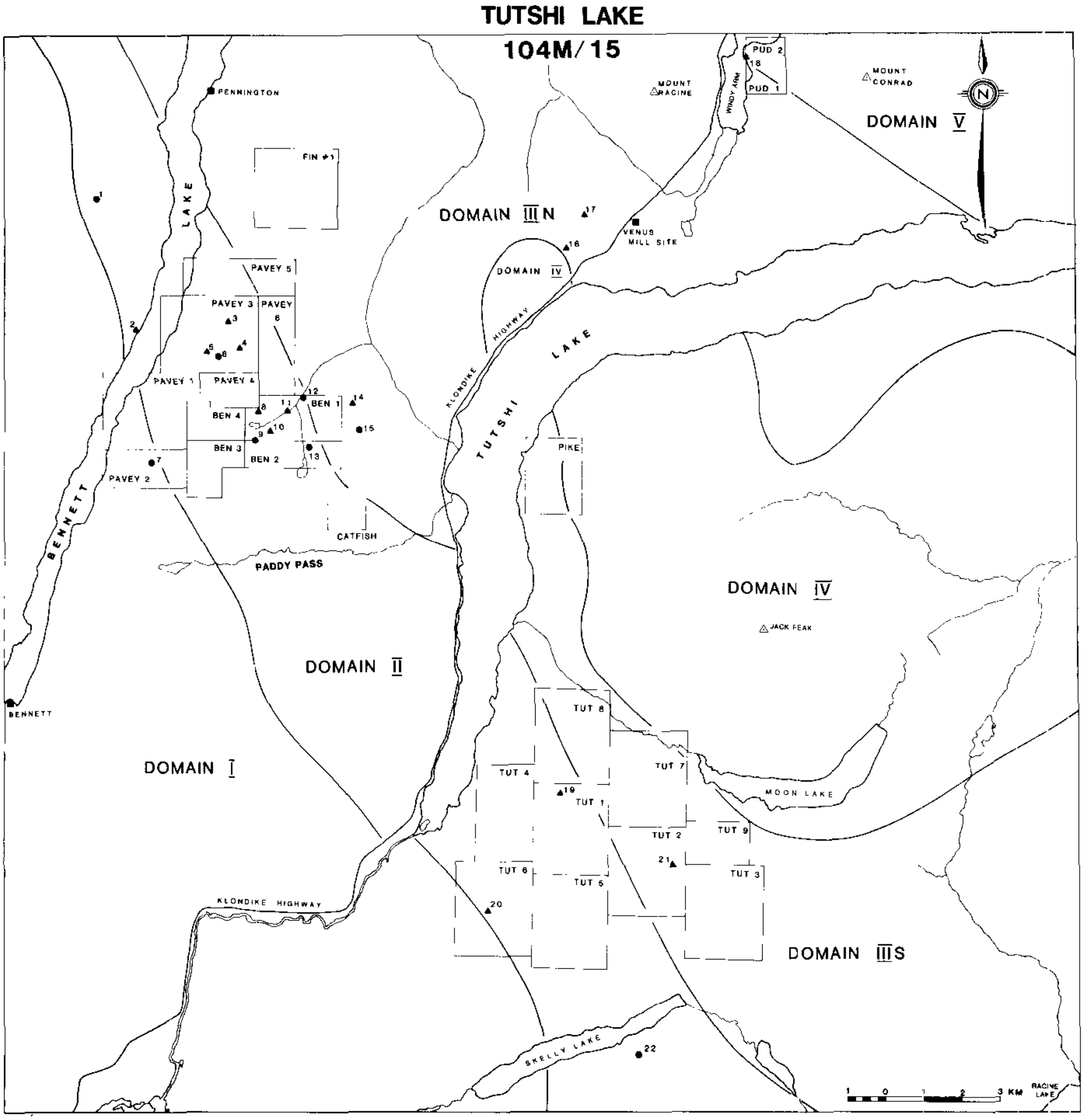

Figure 1-20-3. Distribution of current claims from Mineral Titles Reference Map 104M/15 and geologic domains. MINFILE localities are shown by solid triangles and circles (locations accurate within 250 and 500 metres respectively).

Due to structural complexity, little information on the general thickness, shape or facies relationships between various protoliths has been deciphered. Carbonate layers up to 5 metres or more thick are distinctive horizons within the metamorphic package, but are difficult to follow due to small offsets and shearing that produce discontinuous and podiform bodies. These strata were intruded by granodiorites, gabbros and pyroxenites prior to their final deformation.

The exact age of these rocks is difficult to assess; however, rocks of the Nisling terrane (Tempelman-Kluit, 1976) from north of the British Columbia – Yukon border are correlated with Paleozoic and Proterozoic sequences of the Omineca Belt. A porphyritic and foliated granodiorite that intrudes the metamorphic rocks was radiometrically dated by Bultman (1979) at 215 ± 5 Ma, yielding an upper age limit for the metamorphic suite.

EARLY INTRUSIVES (PTgd)

A diverse assemblage of pre-upper Triassic intrusive bodies occurs both within Domain II and on its faulted

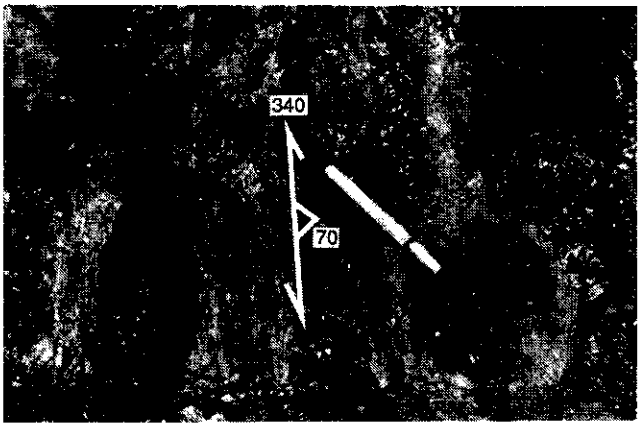

Plate 1-20-2. Llewellyn fault zone where exposed in a creek bed near the east end of Skelly Lake. A 10-metre or more wide zone of foliated fault gouge hosts aligned blocks of altered pre-upper Triassic intrusive rocks. Pen for scale is 13 centimetres long; view to the north-northwest.

eastern margin. Altered quartz diorites to quartz-veined leucogranites within the Llewellyn fault zone display a weak to strong foliation (Plate 1-20-2). Veins are broken and rotated within a matrix containing fine-grained gouge and brecciated and milled, subrounded to elongate, granitoid blocks. Mafic minerals (hornblende ?) comprise up to 20 per cent of the rocks and are altered to chlorite and epidote, while feldspars are clay altered.

Potassium feldspar porphyritic hornblende granodiorite to quartz monzonite is found mainly west of Bennett Lake and may be related to the "porphyritic granodiorite" of Bultman (1979) dated at 215 ± 5 Ma. It is foliated with aligned hornblende (20 per cent, up to 1.5 centimetres) and potassium feldspar phenocrysts up to 2 centimetres (25 per cent), within a plagioclase-rich matrix containing minor epidote, quartz and chlorite.

Pyroxenites to pyroxene gabbros occur adjacent to Bennett Lake. Pyroxenites are holocrystalline, and in places are carbonatized or serpentinized with minor chrysotile. Gabbros weather red and may display rare primary intrusive layering with chloritized pyroxenes in a white plagioclase-rich matrix, or may be sheared so that pyroxenes are boudined between layers of granulated plagioclase.

CACHE CREEK GROUP (MN)

Along the eastern side of Windy Arm, Monger (1975) describes a structureless sequence of massive flows as part of the Nakina Formation, one of the oldest units of the Cache Creek Group. Farther southeast along structural trend with these rocks, underlying Mount Patterson in the northeast part of the map area, a similar package of fine-grained, green, nondescript volcanics crop out. They display a network of chlorite veinlets and irregular dioritic patches and rare, sparsely pyroxene-porphyritic zones. Despite their altered external appearance, these rocks are surprisingly fresh upon microscopic analysis. Alteration is evident in the matrix with the presence of pumpellyite, prehnite(?), chlorite, epidote and sphene; however, unexpected in deformed rocks of this age, essentially pristine plagioclase and augite are also present.

The precise age of these rocks is not known, although if correlative with other Nakina Formation rocks of Monger (1975), they are probably Mississippian. Their contact with overlying rocks of Laberge Group affiliation is problematic. It is disrupted, but not penetratively deformed, and if rotated blocks at the contact preserve the original contact relationships, as appears to be the case, then a stratigraphic continuity is suggested. Upper contacts of Cache Creek rocks are sufficiently rare to warrant critical re-evaluation of that exposed on Mount Patterson. Roots (1982, page 17) documents a similar contact relationship just 7 kilometres to the northeast.

STUHINI GROUP (uTRS)

Rocks of the "Stuhini Group" of Kerr (1948) are equivalent to those north of the British Columbia – Yukon border originally called the "Lewes River series" by Cockfield (*in* Lees, 1934) and later modified to "Lewes River Group" by Wheeler (1961). Five distinct lithologies are recognized as members of the Stuhini Group in the Tutshi Lake area; these are: variegated lapilli and ash tuffs with minor argillaceous wackes and limestones; cobble and boulder conglomerates; coarse pyroxene-porphyry pyroclastics; epiclastics overlain by hornblende-feldspar porphyry breccias and tuffs; and wackes, argillites and conglomerates enclosing a continuous limestone interval 20 to 150 metres thick. These lithologies are generally confined to the area east of the Llewellyn fault.

Composite thicknesses inferred from outcrop patterns vary from 0 to 3000 metres; Stuhini Group deposition probably onlapped metamorphic highlands and was variably eroded prior to Laberge Group deposition (*see* Figure 1-20-4). The lower age limit of the Stuhini Group is well constrained by an extensive macrofossil fauna within the underlying King Salmon Formation (Tulsequah map area; Souther, 1971) that yields a Karnian age. Sparse conodonts acquired from black argillites and carbonates near the top of the Stuhini Group (C. Dodds, personal communication, 1987) yield a Norian age (M. Orchard, personal communication, 1987).

VARIEGATED TUFFS AND SEDIMENTS (uTRSv)

This package of red, brown and grey-green feldspar ± pyroxene-phyric lapilli tuffs locally gives way to immature sediments and thin (50-centimetre), unfossiliferous, marly limestone beds or pods (0.5 by 10 metres). The tuffs display pervasive chlorite alteration as well as patches of epidote up to 30 centimetres across. Lesser feldspar porphyry flows display similar alteration. Sediments are tan to black tuffaceous argillites in beds centimetres to decimetres thick. Where foliated, tuffs and sediments are carbonatized and display orange weathering. These tuffs and sediments are the most voluminous of Stuhini Group units within the map area and may acquire thicknesses of 2500 metres or more.

CONGLOMERATES (uTRSc)

Conglomerates are widely distributed within the Stuhini stratigraphy, occurring as mappable packages both within

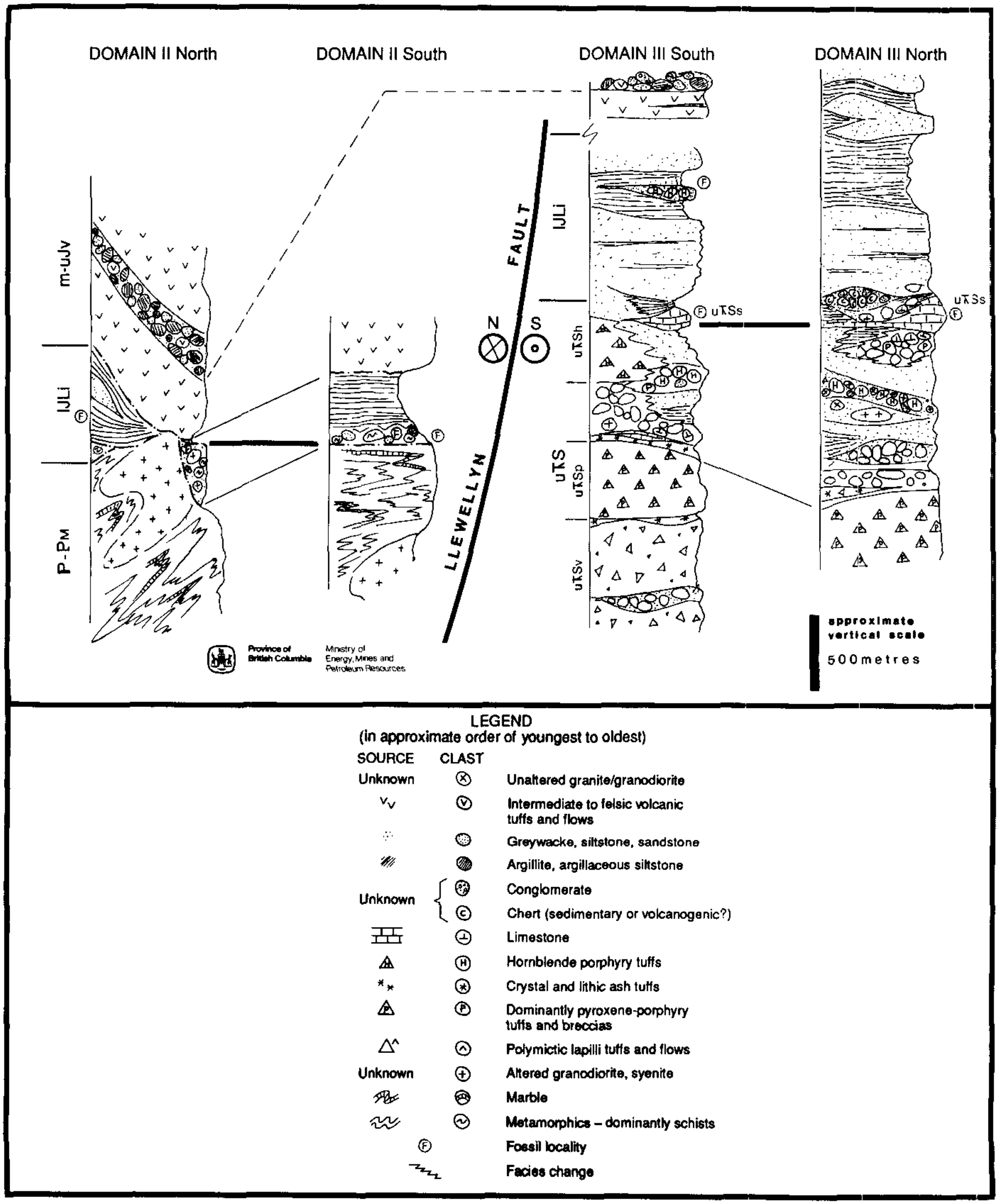

Figure 1-20-4. Stratigraphic correlation chart demonstrates the abrupt change in stratigraphy across the Llewellyn fault zone. Compiled from map outcrop patterns; thicknesses are not direct measurements. Only the Laberge Group of Domain II has both its upper and lower contacts exposed. Fold styles within the metamorphic rocks are diagrammatic, no vergence is implied.

Subunits uŦSv and uŦSh and above uŦSp and uŦSs, as groups of beds up to several hundred metres thick. Clasts are variable but generally dominated by either pyroxene or hornblende porphyries, altered granodiorite to syenite, or limestone. Other clasts include shale, fine-grained volcanic rocks, quartz and metamorphic rock granules. As more petrographic data are collected the presence and/or abundance of metamorphic clasts may be useful criteria in distinguishing Stuhini Group conglomerates from those of Laberge affiliation. Clast size is generally in the gravel to cobble range, but boulders up to 1 metre or more in diameter (particularly intrusive types) are present. These rocks are massive and thick bedded with coarse litharenite and wacke interbeds.

Green Pyroxene Porphyries (uŦSp)

Dark green pyroxene porphyries typify the Stuhini Group within the map area and are at least 450 metres thick. They are normally massive, coarse, monolithologic lapilli tuffs and breccias containing roughly 20 per cent pyroxene (up to 1 centimetre in diameter) and 40 per cent plagioclase. Well-layered interbeds of maroon crystal and lithic ash tuffs are common (2 to 10+ metres thick). Petrographic analyses reveal chlorite and serpentinite pseudomorphically replacing rare olivine phenocrysts. Igneous textures are typically well preserved except near structural or intrusive contacts where extensive alteration of pyroxene by actinolite, chlorite and epidote, and of plagioclase by white micas and prehnite, may occur.

Hornblende-Phyric Tuffs and Epiclastics (uŦSh)

These rocks are seen in two localities, immediately west of the Venus mill site and southwest of Moon Lake (near showing No. 21 on Figure 1-20-3) forming wedge-shaped packages. Observed thickness varies up to approximately 1500 metres.

This unit is characterized by grey-green to mauve and tan, dense, angular, hornblende-feldspar-phyric, fragmental volcanic rocks. Penecontemporaneous conglomerates contain a large proportion of clasts derived from this lithology as well as hornblende granodiorite (up to 1 metre diameter), syenite, limestone and cherty rocks.

Carbonate Unit (uŦSs)

The carbonate forms a continuous belt that can be followed from south of Tutshi Lake to north of the British Columbia–Yukon border within Domain III (Figure 1-20-3). It was mapped by Bultman (1979) as Upper Triassic Sinwa Formation equivalent based on lithologic similarity, and a continuity of its outcrop trend to where better exposed within adjacent map areas (Whitehorse, Wheeler, 1961; Tulsequah, Souther, 1971). It is in part podiform, perhaps representing patch-reef deposition, and is locally offset by small faults oriented nearly normal to its contacts. The carbonates display a striking degree of internal deformation. Disharmonic folding is outlined by graphitic layers, while extensive calcite vein development, up to 2 centimetres thick, accompanies recrystallization. Irregular black cherty stringers are locally present. The lower contact is locally gradational with argillites of decreasing carbonate content, while the upper contact and in places the lower one, are in abrupt contact with limestone-cobble conglomerates and greywackes. Thickness varies from less than 20 metres to approximately 150 metres and appears to be structurally thickened to 350 metres on the south side of Tutshi Lake, however, original depositional thickening due to carbonate build-up cannot be ruled out.

Macrofossils within this unit are sparse although crinoid ossicles, poorly preserved bivalves, and corallites can be found. A possible extension of the carbonate, 7 kilometres south-southwest of Moon Lake, is a sizeable outcrop of limestone with no exposed contacts, containing well-preserved fossils including colonial corals. A sparse conodont fauna collected from near the Venus mill yielded a Norian age (M. Orchard, personal communication, 1987; collected by C. Dodds).

LOWER JURASSIC LABERGE GROUP, INKLIN FORMATION (lJLi)

Cairnes (1910) used the "Laberge Group" to denote conglomerates, greywackes and argillites in a southeast-trending belt of miogeoclinal rocks recognized by Souther (1971) as the deep water Inklin Formation and shallow water Takwahoni Formation of the Whitehorse trough. Inklin Formation rocks underlie much of the eastern part of the map area where they are intruded by granitoid stocks. Thickness is difficult to assess due to widespread folding and minor thrust faults. Thickness estimates for the Inklin Formation within 104M and adjacent map areas range up to 7000 metres (Table 1-20-2). Uninterrupted successions within the western Tutshi Lake map area only reach 630 metres, although the maximum thickness is probably much greater. This thickness diminishes westward to where the Laberge stratigraphy is missing and Middle to Upper Jurassic volcanics rest directly on the Boundary Ranges metamorphic rocks.

Typical Laberge Group lithologies include conglomerate, greywacke, diamictite, immature sandstone and siltstone and both noncalcareous and weakly calcareous argillite. Conglomerates and greywackes tend to form massive beds while

TABLE 1-20-2
TABLE OF FORMATION THICKNESSES FROM ADJACENT AREAS

Group or Formation	Bultman (1979)	Souther (1971)	Wheeler (1961)
Stuhini Group and Lewes R. Group	Division A — up to 800 m Division B — 900–2500 m Division C — 200–450 m	~3600 m atop basal conglomerate	1000+ m
Inklin Fm.	5000–7000 m	~3100 m	1600 m, Montana Mtn.

argillites and siltstones are normally thinly bedded and may be laminated. Conglomerates commonly occur as tabular or lensoid bodies reflecting channelized deposition. Rapid lateral facies changes within the Inklin Formation are well portrayed by Wheeler (1961, Figure 7).

The age of the Inklin Formation in the Tutshi Lake map area is constrained by the Norian age of the underlying carbonate unit described above, and by a fossil collection of probable Toarcian age (H. Tipper and T. Poulton, personal communications, 1987) containing ammonites, brachiopods and pelecypods from within Inklin strata. Ammonites of probable Toarcian age from central Domain IIIN are particularly significant as these strata were originally mapped as Upper Triassic Stuhini Group (Christie, 1957).

MIDDLE TO UPPER JURASSIC VOLCANICS (muJv)

The nomenclature of Mesozoic and Tertiary volcanic rocks in northern British Columbia and southern Yukon is currently in a state of flux. The names used in this report are subject to change as a more refined understanding emerges. The unfossiliferous nature of these dominantly subaerial volcanics underscores the necessity for systematic radiometric age dating to establish relationships between isolated volcanic packages.

Intermediate to felsic pyroclastics and intermediate to mafic flows are found coring synclines in Domain II, as a downfaulted block in Domain V, and as small isolated packages throughout Domain IIIN. Nowhere is a complete section observed, however, a continuous section near Pennington is at least 650 metres thick.

Typical lithologies include: dark grey-brown, bladed-feldspar porphyry flows 5 to 20 metres thick, with interflow lapilli tuffs of the same composition; maroon to green, well-bedded, angular felsic lapilli ash tuffs; massive dark green angular lapilli tuffs; rhyolite ash flows and rare lava flows (mainly in Domain V); maroon, grey and green feldsparphyric flows and coarse pyroclastics; interbeds of conglomerates derived primarily from underlying Inklin Formation strata; bladed-feldspar crystal ash tuff; and polymictic felsic lapilli tuffs.

These rocks are younger than the underlying Inklin Formation (Lower to early Middle Jurassic), and older than a crosscutting granite dyke in Domain II dated at 77.9 ± 1.6 Ma (Table 1-20-3; Bultman, 1979). A deformational event folds these strata, but does not affect the younger Montana Mountain volcanics or crosscutting granites.

MONTANA MOUNTAIN VOLCANICS (uKm)

Montana Mountain volcanics within the map area are so called because of their similarity with rocks of the adjacent Montana Mountain volcanic complex mapped by Roots (1982). The rocks have been previously mapped as "Volcanics of uncertain age" by Christie (1957), Hutshi Group by Wheeler (1961), and Sloko Group by Monger (1975). Roots considered the Montana Mountain complex equivalent in both character and age to better defined Mount Nansen Group rocks exposed in adjacent map areas to the north.

TABLE 1-20-3
ISOTOPIC AGE DATA
(See Figure 1-20-1 for locations)

Source	Sample No.	Isotopes	Age (Ma)
Bultman, 1979	T75 101-4b	K-Ar/biotite	89.5 ± 2.6
Bultman, 1979	T75 102-2b	K-Ar/biotite	77.9 ± 1.6
Bultman, 1979	T75 413-1b	K-Ar/biotite	82.0 ± 2.1
Morrison *et al.*, 1979	WHA9	K-Ar/biotite	64.3 ± 2.2

Within 104M/15 Montana Mountain volcanics are restricted to the northeastern part of the map area. They are dominantly orange-buff weathering and poorly to nonwelded acid lapilli tuffs and rhyolite flows. Remnant feldspars and quartz phenocrysts are recognized in hand sample. Microscopic examination reveals glomeroporphyritic plagioclase (and sanidine ?), partly altered to calcite, chlorite, sericite and epidote, embayed quartz and rare muscovite.

INTRUSIVE ROCKS (uKg, gd, qm, d)

Intrusive rocks of Cretaceous and earliest Tertiary age are widespread throughout the map area, occurring as part of the main mass of the Coast Crystalline belt to the west (Domain I) or as satellite plutons and stocks to the east (Domains III and IV). Dykes are both temporally and compositionally diverse. The predominant rock type is coarse-grained hornblende biotite granite with perthitic, megacrystalline potassium feldspar. Variations to finer grain sizes are common and contacts are typically chilled for widths of over 30 centimetres to many metres, where they appear as quartz-eye porphyries. Due to the high level of intrusion, the country rocks are not extensively hornfelsed, although skarn development may occur within calcareous units tens of metres away from these contacts. Mariolitic cavities were seen at one locality along the eastern shore of Bennett Lake. As further evidence of the high level nature of these intrusive bodies, rapakivi textures exist in the Domain IV Jack Peak stock and Domain III quartz monzonites. These textures are common within intrusive bodies that have been emplaced very near the earth's surface and have associated felsic volcanic outpourings. Compositions vary from granodiorite and quartz monzonite to alkali granite. Garnet and muscovite are rare accessory phases visible in hand sample. Petrographic analyses indicate that sphene and apatite are common.

Two isotopic age dates are available from the plutonic suite within the map area, and two others from adjacent sheets to the north and southeast are shown in Table 1-20-3.

CONTACT RELATIONSHIPS

Contacts within the map area are complicated by extreme fold amplitudes and consequent shearing on fold limbs, and widespread, profound angular unconformities which are, in places, difficult to distinguish from juxtaposition by faulting.

Boundary Ranges Metamorphics: The base of the Boundary Ranges metamorphic suite was not recognized, although pyroxenite bodies in northern Domain II and/or metabasalts may represent the basement lithologies atop which the Boundary Ranges sedimentary and volcanic protoliths were deposited. This speculation requires further investigation.

The upper contact of the metamorphic package is well exposed in Domain II, particularly on the ridges north and west of Skelly Lake, where the Laberge Group rests upon it with angular unconformity. Here an overlying basal conglomerate contains rounded clasts of metacarbonate; strained quartz and muscovite schists typical of the underlying metamorphic suite; a matrix of coarse wacke of Inklin Formation affinity; and well-preserved belemnites (Plate 1-20-3).

Just east of Bennett Lake, "Middle to Upper Jurassic Volcanics" rest directly on altered granodiorites of the Boundary Ranges metamorphics, indicating that the Laberge and Stuhini Group strata have been eroded or were never deposited at this locality. Nearby, the top of the metamorphic suite is represented by a conglomerate more than 500 metres thick, almost exclusively containing clasts of underlying schists and altered granodiorite.

Stuhini Group: The contact between the Stuhini Group and the underlying metamorphic terrane is exposed north of Paddy Pass where it displays attributes of both a stratigraphic and a tectonic contact. At this locality fragmental pyroxene porphyry and sandstone fragments are separated from schists by a carbonate-cemented shear zone 20 centimetres wide. No penetrative fabric suggestive of a tectonic contact is developed within Stuhini Group strata adjacent to the shear; on the other hand, no metamorphic clasts are found within the overlying Stuhini Group.

The top of the Stuhini Group is not clearly marked. Rather, the contact appears gradational in as much as the general lithologies above and below the limestone member are for the most part indistinguishable. Nevertheless the contact must be near the top of the limestone marker as this unit is apparently correlative with Sinwa Formation limestone (Bultman, 1979) that occurs between the Stuhini and Laberge groups.

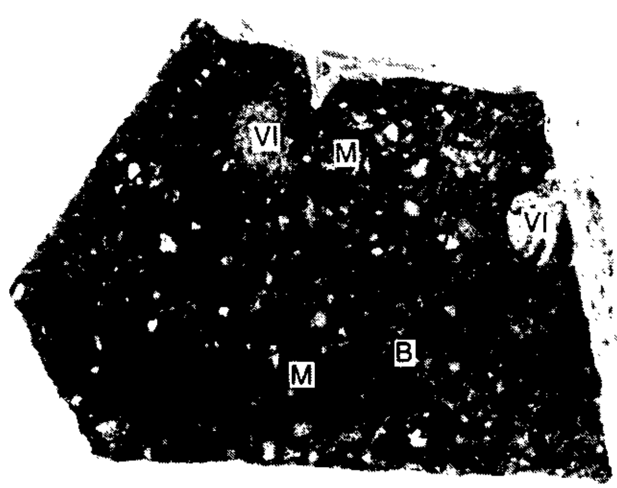

Plate 1-20-3. A conglomerate overlying Boundary Ranges metamorphics on the ridges north of Skelly Lake. Clasts derived from the underlying metamorphic rocks (M) are abundant within a lithic wacke matrix of Laberge Group affinity. Belemnites (B) are common at the locality from where the sample was taken. Clasts of fine-grained intrusive or volcanic origin (VI) are also present (Stuhini Group?).

Laberge Group: The upper contact of Laberge Group strata is exposed at several localities. One of the most continuously exposed contacts is near Pennington, where the contact is undulating and erosional, with olistostromal blocks of Inklin Formation argillites found within Middle to Upper Jurassic volcanic rocks. On the west side of southern Tutshi Lake, bladed-feldspar crystal tuffs, rhyolitic lapilli tuffites and pillow breccias (?) at the base of the Jurassic volcanics appear to have an argillaceous matrix. A thick conglomerate within the volcanic sequence is comprised partly of volcanic clasts, but predominantly of well bedded siltstones and argillites of the underlying Inklin sediments. It is suggested that the volcanics were deposited on an irregular, uplifted but partly submarine surface of Inklin Formation strata.

Contact relationships between the Nakina Formation and the Montana Mountain volcanics and the units described above are unknown in the Tutshi Lake area. However, rocks that are probably related to the Montana Mountain volcanics (Roots, 1982) are exposed in the Tagish Lake area, and appear to have been laid down upon an irregular surface of the Cache Creek Group (Monger, 1975).

STRUCTURE

The dominant structural trend within the map area is outlined by the surface traces of the Llewellyn fault zone (Figure 1-20-2) and major fold hinge surfaces, both oriented at 340 degrees. At this latitude the axis of the Whitehorse trough and bounding terranes are coincident with this trend.

Folds: Fold styles west of the Llewellyn fault are dominantly isoclinal to open and upright horizontal. To the east, horizontal to inclined-plunging folds are common, especially within Laberge Group strata (Plates 1-20-4, 1-20-5). Based upon dip isogons, folds are generally divergent (and chevron) to similar and typically have long limbs. Major folds within Laberge Group strata tend to decrease in amplitude and increase in wavelength toward the northeast, although minor tight folds superimposed upon their limbs are abundant. A strong axial planar foliation is developed within the hinges of tight folds. These axial surfaces are not folded except by late kinks produced by minor fault displacements. Minor warping of major folds has resulted from emplacement of intrusive bodies such as the Jack Peak stock.

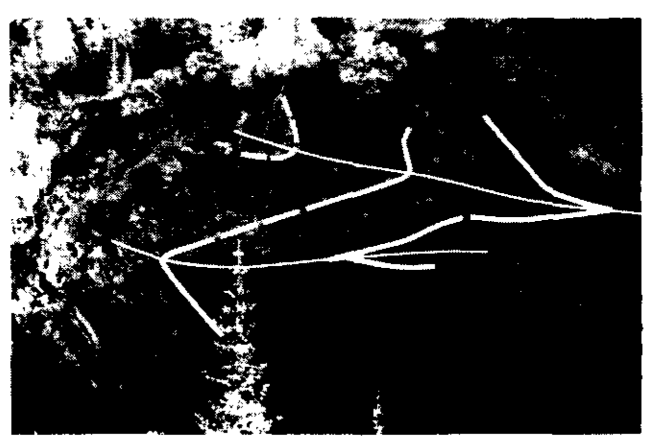

Plate 1-20-4. Open to tight, reclined chevron folds within Inklin Formation strata.

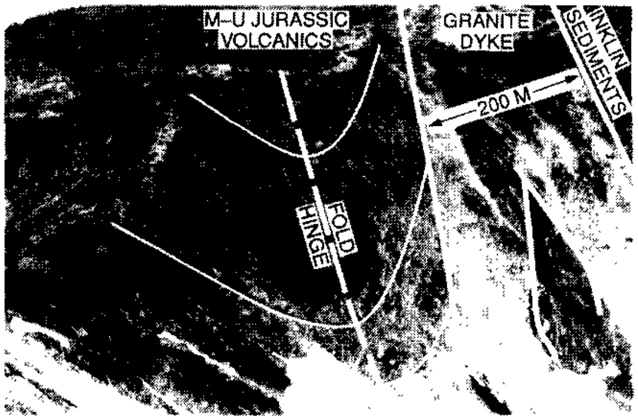

Plate 1-20-5. Close to open fold style within Middle to Upper Jurassic volcanics which overlie Lower Jurassic Inklin Formation rocks on the ridges east of southern Tutshi Lake.

Folding within the metamorphic basement appears to be dominantly coplanar and tight to isoclinal, similar and upright. Metamorphic rocks also display disharmonic folding and limbless or decapitated folds. Hingelines typically plunge less than 20 degrees both northerly and southerly. Vertical folds are not unknown, particularly within zones of disharmonic folding. Evidence for noncoplanar folding is seen in at least one sample where a crenulation cleavage strongly overprints the previous foliation. Curving hinge traces on the map do not necessarily represent a succeeding phase of folding, rather their formation is probably synchronous with formation of the dominant late fold trend.

The deformational history is difficult to ascertain due to the prevalent coplanar folds, the likelihood that prior structures have been transposed into their current configuration by shearing at 340 degrees azimuth, and the lack of continuous marker horizons. An earlier fabric oriented at 290 degrees is preserved in rare instances and is incipiently transposed to 340 degrees (Plate 1-20-1) probably by dominantly dextral shear. Multiple phases of veining, which are later crosscut, folded and rodded, point to a long and continuous deformational process.

Faults: Faults throughout the map area reflect the presence of tight, high amplitude folds with much interstratal slip, or proximity to the Llewellyn fault zone of Bultman (1979). The Llewellyn fault is a major structure that marks the eastern limit of Boundary Ranges metamorphic rocks and a westward change to much thinner Laberge Group strata. As such, it is clearly a feature of regional significance that represents a long-lived zone of structural weakness along which felsic bodies intruded and were later deformed to produce an anastamosing gouge network enclosing sheared, aligned, clay-altered and silicified lenses of intrusive rock (Plate 1-20-2). Latest motion predates felsic crosscutting dykes of the same suite which cut the Jack Peak stock and deformed Middle Jurassic volcanic strata. A west-side-up motion is superimposed on the dominantly transcurrent Llewellyn fault at its south end, in contrast to a east-side-up displacement at its northern end.

Other faults may be related to emplacement of intrusive bodies and do not necessarily conform to the regional trend. An inferred fault defining the southwest boundary of Domain V is thought to have mainly normal motion in juxtaposing Mississippian and Upper Cretaceous strata. Faults cutting intrusive rocks are brittle features represented by zones of shattered and clay-altered rock that are generally less than 2 metres wide.

Low-angle or bedding-parallel faults with demonstrable reverse motion were seldom observed within Inklin Formation strata. However, where exposed along the Klondike Highway at the south end of Tutshi Lake, these rocks are cut by closely spaced faults subparallel to bedding and trending 340 degrees. Motion along these faults is difficult to estimate but at the scale of mapping may be significant, and assuming a consistent reverse sense of motion, they are likely responsible for considerable thickening.

Motion on the Llewellyn fault zone may be partly linked to underthrusting on the King Salmon fault (Bultman, 1979) since the traces of these two fault systems merge near the southern end of Atlin Lake. However, the Llewellyn fault also appears to be involved in the formation of the western margin of the Whitehorse trough, as evidenced by the thinned Early to Middle Mesozoic strata to the west of the fault, and was probably active by Early Jurassic times. Late Early to early Middle Jurassic motion on the King Salmon fault (Thorstand and Gabrielse, 1986) must post-date initial motion on the Llewellyn fault. Displacement on the Llewellyn fault, if consistent with linkage on the King Salmon fault system, must necessarily be dominated by dextral transcurrent motion. Mesoscopic kinematic indicators are consistent with dextral motion but are not totally unambiguous (Plate 1-20-1; a microstructural analysis is currently underway). Subparallel fault zones are evident at many localities within Domain II; however, fault-related deformation appears to be concentrated in a zone several metres to tens of metres across (the Llewellyn fault). Two lines of evidence suggest that total displacement may be considerable: the change in apparent thickness of Laberge sediments from one side of the fault to the other, and the change in abundance of Stuhini Group rocks across the fault.

MINERALIZATION

Exploration within the map area dates back to 1897 when a major influx of prospectors bound for the Klondike goldfields passed the shores of Bennett Lake. Current interest is represented by the distribution of claims shown in Figure 1-20-3; staked ground is largely restricted to the rocks of Domain II. A brief description of each prospect is provided in Table 1-20-4. Host rocks range from Boundary Ranges metamorphics to Late Cretaceous intrusives.

Showings are of two major types: stibnite-bearing veins within dilatent zones with or without concomitant shearing, these also host galena, sphalerite and arsenopyrite; and sheared quartz-carbonate-altered zones within Triassic volcanics, these contain brecciated galena and sphalerite. Showings of more restricted occurrence are of several types: arsenopyrite and pyrite, with or without sphalerite, stibnite and galena, concordant with foliation in chlorite schists of the metamorphic suite; a small body containing angular carbonate fragments in a matrix of massive sphalerite and galena; and altered and sheared mafic volcanics (Stuhini ?)

TABLE 1-20-4
MINERAL OCCURRENCES — NTS 104M/15

No.	Name (MINFILE No.)	Commodity	Assay	Sample width (reference)	Description
1	Bennett Lake (104M 032)	Limestone	NA	NA	Stratified recrystallized limestone within pre-Permian metasediments, local garnet-epidote skarn development.
2	Gridiron (104M 001)	Au	3.2 g/t	grab	Up to 1-metre-wide quartz veins within silicified and talcose fault zones of pre-Permian metamorphics; mineralization has developed along the contact of the Coast complex and the Nisling terrane.
		Ag	315 g/t	grab	
		Pb	2.0%	grab	
		As	1.3%	grab	
		Sb	NA	NA	
		Zn	NA	NA	
			(AR 10425)		
3	Gaug 1 (104M 040)	Ag	93.9 g/t	grab	Disseminated to massive copper-magnetite mineralization concentrated along a 4-metre-wide shear zone within Triassic (?) altered granodiorite.
		Cu	9.5%	grab	
		Fe	NA	NA	
			(AR 11044)		
4	Gaug 2 (104M 039)	Au	1.20 g/t	grab	East-trending shear zone bearing stibnite-arsenopyrite-pyrite-chalcopyrite-sphalerite-galena-rich quartz veins within altered Triassic (?) granodiorite.
		Ag	53.8 g/t	grab	
		Cu	0.71%	grab	
		Sb	0.28%	grab	
		Zn	NA	NA	
		Pb	NA	NA	
			(AR 11044)		
5	Silver Queen-North, Gaug-west (104M 038)	Au	15.9 g/t	1.0m chip	Disseminated to massive stibnite-galena-bearing quartz veins hosted within a 2-metre-wide fracture-controlled zone cutting the border phase of the Coast complex near its contact with Jurassic volcanics.
		Ag	394 g/t	1.0m chip	
		Pb	NA	NA	
		Zn	NA	NA	
		Cu	NA	NA	
		Sb	NA	NA	
			(AR 12554)		
6	Bald Peak, Gaug-South (104M 028)	Au	8.0 g/t	70cm chip	Silicified shear zone within rhyolites of Jurassic age contains mineralized quartz veins up to 70 centimetres wide.
		Ag	212 g/t	70cm chip	
		As	4.8%	70cm chip	
			(AR 11044)		
7	Silver Queen, Net (104M 002)	Ag	NA	NA	Pyrite, chalcopyrite and malachite staining occur along the contact between pre-Permian metamorphics and the Coast complex.
		Cu	NA	NA	
8	Ben Pond (104M 041)	Ag	90.6 g/t	3.3 m chip	A 3-4-metre-wide, disseminated to massive stibnite-galena-sphalerite occurrence follows the northwest-trending fault contact between pre-Permian metamorphics and Jurassic Laberge Group argillites.
		Pb	1.50%	3.3 m chip	
		Sb	1.30%	3.3 m chip	
		Zn	NA	NA	
			(AR 12554)		
9	Ben-Glacier (104M 043)	Au	6.60 g/t	grab	A 2-centimetre-wide fracture cutting Jurassic Laberge Group greywackes contains a primary cobalt mineral, erythrite staining and pyrite.
		Ag	1.70 g/t	grab	
		Co	0.37%	grab	
			(AR 12554)		
10	Ben-Camp (104M 042)	Au	12.5 g/t	grab	An irregular, discontinuous quartz vein appears to follow the pre-Permian metamorphic/Jurassic Laberge Group argillite contact.
		Ag	2136 g/t	grab	
		Pb	—	—	
		Zn	—	—	
			(AR 12554)		
11	Ben Creek (104M 003)	Au	0.32 g/t	1.0 m chip	A 1-metre-wide zone of sulphide mineralization parallels foliation in pre-Permian metamorphics.
		Ag	108 g/t	1.0 m chip	
		Pb	—	—	
		Zn	—	—	
		Sb	—	—	
			(AR 12554)		
12	Paddy (104M 044)	Au	3.7 g/t	grab	A narrow mineralized quartz vein occurs just southwest of a northwest-trending fault contact between pre-Permian schists and Upper Triassic Stuhini Group volcanics.
		Ag	338 g/t	grab	
		Pb	2.3%	grab	
		Cu	—	—	
		Zn	—	—	
			(AR 12554)		
13	Ben-Four (104M 047)	Au	22.7 g/t	grab	A 30 to 50-centimetre quartz vein is hosted within pre-Permian metamorphics.
		Ag	8.0 g/t	grab	
			(AR 12554)		
14	Ben-Northwest (104M 045)	Au	13.4 g/t	grab	Arsenopyrite-rich quartz veins up to 30 centimetres wide occur within three parallel shear zones in Upper Triassic Stuhini Group volcanics.
		Ag	1.20 g/t	grab	
			(AR 12554)		

TABLE 1-20-4—*Continued*
MINERAL OCCURRENCES — NTS 104M/15

No.	Name (MINFILE No.)	Commodity	Assay	Sample width (reference)	Description
15	Ben-Southeast (104M 046)	Au Ag Pb Cu	0.10 g/t 253.7 g/t 1.40% —	grab grab grab —	Galena-chalcopyrite-rich vuggy quartz veins up to 30 centimetres wide occur in Upper Triassic Stuhini Group volcaniclastic breccias.
			(AR 12554)		
16	Unknown	mag Cu	NA NA	NA NA	A 1.5-metre-wide northwest-trending fault-controlled magnetite-rich zone is exposed by trenches in Upper Triassic Stuhini Group pyroxene porphyries.
17	Unkown	NA	NA	NA	An adit follows a 1.5-metre-wide silicified shear zone trending northwest and containing 2–3% disseminated pyrite and chalcopyrite within Upper Triassic Stuhini Group sediments.
18	Pud	NA	NA	NA	Near its contact with Mid-Jurassic Laberge Group argillaceous shales, pre-Late Cretaceous Mount Nansen Group volcanics host a 1-metre-wide discontinuous quartz vein within a clay-altered shear zone.
19	Nasty Cirque	Au Ag Pb Zn	78 g/t 617 g/t NA NA	grab grab NA NA	Localized 3 by 4-metre high-grade galena-sphalerite mineralization of enigmatic origin.
			(AR 15500)		
20	Jessie, Big Thing (104M 027)	Au Ag Cu Pb Zn	5.2 g/t 809 g/t 4.9% NA NA	1.5 m chip 1.5 m chip 1.5 m chip NA NA	A 1.8-metre-wide northwesterly trending shear zone occurs in pre-Permian metamorphics at the eastern contact of the Coast Complex.
			(EMPR AR 1929, Pg 120)		
21	Moon Lake (104M 057)	Au Ag Cu Pb Zn As	6.4 g/t 490 g/t 4.0% 1.4% 0.3% 1.4%	grab grab grab grab grab grab	Disseminated arsenopyrite-pyrite-galena-chalcopyrite-sphalerite mineralization is hosted in quartz-carbonate-altered Upper Triassic Stuhini Group pyroxene porphyries, tuffs and breccias.
			(AR 15500; EMPR-Schroeter, 1986)		
22	Shelly (104M 052)	Cu Pb	NA NA	NA NA	Small skarn zones within pre-Permian metamorphics display minor disseminated pyrite-chalcopyrite-galena; mineralization develops near the metamorphic/Coast intrusive contact.

NA = not available.

hosting disseminated pyrite and chalcopyrite within the Llewellyn fault zone. For a review of showings between Venus mine and the Engineer mine *see* Schroeter, 1986.

Stibnite-bearing Veins: These veins are widespread on the Ben and Gaug claim blocks. They occur within altered pre-Triassic felsic intrusives (Table 1-20-4, No. 4); at the sheared contact between Boundary Ranges metamorphics and Laberge Group argillites (Table 1-20-4, Nos. 8, 10, 12); and within the chilled margin (quartz-eye porphyry) of the granitic Coast intrusions (Table 1-20-4, No. 5). At the first four occurrences, veins typically have sheared walls, as exposed by trenches over strike-lengths of up to 4 metres. Occurrence 5 is a vein system continuous over at least 15 metres and striking parallel to the prevalent joint direction of 065 degrees.

If all stibnite-bearing veins represent the same mineralizing event then they must all post-date the Upper Cretaceous granitic host of occurrence 5 and are thus likely related to the late-stage, low-temperature thermal aureole associated with Upper Cretaceous intrusions.

Quartz-carbonate Alteration: An orange-weathering quartz-carbonate-altered shear zone within Stuhini volcanics was the most active prospect within the map area in 1987 (Table 1-20-4, No. 21). The main mineralized zone measures approximately 100 by 300 metres with similarly altered but weakly mineralized or barren rocks occurring within a belt having a strike length of at least 2.5 kilometres. The mineralization is brecciated and sheared parallel to the regional trend and lies immediately adjacent to the Llewellyn fault. Galena and sphalerite locally comprise up to 25 per cent of the rock and weather out from the carbonate-rich matrix. Best available assays to date are 6.4 grams per tonne gold and 490 grams per tonne silver. The alteration and structural setting of this prospect are analogous to that of the Polaris Taku mine to the south (Tulsequah map area; produced from 1937 to 1951). A MINFILE survey of 104M and 104K shows that in over 50 per cent of the prospects where data are available mineralization is associated with shear zones.

Within 104M/15 preliminary analytical results from shears and veins (Figure 1-20-5) indicate that Stuhini Group volcanics have anomalous background gold values with respect to most other rock types in the area. It is not known whether this is a function of the primary abundance of gold in Stuhini Group rocks or the suitability of these rocks as a locus for auriferous mineral deposition. In light of the fact that most prospects within 104M and 104K are shear related, and past producing mines such as the Polaris Taku have this same structural setting, major fault zones within Stuhini Group rocks are likely exploration targets.

Polymetallic Sulphide Replacement Zones found within the Boundary Ranges metamorphic suite are subparallel with foliation (Table 1-20-4, No. 11) or, in one instance, form a subvertical discordant body of carbonate breccia with massive sulphide matrix (Table 1-20-4, No. 19). The ability to trace the continuation of such bodies within the metamorphic rocks is largely contingent upon accurately interpreting structures and calculating the direction and amount of displacement on minor faults.

Sheared Basic Volcanics: A grab sample of sheared basic volcanics (Stuhini ?) crosscut by hypabyssal dioritic intrusives, collected from where the Klondike Highway crosses the trace of the Llewellyn fault, contained minor disseminated pyrite, chalcopyrite and chalcocite and assayed 100 ppb gold.

Late and extensive vein systems, such as those at the Venus and Engineer mines, are mesothermal fissure-filling veins within Montana Mountain volcanics and Inklin Formation respectively. Evidence of shearing along vein margins is abundant in the Venus mine, while at the Engineer, pay veins tend to occur along splays of the Llewellyn fault. Clearly these faults are important conduits for the upward movement of mineralizing solutions. Similar faults occur throughout the Tutshi Lake area, due to the convergence of tectonic elements and a complex geologic history. Understanding the relationship between tectonic activity and mineral deposit genesis is one of the objectives of this continuing study.

Sample No.	UTM Coordinates E	N
MMF 22-7	510350	6649050
MMM 3-2	501945	6650500
MMM 5-2	501215	6655000
MMM 2-7	503945	6614375
MMM 8-4	502355	6642200
MM 21-12	507175	6647875
MM 23-5	507750	6646800
MMF 2-4	514350	6641050
MM 26-7	522200	6627275
MM 0-1	516050	6646250
MMF 1-6	517300	6644900
JR 1-3	501540	6645600
MM 10-5	514950	6645300
MM 28-7	517350	6629725
MM 6-2	511750	6637800
MMF 8-2	514500	6645250
MMM 27-2	520700	6629600
MMM 27-5	520400	6629800
MM 11-9	509200	6639400
MM 24-5	502000	6650575
MM 24-6	501775	6650350
MMM 12-1	501175	6635500
MM 24-7	501700	6650075
MMM 24-3	502375	6648875
MM 25-1	502450	6647450
MM 25-4	502200	6646850
JR 23-4A	501800	6646200
JR 23-4B	501800	6646200
MMF 24-3	502450	6647500
MMF 23-7	501600	6648650

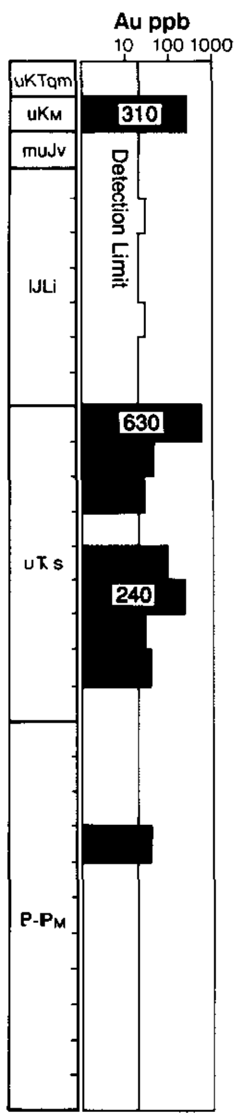

Figure 1-20-5. Histogram of gold analyses as a function of stratigraphic position. Sample MMM 3-2 is from a MINFILE occurrence (Pud claims, No. 18 on Figure 1-20-3).

SUMMARY

New fossil data indicate that the Jurassic Inklin Formation is more widespread within the map area than was previously recognized. In the west-central map area these strata appear to be deposited on pre-Permian metamorphic "basement" termed the "Boundary Ranges metamorphics". A major fault zone, considered the extension of the Llewellyn fault of Bultman (1979), bisects the map area and is parallel to the dominant structural trend of 340 degrees. This fault marks the eastward extent of the Boundary Ranges metamorphics and a significant change in the thickness of Mesozoic strata, suggesting considerable fault displacement.

Latest folding post-dated a probable Middle to Upper Jurassic volcanic package and pre-dates the Montana Mountain complex of pre-Late Cretaceous age.

Although data are preliminary, analytical results from veins, shears and mineralized zones within Stuhini Group strata yield background gold values that are anomalous with respect to other map units within the study area. Also, many of the past gold producers within the same physiographic belt in northernmost British Columbia are associated with fault structures. Clearly Stuhini volcanics adjacent to the Llewellyn fault zone are an attractive mineral exploration target, but the potential of other lithologies as hosts to economic mineralization in this structural environment should not be ignored.

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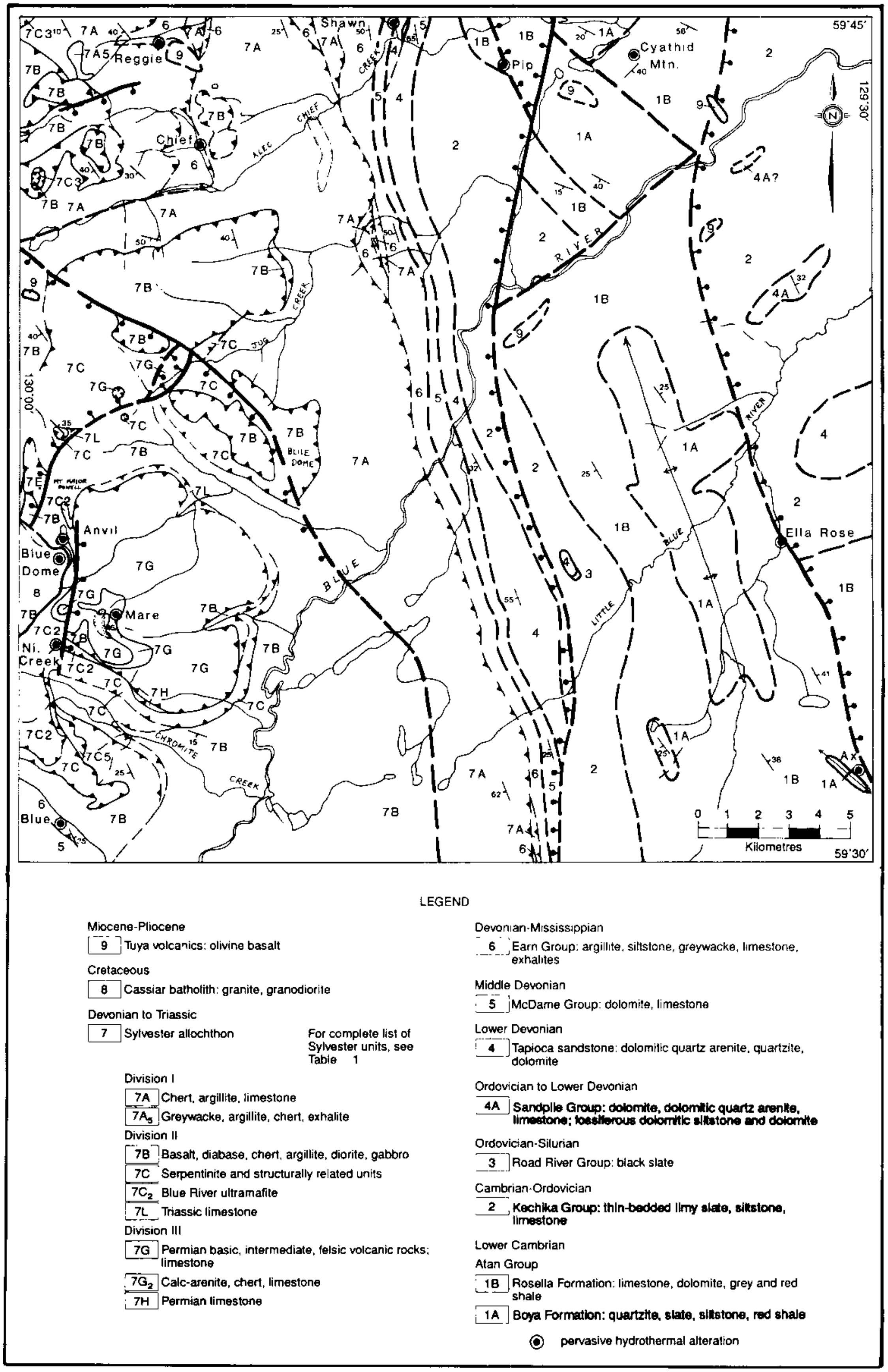

Figure 1-21-2. Geology and mineral occurrences, 104P/12.

GEOLOGY AND PATTERNS OF MINERALIZATION, BLUE DOME MAP AREA, CASSIAR DISTRICT* (104P/12)

By J. Nelson, J.A. Bradford, K.C Green and H. Marsden

KEYWORDS: Regional geology, Blue Dome, Cassiar platform, Sylvester allochthon, Blue River ultramafite, Midway deposit, sedex deposits, polymetallic veins, chromite platinum.

INTRODUCTION

The Blue Dome map area is located about 60 kilometres north of Cassiar and 40 kilometres west of the Stewart-Cassiar Highway (Figure 1-21-1). It is currently accessible only by horse or helicopter. Mapping at 1:25 000 scale was completed in the summer of 1987, as the second of three seasons' work which is planned to cover the area between the Yukon border north of the Midway silver-lead-zinc manto occurrence and the Erickson gold mine near Cassiar.

Objectives of this study are:

- To map the geology in detail and determine the settings and controls of known mineral deposits.
- To identify structural-stratigraphic settings that are likely to host Midway-type manto deposits.
- To map the Sylvester allochthon in terms of significant lithotectonic units, to identify those units within it that are favourable for Erickson-type gold-quartz occurrences and to evaluate the asbestos potential of Sylvester ultramafite bodies.
- To investigate other potential metallic and nonmetallic resources.

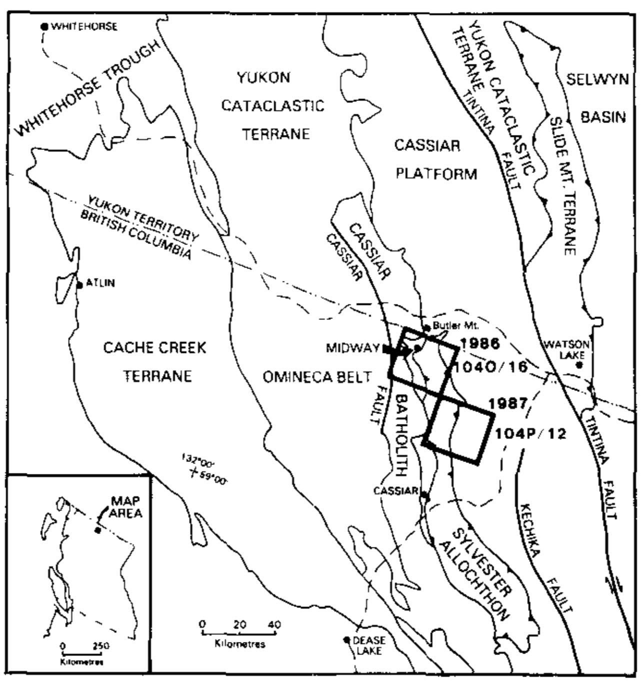

Figure 1-21-1. Location of the Blue Dome map area, 104P/12.

As the focus of mapping moves progressively southward, the third objective assumes greater importance. As discussed in the section on mineralization following, in the Blue Dome map area the Lower Cambrian Rosella Formation replaces the McDame Group as the major host for epigenetic mineralization. In the current study area the investigation of potential resources includes platinum potential in the Blue River ultramafite, a layered dunite-peridotite intrusion; and also syngenetic barite mineralization.

GENERAL GEOLOGY

The general geologic-tectonic setting of the Blue Dome area is identical to that described for Midway (Nelson and Bradford, 1987). Both are situated in the Cassiar platform, with an exposed autochthonous stratigraphy ranging in age from Early Cambrian to Early Mississippian. In the Blue Dome area, these strata form a southwest-dipping panel, disrupted to the east by high-angle faults (Figure 1-21-2). The Sylvester allochthon structurally overlies the Cassiar platform; the interface is either a thrust or a regional décollement. Components of the allochthon in 104P/12 probably range from Early Mississippian to Late Triassic. They are not indigenous to the Cassiar platform. Some are of very distal North American affinity; others entirely lack ties to North America.

The mid-Cretaceous Cassiar batholith cuts and metamorphoses the Sylvester allochthon in the southwest corner of the area. A major strand of the dextral Kechika fault lies immediately east of 104P/12 (Gabrielse, 1963). High-angle faults in the eastern part of the area may be related to it, although only stratigraphic (vertical) throws can be documented. Silicified breccia occurrences with chalcopyrite, bornite, sphalerite and galena are spatially related to these faults.

MIOGEOCLINAL STRATA

UNIT 1: ATAN GROUP (LOWER CAMBRIAN)

The Atan Group crops out over broad areas in the eastern half of the map area (Figure 1-21-2). Most exposures are of the younger carbonate-rich Rosella Formation, which consists of limestone with lesser yellowish crystalline secondary dolomite. Limestone beds are generally very thick

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

and intercalated with thinner platy beds, commonly bioturbated micrites. Scattered rich accumulations of archaeocyathids indicate local reef buildups. Grey and red shales are interbedded with pure limestone in some Rosella outcrops.

The Rosella Formation hosts several quartz-breccia zones with base metal and, less commonly, precious metal mineralization, as at the Pip, Ella Rose, Ax and other prospects. The One Ace Mountain copper-bearing quartz vein showings to the north (104P/13) also lie within Rosella limestones.

The older Boya Formation is restricted and poorly exposed. In addition to quartzite and siltstone, it includes red shales immediately below the base of the Rosella Formation (in the core of the anticline north of Little Blue River). In contrast to map sheet 104O/16, no turbiditic siliciclastic rocks were seen in the Boya Formation here.

UNIT 2: KECHIKA GROUP (CAMBRIAN-ORDOVICIAN)

Monotonous thin-bedded calcareous shales and limestones of the Kechika Group outcrop in the eastern part of the map area. They weather in characteristic light shades of gold, yellow, orange and light olive-green. Identical lithologies make up the Kechika Group in the northeastern corner of 104O/16. These thin-bedded argillaceous rocks show strong to extreme deformation, in contrast to the gently warped Rosella limestones. Together with the overlying Road River slates they are the locus of a major décollement.

UNIT 3: ROAD RIVER GROUP (ORDOVICIAN-SILURIAN)

Black slates of the Road River Group were only observed in one outcrop. This absence of exposure is probably due to southward thinning of the unit from the Midway area, in addition to its friable, recessive character.

UNIT 4: TAPIOCA SANDSTONE (LOWER DEVONIAN)

The Tapioca sandstone in the present area consists almost entirely of quartz arenite, without the extensive dolomites and sandy dolomites that occur in 104O/16. Fragments of quartz arenite within the overlying McDame Group at two localities, the Shawn Barite prospect and near the centre of the map area, suggest erosion of the Tapioca prior to McDame deposition.

UNIT 4A: SANDPILE GROUP (ORDOVICIAN TO LOWER DEVONIAN)

East of the main Kechika fault, Gabrielse (1963 and personal communication, 1986) points out that Lower Paleozoic stratigraphic relationships differ from those adjacent to the Sylvester allochthon. The Road River Group is restricted to Ordovician age; Silurian strata are platformal rather than slope facies dolomites, dolomite breccias, dolomitic quartzites, cherty dolomites and quartzites. These are included in the Sandpile Group. Superficially the Sandpile and the Tapioca sandstone are similar. They differ in time-span of deposition and details of lithology. For instance, highly fossiliferous strata only occur in the Sandpile Group. The Tapioca sandstone is characteristically barren. The quartz arenites and dolomitic quartz arenites, which dominate the Tapioca, are subordinate to dolomites in the Sandpile.

In the eastern third of the map area, strata overlying the Kechika Group include dolomite, dolomitic quartz arenite, dolomitic siltstone, dolomite breccia and limestone. Graptolites and crinoids are abundant in some exposures. This fossiliferous character distinguishes the sequence, shown as Sandpile Group on Figure 1-21-2, from the Tapioca sandstone that occurs further to the west, beyond throughgoing, northwest-striking faults.

UNIT 5: MCDAME GROUP (MIDDLE DEVONIAN)

The McDame Group shows considerable facies variation, although outcrops are too scarce to allow reconstruction of paleogeography. In several of the existing exposures, the McDame consists of fossiliferous fetid dolomites identical to those exposed near the Tootsee River in 104O/16. At other localities, however, notably in the canyon of Jug Creek, spectacular mixed-clast dolomite breccias and megabreccias underlie Earn argillites; they apparently represent a fore-reef accumulation.

UNIT 6: EARN GROUP (UPPER DEVONIAN - LOWER MISSISSIPPIAN)

The thick turbiditic package that forms the Earn Group in the Midway area, with its characteristic thick chert-quartz sandstones and pebble conglomerates, thins to the south such that in the Blue Dome area, only distal equivalents are present. Here, the Earn Group is about 200 metres thick and consists of black argillite with minor thin siltstone and limestone. In the southwestern corner of the area, it interfingers with the grey Gunsteel slate. Exhalites are common within it, occurring both here (Blue claims) and north of Alec Chief Creek.

THE SYLVESTER ALLOCHTHON

The northern Sylvester allochthon consists of three major divisions (Figure 1-21-3; Table 1-21-1). In ascending structural order, they are:

I. A basal northeastward thickening wedge of para-autochthonous sedimentary rocks, mainly cherts and argillites with lesser limestone and chert arenite, minimal diorite/diabase sills and no serpentinite.

II. A middle division dominated to the northeast by basalt and diabase slices with minor chert and argillite rafts, and which includes significant amounts of serpentinite further to the southeast. This division also includes slices of lower crustal gabbro, amphibolite, the Blue River ultramafite, Triassic limestone and syntectonic (?) fanglomerate.

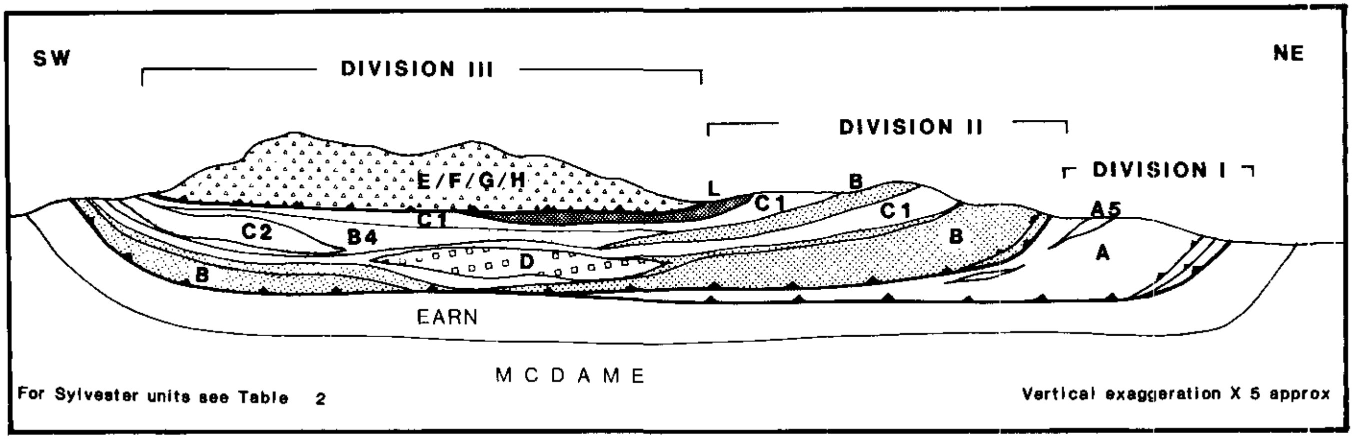

Figure 1-21-3. Schematic cross-section of the Sylvester allochthon, 104O/16 and 104P/12.

TABLE 1-21-1. THE SYLVESTER ALLOCHTHON: MAJOR DIVISIONS AND THEIR COMPONENT LITHOTECTONIC UNITS

Unit in Figure 1-21-2 (this report) and Figure 3-6-2 (Nelson and Bradford, 1987)	Lithologic Subpackages	Description	Localities	Relationship to Other Lithologic Subpackages
		DIVISION I		
7A — Chert, argillite, limestone, greywacke	(1) Grey, green, black chert, grey-black argillite component	Bedded chert with intercalated argillite; also black ribbon chert. Black argillite may include (2) and (3). Conodont ages in 104O/16 Early Mississippian — Pennsylvanian. Minor igneous bodies.	Extensive	
	(2) Limestone	Impure limestone with lithic fragments; purer grey limestone. Small lenses to continuous beds.	Shambling Mtn. (104O/16); NW corner, 104P/12	With (1). Some at least is depositionally within the chert-argillite sequence. Related to (3).
	(3) Limestone extensively replaced by massive black chert	In places silicification is so extensive that the unit is a massive black chert with minor limestone blobs.	104O/16, NW corner; 104P/12	In apparent depositional contact with chert-argillite.
	(4) Salmon and green chert	Salmon-coloured to tan to green chert with interbedded sea-green argillite; minor rusty weathering limestone.	104O/16 only	Thin continuous intercalations in (1): tectonic and/or depositional contacts.
	(5) Greywacke	Interbedded with argillite, chert; may be intruded by diorite/diabase. Contains detrital muscovite, zircon, tourmaline.	NW corner, 104P/12; minor occurrences throughout (1) in both map areas	Depositional relationships with (1).
	(6) Red argillite to argillaceous chert; green to green-grey chert		Alec Chief Creek, NW corner 104P/12	Depositional contacts with (1).
		DIVISION II		
7B — Basalt, diabase, chert, argillite, diorite, gabbro	(1a) Diabase-basalt sill complex with lesser chert, argillite	Unit characterized by up to 95% fine to medium-grained mafic intrusive (mainly sills). Sedimentary component variable: black argillite; black, red, green to grey chert; argillite.	104O/16, widespread; 104P/12, widespread	Transitional to 7B(2).

Unit in Figure 1-21-2 (this report) and Figure 3-6-2 (Nelson and Bradford, 1987)	Lithologic Subpackages	Description	Localities	Relationship to Other Lithologic Subpackages
	(1b) Argillite, chert, diorite, basalt	Argillite and/or chert with minor (<10%) sills. Transitional to 7A.	104P/12; NW quarter	
	(2) Aphanitic basalt flows, pillowed flows, flow and pillow breccia; local red and green chert	Extrusive suite equivalent to 7B(1). In 104O/16, contains areas of chert-matrix breccia with flattened clasts; in 104P/12, extensive flow breccia.	104O/16, widespread; 104P/12, widespread; north of major normal fault (NW quarter)	Transitional to 7B(1a).
	(3) Basalt, tuff, chert, tuffaceous siltstone	Orange-weathering, dark green fine-grained tuff, tuffaceous siltstone, laminated tuff, cherty tuff, chert. Tuffs contain scattered mafic and siliceous fragments.	104P/12, NW quarter	
	(4) Pillow basalt, diabase, gabbro, chert, argillite, black slate, tuff	Highly heterogeneous unit that contains extrusive and intrusive basaltic component, sediments and tuffs interbedded with basalt (including Mississippian chert with radiolaria in 104O/9). In part shows very strong deformation, greenschist facies metamorphism.	104P/12, SW quarter	Close structural association with Blue River ultramafite.
7C — Serpentinite and structurally associated units	(1) Serpentinite	Texturally pristine to highly tectonized.	104O/16, large masses on Foggy and Gum Mtn., South Post Ridge; 104P/12, large masses on Blue Dome and near Chromite Creek	
	(2) Blue River ultramafite	Peridotite, dunite, in part layered. Contains chromite layers, concentrations. Texturally pristine with minor serpentinization.	Chromite Creek to Ice Lake (104P/12 – 104O/0).	
	(3) Polymictic breccia	Highly variable breccia-conglomerate. Angular to rounded clasts of basalt, diabase and greenschist equivalents; serpentinite, coarse-grained gabbro, chert, felsic volcanics. In places monolithologic. Rare sand lenses.	104P/12, Blue Dome, NW corner; 104O/16, Foggy Mtn.?, Rocky Top	Contains clasts from 7B, C, D, G.
	(4) Greenschist, brecciated greenschist	Plagioclase-quartz-actinolite schist with strong mylonitic fabric. Brecciated with epidote-rich matrix.	104O/16, Foggy Mtn.; 104P/12, Blue Dome	Close association with 7C(3).
	(5) Amphibolite	Fresh hornblende-plagioclase rock, strong planar to linear fabric.	104O/16, Foggy Mtn.; 104P/12, Chromite Creek	Included in 7D in 104O/16.

Unit in Figure 1-21-2 (this report) and Figure 3-6-2 (Nelson and Bradford, 1987)	Lithologic Subpackages	Description	Localities	Relationship to Other Lithologic Subpackages
7D — Coarse-grained, in part foliated, gabbro, locally brecciated and/or cut by dykes	(1) Gabbro	Coarse-grained to pegmatitic, originally pyroxene gabbro. Has undergone upper greenschist/lower amphibolite facies metamorphism. In places highly foliated to mylonitized.	104O/16, Foggy Mtn. and vicinity	Clasts of this gabbro occur in limy-matrix breccia on Gum Mtn. Preliminary conodont age is Early Mississippian.
	(2) Gabbro dyke complex	Foliated gabbro cut by extensive very fine-grained mafic dykes (not foliated).	104O/16, Foggy Mtn.	
7L — Triassic limestone		Grey platy limestone with halobia, ammonites, belemnites. Upper Triassic age.	104P/12, south of Oblique Creek	
		DIVISION III		
7E — Trachyandesite flows, subvolcanic intrusives, pyroclastic-epiclastic sediments; minor dacite and rhyolite		These units occur in a gradational sequence on South Post Ridge with a centre marked by predominance of subvolcanic lithologies (plagioclase porphyries) at its east end. K-spar is nearly ubiquitous. This unit is not seen in 104P/12.	104O/16 only; South Post Ridge, Rocky Top	
7F — Zoned hornblende gabbro-granodiorite complex			104O/16, mountain east of Gum Mtn.	Cut by trachyandesite dykes of identical chemistry and mineralogy to 7E. May be basement to 7E.
7G — Lower Permian basic, intermediate and felsic volcanic rocks and limestones	(1) Augite and plagioclase porphyries; epiclastic breccias; limestone with volcanic clasts; tuff		104P/12, south of Oblique Creek, north of Chromite Creek	
	(2) Well-bedded calcarenite and chert		104P/12, south of Oblique Creek.	Intimately related to to 7G(1).
7H — Permian limestone	Massive grey to white limestone with parafusulina		104P/12, north of Chromite Creek	

III. An upper division composed of intermediate to felsic volcanic rocks and shallow-water limestones. In the Midway area, the upper division consists of a basaltic trachyandesite edifice built on an earlier zoned calc-alkalic intrusion (Nelson and Bradford, 1987; Figure 1-21-4). In 104P/12, the upper division contains intermediate volcanic rocks with interbedded Lower Permian limestone, Permian parafusilina limestone and undated, but probably Permian, bedded calcarenites.

Detailed lithologic descriptions of Sylvester units are given in Table 1-21-1. This table is modified after Table 3-6-1 of Nelson and Bradford (1987) with the addition of new units from the current area. It is arranged according to the threefold structural breakdown summarized above, which derived from work in the 1987 season. The divisions

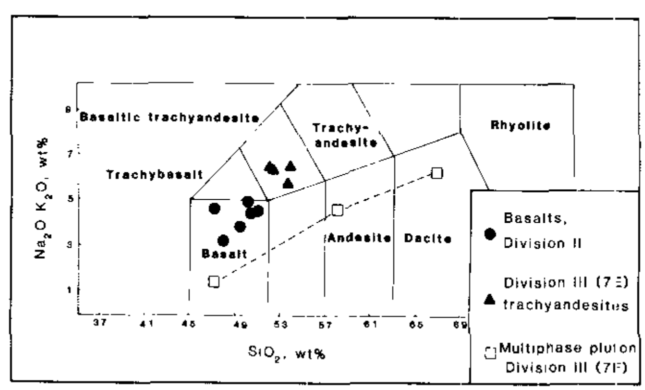

Figure 1-21-4. Alkali-silica plot for igneous rocks from the Sylvester allochthon in 104O/16.

were created primarily as easily mappable major units. The inclusion of upper crustal basalts, limestones and ultramafic material within Division II does not imply co-origin, but that these units are tectonically intercalated at a scale too fine to be depicted on any but very detailed geologic maps. The distinction between Divisions I and II will probably break down in subsequent mapping further south, since existing maps of 104P/04 and 104P/05 show volcanic material and serpentinite near the eastern limit of the Sylvester allochthon (Diakow and Panteleyev, 1981; Gordey *et al.*, 1982). Division III, however, is a variable but coherent entity that differs radically from the lower structural divisions.

In the Blue Dome map area, Division I is transitional across a strongly telescoped contact to the uppermost autochthonous North American stratigraphic unit: the Devonian – Lower Mississippian Earn Group. In several localities near its base, thrust imbrications interleave Earn and Sylvester sediments. Most of these repetitions occur within 100 metres of the main Sylvester-Earn break (Figure 1-21-2). In the northwest corner of 104P/12, a package of dark grey chert-quartz arenite, black slate, black and green argillite, black bedded chert and baritic to siliceous exhalite forms the structural top of Division I, 500 metres above its base. Sandstones within this package contain detrital muscovite, tourmaline and zircon. They and the exhalites link it almost certainly to the autochthonous Earn. In contrast to the "true" Earn, however, this package is intruded by diabase and diorite-leucogabbro sills allied to the mafic intrusive and volcanic suites of Division II. It thus provides a tie between the lower part of the Sylvester allochthon and the distal edge of Late Paleozoic North America.

The contact between Divisions I and II is invariably structural, and varies from abrupt to somewhat transitional. In some localities, massive basalt or diabase, with only minor chert rafts, is thrust over cherts and argillites lacking any igneous component. In many cases, however, a transitional facies separates the two divisions: argillite and/or chert with significant diabase sills; or basaltic tuffs intercalated with other sediments. This pattern of successive thrust slices having an increasing igneous component upwards is suggestive of a collapsed lateral facies progression.

The contact between Divisions II and III is abrupt, profound and demonstrably a thrust of regional proportions. East of Mount Major Powell, Lower Permian volcanics and sediments structurally overlie Upper Triassic limestone. Elsewhere the base of Division III is observed in contact with every other lithotectonic element of Division II.

DIVISION I

This lowest division of the Sylvester allochthon (Unit 7A in Nelson and Bradford, 1987) is nearly devoid of igneous rocks, except for diabase and diorite sills in the transition to Division II. It contains no serpentinite. It comprises a number of lithologic variants, but few mappable subunits. Conodont data from 104O/16 so far show Early Mississippian to Pennsylvanian ages (Irwin and Orchard, this volume). It structurally overlies the autochthonous Earn Group, which ranges up to Early Mississippian (Irwin and Orchard, this volume). Thus the base of Division I in 104O/16, albeit a zone of strong structural discontinuity, is not a thrust *sensu stricto*, but rather a regional-scale décollement. The internal structural style of Division I remains enigmatic due to lack of detailed microfossil control.

DIVISION II

Although it contains a wide variety of lithotectonic elements, Division II retains a peculiar integrity based on its structural position; the recurrence of major units in it such as basalt, diabase and serpentinite; and its unique interleaved tectonic style. The role of serpentinite seems to have been crucial in the development of Division II, whether as thin "lubrication" separating adjacent sheets, or as a low strength medium surrounding blocks and slices of more competent lithologies.

Major lithotectonic units within Division II are listed in Table 1-21-1. The extrusive basalt unit and the diabase-basalt-chert-argillite unit represent parts of a single intrusive-extrusive igneous suite (Unit 7B). Transitional contacts from diabase with chert rafts to 100 per cent extrusive (?) basalt breccia have been observed. Red and green chert, where intruded by basalt sills, shows soft-sediment deformation textures, indicating penecontemporaneous sedimentation and igneous activity. Radiolaria from one of these cherts in the Midway map area gave an Early to Middle Permian boundary age (T. Harms, personal communication, 1986). It should be emphasized that none of the basalts and diabases are typically ophiolitic, that is, they are not primary oceanic crust. They were emplaced into a pre-existing sedimentary basin developed on older crust, the nature of which is unknown. Whole-rock geochemical analyses of Division II basalts and diabases in the Midway area have been obtained. On an alkali-silica diagram (Figure 1-21-4) they plot as normal basalts. Trace element analyses are in progress.

In the Blue Dome area, the northeastern margin of Division II is a set of basalt and diabase-dominated thrust sheets and wedges. Most contacts are gently dipping, except for eastward ascending thrust ramps developed at the northeastern limit of exposure of Division II. Toward the southwest in 104P/12 and throughout 104O/16, Division II is mechanically and in some localities volumetrically dominated by masses of scaly serpentinite, which separate slivers and blocks of other lithotectonic units. Basalt, basalt breccia and diabase-chert form slivers throughout, but at higher structural levels may alternate with slices of amphibolite, greenstone and polymictic fanglomerate, for instance on Blue Dome. This structural style suggests initial juxtaposition by thrusting(?) of mantle and lower crustal rocks over upper crustal lithologies, followed by extensive imbrication of the package. East of Mount Major Powell, Triassic limestone occurs as the highest structural slice in Division II, covered by a thin skin of serpentinite that further southwest widens abruptly to become the Blue River ultramafite.

The polymictic fanglomerate unit offers insights into the structural history of Division II. Textures in it vary from monolithologic breccias of angular coarse-grained gabbro or diabase clasts to waterlain polymictic conglomerates that contain pebbles to boulders of gabbro, metabasalt, basalt, diabase, chert, serpentinite and plagioclase-augite porphyry (dacite/andesite) and are intercalated with sandstone and siltstone. All of these lithologies can be assigned to lithotectonic units within Division II, except the plagioclase porphyries, which are identical to lithologies within Division III. The structural involvement of Triassic limestone at the contact between Divisions II and III indicates that felsic rocks were not in proximity to Division II until after Carnian time. These breccias and conglomerates may have formed during emplacement of the allochthon, in front of thrust toes which then moved over their own debris.

DIVISION III

The highest structural division in 104P/12 lies above the highest serpentinite. In ascending order, it consists of the following units:

(1) Permian *parafusilina* limestone north of Chromite Creek.

(2) Augite and plagioclase porphyry flows and pyroclastics; epiclastic intermediate to felsic volcanic conglomerate; welded tuff-breccias with strong planar fabric; and green tuffaceous limestone containing volcanic clasts from penecontemporaneous extrusion and a variety of fossils including *spirifirella* (Early Permian, E.W. Bamber, personal communication, 1987), fusulinids, crinoids, bryozoa and horn corals.

(3) Coarse to fine-grained, well-bedded limestone turbidites, including calcarenites with graded bedding intruded by numerous augite porphyry dykes, overlain in transitional depositional contact by sea-green chert and tectonically by maroon tuffs and crinoidal limestone.

(4) Intermediate to felsic volcanic rocks, similar in lithologies to (2).

Contacts between the four units are thin (1 to 2 metre) mylonitic zones; the amount of transport across them is not known. In general, the lack of internal deformation in Division III contrasts strongly with the tectonic style exhibited in Division II. A notable exception to this is the intense folding in the limestone turbidites, which has resulted in major overturns of that package.

Division III in 104O/16 is so far undated, although a zircon separate is in progress. Its character, however, alkalic intermediate rocks superimposed on calcalkalic intrusive basement (Figure 1-21-4), is consistent with the nature of Division III in 104P/12. The reefal limestones in 104P/12 suggest shallow-water deposition, and thus thicker crust than that expected for the mafic sequences and chert-argillite packages of Division II. In both map areas, intermediate igneous rocks are restricted to the uppermost structural division. A further extension of this overall pattern may be found south of Cassiar, where Gordey *et al.* (1982) mapped augite porphyry basalts and limestones of Pennsylvanian age at the highest exposed structural level in the Sylvester allochthon. Although they may be more mafic than the augite porphyries in the Blue Dome map area, these rocks are of a different lineage than the basalt/diabase of underlying structural panels.

IMBRICATION AND EMPLACEMENT OF THE SYLVESTER ALLOCHTHON

In general, successively higher tectonic slices in the northern Sylvester allochthon contain facies that are successively more distal, that is, more allochthonous to North America. From base to exposed top, the allochthon consists of para-autochthonous sedimentary rocks, imbricated with and transitional to the youngest North American strata; structurally overlain in transitional contact by basaltic intrusive and extrusive rocks, which become imbricated, particularily at higher structural levels, with serpentinite and lower crustal material; and finally a relatively intact suite of intermediate igneous rocks and limestones. Division I sediments show a clear North American affinity. Their upward transition to Division II is best explained as a thrust-telescoped facies boundary. Thus only the highest structural division lacks elements which are spatially linked to North America. It is truly exotic, not simply with respect to the Cassiar platform, as is the case for Divisions I and II. Its emplacement must have involved at least hundreds of kilometres of relative movement, much of which was taken up within the structural packages below it. The schematic cross-section (Figure 1-21-3) shows marked eastward thickening of Division I. As the allochthon was emplaced, a series of thrust imbricates propagated in front of it within the highest levels of the distal North American sedimentary sequence, creating a wedge of slices like snow in front of a plough.

Deformation within Division II was far more complex. Near its eastern, leading edge, thrust ramps climb both at the base and between slices from an overall flat floor, probably because of the eastward thickening wedge of sediments in front of it. At higher levels and further west, ultramafites and lower crustal rocks were emplaced in a sheet or sheets over the basalts.

STRUCTURE

The internal structure of the Sylvester allochthon is discussed above. Structural patterns in the autochthonous rocks are consistent with the duplex model for the Cassiar platform (Harms, 1986; Nelson and Bradford, 1987): décollements are likely within the highly deformed Earn and Kechika groups, while the more competent massive carbonates and siliciclastic strata show far less internal folding and faulting. A few local thrust ramps were noted, particularly in the southwest corner of 104P/12, where Earn-McDame repetitions occur on the steep slopes below the base of the Sylvester. Their vergence is unknown.

Late high-angle faults are identified by their stratigraphic throws. The two most continuous faults trend north-northwest (Figure 1-21-2). Shorter faults connect them, some causing block rotations and anomalous steep southeastward dips. The presence of inferred Sandpile Group rocks to the east of the eastern fault and Tapioca sandstone to the west of the western fault (*see* Units 4, 4A above) suggests that these faults coincide with a lower Paleozoic shelf-slope facies transition. They may be strands of the Kechika fault system. Another major strand lies immediately to the east of the Blue Dome map area, along Tisigar Lake (Gabrielse, 1963).

MINERALIZATION AND EXPLORATION POTENTIAL

Six different styles of alteration and mineralization occur in distinct geologic settings within map area 104P/12: (1) sediment-hosted baritic exhalites in the McDame and Earn groups; (2) polymetallic veins hosted by Lower Cambrian platformal carbonates; (3) quartz veins in marine sediments and mafic volcanics of the Sylvester allochthon and Earn Group; (4) sulphide-bearing alteration zones in intermediate volcanic hosts; (5) magmatic oxides and sulphides in the Blue River ultramafite; and (6) molybdenite in the Cassiar batholith. Individual showings are discussed following and are summarized in Table 1-21-2 with locations indicated in Figure 1-21-2.

Nelson and Bradford (1987) discussed the mineral deposits in the Midway area in terms of three mineralizing episodes: one syngenetic in the Devono-Mississippian; another in the Mid-Cretaceous, related to the main phase of the Cassiar batholith; and a third in the Late Cretaceous to Eocene, related to small fluorine-rich intrusive bodies. The syngenetic deposits in the Blue Dome area occur over a somewhat greater time span than in 104O/16 (as old as Givetian, as opposed to Famennian through Early Mississippian). The polymetallic veins differ somewhat in style, mineralogy and setting from late epigenetic deposits in 104O/16 such as Midway. Some of them are located along faults, although not within a single swarm like the Tootsee River fault system (Nelson and Bradford, 1987). The sulphide-bearing alteration zones and the ultramafic-hosted magmatic deposits in the Sylvester have no known correlatives in the Midway area. Some of the epigenetic deposits are localized along faults, but none of them can be linked to a single, dense set of high-angle faults like the Tootsee River system.

SEDIMENT-HOSTED EXHALATIVES

At the Shawn (Captain Lake) showing, Middle Devonian McDame Group platformal carbonates host coarse-grained, white, stratiform barite interbedded with dolomitic siltstones 100 metres above the McDame-Tapioca contact. Barite also occurs as crosscutting veins and breccia clasts or replacement zones up to 1 metre across in both the McDame Group and Tapioca sandstone. Graded sedimentary breccias, with barite, McDame and Tapioca clasts, occur stratigraphically above the bedded barite. This style of mineralization suggests a continuum between crosscutting veins and exhalative barite. The overlying sedimentary deposits may have resulted from coeval mineralization and fault movement locally exposing Tapioca sandstone.

Devono-Mississippian Earn Group E-turbidites host the Chief and Blue showings, which consist of laminated fine-grained quartz-barite-pyrite exhalites with local minor galena and/or sphalerite. Crosscutting sulphide-rich mineralization occurs at both showings, although contacts with the exhalites is not exposed. An economically insignificant exhalite was noted in an Earn analogue within the Sylvester in the northwestern corner of the map area.

The Earn exhalites closely resemble Devono-Mississippian occurrences in the Midway area (Nelson and Bradford, 1987) while the Sylvester occurrence may be a lateral, time-equivalent exhalite. The Shawn Barite showing extends the known time span of exhalative mineralization in the Cassiar platform to include the mid-Devonian.

POLYMETALLIC VEINS IN PLATFORMAL CARBONATES

Five zones of silicification and stockwork quartz veining occur within Lower Cambrian platformal carbonates. Two of these, the Ella Rose and Cyathid Mountain, were discovered in the course of our mapping in 1987. The Ax showing, which was trenched in 1969, subsequently lay idle until it was rediscovered in 1987, nearly simultaneously by our crew and an independent prospector.

The Pip (Captain Lake) showing consists of anastomosing quartz veins in silicified carbonate breccias with locally abundant copper mineralization. It lies adjacent to a highly brecciated fault zone between Rosella carbonates and

TABLE 1-21-2
MINERAL OCCURRENCES
104P/12

Type/Age	Name(s)	MINFILE No.	Economic Minerals	Description
1. Sediment-hosted exhalatives				
(1) McDame Group (mid-Devonian)	Shawn Barite, Captain Lake	104P-049	barite, chalcopyrite	Coarse stratiform barite beds up to 1 metre thick, associated veins, replacements within McDame dolomitic breccia and siltstone. Barite contains minor chalcopyrite. $BaSO_4$ from 52.1 to 90.1 weight per cent (W.H. Thompson, 1982, Assessment Report 10334).
(2) Earn Group (Devono-Mississippian)	(a) Chief Southwest	104P-103	barite, chalcopyrite, pyrrhotite	Bedded quartz-pyrite-barite exhalites in Earn clastics. Large boulder of quartz stockwork with chalcopyrite and locally massive pyrrhotite-pyrite.
	(b) Blue	104P-104	barite, galena, sphalerite	Bedded quartz-pyrite-barite exhalites from 0.5 to 11.0 metres thick are exposed at four locations along a 7-kilometre strike length. All localities contain minor galena with only local yellow sphalerite and low silver values (Cordilleran Engineering Ltd., 1982, Assessment Report 10751).

TABLE 1-21-2—*Continued*
MINERAL OCCURRENCES
104P/12

Type/Age	Name(s)	MINFILE No.	Economic Minerals	Description
2. Polymetallic veins in carbonates (Upper Cretaceous)	(a) Ax	104P-106	galena, chalcopyrite, barite, chalcocite, sphalerite	Silicified zone 10 to 15 metres wide with 30-centimetre to 1-metre-wide mineralized zone exposed along 300 metres. Contains massive to disseminated galena, coarse white quartz with chalcopyrite-barite-chalcocite and late brecciated quartz with iron oxides and galena blebs. Grab samples assayed 248, 2 and 40 ppm silver, <20, <200 and <20 ppb gold, respectively. Hosted in Lower Cambrian Rosella Formation.
	(b) Ella Rose (new discovery)	104P-097	chalcopyrite, covellite	A 20-metre-wide zone of silicification in dark grey brecciated dolomite. Quartz is fine grained and vuggy with limonite and malachite. Chalcopyrite, covellite, brown sphalerite and galena occur in boulders in a sloughed creek bank 20 metres north of the outcrop. A grab sample from the showing assayed 24 ppm silver and <20 ppb gold.
	(c) Captain Lake, (Pip)	104P-060	chalcopyrite, chalcocite	Silicified zone with locally intense stockwork with chalcopyrite-chalcocite occurs along a highly brecciated fault contact between Kechika calcareous shale and Atan carbonates. The zone is up to 40 metres wide and exposed along 125 metres. Best assays reported are 1.36% copper over 25 metres (N.B. Vollo, 1976, Assessment Report 6087). An old trench exposes similar mineralization 600 metres on strike to the northwest.
	(d) Cyathid Mtn. (new discovery)	104P-098	chalcopyrite	A strong quartz stockwork with very minor chalcopyrite is exposed over 70 metres by 15 metres. Grades into a limonitic calcite breccia zone 1.5 kilometres along strike to the northeast.
3. Veins in marine sediments and volcanics (Upper Cretaceous to Eocene)	(a) Chief East	104P-102	pyrite, chalcopyrite	A northwest-trending gossanous zone (0.5 by 3.5 kilometres) of strong quartz-sericite-pyrite alteration that hosts numerous quartz veins with pyrite and chalcopyrite. Hosted in Sylvester chert-argillite.
	(b) Reggie (new discovery)	104P-099	galena, pyrite	*En échelon* tension gashes in a narrow zone up to 0.7 metre wide with disseminated galena and minor pyrite.
	(c) Lat. 59°45′, Long. 130°00′			Intense quartz veining with minor graphite in Sylvester sediments is exposed over 800 by 250 metres.
4. Alteration within Division III intermediate volcanics (age uncertain)	(a) Mare	104P-105	chalcopyrite, pyrite	Numerous small zones of quartz-carbonate-clay-pyrite-chalcopyrite alteration. Extensive sampling by Falconbridge Limited yielded only two anomalous samples: 222.13 grams per tonne silver, no gold; 4.6 grams per tonne silver, 2.38 grams per tonne gold (T. Bruland, 1983, Assessment Report 11335)
	(b) Lat. 59°34′, Long. 129°38′		chalcopyrite, pyrite	Small zone of quartz-carbonate-clay-pyrite-chalcopyrite alteration with thin quartz-carbonate veinlets.
5. Magmatic ultramafic-hosted mineralization	(a) Ice Lake	104P-055	chromite	Disseminated to semimassive chromite as pods in peridotites at two locations in the Blue River ultramafite. Largest pod is exposed over 15 centimetres by 15 metres. In 104O/09 adjacent to 104P/12.
(1) Chromite (age uncertain, probably between Upper Devonian and Late Permian)	(b) Anvil chromite (new discovery)	104P-100		Semimassive to massive chromite occurs over 3 metres by 50 centimetres in talc-altered peridotite within the Blue River ultramafite.
(2) Nickel (age uncertain)	(c) Nickel Creek, Blue River Nickel, Heazlewood	104P-001	heazlewoodite	Heazlewoodite was identified by X-ray diffraction in partially serpentinized dunite. Assays to 0.21% nickel (Wolfe, 1969).
	(d) Anvil Nickel (new discovery)	104P-100	pyrrhotite, pentlandite	Semimassive net-textured sulphides and plagioclase occur along the margin of a coarse-grained, foliated gabbro within the Blue River ultramafite.
6. Molybdenite in the Cassiar batholith (Late Cretaceous)	(a) Blue Dome	104P-054	molybdenite	A small pod less than 1 metre long with 5% MoS_2 was reported by Wolfe (1969) within the Cassiar batholith.
	(b) Anvil Molybdenum (new discovery)	104P-101	molybdenite	A 0.5-metre-wide quartz vein with <1% molybdenite is exposed along a 100-metre strike length, adjacent to a biotite granodiorite dyke cutting the Blue River ultramafite.

Kechika calcareous phyllite. The Cyathid Mountain showing is similar but is not adjacent to a fault contact and contains only very minor chalcopyrite. The Ax and Ella Rose showings are narrow, high-angle silicified zones containing fine-grained, vuggy and coarse white quartz with significant copper sulphides, galena and sphalerite, and abundant malachite and azurite. A sample from a galena-rich pod at the Ax showing assayed 248 grams per tonne silver. A small zone of silicification, with no visible sulphides, was noted 3.5 kilometres northwest of the Ax.

The Ella Rose and Pip showings are located on fault contacts between Atan and Kechika groups (Figure 1-21-2). The Ax showing is on the southern extension of the same fault as the Ella Rose. The Cyathid Mountain stockwork grades into a zone of brecciation and calcite spar 1.5 kilometres to the northeast. These features all point to the importance of structural control for this kind of mineralization. These showings may be related to an episode of late Cretaceous to Eocene intrusion and lead-zinc-silver mineralization (Panteleyev, 1980; Nelson and Bradford, 1987).

VEINS IN MARINE SEDIMENTS AND MAFIC VOLCANIC ROCKS

Numerous quartz veins occur throughout the Devono-Mississippian Earn Group and Late Tournaisian to Permian(?) oceanic sediments and mafic volcanics of the Sylvester allochthon. Three of these zones are of potential economic interest. The Chief East showing is a north-trending zone of rusty weathering quartz-sericite-pyrite alteration in Sylvester sediments, 500 metres wide and up to 3.5 kilometres long. This zone contains numerous quartz veins with malachite staining and oxidized pyrite and chalcopyrite, and is coincident with a smaller lead-zinc-silver anomaly reported in soils by Cordilleran Engineering Ltd. (Assessment Report 10974). The alteration superficially resembles that associated with Late Cretaceous fluorine-rich intrusives southeast of the Midway deposit (Nelson and Bradford, 1987).

The Reggie showing consists of *en échelon* quartz-filled tension gashes with galena and minor pyrite in Earn Group graphitic argillite.

In the extreme northwest corner of the map area, a 250 by 800-metre east-trending zone of intense quartz veining cuts unaltered, highly folded Sylvester sediments.

ALTERATION WITHIN INTERMEDIATE VOLCANICS

Plagioclase and/or pyroxene porphyritic flows and pyroclastic rocks in Division III of the Sylvester allochthon host minor disseminated pyrite and chalcopyrite in widely distributed, small alteration zones. The Mare showing consists of several small gossanous exposures of quartz, carbonate, clay, pyrite and chalcopyrite alteration which occur within a broader zone of bleached, carbonate-altered volcanics. These zones have been extensively sampled by Falconbridge Limited and are generally low in gold and silver (*see* Table 1-21-2). A smaller, mesoscopically similar zone occurs on the west flank of Mount Major Powell.

These alteration zones are irregular in shape and generally unrelated to significant geological structures. An exception is the showing east of Mount Major Powell, which is located on a normal fault of probable Cretaceous or Eocene age.

ULTRAMAFITE-HOSTED MAGMATIC MINERALIZATION

The Blue River ultramafite hosts two types of magmatic mineralization. The Ice Lake chromite showing (104O/09) contains two separate pods of massive to disseminated chromite within poorly layered peridotite and dunite. Similar chromite occurrences were noted at three other widely separated localities within the ultramafite, including the Anvil showing where massive chromite occurs within serpentinite and talc-altered peridotite. Disseminated to semimassive magnetite occurs as layers within partially serpentinized dunite between Chromite and Nickel creeks. These may have been chromite layers that were altered to magnetite during serpentinization of the olivine. These ultramafite-hosted chromite layers may contain significant platinum group metals. Rock and stream sediment analyses are in progress.

Magmatic, net-textured, semimassive pyrrhotite occurs at the Anvil nickel showing along the margin of a foliated gabbro within the Blue River ultramafite. Two other semimassive pyrrhotite occurrences, of magmatic or contact metasomatic origin, were noted within ultramafic rocks near the margin of the Cassiar batholith. The pyrrhotite may be associated with nickel and possibly with platinum group metals. Analyses are pending.

Wolfe (1965) identified heazlewoodite (NiS_2) using X-ray diffraction techniques on samples of dunite from Nickel Creek that contained up to 0.49 per cent nickel, but nickel sulphides have not been identified in the field.

MINERALIZATION WITHIN THE CASSIAR BATHOLITH

The Anvil molybdenum showing is a single quartz vein, 50 centimetres wide, that runs parallel to a granodiorite dyke cutting the Blue River ultramafite. Wolfe (1965) also reported the presence of a pod of molybdenite 1 metre long within the Cassiar batholith.

SUMMARY

Polymetallic silver-bearing vein deposits hosted by Lower Cambrian Atan carbonates constitute the most significant exploration targets in map area 104P/12. The known showings extend across the eastern half of the map area and to the north (104P/13) where a similar showing is exposed on One Ace Mountain. They appear to be localized along high-angle faults that may be minor fault strands related to westward stepping of the Kechika fault. There are many quartz veins in the Sylvester allochthon and Earn Group although few contain visible sulphides and all lack significant alteration haloes and structural controls that are readily apparent in the Cassiar gold camp. The magmatic sulphides and oxides in the Blue River ultramafite are an under-explored target for platinum group metals.

CONCLUSIONS

Geologic mapping of the Blue Dome map area (104P/12) has added two important pieces of information to the ongoing study of the Midway-Cassiar region:

(1) The northern Sylvester allochthon shows a consistent large-scale stacking order. The highly allochthonous Division III, characterized by intermediate igneous rocks and shallow-water limestones, lies above Divisions I and II, which are related to North America, but not indigenous to the Cassiar platform where they currently rest. The allochthon appears to become progressively more exotic upwards, with the furthest travelled, most foreign material at the structurally highest levels. This premise will allow reconstruction of marginal rift-basin geometry and facies for Divisions I and II.

(2) Two significant mineralized quartz breccia systems in Rosella carbonates, the Ella Rose and the Ax showings, have been added to existing knowledge of mineralization in the Blue Dome area. At the Ella Rose, high-angle fault control is clear; at the Ax, it is more cryptic but nevertheless likely, as shown by steep northwest vein trends, proximity to the inferred extension of the fault that hosts the Ella Rose, and local slickensides.

These occurrences are different in style from the manto mineralization at Midway and Butler Mountain, but they are similarily keyed to massive carbonates and late faulting, probably related to regional dextral movement. Thus the interaction of transcurrent faulting and Paleozoic carbonate hosts, proposed as ore controls further north (Abbott, 1984; Nelson and Bradford, 1987), remains valid at least as far south as the French River and probably beyond.

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GEOLOGICAL TRANSECT ACROSS THE SYLVESTER ALLOCHTHON NORTH OF THE BLUE RIVER, NORTHERN BRITISH COLUMBIA* (104P/12)

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KEYWORDS: Structural geology, stratigraphy, Sylvester allochthon, oceanic lithology, transect, Blue River, structural stacking.

INTRODUCTION

In Cry Lake (104I), McDame (104P) and Jennings River (104O) map areas the Sylvester allochthon is juxtaposed against Paleozoic North American continental margin carbonates and clastics of the Cassiar platform across the basal Sylvester fault as a vast klippe (Gabrielse, 1963, 1970, 1979; Gabrielse and Mansy, 1980; Harms, 1986a). Regionally, the Sylvester assemblage consists of a suite of oceanic lithologies: banded radiolarian chert, siliceous argillite, argillite, carbonate, minor coarse clastics, basalt and pillow basalt, gabbro and diorite, serpentinite and ultramafics. Various units of the Sylvester have been dated and range in age from Middle (?) Devonian to Late Triassic (Mamet and Gabrielse, 1969; Gordey *et al.*, 1982; Harms, 1986a). In contrast, immediately underlying North American units, carbonates of the McDame Group, and black argillite and chert arenite of the Earn Group and equivalent black and grey argillites, range in age up to earliest Mississippian. The basal Sylvester fault which separates these two disparate assemblages is planar, not significantly deformed, and subhorizontal to broadly synformal. Nevertheless, both the Sylvester allochthon and the underlying autochthonous strata are deformed into separate complex structural systems.

Geological mapping during the 1987 field season in the Blue Dome (104P/12) map area, conducted as part of the Midway-Cassiar project of the Canada/British Columbia Mineral Development Agreement (*see* Nelson and Bradford, this volume), broadened documentation of the distinctive internal structural style which characterizes the Sylvester allochthon (Gordey *et al.*, 1982; Harms, 1984, 1985, 1986b; Nelson and Bradford, 1987). For the first time, a complete and detailed transect across the structural strike of the Sylvester allochthon was mapped at a scale of 1:25 000. This report presents a structural cross-section over 20 kilometres long, along that transect (Figure 1-22-1), which elucidates the complex deformation within the allochthon.

STRUCTURAL STYLE OF THE SYLVESTER ALLOCHTHON

The Sylvester allochthon is composed of innumerable, discrete, fault-bounded lithotectonic slices. This is a consistent, very large-scale structural fabric which is a fundamental distinguishing characteristic of the allochthon. Each of the lithotectonic slices which make up the Sylvester assemblage may include only one, or several lithologies. Some lithotectonic units are repeated in several telescoped slices, or can be shown to be one of a suite of lithologically related slices; however, many have no inherent relationship to any of the other Sylvester units. These lithotectonic slices are commonly thin, and pinch out laterally in all directions. Where units of the Sylvester can be dated, older-over-younger relationships are common. The sequence of lithologies seen in the Sylvester is thus a completely tectonic "stratigraphy"; it was developed almost entirely by faulting and varies widely from place to place.

BLUE DOME (104P/12) TRANSECT

Figure 1-22-2 presents a composite structural section, which crosses the Sylvester allochthon approximately perpendicular to its large-scale northwesterly structural grain, just north of the Blue River in 104P/12 map area. A line of section was chosen which best illustrates the structural style of the Sylvester, and so as to cross units which could be accurately projected from one line of section to another. This transect provides for the first time a complete trans-Sylvester cross-section drawn from detailed mapping and it is shown in as much detail as possible. Major suites of lithotectonic slices (Divisions I, II and III) drawn from Nelson and Bradford (this volume) are indicated. However, specific lithotectonic

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

units shown on the transect may not be directly correlatable with the more generalized units used in the large-scale compilation map which appears in that report, or integrated with units used by Nelson *et al.* (1987, open file 1:25 000 map, in preparation).

The pervasive, fault-bounded lithotectonic nature of the Sylvester assemblage and its tectonic "stratigraphy" are readily apparent from the cross-section. Most contacts shown are low-angle faults. Even the same or clearly related lithologies are repeated and juxtaposed by faults. Undisrupted original relationships are seen only in the intrusive contacts of Unit IIPv basalt with Unit IIPzPc Mississippian-Permian (?) grey to green and red-banded radiolarian cherts, and in the intrusive contacts of Unit IIIPvs basalt and andesite with Unit IIIPls Permian fusulinid-bearing tuffaceous carbonate. The many faults which bound the remainder of the Sylvester lithotectonic units are recognized by a number of factors. First among these is map scale, along-strike truncation of units. Abrupt juxtaposition of unlike lithologies, with no intervening transitional facies, and of depositionally incompatible lithologies such as silicified metachert (Unit IIc) and *Halobia*-bearing carbonate (Unit IITrls) also indicate

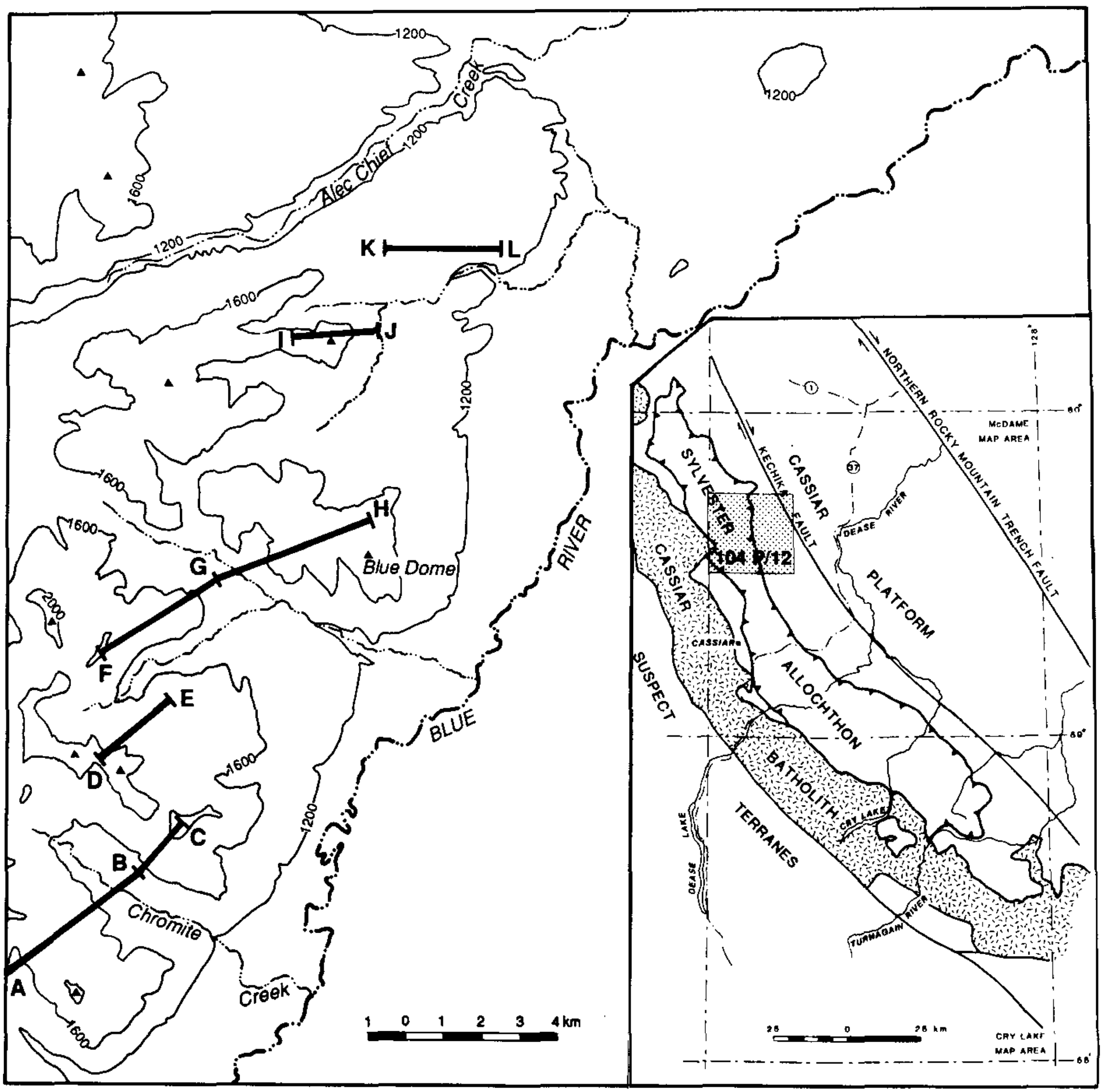

Figure 1-22-1. Location of lines of composite transect through the Sylvester allochthon in 104P/12 map area. Contours in metres. Solid triangles denote prominent peaks.

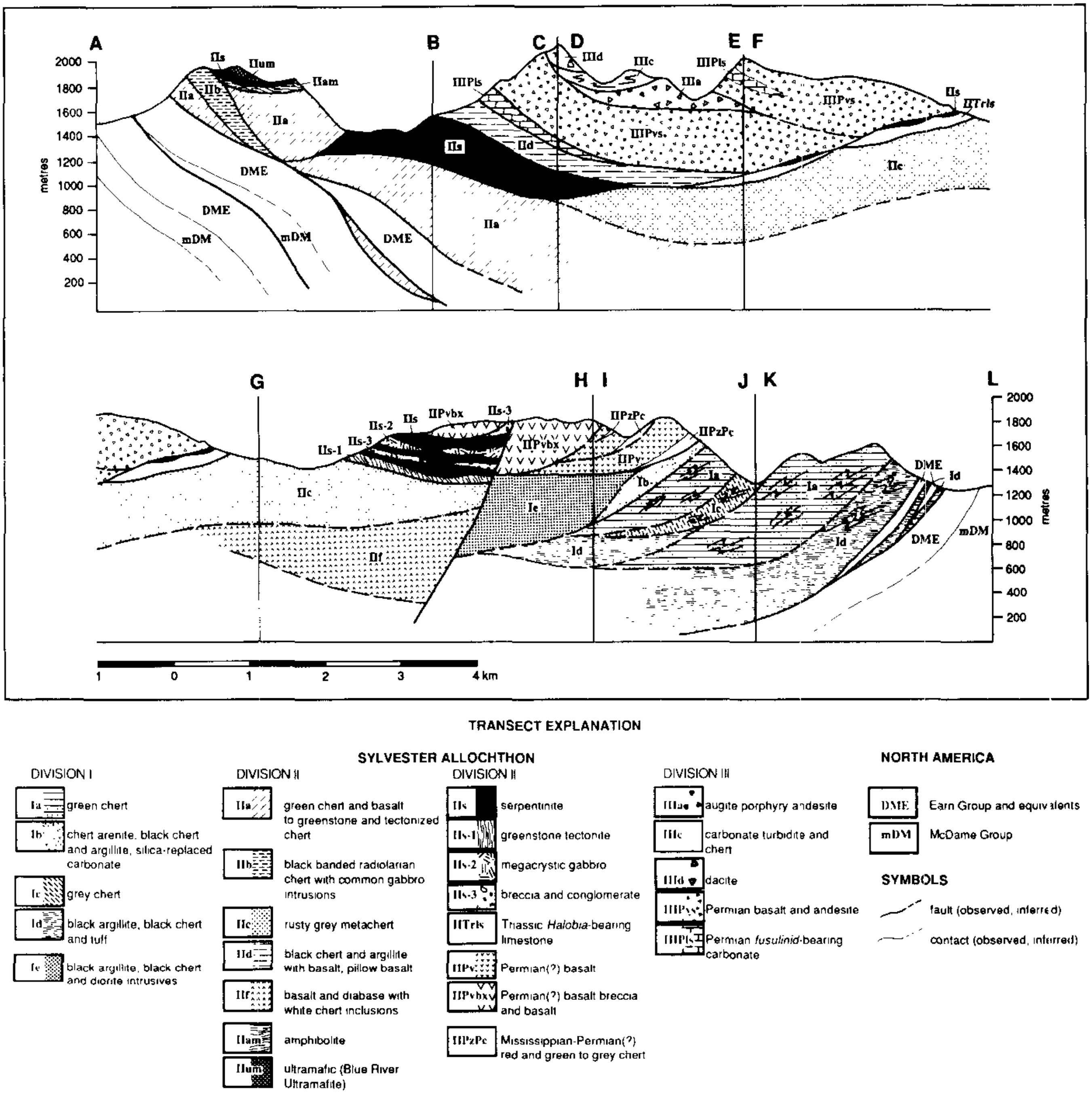

Figure 1-22-2. Composite geologic cross-section through the Sylvester allochthon. 1.6 × vertical exaggeration. Line of section located in Figure 1-22-1.

tectonic convergence. Most slice-bounding faults are planar and not significantly deformed. In contrast, units between these faults are commonly deformed. Banded chert (Units Ia, Ic and Ie) and rhythmically bedded carbonate turbidite (Unit IIIc) are isoclinally folded between unfolded parallel contacts. Unit IIam, a strongly foliated and lineated amphibolite, and Unit IIs-1, a foliated siliceous-greenstone tectonite are considerably more penetratively deformed and of higher metamorphic grade than the lithotectonic units around them. This structural disharmony between adjacent units provides further evidence of tectonic emplacement.

Clear demonstration of the geometry and pattern of the juxtaposition of lithotectonic slices across the Sylvester allochthon is an intriguing result of this transect. The tectonic slices of the Sylvester, on a regional scale, are nested together in a "pancake" stack which is interleaved in all directions. Lithotectonic slices are grossly lensoidal; they taper and pinch-out, both along and across strike. East dips to fault surfaces predominate in the western Sylvester and west dips in the east; however, on a regional scale lithotectonic slices are for the most part subhorizontal with overlapping lateral pinch-outs. In such a stacking, a unit may be structurally highest locally, but no one unit can be said to overlie all others. The internal structural style of the Sylvester allochthon is therefore not strictly imbricate as are imbricate stream pebbles, roof shingles or fish scales. This is fundamentally different in nature from the truly imbricate internal structural style which is commonly attributed to subduction-related accretionary assemblages (Seely *et al.*, 1974; Karig and Sharman, 1975; Sample and Fisher, 1986). Recognition of the nested character of the Sylvester lithotectonic slices provides a more accurate and powerful model for prediction or extrapolation within the allochthon, and suggests that simple subduction zone genetic models may be inadequate to describe the telescoping of upper oceanic crust which is evident in the structural style of the Sylvester allochthon.

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CONODONT BIOSTRATIGRAPHY, MIDWAY PROPERTY, NORTHERN BRITISH COLUMBIA*
(104O/16)

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KEYWORDS: Jennings River, conodont faunas, Earn Group, McDame Group, Sylvester allochthon.

INTRODUCTION

This is a preliminary report on the conodont faunas which have been collected from the area of the Midway silver-lead-zinc manto deposit in Jennings River map area (104O/16), 80 kilometres west of Watson Lake, Yukon and 10 kilometres south of the British Columbia – Yukon border. Approximately 40 conodont collections have been recovered in the area since 1982, as part of property and regional mapping projects. During the summer of 1987, 78 samples were collected for conodont processing by S. Irwin. These samples form part of a broader study of the Devonian-Mississippian conodont faunas and biostratigraphy of the metalliferous Earn Group within miogeoclinal areas of northern British Columbia.

GEOLOGY

Previous work around the Midway deposit area includes 1:250 000-scale reconnaissance mapping by Gabrielse (1969) and 1:25 000 reconnaissance mapping by Nelson and Bradford (1987). Additional property mapping has been carried out by Cordilleran Engineering Ltd.

McDAME GROUP

The Middle Devonian McDame Group is composed of shallow, warm-marine carbonates that were deposited onto a subsiding shelf or platform (Gabrielse, 1963). In this study area the McDame is made up of a lower, dark grey, tan-weathering, massive to laminated, fetid dolostone and an upper, dark grey, fossiliferous platy limestone. Devonian macrofauna accumulations suggest an abundant but low diversity fauna, indicative of intertidal to subtidal environments. The McDame has undergone extensive karsting, at least some of it related to processes that predate Earn Group deposition. In the Midway area, the McDame Group is conformably (?) underlain by Lower Devonian Tapioca sandstone (Nelson and Bradford, 1987).

EARN GROUP

The Devono-Mississippian Earn Group comprises a turbiditic sequence that was originally included in the Lower Sylvester Group (Gabrielse, 1969). It has been reassigned to the Earn Group as named by Gordey *et al.* (1982a). The group consists of black slate, thin-bedded (occassionally) calcareous siltstone, thin to thick-bedded sandstone and chert-pebble conglomerate. There are economically significant baritic, siliceous and sulphide-rich exhalites within this unit (Nelson and Bradford, 1986). Two generally coarsening-upward sequences have been identified in the Earn around Midway by Cordilleran Engineering Ltd. The basal black shales of the Earn were deposited unconformably over the McDame carbonates. The upper contact is the basal thrust of the Sylvester allochthon (Nelson and Bradford, 1987).

SYLVESTER GROUP

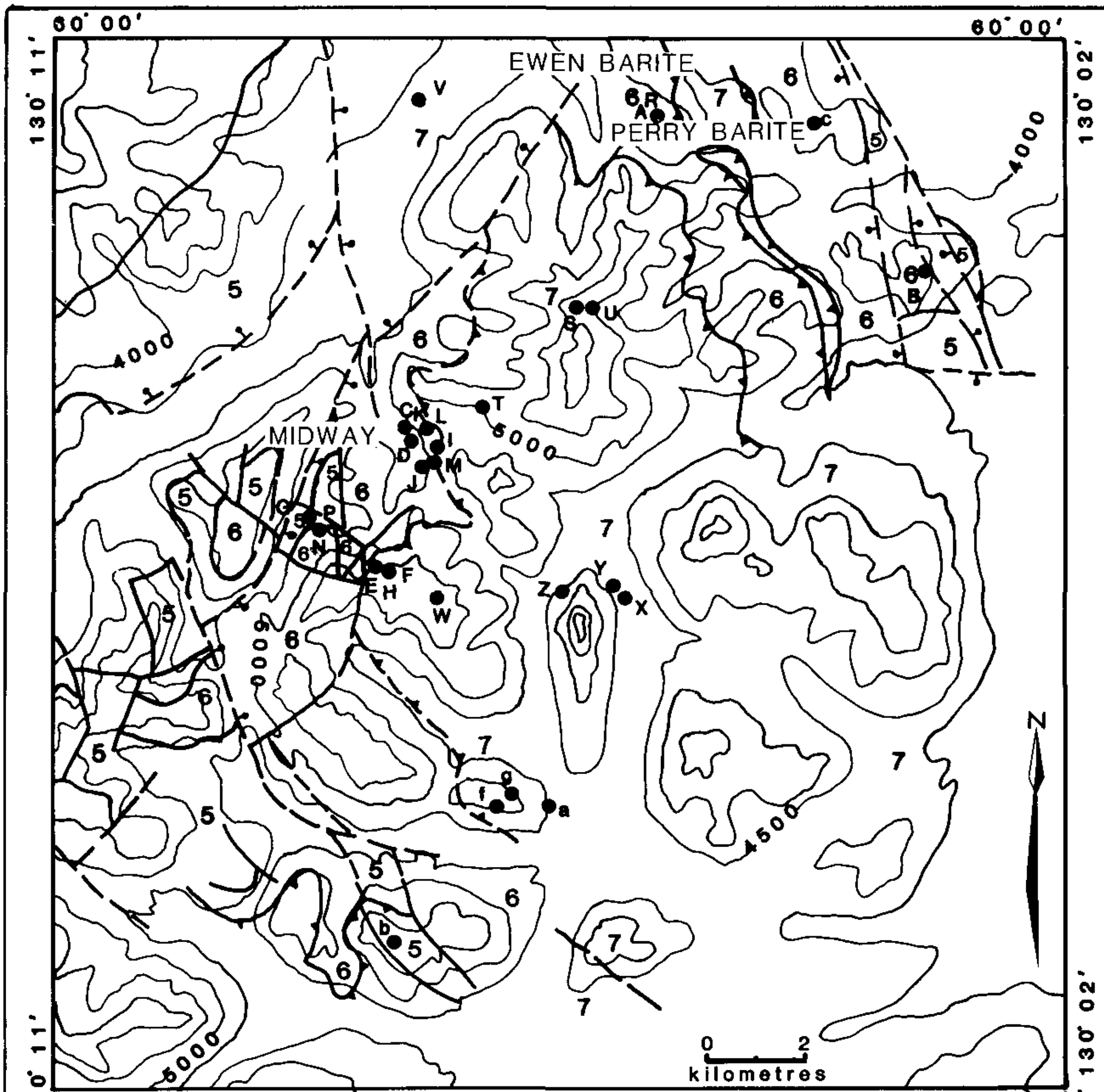
The Sylvester Group (used here in a restricted sense to exclude autochthonous strata) consists of an allochthon of Upper Paleozoic to Triassic chert, limestone, greenstone, clastic and ultramafic rocks thrust over autochthonous or parautochthonous strata along the continental margin of North America in Middle Jurassic to Early Cretaceous time (Gordey *et al.*, 1982b). It was originally mapped as autochthonous Sylvester Group by Gabrielse (1963). Nelson and Bradford (this volume) have subdivided the allochthon into three lithotectonic units, the lowest of which contains all the conodont faunas reported here. The tectonic signature was developed during two or more independant tectonic episodes (Harms, 1986; Nelson and Bradford, 1987).

CONODONT FAUNAS

At present, conodont faunas are known from the McDame Group, Earn Group and Sylvester allochthon. This has provided broad constraints on the age of these units. Within the area shown in Figure 1-23-1, the conodonts range in age from Middle Devonian through Late Carboniferous. Six conodont faunas are identified and discussed below:

I. Frasnian *Palmatolepis*.
II. Famennian *Palmatolepis*.
III. *Siphonodella*.
IV. *'Hindeodella' segaformis*.
V. *Gnathodus bilineatus*.
VI. *Idiognathoides*.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.



LEGEND

Devonian? to Triassic

7	**Sylvester Allocthon** chert, argillite, limestone, volcanics, serpentinite, gabbro.

Devonian-Mississippian

6	**Earn Group** slate, siltstone, greywacke, chert pebble conglomerate.

Middle Devonian

5	**McDame Group** dolomite, limestone.

A, a — conodont sample locations (see Table 1)

contours in feet

Figure 1-23-1. The collection sites of conodont-bearing samples (A to g), and simplified geology of the Midway area (after Nelson and Bradford, 1987).

FAUNA I

This fauna was recovered from dolomitic siltstone occupying hollows at the top of the McDame limestone at one locality. It comprises poorly preserved specimens of *Icriodus*, *Palmatolepis* and *Polygnathus*. Although these have not been determined to species level, they compare closely with early Late Devonian, Frasnian forms. Additional material should provide a more precise age for this faunule, which is important because it provides the first clear evidence for Late Devonian sedimentation prior to that of the Earn Group. It should also provide information on the nature and magnitude of the hiatus between the two groups.

A representative suite of lithotypes from core material of the McDame limestone (provided by D. Mundy, Cordilleran Engineering Ltd.) was analysed for conodonts, but few were recovered; they can only be broadly dated as Devonian. This probably results from a generally inhospitable environment, but large samples taken selectively might produce diagnostic collections.

Elsewhere within the Cordilleran miogeocline, Frasnian conodont collections are commonly found in Earn Group strata. Many collections of this age are associated with barite deposits in the Selwyn Basin, Yukon Territory (Dawson and Orchard, 1982).

FAUNA II

This fauna is known from the basal 1AC unit of the Lower Earn Group in two drill cores from the Midway property (Table 1-23-1). The fauna is characterized by abundant conodonts: the frequency is suggestive of either very slow rates of sedimentation and concentration as conodont lag deposits, or an extremely productive environment that has experienced a kill.

Fauna II is dominated by representatives of *Palmatolepis* ex gr. *glabra* Ulrich and Bassler, accompanied by *P. minuta* Branson and Mehl, *P. subperlobata* Branson and Mehl, *P.* cf. *P. regularis* Cooper, *P. quadrantinodosalobata* Sannemann, and *P. triangularis* Sannemann. Collectively, these conodonts represent the early to middle Famennian conodont zones of Upper *P. crepida* or *P. rhomboidea*. The fauna belongs to the offshore-basinal biofacies of *Palmatolepis* and lacks all indicators of shallow water deposition.

This fauna is widespread in the epicratonic region of western Canada. It is a typical Earn Group association (for example, Gordey *et al.*, 1982a, Fauna VI) in Yukon and the Kechika trough. South of Midway, in the Driftpile-Gataga area, approximately coeval faunas bracket mineralized horizons within the Earn Group (McClay and Insley, 1985; McClay *et al.*, 1986).

FAUNA III

This fauna characterizes the 2AC unit of the Earn Group in two drill cores on the Midway property (Figure 1-23-1, K, M), and has also been recovered from two localities within the outcrop of the Ewen and Perry barites. Fauna III is recognized by the occurrence of *Siphonodella*, the range of

TABLE 1-23-1. DETAILS OF THE CONODONT DATABASE DISCUSSED IN THIS PAPER

Loc. No. (Fig.1-23-1)	GSC Locality Number; Sample Number	Collector, Year	Stratigraphic Unit, Collector Assignment	Fauna No.	C.A.I.	Age
A	C-087737; 82MJO-BVH2	B. Hall, 1982	Earn Group, Ewen Barite	III–IV	6	Early Carboniferous
B	C-087738; 82MJO-BVH3	B. Hall, 1982	Earn Group, 2a	–	5	Middle Devonian–Early Carboniferous
C	C-102870; 82MW-82024	D. MacIntyre, 1982	Earn Group	–	5	Indeterminate
D	C-102871; 82MW-820031	D. MacIntyre, 1982	Earn Group	?III–IV+	5	Late Devonian–Early Carboniferous
E	C-116407; 84GAH-235F	T.A. Harms, 1984	Sylvester Group	IV	5	Early Carboniferous
F	C-116408; 84GAH-238F	T.A. Harms, 1984	Sylvester Group	VI?	5	Late Carboniferous–Early Permian
G	C-118251; 84MJO-SVMTN	W. Jakubowski, 1984	McDame Group	?III–IV+	5	Late Devonian–Early Carboniferous
H	C-118252; 84MJO-WJ84-1	W. Jakubowski, 1984	Sylvester Group	VI	5	Early Carboniferous
I	C-118253; 84MJO-83-34	W. Jakubowski, 1984	Earn Group (1AC)	II	5	Late Devonian
J	C-118254; 84MJO-83-27	W. Jakubowski, 1984	Earn Group (2AC)	–	5	Indeterminate
K	C-118255; 84MJO-83-28.2AC	W. Jakubowski, 1984	Earn Group (2AC)	III	6	Early Carboniferous
L	C-118256; 84MJO-83-28.1AC	W. Jakubowski, 1984	Earn Group (1AC)	II	5	Late Devonian
M	C-118258; 84MJO-82-13	W. Jakubowski, 1984	Earn Group (2AC)	III	5?	Early Carboniferous
N	C-118266; 84MJO-MD-2	D. Mundy, 1984	McDame Group	–	5	Devonian
P	C-118272; 84MJO-MD-8	D. Mundy, 1984	McDame Group	–	5	Middle–Late Devonian
R	C-118275; 84MJO-EWEN	W. Jakubowski, 1984	Earn Group, Ewen Barite	III	6	Early Carboniferous
S	C-143630; 86JB34-01-01	J. Bradford, 1986	Sylvester Group	V	5	Early Carboniferous
T	C-143629; 86JB17-18-01	J. Bradford, 1986	Sylvester Group	?III–IV+	5	Early Carboniferous
U	C-143625; 86JB15-01-01	J. Bradford, 1986	Sylvester Group	IV	5	Early Carboniferous
V	C-143632; 86JB13-07-01	J. Bradford, 1986	Sylvester Group	IV	5	Early Carboniferous
W	C-117623; 86TH02-06-01	T.A. Harms, 1986	Sylvester Group	III–IV+	5	Late Devonian–Early Carboniferous
X	C-143636; 86KG21-01-01	K. Green, 1986	Sylvester Group	–	5	Indeterminate
Y	C-143637; 86KG21-02-01	K. Green, 1986	Sylvester Group	IV	5	Early Carboniferous
Z	C-123645; 86JN30-07-01	J. Nelson, 1986	Sylvester Group	–	5	Carboniferous
a	C-117561; 86JN22-19-01	J. Nelson, 1986	Sylvester Group	IV	5	Early Carboniferous
b	C-143101; 86JN03-06A	J. Nelson, 1986	'McDame Group'	I	5	Late Devonian
c	C-143102; 86JN-05-08	J. Nelson, 1986	Earn Group, Perry Barite	III	5	Early Carboniferous
f	C-143106; 86JN-22-04	J. Nelson, 1986	Sylvester Group	III	6	Early Carboniferous
g	C-143107; 86JN-22-01	J. Nelson, 1986	Sylvester Group	–	5	Indeterminate

which approximates the early to middle Tournaisian (Kinderhookian). *Siphonodella*, the offshore successor to Late Devonian *Palmatolepis*, is found alone in some collections, but more commonly, species of *Gnathodus*, *Polygnathus*, *Protognathodus* and *Pseudopolygnathus* are associated, as for example at the Perry Barite property (c). High diversity faunules such as this are certainly conducive to improved zonal resolution, which may become critical to the question of Earn-Sylvester separation.

The occurrence of Fauna III also in strata assigned to the Sylvester Group (f) underlines this problem. This sample contains each of the genera listed as occurring in the Perry Barite collection, but in addition includes *Bispathodus* ex gr. *stabilis*, a relatively long-ranging taxon that occurs more commonly, possibly exclusively, in samples referred to the Sylvester Group (*see* below).

Elsewhere, *Siphonodella* is known to occur both in the Antler Formation of east-central British Columbia (Struik and Orchard, 1986), which belongs in the same tectonostratigraphic terrane as the Sylvester Group, and in the Earn Group of the Selwyn basin.

FAUNA IV

This fauna, known from four localities referred to the Sylvester Group, is typified by *'Hindeodella' segaformis*. In each of these collections (E, U, V, Y), *Bispathodus* ex gr. *stabilis* also occurs, as do fewer *Polygnathus* and *Pseudopolygnathus*. The last two genera also occur in Fauna III, but *B.* ex gr. *stabilis* is not known to occur for certain below Fauna IV. Some Midway samples (D, G, T) contain questionable specimens of *Bispathodus* and are therefore assigned a range of age, including levels younger than Fauna IV (IV + = Early Visean). One additional collection from the Sylvester Group (a) lacks the *segaformis* element, but contains *Eotaphrus*; both these taxa are of Early Carboniferous, Late Tournaisian (lower Osagean) age and are therefore combined in Fauna IV.

The *segaformis* element is widespread in areas marginal to the craton, and has been reported from stratiform barite deposits in Yukon Territory (Dawson and Orchard, 1982).

FAUNA V

In the study area, Fauna V is known from a single locality within the Sylvester Group. It consists of *Gnathodus bilineatus*, *G. girtyi*, *Lochriea commutata* and *Idioprioniodus*, an association indicative of the Late Visean to Early Namurian (Late Mississippian). Elsewhere in the Cordillera, this fauna is one of the most widespread (Orchard, 1987); it occurs in both the Antler and Fennell formations of the allochthonous Slide Mountain terrane, and in limestone-quartzite units of autochthonous Yukon strata (for example, Gordey *et al.*, 1982, Nos. 1-4, 7).

FAUNA VI

This fauna is known from one or two localities within the Sylvester Group. It is characterized by *Idiognathoides*, which indicates a Late Namurian to Bashkirian (Early to early Middle Pennsylvanian) age. As in other collections from the Slide Mountain terrane (Orchard, 1986), one faunule (H) also includes primitive *Neogondolella*. A second collection (F) contains *Idiognathodus*, a genus that is commonly found with *Idiognathoides*, although the former ranges through the Upper Carboniferous and lowermost Permian.

CONCLUSIONS

Within the study area, the following conodont-based biostratigraphic conclusions are reached:

(1) Dolomitic siltstone occupying hollows at the top of the McDame Group are Late Devonian in age, but significantly older than basal Earn Group.

(2) The hiatus between the McDame and the Earn groups is equivalent to an undetermined part of the Frasnian plus about five conodont zones within the Famennian.

(3) Informal Unit 1AC, which occurs at or near the base of the Earn Group in the Midway area, is referred to the Upper *Palmatolepis crepida* Zone or *P. rhomboidea* Zone of the early to middle Famennian.

(4) Both the informal Unit 2AC of the Earn Group, and strata associated with the Ewen and Perry barites, are Early to Middle Tournaisian in age. This is also the age range assigned to the oldest conodonts identified within Sylvester Group.

(5) In the study area, the Sylvester Group, as presently conceived, includes limestone of four different ages: Early to Middle Tournaisian (Fauna III), Late Tournaisian (Fauna IV), Early Namurian (Fauna V), and Late Namurian to Bashkirian (Fauna VI).

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JoAnne Nelson and John Bradford provided excellent support in the field. Access to the Midway property and drill cores, given to us by Henrik Thalenhorst of Strathcona Mineral Services Limited, and the hospitality shown to us at the Midway camp, were greatly appreciated. The following collectors of conodont samples are thanked: B. Hall, D. MacIntyre, T.A. Harms, W. Jakubowski, D. Mundy, J. Nelson, J. Bradford and K. Green.

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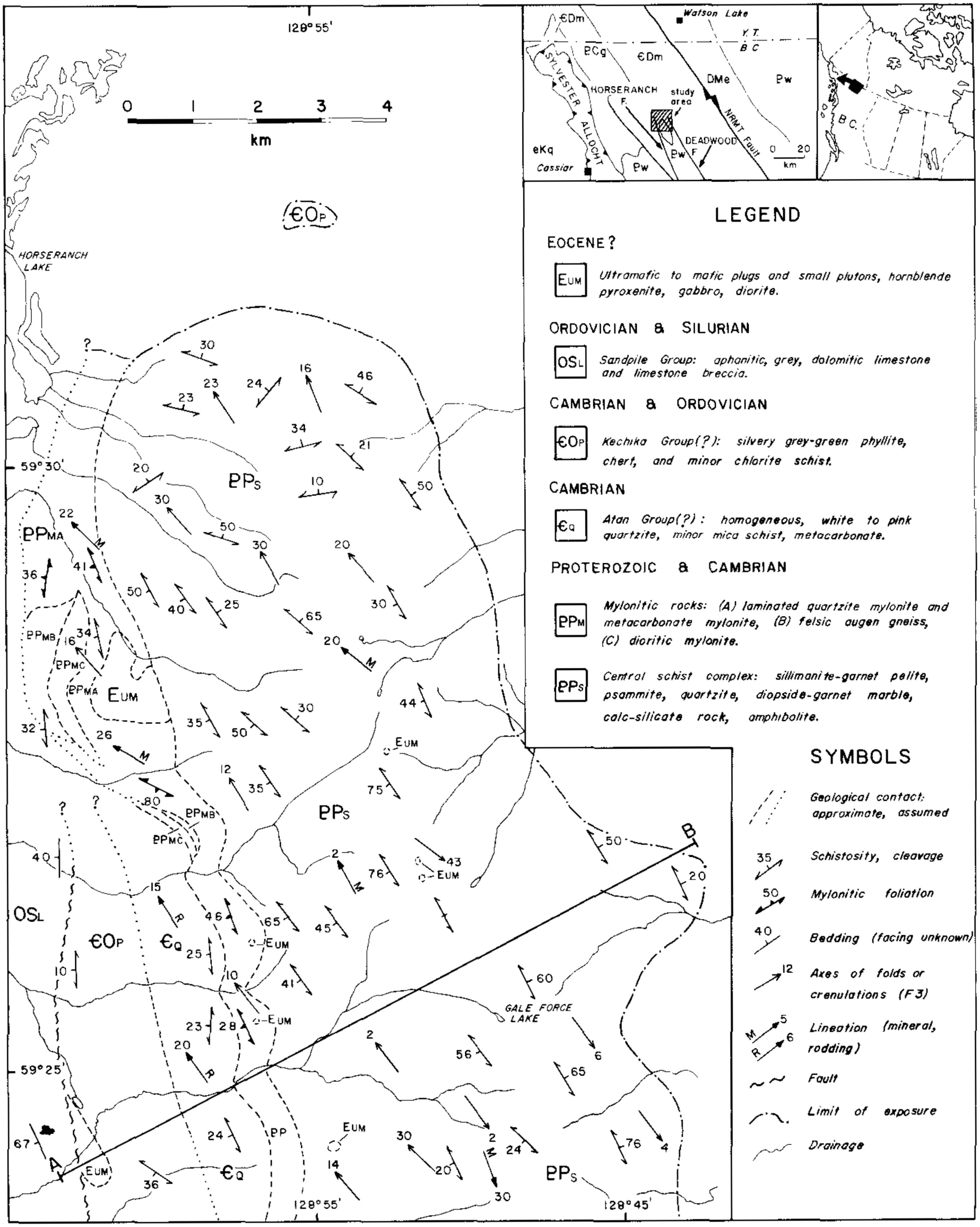

Figure 1-24-1. Geology of the northern Horseranch Range. Inset shows index map and regional geology. Line A-B is the location of the cross-section in Figure 1-24-2.

GEOLOGICAL STUDIES IN THE HORSERANCH RANGE, NORTHERN BRITISH COLUMBIA (104P/07, 10)

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KEYWORDS: Regional geology, Horseranch Range, schist complex, Cassiar terrane, regional correlations, structural geology.

INTRODUCTION

This report presents the results of field study of a high-grade schist complex exposed in the Horseranch Range of northern British Columbia. Data from reconnaissance mapping (Gabrielse, 1963 and personal communication, 1985) and the regional antiformal structure of the range suggested that it may be a metamorphic core-complex. This project was undertaken to investigate the structure, metamorphism and age of the complex, to assess its mineral potential, and to contribute to the study of basement tectonics in the northern Cordillera.

LOCATION AND ACCESS

The area is located in the Cassiar Mountains approximately 65 kilometres southwest of Watson Lake, Yukon (Figure 1-24-1). It is within 1:50 000 map sheets 104P/07 and 104P/10. Mapping was carried out from fly-camps positioned and supplied by helicopter from Watson Lake during July and August 1987.

REGIONAL SETTING AND PREVIOUS WORK

The Horseranch Range lies in 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. The range is bounded to the east and west by the Deadwood and Horseranch faults (Gabrielse, 1985) (Figure 1-24-1). It is underlain by a thick sequence of schistose Proterozoic and/or lower Cambrian, shallow-water metasedimentary rocks, by orthogneiss, and by post-tectonic ultramafic and granitoid intrusions. The structure of the range is that of a northerly trending, doubly plunging anticlinorium. Contacts with younger platformal rocks to the west and east are drift covered or faulted.

Gabrielse (1963) reported mesoscopic tight folds in quartzite and gneiss, with axial planes forming an upward-converging fan centred on the main anticlinorial axis, crenulations in quartz-mica schist, and a-c joints related to the major anticline. At least 2 kilometres of vertical uplift is postulated along the Horseranch and Deadwood faults (Gabrielse, 1985). On the basis of regional correlations, the rocks were thought to be upper Proterozoic and/or Cambrian. Uranium-lead ages of detrital zircons from the schist complex suggest a source-rock age of 2.22 billion years (Erdmer and Baadsgaard, 1987), similar to source-rock ages elsewhere in the Cassiar terrane. The age of metamorphism(s) and uplift is unknown.

LITHOLOGY

The schist complex (Horseranch Group of Gabrielse, 1963) consists of interlayered pelitic to psammitic schist, quartzite, marble and minor amphibolite, intruded by granitic and mafic to ultramafic rocks. A moderately west-dipping mylonite zone is developed at the western boundary between the schist complex and lower grade, homogeneous quartzite. Chloritic phyllite, overlain by unmetamorphosed dolomitic limestone, overlies the quartzite at the western margin of the Horseranch Range. A fault separates the unmetamorphosed sedimentary rocks to the west and the phyllite and ultramafic to mafic intrusive rocks to the east (Figures 1-24-1 and 1-24-2).

METASEDIMENTARY AND SEDIMENTARY ROCKS

Central Schist Complex

The central schist complex is the most extensive and structurally the lowest unit in the map area. It consists of interlayered, fine to medium-grained pelitic to psammitic schist, quartzite, marble, fine to medium-grained granitic to granodioritic orthogneiss and minor amphibolite. Compositional layering (defined by quartz-rich, carbonate-rich and mica-rich layers) approximately 5 centimetres to 20 metres thick is parallel to the main schistosity. Quartz and feldspar stretching lineations are locally developed in psammite, quartzite and orthogneiss. Centimetre to metre-scale concordant quartz veins, boudins and lenses are common in the schist. Locally, veins of quartz and aplite 0.1 to 0.5 centimetre thick are tightly to isoclinally folded with axial surfaces parallel to the main schistosity. The limbs of these folds and other veins of quartz and granitic rock are boudinaged. This suggests that at least some quartz veins and granitoid intrusions are syntectonic with respect to the schistosity. Quartz veins and granitoid intrusions also cut the foliation (*see* below).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

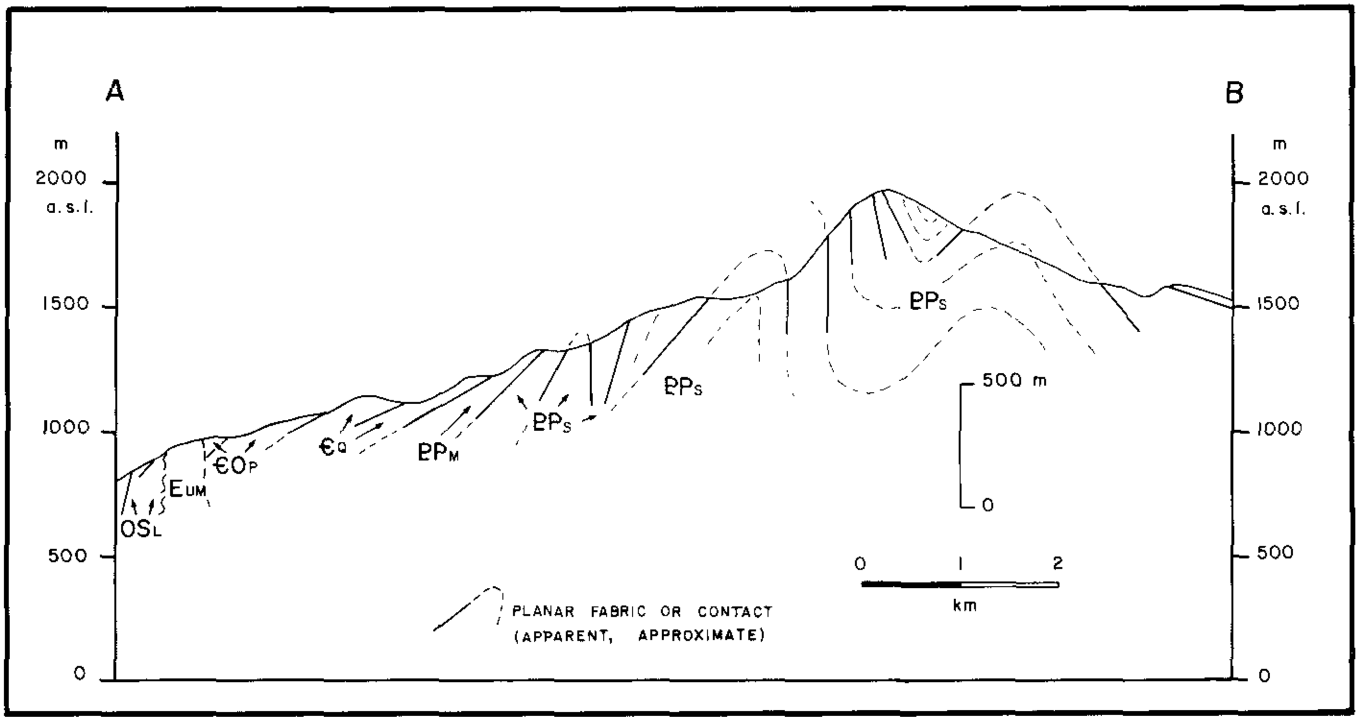

Figure 1-24-2. Structural cross-section through the Horseranch Range (*see* Figure 1-24-1 for section location).

Quartzite is fine to medium grained, and contains minor biotite and muscovite, and locally garnet. Quartzite adjacent to marble layers contains disseminated pyrite. Fine to medium-grained, white to buff marble characteristically contains layers of quartz, quartzite, chert and calc-silicate (diopside-garnet-rich) rock 0.5 to 5 centimetres thick, which are oriented parallel to the foliation and are locally boudinaged or pinch and swell. Specks of graphite(?) are commonly disseminated in marble.

Fine to medium-grained granitic to granodioritic orthogneiss locally forms layers 5 to 15 metres thick and concordant lenses within the central schist complex.

A pinching and swelling amphibolite layer is exposed in biotite schist on the eastern shore of Gale Force Lake (Figure 1-24-1). Relict ophitic texture is preserved in the centre of the layer. Its schistose margins indicate that the biotite schist and the amphibolite have been deformed together.

Mylonite Zone

Mylonite is developed in a zone 400 metres to 1 kilometre wide and at least 13 kilometres long between the central schist complex and overlying quartzite along the western margin of the Horseranch Range (Figure 1-24-2). The mylonite zone includes part of the central schist complex, dioritic rocks of unknown affinity and medium to coarse-grained granitoid rocks. Granitic, ultramafic and mafic rocks that intrude the mylonite are not deformed. No widespread retrogression is associated with the mylonite zone.

Homogeneous Quartzite and Phyllite

Homogeneous, white to pink, fine to medium-grained quartzite structurally overlies the mylonite zone. The quartzite is well jointed and finely rodded, and commonly contains pyrite as stringers and disseminated blebs. Locally, irregular discordant pods of low-grade metacarbonate rock and concordant continuous layers of crenulated biotite schist are exposed within the quartzite. This compositional variation may reflect original sedimentary layering. The quartzite unit is distinguished from quartzite layers in the central schist complex by its greater areal extent and homogeneity.

Structurally (and stratigraphically ?) overlying the quartzite is a zone of chloritic, fissile, aphanitic, silvery green-grey phyllite locally interlayered with chlorite schist (possibly metatuff). It characteristically contains cherty layers 1 to 15 centimetres thick which are commonly boudinaged or tightly folded and are cut by a phyllitic cleavage which is axial planar to tight folds.

Dolomitic Limestone

Unmetamorphosed, fractured and locally brecciated, aphanitic, dark grey dolomitic limestone is exposed west of the phyllite. The limestone is commonly cut by a fine network of chert veinlets and is brecciated near the inferred contact with metamorphic and plutonic rocks to the east, suggesting the presence of a fault zone (Horseranch fault of Gabrielse, 1963, 1985).

REGIONAL CORRELATIONS

Gabrielse (1963 and personal communication, 1985) suggested a correlation of some of the rocks structurally beneath the mylonite with the lower quartzite of the Cambrian Atan Group. However, the homogeneous quartzite that overlies the mylonite is lithologically more similar to the Atan quartzite than is quartzite beneath the mylonite. Exposure at the contact between the overlying quartzite and phyllite is poor, and no limestone which would correlate with the upper limestone division of the Atan Group is exposed, which makes any interpretation tentative. However, assuming that the apparently condensed section results from a local hiatus, the homogeneous quartzite is correlated here with the Atan Group. The question of whether any part of the central schist complex correlates with the Atan Group will require testing by radiometric age determinations.

The phyllite has been correlated with the Devono-Mississippian Sylvester Group, a sequence of greenstone and clastic metasedimentary rocks (Gabrielse, 1963). However, as metavolcanic rocks are a minor component of the phyllite in the study area, and as the unit is lithologically more similar to phyllite of the Cambro-Ordovician Kechika Group in adjacent areas, it is correlated here with the Kechika Group (Figure 1-24-1). Confirmation of this correlation will require fossil age determinations. The dolomitic limestone along the western margin of the map area has been demonstrated, on the basis of fossil ages, to correlate with the Ordovician-Silurian Sandpile Group (Gabrielse, 1963).

INTRUSIVE ROCKS

Mafic and Ultramafic Rocks

Dark green to black, medium to coarse-grained, massive diorite, gabbro and hornblende pyroxenite intrude the central schist complex, the mylonite, the homogeneous quartzite and the phyllite. The intrusions commonly form small plugs 6 to 10 metres across. A large, irregularly shaped body of coarse-grained, massive hornblende pyroxenite, approximately 1.5 square kilometres in area, crops out in the northeastern part of the map area (Figure 1-24-1). This body contains inclusions of fine-grained tourmaline and garnet-bearing felsic rocks, and of quartzite of unknown affinity. No contact metamorphic effects are associated with the mafic to ultramafic intrusions.

Granitoid Rocks

Granitic dykes and sills are widespread in the central schist complex, and generally postdate penetrative fabrics in all units, and F_3 folds (*see* below). Their composition ranges from two-mica granodiorite to granite. Grain size is variable and commonly less than 1 centimetre. Large alkali or perthitic feldspar phenocrysts are common in medium to fine-grained phases. Tourmaline, developed locally as radiating sprays up to 4 centimetres long, and euhedral garnets 1 to 5 millimetres across are common accessories. Quartz veins cut and are cut by the granitoid intrusions.

Injection migmatite is locally developed between late syn to post-tectonic granitoid dykes and sills and semipelitic schist of the central schist complex.

STRUCTURAL GEOLOGY

PLANAR FABRICS

No unequivocal primary sedimentary structures are preserved in the central schist complex. Local F_1(?) folds and sheared quartz veins and granitic dykes suggest some transposition of primary fabric (Plate 1-24-1), and local compositional layering is interpreted as tectonically modified bedding.

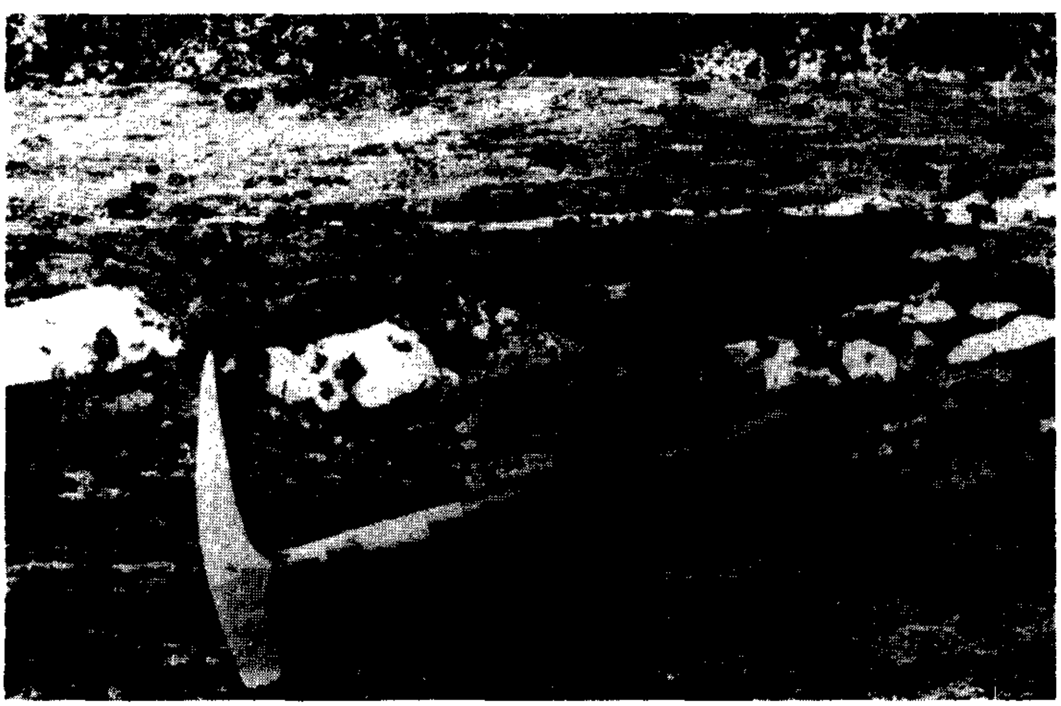

Plate 1-24-1. Type 2B asymmetrical pull-aparts in a quartz vein in the central schist complex, indicating sinistral shear along a nearly vertical foliation surface (terminology after Hanmer, 1986). Note normal, extensional shears at the pinches.

The parallel alignment of micas and tabular quartz and feldspar grains defines the main schistosity in the central schist complex. In the mylonite, foliation is defined by fine colour banding in quartzite, strung-out quartz and feldspar aggregates in psammite and granitoid rocks, and ductile flow banding in metacarbonate rocks. The contact between the central schist complex and the mylonite zone is placed at the first appearance of highly strained marble, calc-silicate rock, or finely banded quartzite. On the basis of minimum covered intervals between outcrops of mylonite and nonmylonitic schist, the contact zone is approximately 5 to 10 metres wide. Foliation in the mylonite is concordant with the schistosity in the underlying schist and with the foliation in the overlying quartzite.

LINEATIONS

A northwesterly trending (320°), horizontal to gently northerly plunging quartz and feldspar stretching lineation is common in quartzite and psammite of the central schist complex. A local rodding in concordant quartz veins and in fine-grained quartzite is parallel to the stretching lineation.

In the mylonite, quartz rodding and quartz and feldspar stretching lineations trend northwesterly (300 to 330°) with moderate plunge (12 to 33°).

FOLDS

Distinction of fold phases is hindered by the paucity of refolded folds. However, on the basis of the planar fabrics they deform, and of the units in which they are developed, three phases of folding are recognized in the central schist complex, mylonite zone, and quartzite sequence, and two in the phyllite.

The earliest folds (F_1) in the schist complex are tight to isoclinal, locally transposed, centimetre-scale folds with axial planes parallel to the foliation. They deform quartz and aplite veins 1 to 5 millimetres wide which also cut the foliation, indicating that F_1 folds may result from local flattening during foliation development.

F_2 folds deform the foliation in the mylonite. They range from folds with axial surfaces parallel to the mylonitic foliation, to west-northwesterly trending, moderately plunging folds with steeply dipping west-southwesterly striking axial surfaces (Plate 1-24-2). Differential weathering between carbonate-rich layers and resistant quartz-rich layers highlights F_2 structures in mylonitic metacarbonate rocks. Fold limbs in competent layers are commonly attenuated or boudinaged; boudins are dextrally, and locally sinistrally, rotated and exhibit well-developed tails (Plate 1-24-3).

Ubiquitous, gentle to tight, northwesterly trending F_3 crenulations and mesoscopic folds (wavelengths of 0.1 to 2.0 metres, amplitudes of 0.1 to 0.5 metre) are prominent structures in the schist complex and are congruent with the Horseranch anticlinorial structure. These folds are commonly upright or steeply inclined and plunge gently northwest. In the south, F_3 folds vary from upright to recumbent, with hinge lines from horizontal to gently southeasterly plunging. This variation probably reflects the proximity of the central inflection of the anticlinorium outlined by Gabrielse (1963).

Northwesterly trending, gently plunging mesoscopic folds and crenulations locally deform the mylonitic foliation and mica schist layers in the homogeneous quartzite, demonstrating that F_3 folds postdate mylonitization.

Parallelism between F_3 fold axes, mineral stretching lineations and quartz rodding, and the presence of a-c joints

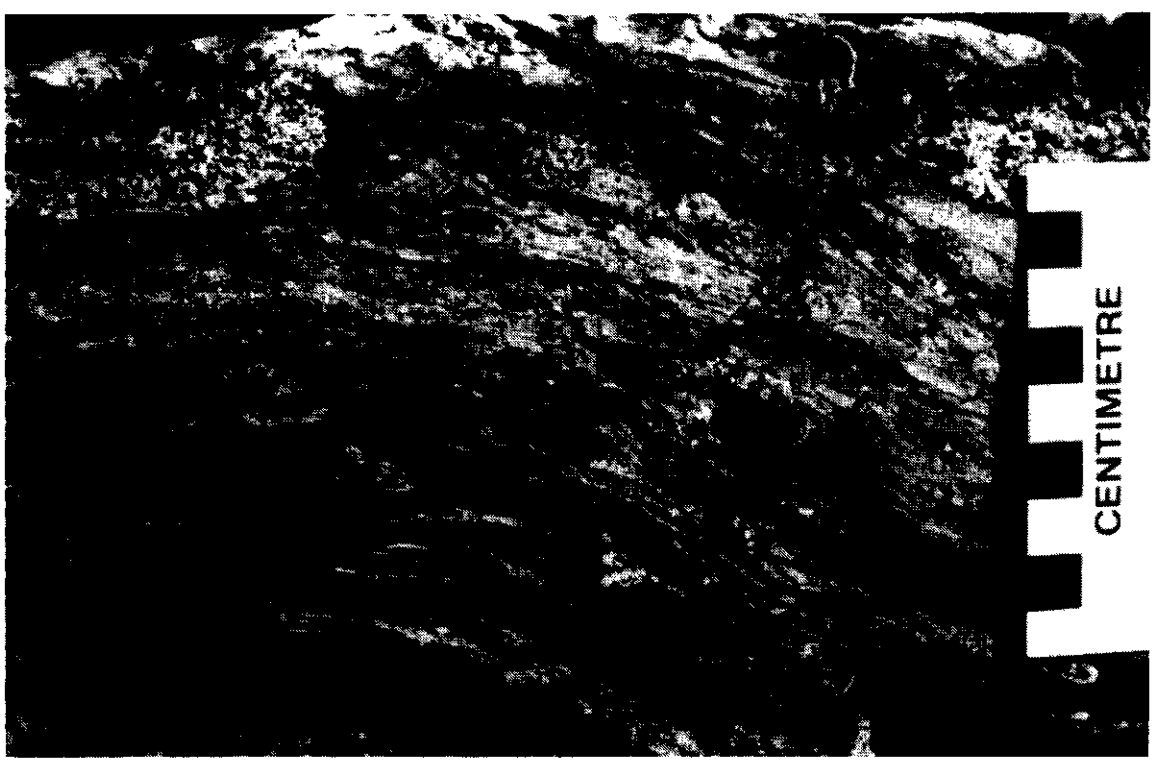

Plate 1-24-2. Tight to isoclinal folds (F_2) in mylonitic metacarbonate.

Plate 1-24-3. δ-type porphyroclast systems (Passchier and Simpson, 1986) of calc-silicate rock in a metacarbonate mylonite, viewed looking southwest, indicate top-to-the-northwest shear.

normal to F_3 axes, suggest that the latest strain was extension parallel to F_3 axes.

In the phyllite, tight to isoclinal horizontal folds in fine-grained calcareous layers (2 to 15 centimetres wide) have northwesterly trending axes and moderately southwest-dipping axial surfaces. These folds are cut by an axial planar phyllitic cleavage. West-southwesterly trending, gently westerly plunging kinks and mesoscopic chevron folds deform this cleavage.

KINEMATIC INDICATORS

Kinematic indicators in the mylonite include: (1) asymmetrically folded or rotated boudins of chert, quartz and calc-silicate rock in marble (Plate 1-24-3); (2) tight to isoclinal asymmetric folds in banded quartzite; (3) granitic pull-apart "fish" and rotated quartz boudins derived from originally continuous veins, sills and dykes; and (4) C-S planes in orthogneiss and schist (Plate 1-24-4).

Plate 1-24-4. C-S planes in oriented, slabbed sample of mylonitic orthogneiss, viewed looking southwest, indicate top-to-the-northwest shear. Type σ_b-porphyroclast systems are feldspar.

Most observations indicate that lineation in the mylonite (and in the central schist complex) is approximately parallel to a principal extension axis. The lineation, together with C-S planes, pull-apart fish and asymmetrical folds, indicates an overall top-to-the-northwest shearing. Boudins of chert, quartz, and calc-silicate rock locally have well-developed tails defining both σ_b-type and δ-type porphyroclast systems (Passchier and Simpson, 1986). In almost all cases these porphyroclast systems indicate top-to-the-northwest shearing. Notwithstanding a few σ_a-type systems and sheared quartz veins indicating top-to-the-southeast shear, the overall displacement recorded in the mylonite zone is top-down-to-the-northwest or right-normal.

METAMORPHISM

Diagnostic metamorphic mineral assemblages include sillimanite and garnet in pelitic schist, and diopside and grossular in marble. Evidence of partial melting is not visible. Quartzofeldspathic layers lack mafic selvages, and many can be traced into late granitoid intrusions. Sillimanite and muscovite are stable in pelitic schist and potassium feldspar is absent, indicating amphibolite facies pressure-temperature conditions of approximately 550 to 650°C at assumed pressures of 200 to 500 kilopascals (2 to 5 kilobars). Locally well-developed sillimanite porphyroblasts cut across the schistosity in the central schist complex, indicating that metamorphism postdates the development of foliation in these rocks.

The metamorphic grade decreases outwards away from the core structure. An abrupt change from amphibolite grade (sillimanite zone) to greenschist grade (biotite zone) across the mylonite zone is interpreted as the result of tectonic thinning. In addition, the absence of pervasive retrogression in the mylonite suggests that deformation occurred at elevated temperatures.

MINERALIZATION

Mineralization in economic quantities was not observed in the map area. Disseminated pyrite is present in the ultramafic to mafic intrusions and in quartzite. Jarosite(?) and iron-oxide gossan is observed locally in pelitic schist and is related to minor disseminated sulphides. Beryl reported in pegmatite south of the map area (Gabrielse, 1963) was not observed in this study.

DISCUSSION AND CONCLUSIONS

The Proterozoic(?) schist complex of the Horseranch Range has been metamorphosed to amphibolite grade and subsequently mylonitized along its contact with lower grade Cambrian(?) rocks. The absence of extensive retrogression in the mylonite zone suggests mylonitization at elevated temperatures. Kinematic indicators reflect top-to-the-northwest, partly down-dip movement in the west-dipping mylonite zone (that is, extensional strain). Although the regional tectonic significance of this strain is still unclear, the sense of displacement in the mylonite zone suggests large-scale tectonic denudation.

Folding about an upright, northwest-trending regional axis parallel to the latest mesoscopic folds (F_3) apparently postdates the mylonitization, but additional data from the northern and eastern parts of the range are required to confirm this interpretation. The Horseranch fault postdates F_3 folds. The relationship of strain in the phyllite to that in the schist complex is unknown.

Future work, including detailed mapping, petrography, macro and microscopic structural analysis, and uranium-lead and ^{40}Ar-^{39}Ar isotopic dating will address the following:

(1) Depositional and metamorphic age of the schist complex.

(2) Structural relationships between the phyllite, the quartzite and the schist complex.

(3) Timing, rate and mechanism(s) of uplift of the Horseranch Range.

(4) Regional extent and tectonic significance of the mylonite zone and the absolute timing of mylonitization.

(5) Origin of the ultramafic to mafic and granitic rocks.

ACKNOWLEDGMENTS

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Mineral Deposit Studies

GOLD-ENRICHED SKARN DEPOSITS OF BRITISH COLUMBIA*

By A. D. Ettlinger and G. E. Ray

KEYWORDS: Economic geology, gold, skarn, Texada Island, Banks Island, Nanaimo Lakes, Zeballos, Benson Lake, OKA, Dividend-Lakeview, Greenwood, Hedley, Teepee Peak.

INTRODUCTION

This report summarizes field studies of selected gold-bearing skarns in British Columbia (Figure 2-1-1). A comprehensive study of the petrology, geochemistry and distribution of gold skarn minerlization in the province is now in progress. The distribution and description of these deposits will be presented as an Open File report in early 1988.

Thirty-six per cent of the approximately 340 known skarn occurrences in British Columbia reportedly contain anomalous gold values. As gold production from 50 skarn deposits worldwide exceeds 1000 tonnes (Meinert, 1987), the poten-

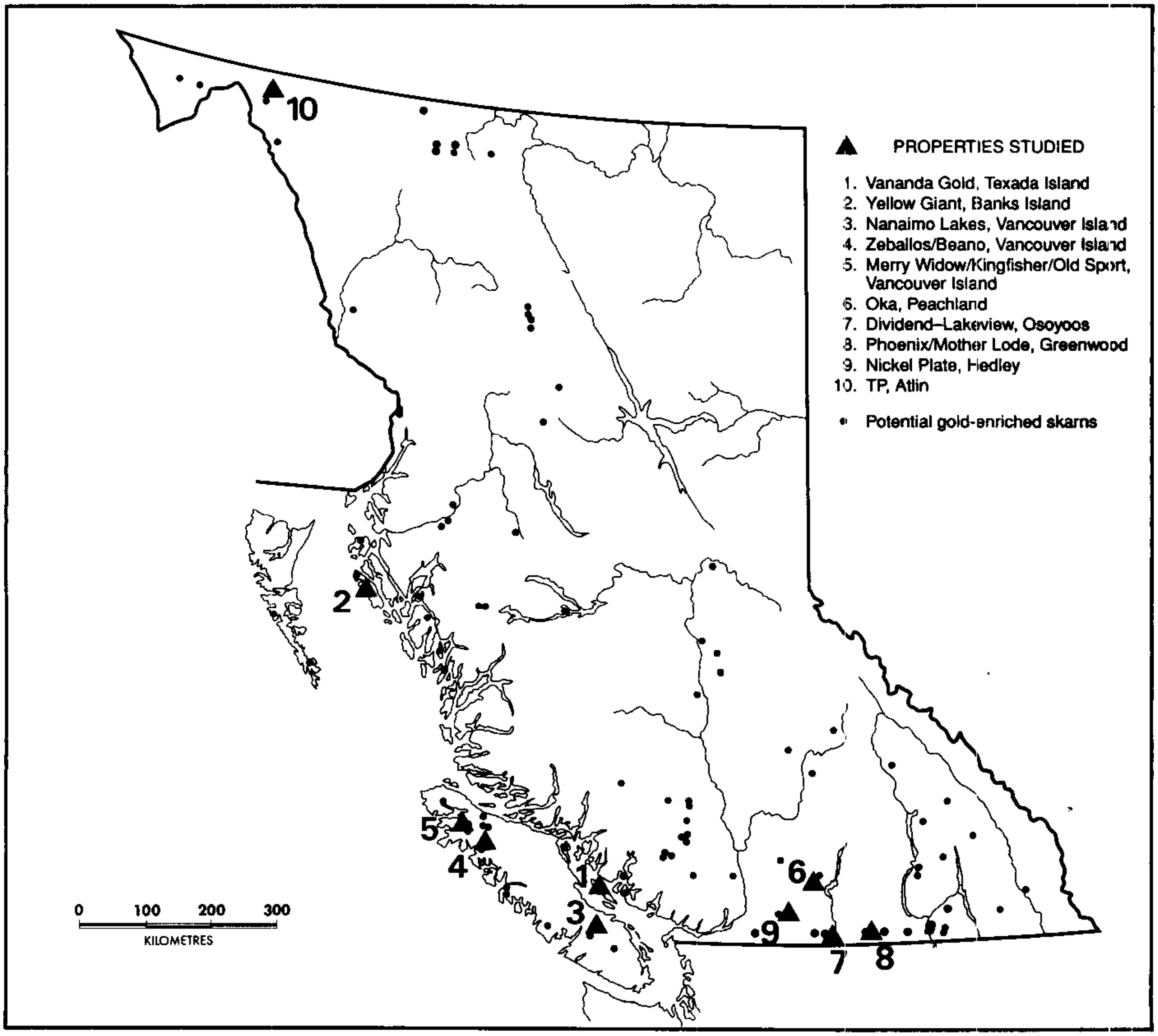

Figure 2-1-1. Location map of deposits studied.

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

tial economic importance of skarns as a source of gold in British Columbia is clear.

The following property descriptions are from skarns visited during the 1985, 1986 and 1987 field seasons. These occurrences were selected for on-site study based on the following criteria: style of skarn mineralization present (that is, copper, iron, gold skarn); gold content; current exploration interest; exposure and access. British Columbia Mineral Inventory Numbers (MINFILE) are given for each property visited.

GEOLOGY OF SELECTED DEPOSITS

TEXADA ISLAND SKARNS

(MINFILE 092F-105 to 107, 110, 112, 113, 257 to 259, 269 to 271, 295; 92F/10E, 15E)

Iron and copper-gold skarn mineralization occurs along a continuous belt between the villages of Vananda and Gillies Bay on northern Texada Island (Figure 2-1-2). During the period 1896 to 1976 this area produced 21 million tonnes of ore (Peatfield, 1987). Copper-gold skarns were worked in the Little Billie, Marble Bay, Copper Queen and Cornell mines (Table 2-1-1), while magnetite skarn was exploited in the Prescott, Paxton, Lake and Yellow Kid mines. The copper-gold skarns occupy the northern part of the belt near Vananda and contain mineralogies similar to other copper skarns described by Einaudi *et al.* (1981) and Meinert (1983). The magnetite skarns, which were described by Meinert (1984), are situated in the southern part of the belt, near Gillies Bay, approximately 6 kilometres south of the Vananda camp. Between these two centres of mining activity there are numerous showings of manto-type massive sulphide replacement of limestone, sulphide-rich skarn and mineralized shear zones.

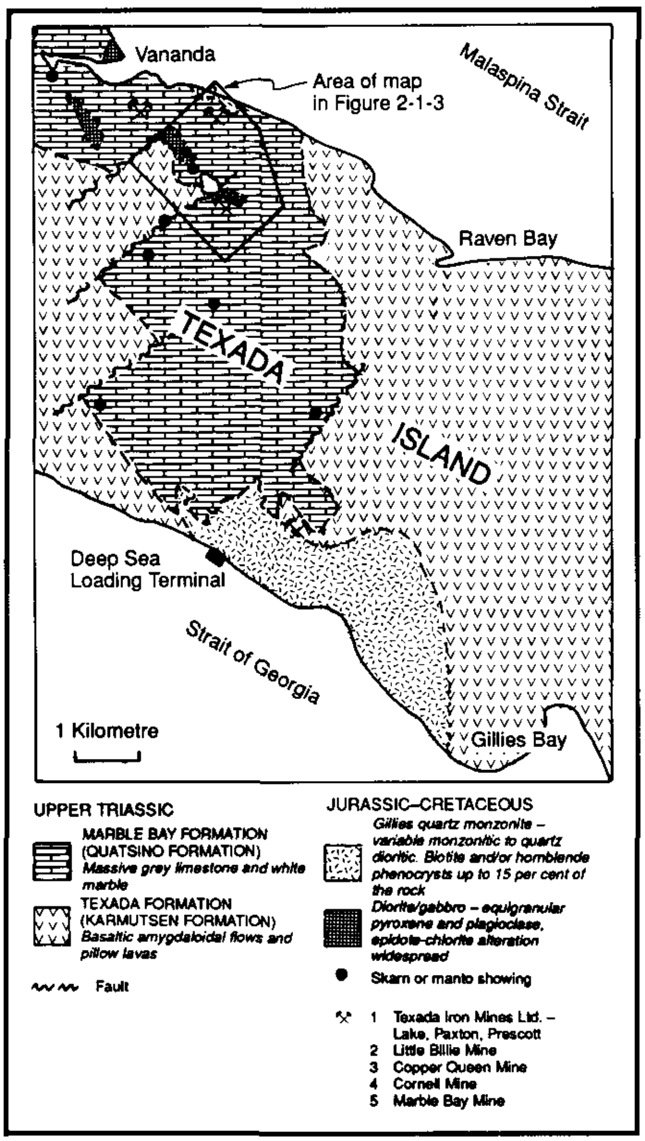

Figure 2-1-2. Location map of Texada Island skarns.

TABLE 2-1-1
PRODUCTION FIGURES FOR TEXADA ISLAND SKARN DEPOSITS
(Modified from Peatfield, 1987)

Mine	Period	Ore (t)	Au (g)	Ag (g)	Cu (kg)
Copper-gold Skarns					
Copper Queen	1903-1917	4 075	47 066	354 618	180 747
Cornell	1897-1919	40 687	471 085	2 194 471	1 368 513
Little Billie	1896-1952	63 711	363 168	1 198 304	819 098
Marble Bay	1899-1929	199 210	1 544 100	12 620 500	6 788 900
Total		307 683	2 425 419	16 367 893	9 157 257
Iron Skarns					
Texada Iron Mines Ltd. (Prescott, Lake, Paxton and Yellow Kid mines)	1885-1976	20 880 900	887 560	23 644 310	26 740 300

Host Rock Lithology

The host rocks are Triassic Marble Bay limestones which are stratigraphically equivalent to the Quatsino limestone on Vancouver Island. This unit comprises bedded, grey, fine-grained limestone and coarsely crystalline, white to light grey marble, extending southwards, in a belt 3 kilometres wide, from the village of Vananda to the Texada Iron Mines Ltd. property. Lower greenschist metamorphosed basalts outcrop either side of the carbonate belt. These amygdaloidal and pillow lavas are probably correlative with the Karmutsen Formation which underlies the Quatsino limestone on Vancouver Island. At the Lake magnetite mine, bedded limestone conformably overlies the basalt which has been replaced by skarn. Bedding strikes northwest and dips 30 degrees southwest.

The volcanics and limestones are intruded by Mesozoic (?) felsic granodiorites and quartz monzonites which are spatially associated with skarn at the Texada Iron and Little Billie mines, and by a gabbroic suite associated with skarn mineralization at the Cornell mine and in the Florence-Security area (Figure 2-1-3). Major element oxide analyses for these two intrusive suites are presented in Table 2-1-2. Sample 800N960E is similar to the granodiorite described by Le Maitre (1976) but sample 275N37E is silica undersaturated and lies between a gabbro and a nephelinite.

Skarn Mineralization

Gold-silver-copper mineralization occurs in irregular pipe-like bodies along a granodiorite-marble contact at the Little Billie mine. The ore zones plunge 45 degrees south along the contact and are open to depth. Coarse-bladed wollastonite and garnet-diopside skarns contain bornite, chalcopyrite, pyrite, molybdenite, magnetite, sphalerite, galena, scheelite, gold and silver. Reflected light microscopy shows native gold is associated with blebs of bornite. Wollastonite-garnet textures exhibiting flow banding indicate that these two phases probably crystallized simultaneously and are of metasomatic origin. Early tan-coloured garnet is cut by later dark brown garnet veinlets. Electron microprobe analyses at Washington State University show the composition of the early garnet phase as Ad_{17} (andradite) to Ad_{66} while the later garnet is more iron rich. Only one diopside replacement event has been identified, with compositions ranging from Hd_2 (hedenbergite) to Hd_{58}.

Skarn associated with the Gillies quartz monzonite at the Texada Iron Mines property is distinctively more iron rich and contains lower gold grades. Endoskarn in the quartz monzonite occurs as a widely spaced epidote stockwork with white albitic(?) envelopes. The stockwork becomes denser and garnet-amphibole skarn also replaces quartz monzonite toward the intrusive contacts. Magnetite occurs in all three hosts (limestone, volcanics and quartz monzonite), however, sulphide mineralization is best developed in skarn replacing limestone. Skarn minerals include garnet, diopside, epidote, amphibole, albite, magnetite, pyrite, chalcopyrite and erythrite.

In summary, there are at least two distinctly different types of skarn deposits on the northern end of Texada Island. Iron skarns with low gold-copper values to the south near Gillies Bay, and copper skarns with higher gold and low iron to the north near Vananda, may represent the end-members of a metallogenically zoned suite of Texada Island skarns.

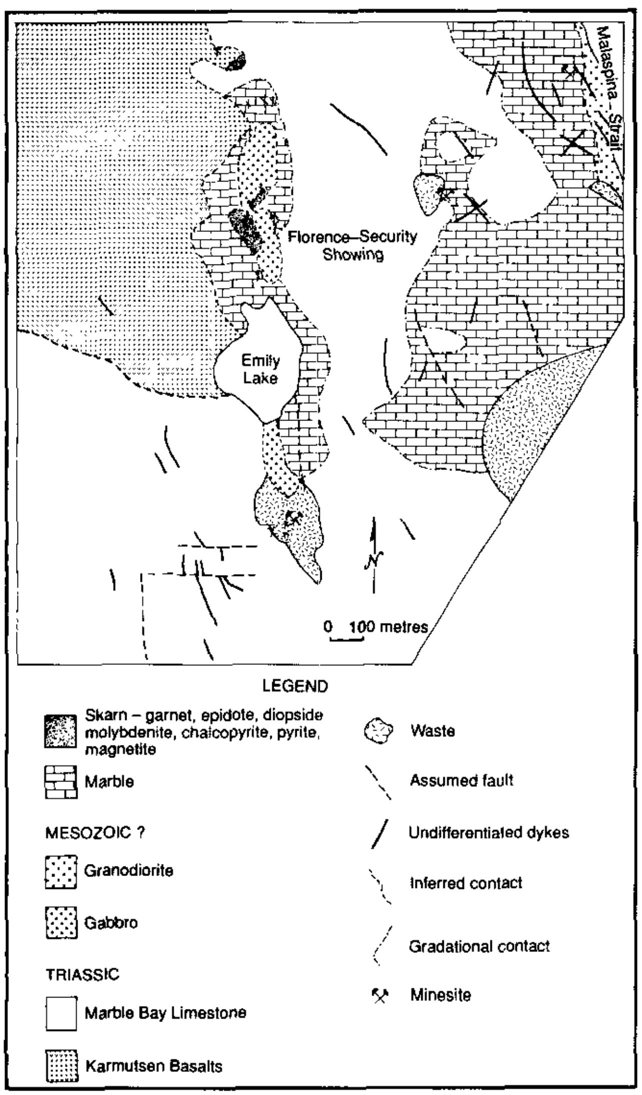

Figure 2-1-3. Surface geology of Vananda gold-copper skarns.

TABLE 2-1-2
MAJOR OXIDE COMPOSITIONS OF
TEXADA ISLAND GABBRO AND GRANODIORITE[1]

Oxide	Gabbro 275N37E	Granodiorite 800N960E
SiO_2	46.38	66.76
Al_2O_3	17.07	16.18
TiO_2	1.045	0.498
Fe_2O_3	11.93	4.91
MnO	0.182	0.096
MgO	5.64	1.62
CaO	11.13	4.32
K_2O	1.32	1.58
Na_2O	2.78	3.74
P_2O_5	0.367	0.120
Total	97.844	99.824

[1] Analyses performed at Washington State University, Basalt Research Laboratory.

BANKS ISLAND
(MINFILE 103G-024 to 026; 103G/8E)

Gold mineralization was first discovered on Banks Island in 1960 by Ventures Ltd. at the Discovery deposit along the southern end of Hepler Lake (Figure 2-1-4). Additional gold mineralization was identified at the Bob zone in 1964. Surface trenching during 1987 has exposed mineralization at the Tel deposit. Drill-indicated probable reserves at the Tel are reported by M. Vulimiri of Trader Resource Corporation as 97 500 tonnes grading 16.2 grams per tonne gold and at the Discovery as 38 200 tonnes averaging 17.1 grams per tonne gold.

Host Rock Lithology

Banks Island is mainly underlain by plutonic rocks of the Coast complex and less extensive metasedimentary rocks (Figure 2-1-4). Intrusive rocks are compositionally zoned from a monzonitic to granodioritic core surrounded by a quartz dioritic phase which in turn grades to a gneissic dioritic-gabbroic migmatite margin. Late alaskitic dykes crosscut these rocks. Surface mapping and detailed petrographic work by Trader Resource Corporation indicates that the intrusive rocks are inter-related and part of the same zoned pluton (Shearer, unpublished report, 1987).

Pendants of metasedimentary rocks, comprising coarse-banded light grey to green marble, gneiss and migmatite, form long lenticular northwest-striking bodies along the margins of the intrusions. These Paleozoic(?) sediments are the host to skarn mineralization at the Bob zone and Discovery deposit.

Structure

Subvertical, northwest-striking right-lateral faults bound Banks Island. Subparallel with these are near-vertical faults bordering the metasedimentary packages. These structures are cut by westerly trending lineaments defining subsidiary shears and tensional fractures. The intersections of these discordant structural features were the original exploration targets for early prospectors.

Skarn Mineralization

Skarn at the Discovery deposit occurs along a northwest-striking fracture zone at the contact between biotite quartz monzonite and marble (Figure 2-1-5). Alteration in intrusive rock (endoskarn) consists of subequal amounts of dark green, fine to medium-grained amphibole and dark green euhedral zoisite with minor amounts of garnet and diopside. This skarn grades into exoskarn replacing the marble. The exoskarn contains dark brown medium-grained garnet as the primary calc-silicate phase, with lesser diopside, amphibole and epidote. Remnant patches of marble are observed within the skarn zones. Sulphide minerals present in skarn are pyrite, pyrrhotite, arsenopyrite, sphalerite and chalcopyrite.

Two types of gold mineralization are identified in diamond-drill core (Figure 2-1-5). The first type is associated with massive pyrrhotite that replaces marble. The pyrrhotite contains up to 1 per cent pyrite with trace amounts of chalcopyrite. The gold appears to be directly associated with the pyrrhotite which yielded assays exceeding 100 grams per tonne over a 2-metre intercept.

The second type is hosted by a brecciated quartz-pyrite vein. It appears to be filling a fracture zone which crosscuts both garnet skarn and marble. Massive white to medium-

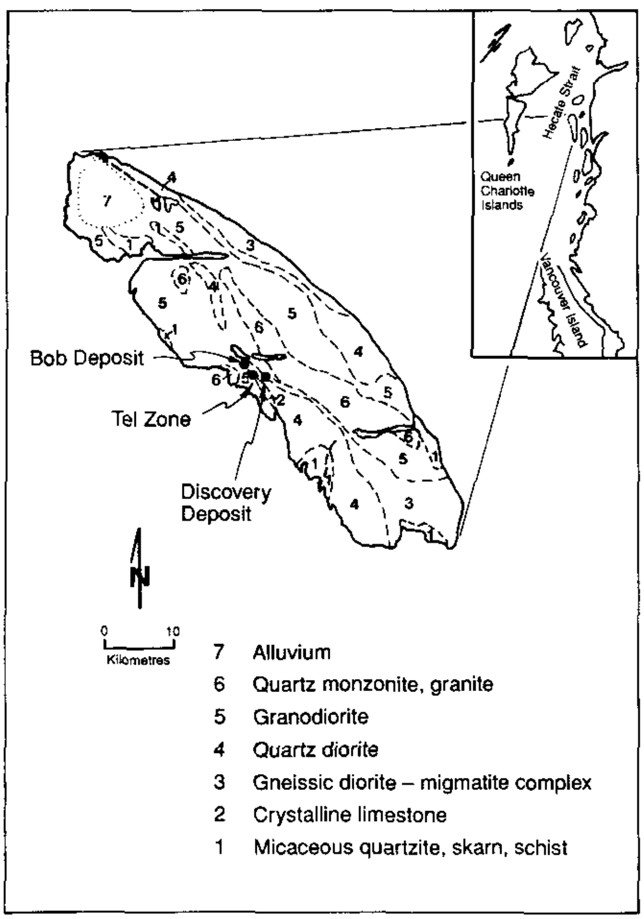

Figure 2-1-4. Location map of Banks Island deposits.

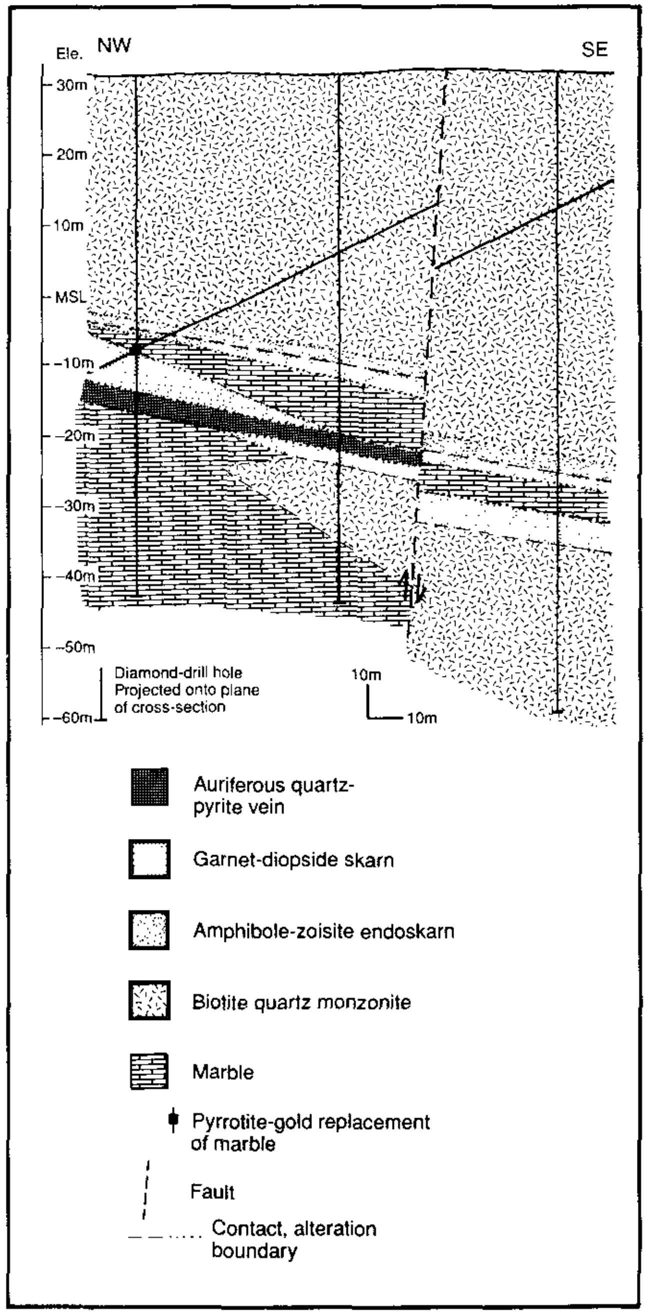

Figure 2-1-5. Cross-section of Discovery deposit, Banks Island.

grey quartz with coarse pyrite is fragmented and sometimes healed by a quartz-carbonate stockwork. Vuggy quartz commonly fills voids left by the oxidation and removal of pyrite. The possibility of a genetic link between skarn and quartz-pyrite vein mineralization is suggested. Both contain anomalous gold values and the healing of breccia textures by the quartz-carbonate stockwork indicates a complex hydrothermal history.

The recently discovered, previously undescribed mineralization of the Tel deposit is not directly related to skarn alteration but will nevertheless be briefly described. An anastomosing quartz-sulphide vein occurs within northwest-striking banded marbles and metapelites dipping approximately 60 degrees northeast. Mineralization is controlled by a westerly striking fracture zone near its intersection with a major northwest-striking lineament. The steeply dipping vein outcrops discontinuously for approximately 200 metres and varies in thickness from 1 centimetre to 3 metres. Drilling in 1987 indicates that the vein persists at depth and along strike, with the mineralization pinching and swelling in both directions.

The Tel vein is asymmetrically zoned. A breccia zone, approximately 20 to 30 centimetres wide and containing marble and quartz-calcite fragments, forms the northern margin of the vein. The breccia contains significant chlorite and a soft, light green mineral thought to be talc. Minor galena, sphalerite and pyrite occur within the matrix. This zone is not always present but is typically developed near northwest-striking crossfaults.

The inner edge of the breccia zone is marked by a 5 to 10-centimetre hematitic gouge consisting of fine sand and silt-sized material. Any original sulphides in this zone have been completely oxidized.

The primary sulphide-bearing part of the vein is approximately 40 to 50 centimetres wide and consists of massive pyrite with sporadic amounts of blackjack sphalerite, arsenopyrite, galena, chalcopyrite and tetrahedrite in dark grey quartz. This sulphide-rich zone is bounded to the south by a 20-centimetre bull-quartz zone with variable amounts of disseminated pyrite.

Fine-grained quartz + chlorite + pyrite with stringers of a very fine-grained sulphide, tentatively identified as galena, form the southern wall of the vein. This zone may be totally absent and is thought to represent a sheared mafic dyke.

Country rocks surrounding the vein are finely interbedded metapelites and marbles intruded by a quartz diorite of uncertain origin. Alteration of the host rocks is limited to hornfelsing of the pelitic layers and development of epidote-chlorite bands in the silty lenses. The marble is bleached and has limonitic staining adjacent to the vein. A brown phlogopitic alteration, differing slightly from biotite hornfelsing typically observed in pelitic sediments adjacent to hot plutons, replaces the sediments at depth. This alteration may be fracture controlled and hence metasomatic rather than contact metamorphic in origin. Only minor quantities of pink to reddish brown garnet and green diopside occur at the margins of alaskite dykes.

The limited development of garnet-diopside skarn at depth, and minor epidote alteration of the sediments on the surface, probably reflects the low permeability and porosity of the host rocks. This may be due to total recrystallization of the host during regional metamorphism prior to pluton emplacement. Metasomatism is limited to early potassium alteration, incipient garnet-diopside formation along contacts, and minor epidote veining in the upper levels of the system.

NANAIMO LAKES (MINFILE 092F-182, 384; 92F/1W, 2E)

Byproduct-gold skarn mineralization is seen on the Jane, Toni, Kathy and Larry (JTKL) claims held by Goldbrae Developments Ltd., and the adjacent Villalta deposit held under option by Southern Gold Ltd., along the Nanaimo River approximately 40 kilometres west of Nanaimo. Gold mineralization occurs in a hematite-altered breccia of uncertain origin on the Villalta claims, and in massive garnet-diopside-amphibole skarn on the JTKL claims. While the Villalta mineralization is not skarn hosted, a genetic link between the two deposits is possible.

Host Rock Lithology

Paleozoic Sicker Group volcanic and sedimentary rocks underlie most of the study area which is within the northwest half of the Cowichan – Horne Lake uplift described by Muller (1980). The Myra and overlying Buttle Lake formations, which form the upper two-thirds of the Sicker Group, outcrop on both claim groups and are host to the skarn mineralization on the JTKL property. The Myra Formation comprises medium to dark green siliceous tuff and black argillite which are locally altered to a brown biotite or pale green diopside hornfels. The Buttle Lake Formation comprises a massive crinoidal limestone which has been recrystallized to a white marble. Minor siltstone and chert form interbeds within the limestone.

The stratigraphic relationships above the Buttle Lake Formation become less clear. On the Villalta claims, a brecciated potassium-feldspar rhyolite porphyry up to 2.5 metres thick lies between the limestone and an unconformably overlying heterolithic breccia. The breccia has been variously described as Cretaceous Nanaimo Group conglomerate (Chandler and Runkle, 1985), or Paleozoic volcanic agglomerate (S. Quin, personal communication, 1987). The breccia consists of angular clasts of fine-grained dark green volcanic rock and lesser amounts of subrounded granitic and cherty fragments. The volcanic fragments are similar to lithologies observed on the JTKL claims. The matrix is generally dark green to brown and composed of fine to medium-grained particles of probable volcanic origin. The large volcanic component to this breccia, and the lack of marine or fluvial features commonly seen in Nanaimo Group sediments, suggest it is part of the Sicker Group.

Plutonism in this area is represented first by early to middle Jurassic Island Intrusions of granodioritic to dioritic composition. Skarns are developed where these diorites have intruded near limestone-volcanic contacts. Tertiary Catface intrusions are sparsely represented by small outcrops and short drill-hole intersections of hornblende feldspar porphyry sills and dykes.

Skarn Mineralization

Skarn mineralization on the JTKL claims occurs both in the lower Buttle Lake limestone and upper Myra volcaniclastic rocks. Jurassic quartz diorite contains epidote-amphibole endoskarn at surface and is associated with massive garnet-wollastonite skarn replacing limestone at depth. The latter consists of coarse-grained euhedral garnet varying from a massive yellow grossularite(?) to a later, fracture-controlled, brown andradite. The wollastonite is fine grained and forms the matrix surrounding garnet. The calc-silicate mineralogy seen on these claims is unique in that massive garnet outcrops exhibit crustiform banding, bladed and cockscomb crystal clusters, and a euhedral megacrystal habit possibly indicative of a low pressure (that is, near surface) environment of formation.

Where skarn replaces Myra volcaniclastic rocks, the garnet-diopside ratio decreases. Dark green amphibole increases and, together with epidote, replaces the earlier garnet; wollastonite is absent. Veinlets of earthy hematite crosscut the skarn and bright red hematite completely replaces zoned garnet. Coarse specular hematite and a fibrous form of magnetite, also observed at the Little Billie mine on Texada Island, occur in minor amounts.

Sulphide content of the skarn is generally low. Pyrite occurs in minor amounts as fine-grained clots and irregular disseminations throughout the skarn and scattered through the underlying volcaniclastic rocks. Chalcopyrite is present in trace amounts, associated with disseminated magnetite. Arsenopyrite was noted in one drill-hole intercept.

ZEBALLOS
(MINFILE 092E-002, 092L-027, 068; 92E/15W, 92L/2W)

Amphibole-rich gold-bearing skarn mineralization occurs near the village of Zeballos on the northwest coast of Vancouver Island. Limited placer activity began along the Zeballos River in 1907 and lode gold was discovered in 1924. Zeballos Iron Mines Ltd. produced magnetite from skarn on the FL property in the early 1960s. Current activity is focused at the Privateer gold mine, a quartz vein deposit, in Spud Valley.

Host Rock Lithology and Mineralization

The Hiller (Artlish, MINFILE 092L-027, 068) showing outcrops along Toray Creek approximately 15 kilometres northwest of Zeballos (Figure 2-1-6). Potential gold-skarn mineralization is hosted by volcaniclastic and marine sediments originally assigned to the lower Bonanza Formation by Hoadley (1953) and subsequently described as Parson Bay Formation by Muller (1977). Lithologies observed are intercalated aquagene tuffs, argillites, impure limestones and volcanic breccias which dip 20 to 30 degrees to the west, toward the Zeballos batholith. This sequence is underlain by the Quatsino limestone.

Skarn and unaltered host rock are complexly interfingered, reflecting both the original variability of the protolith and pre-skarn and post-skarn structural features. A simplified cross-section, based on 1984-1985 diamond drilling through the A-25 showing, is presented in Figure 2-1-7.

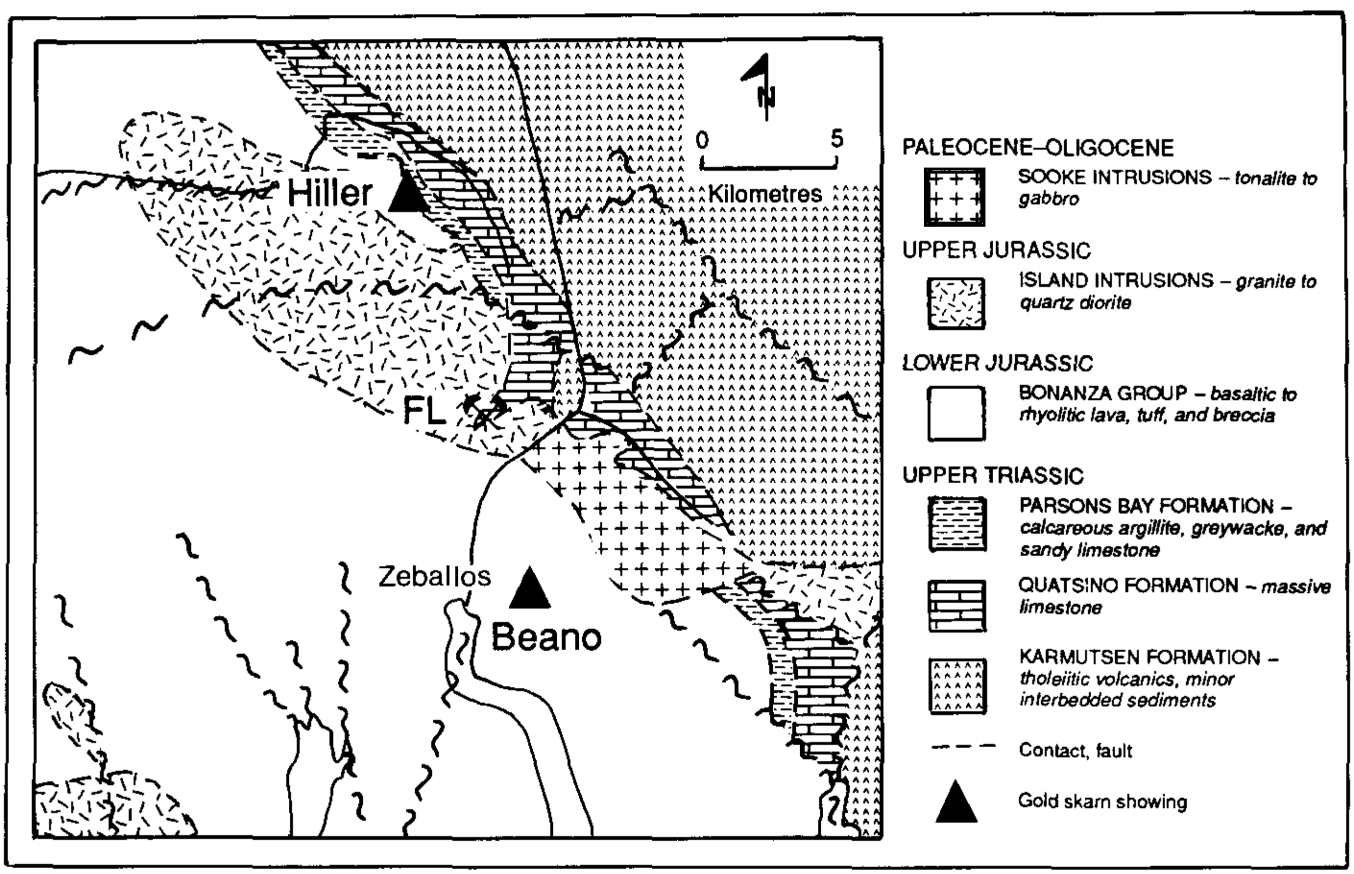

Figure 2-1-6. Location map of gold skarns near Zeballos.

Six separate units are identified in this section. Skarn occurs in a zone with an apparent thickness of 60 to 90 metres. Above and below this zone are unaltered calcareous Bonanza volcaniclastics, argillite and siltstone. Two different skarn types are present. One type, which is hosted by the Bonanza sequence, comprises dark green, fine to medium-grained felted masses of euhedral amphibole, and lesser light green euhedral pyroxene, calcite, quartz, chlorite, pyrrhotite, magnetite, pyrite and chalcopyrite. In thin section, the amphibole is zoned with strong pleochroic light to dark green cores and clear to pale green rims. Chemical analyses by electron microprobe indicate the cores are probably hastingsitic hornblende while the rims are ferro-actinolite.

The second skarn type replaces an intermixed sequence of limestone and volcaniclastic/argillite hosts. It contains abundant pyroxene, carbonate and sulphides, with lesser amphibole compared to the previously described skarn. It is commonly brecciated and contains rare pods of unreplaced marble and blocks of amphibole-rich skarn.

Gold mineralization favours this mixed protolith skarn. An analysis of the aggregate length of intercepts of each lithology in 2450 metres of drill core, and the distribution of gold assays greater than 1 gram per tonne in each of these lithologies, is presented in Table 2-1-3. These data show that

TABLE 2-1-3
AGGREGATE LENGTH OF INTERCEPTS OF EACH LITHOLOGY IN 2450 METRES OF DRILL CORE, AND DISTRIBUTION OF GOLD ASSAYS GREATER THAN 1 GRAM PER TONNE

Lithology	% of Total Core Recovered	# Assays >1 g/t Au
Skarn; volcanic protolith	26	7
Volcanics/argillites	20	2
Dykes and sills	18	1
Skarn; volcanic/limestone mixed protolith	13	20
Skarn; limestone protolith[1]	12	6
Limestone and marble	9	3
Hornfels	2	

[1] This skarn consists of light green granular pyroxene, carbonate and minor amphibole. It is not exposed in the section presented in Figure 2-1-7.

although the second skarn-type only comprises 13 per cent of the lithology drilled, more than half of the assays greater than 1.0 gram per tonne gold are from this zone.

A similar amphibole-rich gold-bearing skarn outcrops on the Beano claims, approximately 3 kilometres east of Zeballos (Figure 2-1-6). The main Beano showing lies at the

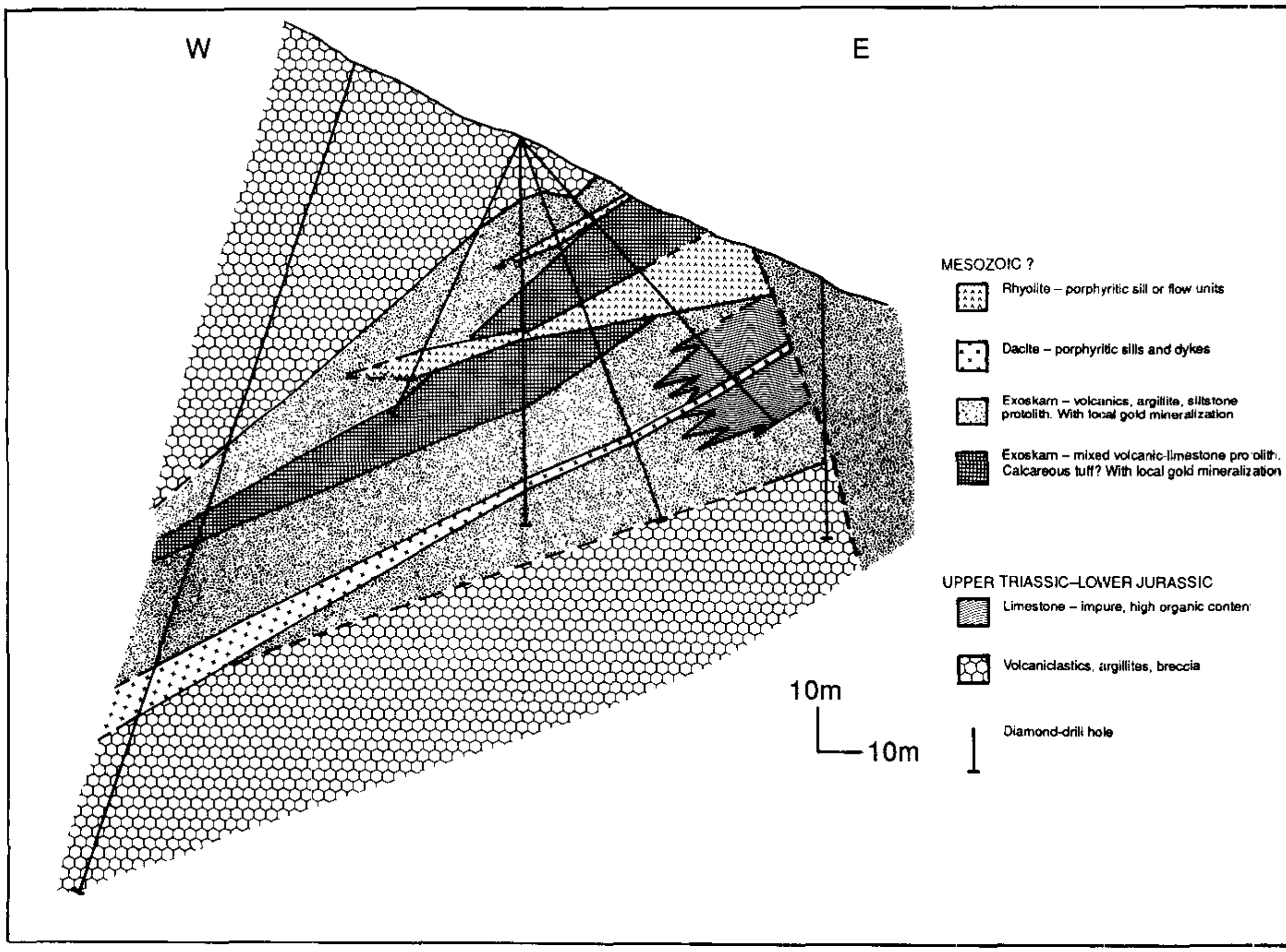

Figure 2-1-7. Cross-section through A-25 (Hiller) showing, Zeballos.

bottom of Bingo Creek canyon, at an elevation of about 760 metres. This showing is described by Muller *et al.* (1981) as a pyrrhotite-rich actinolitic skarn occurring in Bonanza volcanics. Mineralization consisting of fibrous actinolite, pyrrhotite and lesser chalcopyrite, is hosted by a limestone unit intruded by diorite. Quartz-carbonate veins containing auriferous pyrrhotite are also reported.

The showings along the west rim of the canyon, at the head of an old aerial tramway, were visited by the senior author. Workings consist of an adit and a stripped area on a heavily rusted outcrop of massive, fine to coarse-grained amphibole skarn containing pyrrhotite, arsenopyrite and pyrite.

Dark greenish grey fine-grained volcanic rock was the only rock type observed. The volcanics are hornfelsed and have undergone minor silicification. Dark green amphibole veins with white albitic(?) envelopes cut the hornfelsed volcanics.

MERRY WIDOW, KINGFISHER, OLD SPORT (MINFILE 092L-035, 044, 045; 92L/6)

The area south of Benson Lake, approximately 30 kilometres southwest of Port McNeill, contains iron and copper skarn mineralization described by Lund (1966), Sangster (1969) and Meinert (1984). During the period from 1962 to 1973, the Old Sport mine produced 3869 kilograms of gold, 1731 kilograms of silver and 41.2 million kilograms of copper from 2.7 million tonnes of ore. From 1957 to 1967, 3.4 million tonnes of iron ore were mined from the Merry Widow and Kingfisher pits. While no gold production is reported from these two mines, seven grab samples collected from sulphide mineralization in the Merry Widow orebody returned an average of 19.2 grams gold per tonne (Eastwood and Merrett, 1962). Collectively, these mines form a series of gold-copper and iron-gold-enriched skarns associated with the same batholith and occurring at limestone-volcanic contacts.

HOST ROCK LITHOLOGY AND MINERALIZATION

The orebodies lie at the contact between the Coast Copper stock and the Karmutsen, Quatsino and Bonanza formations. The Merry Widow and Kingfisher iron-gold skarns are located where a gabbroic phase of the batholith intrudes Bonanza volcaniclastics and underlying Quatsino limestone. Gold-copper skarn mineralization at the Old Sport mine is localized near the contact between the Coast Copper stock, Quatsino limestone and underlying Karmutsen basalts.

The occurrence of iron-gold and gold-copper-enriched skarns within the same district, and with intrusive rocks of similar composition and age relationships, was observed by the authors elsewhere (Jessie and Lily mines, South Moresby Island; Texada Iron and Little Billie mines, Texada Island; and Phoenix and Emma mines, Greenwood). The recognition of metallogenic zoning within individual skarn camps may have increasing exploration significance in the future (*see* Ray *et al.*, 1988, This Volume).

Skarn at the Merry Widow mine occurs primarily in volcaniclastic rocks of the Bonanza Group (Figure 2-1-8). Lapilli and crystal tuffs are replaced by garnet-epidote-diopside-amphibole skarn and illustrate the potential for skarn development in carbonate-poor hosts. Several discontinuous magnetite-calcite breccia zones, rimmed by coarse brown garnet, occur at the volcanic-limestone contact and may crosscut the stratigraphy. The skarn is commonly characterized by repetitive bands of massive magnetite interlayered with zones rich in epidote, amphibole, calcite or garnet (Plate 2-1-1).

Massive, dark grey, fine-grained volcanic rock is commonly recrystallized to a brown biotite hornfels and crosscut by a pale green diopside stockwork. This style of alteration is also observed in the Hedley gold camp and on the JTKL claims near Nanaimo Lakes.

Sulphide mineralization is best developed either within limestone, or along volcanic-limestone contacts. Sulphides present include chalcopyrite, pyrite, sphalerite and arsenopyrite. Cobalt mineralization occurs as erythrite in a zone of light-coloured calc-silicate alteration with possible manganese-rich pyroxene and potassium feldspar replacing volcanics.

The Old Sport mine is located approximately 3 kilometres north of the Merry Widow pit. The workings are no longer accessible, however Jeffrey (1960) and McKechnie and Merrett (1967) describe the geology of the mine area. The ore zone is located in a series of sills and skarn replacing basic volcanic rocks and marble. Samples collected from the dump indicate the skarn is pyrrhotite and chalcopyrite rich. Fibrous magnetite is intergrown with calcite and dark green amphibole. Considerable epidote, lesser dark green-black garnet and minor diopside were also observed.

OKA CLAIM GROUP (MINFILE 082E-025; 82E/13W)

This occurrence is situated along Greata Creek, approximately 15 kilometres west-northwest of Peachland (Figure 2-1-9). During the 1987 field season Fairfield Minerals Ltd. was actively engaged in a surface stripping and sampling program at the Bolivar and Iron Horse showings within the claim block.

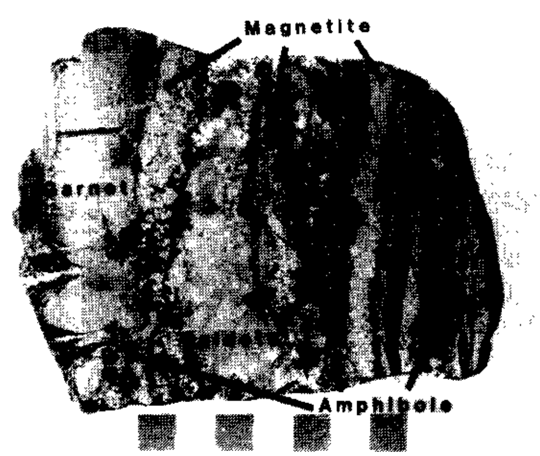

Plate 2-1-1. Banded magnetite-actinolite-epidote skarn, Merry Widow mine.

Host Rock Lithology

The district was mapped by Little (1961) who identified granodioritic and dioritic rocks of the Cretaceous(?) Nelson batholith underlying much of the area. Upper Triassic Nicola Group rocks form pendants within the diorite and consist of crystal tuff, argillite, limestone and conglomerate. These sediments are believed to be similar in age to the Hedley Formation which hosts the gold skarns at the Nickel Plate mine to the south.

Skarn Mineralization

The Iron Horse claim is underlain by Nicola Group limestones which have been recrystallized to a light to medium grey, medium-grained marble. These rocks are intruded by

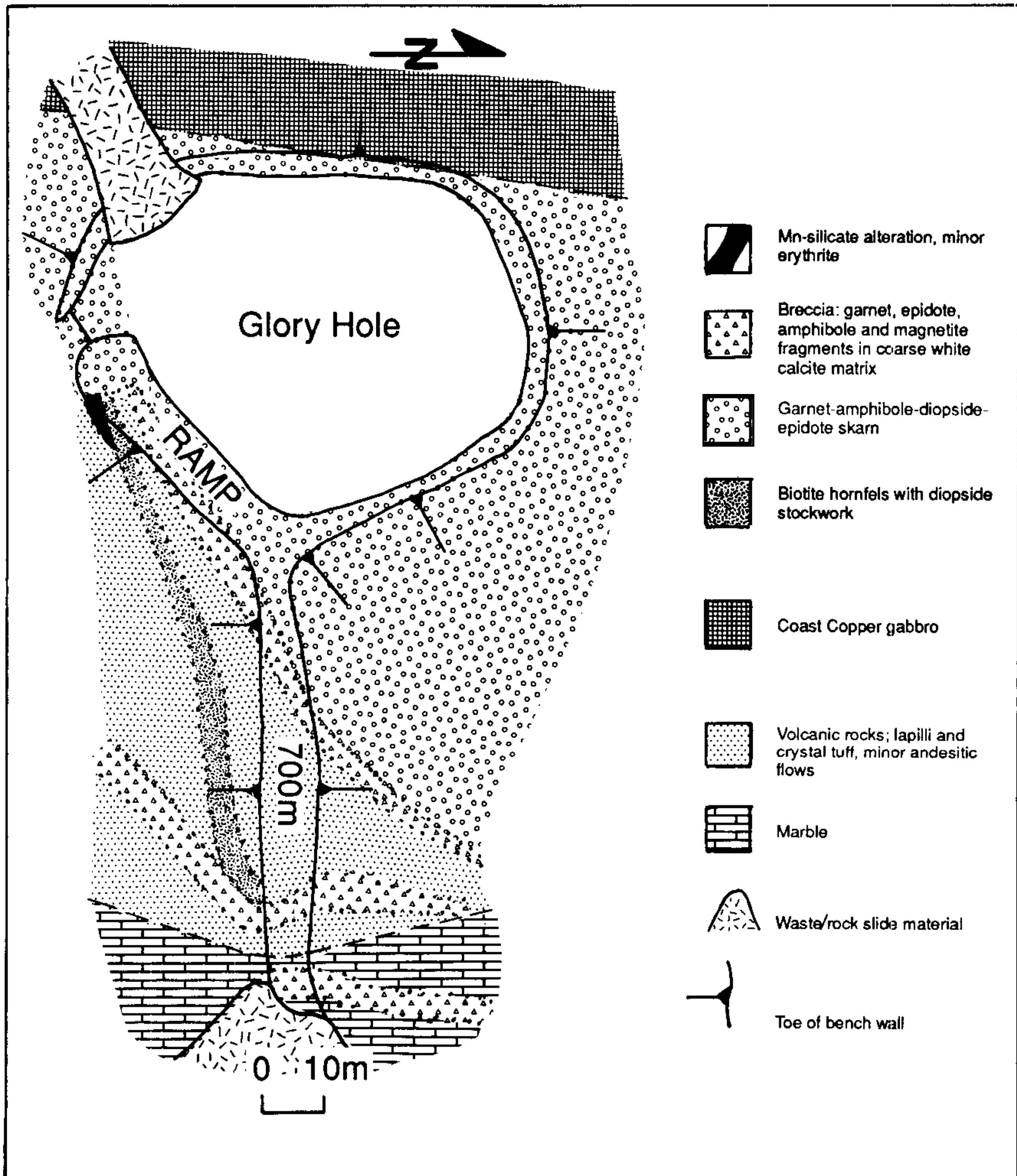

Figure 2-1-8. Geology of Merry Widow pit.

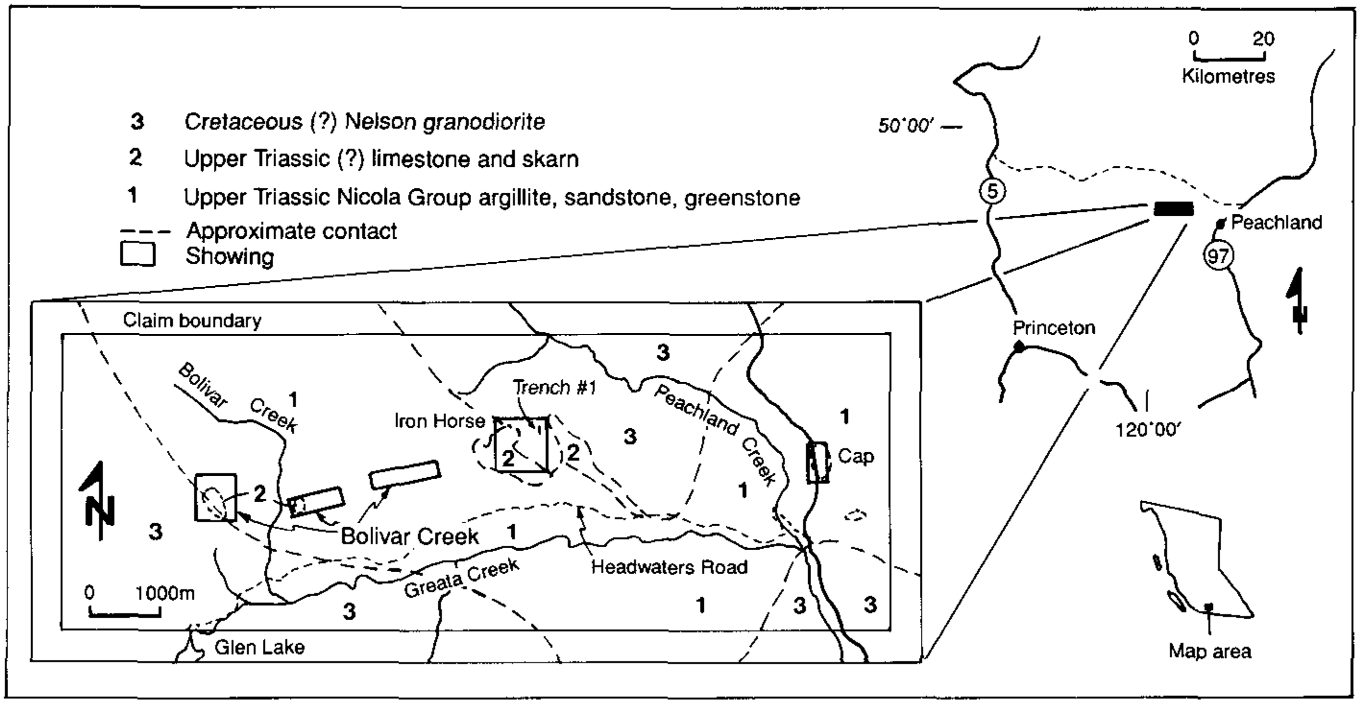

Figure 2-1-9. Location map of OKA deposits.

small stocks, dykes and sills of variable composition. Plugs of dioritic composition appear to be the earliest intrusions and result in skarn formation. The diorite has a poorly developed porphyritic texture with variable amounts of hornblende, biotite and plagioclase phenocrysts.

A general zoning pattern is seen in the stripped areas. Endoskarn within diorite consists of dark red-brown garnet and medium green diopside with variable amounts of dark green epidote and tan tremolite. Adjacent to the diorite, in the marble, skarn consists of medium brown garnet, pale green diopside, quartz and calcite. Further into the marble, a zone of fine-grained wollastonite and light brown garnet is sometimes present. Sulphides, comprising pyrite, pyrrhotite, arsenopyrite and chalcopyrite, occur at the skarn front, immediately adjacent to the unaltered marble. The sulphides form irregularly shaped massive pods, generally less than 20 metres across, which contain fine-grained quartz and diopside disseminated with the sulphides. Minor interbedded tuffaceous or cherty units have been hornfelsed to a fine-grained dark green diopsidic rock. This pattern can be seen in Trench 1 (Figure 2-1-10) where a biotite quartz diorite intrudes limestone and forms skarn. Remnant patches of quartz diorite are contained within a coarse garnet-diopside skarn and, toward the marble, the calc-silicate minerals become generally paler in colour, possibly representing decreasing iron content. Only sporadic minor amounts of pyrite are present.

The controls to the primary gold mineralization on the OKA properties are currently uncertain; in addition to the primary skarn-related gold, some secondary enrichment along late fractures may be present. Gold assays in chip samples "greater than 1 gram per tonne" are reported by Fairfield Minerals from diorite and massive sulphides, although not all sulphide pods contain this amount of gold. Similar anomalous gold values occur in the footwall of a northeasterly striking reverse fault which crosscuts one of the sulphide pods.

DIVIDEND-LAKEVIEW MINE (MINFILE 082/SW-001; 82E/3W, 4E)

Gold-enriched skarn mineralization occurs approximately 3 kilometres southwest of Osoyoos (Figure 2-1-1). During the period from 1907 to 1939, 504 kilograms gold, 88 kilograms silver and 73 000 kilograms copper were produced from 111 300 tonnes of ore. This deposit consists of garnet-epidote skarn that replaces volcanic rocks and thinly interbedded marbles of either the Anarchist Group or Kobau Group of probable Permo-Triassic age.

Host Rock Lithology

Cockfield (1935) placed the rocks in the property area within the Anarchist Group, but later work by McKechnie (1964) suggested they belong to the Kobau Group. They comprise micaceous quartzites, mica and chlorite schists, limestone and greenstone; all rocks, other than the limestones, are sheared and exhibit schistose textures. The limestones form discontinuous lenses which have been totally recrystallized near ore-bearing horizons. Within the claims there are also andesitic to basaltic flows which are altered to an epidote-calcite-sericite rock and garnet-quartz-epidote-hematite skarn.

Intrusive rocks outcropping on the property are part of the Cretaceous Nelson batholith which is exposed over a wide area of southeastern British Columbia and northern Washington. This pluton is quartz dioritic to dioritic in composition and generally comprised of medium-grained and equigranular subhedral biotite, hornblende and plagioclase phenocrysts in a groundmass of anhedral quartz, plagioclase and potassium feldspar. However, no diorite was identified in the pit area and the closest dioritic outcrops are about 1 kilometre to the north.

Skarn Mineralization

The immediate area of the Dividend-Lakeview mine is underlain by altered andesitic flows and tuffs that exhibit a weak to moderate schistose foliation. An epidote stockwork

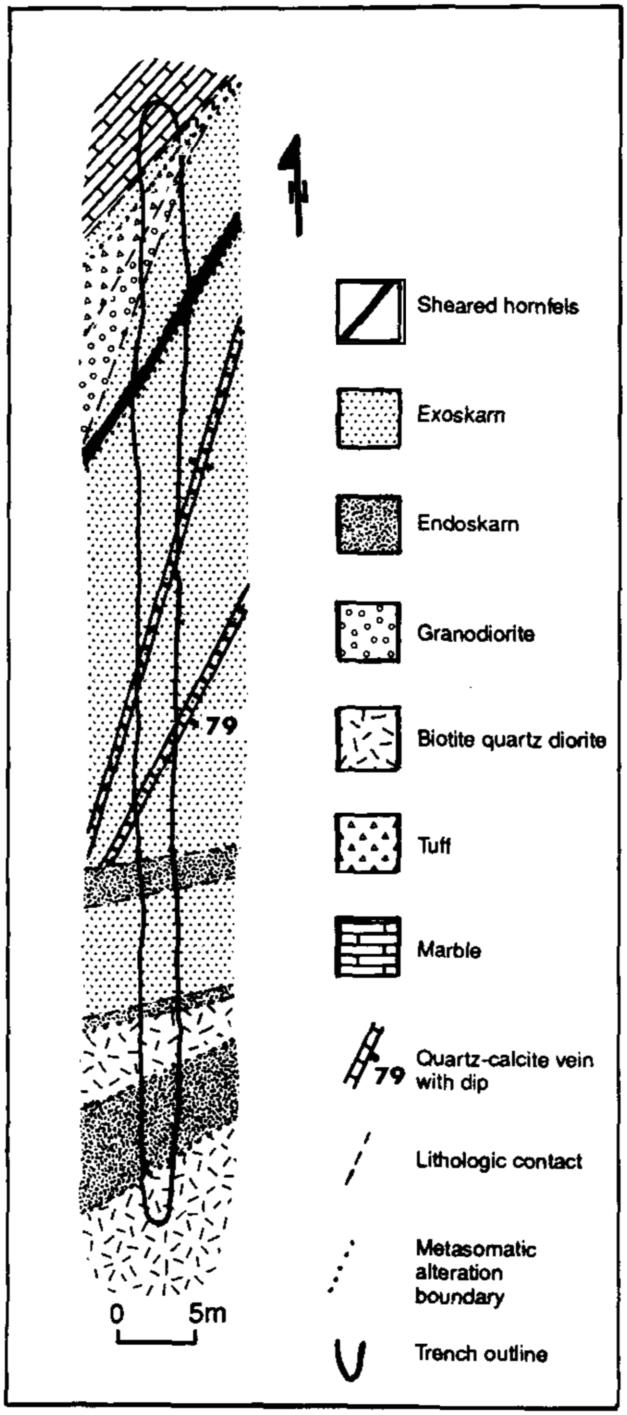

Figure 2-1-10. Iron Horse trench geology, OKA deposit.

and intense chlorite-carbonate alteration of the volcanics extends throughout the property and is overprinted by skarn in the mine area. Quartz-calcite veining with pyrite, chalcopyrite and minor malachite and azurite staining cuts the sheared volcanics and extends well beyond the area replaced by skarn.

Garnet, epidote, amphibole and minor diopside replace greenstone and a thin limestone lens at the minesite. Where coarse-grained calc-silicate minerals are not developed, the volcanic rocks are hornfelsed and the limestone has been recrystallized to a light grey to white, medium-grained marble.

Skarn silicates and magnetite are more common in the volcanic host while sulphides are more abundant in skarn that replaces limestone. Arsenopyrite, pyrrhotite, pyrite and minor chalcopyrite occur in irregular massive pods surrounded by a light yellowish brown oxidation product. Limestone is totally replaced by sulphides while the volcanics above and below the marble lens are altered to garnet-epidote skarn. Massive magnetite with minor chalcopyrite occurs in a mine pillar and is associated with deep brown, coarse-grained garnet at the limestone-volcanic contact. Elsewhere, garnet is pale amber in colour and fine to medium grained.

Similar mineralization can be followed along a westerly strike from the Dividend-Lakeview pit. Several small exploration pits expose garnet-epidote skarn with disseminated pyrrhotite, arsenopyrite, pyrite and chalcopyrite. This linear trend of mineralization, together with strong shearing of the volcanics in the mine area, is a strong indication of a structural control to skarn mineralization.

GREENWOOD MINING CAMP

(MINFILE 082/SE-013, 014, 020, 021, 025, 026, 031, 034, 062, 063; 83E/2E)

Gold-bearing copper and/or iron skarn mineralization occurs at several locations in the Greenwood mining camp. The Greyhound, Mother Lode, Oro Denoro, Phoenix and Marshall deposits (Figure 2-1-11) produced a total of 36 tonnes of gold, 217 tonnes of silver and 270 000 tonnes of copper from 31.8 million tonnes of ore.

The district is the site of several styles of mineralization resulting from multiple stages of intrusive activity and a complex structural history characterized by north-northwest-trending basin-and-range faulting. The economic geology, structural evolution and stratigraphy of the Greenwood camp have been described by Peatfield (1978), Little (1983) and Church (1986).

Host Rock Lithology

The oldest rocks in the area are the Paleozoic Attwood and Knob Hill groups. Bedded argillites, limestones, turbidites and mafic lavas characterize the Attwood Group while cherts, mica schists, amphibolite and marble dominate the Knob Hill Group. The Brooklyn Group unconformably overlies these Paleozoic basement rocks and is host to most of the economic skarn mineralization in the district. The lower part of the Brooklyn Group consists of a sharpstone conglomerate unit, which is altered to skarn in the southern end of the Phoenix pit. A massive light grey limestone with minor siliceous partings overlies the conglomerate in the Phoenix and Brooklyn mines. Locally it has been highly brecciated as at the Greyhound and Oro Denoro mines. Skarn development in the district is preferentially controlled by this limestone and the underlying conglomerate beds. The upper part of the Brooklyn assemblage contains limestones, tuffs, volcaniclastic rocks and minor flows. Fossil evidence from an interbedded limestone lens shows this unit to be Late Triassic (Little, 1983). The Brooklyn Group is unconformably overlain by the Tertiary Penticton Group described by Church (1986). This sequence is made up of the Kettle River Formation and overlying Marron Formation.

Eight intrusive phases have been identified by Church (1986). The major intrusive event is represented by the Cretaceous Greenwood and Wallace Creek batholiths which are considered to be part of the Nelson batholithic mass and genetically related to skarn development in the Greenwood camp. Earlier intrusive activity involves diorite, microdiorite, quartz feldspar porphyry and gabbro bodies that show varying degrees of alteration, but are not considered to be associated with economic skarn mineralization.

Post-Nelson intrusive activity includes several small late Mesozoic ultrabasic bodies, monzodiorite and pulaskite sills and dykes, and the alkalic Coryell intrusions, all of Tertiary age. These intrusions are associated with several types of mineralization exposed at numerous showings throughout the district. None have received much attention for their gold skarn potential.

Skarn Mineralization

There are two main types of skarn within the Greenwood district: gold-enriched copper skarn as represented by the Mother Lode, Phoenix and Marshall deposits; and gold-enriched iron skarn as represented by the Oro Denoro and Emma deposits. In both skarn types, garnet, epidote and diopside are the primary calc-silicate minerals. The copper-bearing skarns contain chalcopyrite, pyrite, specular and earthy hematite, and lesser magnetite and pyrrhotite as the primary opaque phases; the iron-rich skarns contain magnetite, chalcopyrite and pyrite.

At the Marshall deposit, approximately 1.5 kilometres northwest of the Phoenix pit, skarn is developed at the contact between Brooklyn limestone and an underlying siliceous siltstone. At the main showing, massive pyrrhotite with minor chalcopyrite replaces limestone, remnants of which are recrystallized to a medium-grained marble. Fine-

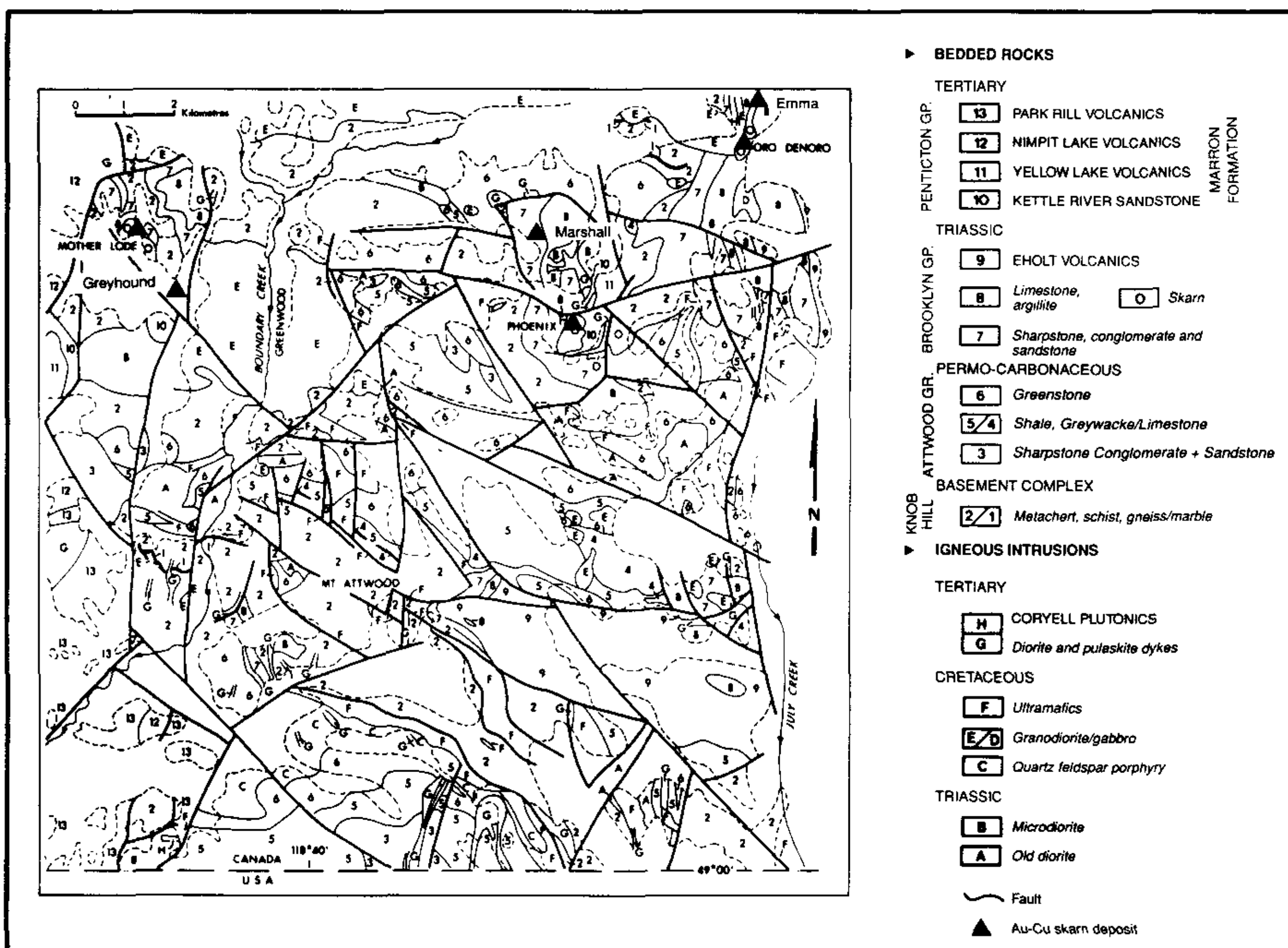

Figure 2-1-11. Location map of skarn deposits in Greenwood camp.

grained, dark green amphibole occurs sporadically in the marble and adjacent hornfelsed siltstone. At one location, a small pod of diopside-amphibole skarn is separated from marble by a lens of massive pyrrhotite-chalcopyrite-magnetite. An altered outcrop of microdiorite occurs in the area. This deposit may represent skarn formation resulting from pre-Nelson intrusive activity.

In the Phoenix mine, sharpstone conglomerate contains angular chert clasts and greenstone fragments in a sandy, chloritic matrix. However, due to skarning, clasts are generally hard to distinguish. Dark brown garnet, chlorite and epidote are the primary minerals replacing both the matrix and fragments. Chalcopyrite and pyrite are observed in skarn near the contact between the conglomerate and Brooklyn limestone along the southern benches. Magnetite was only found in waste piles. However, specular hematite occurs in veinlets crosscutting garnet skarn over a wide area; it commonly occurs as coarse plates associated with calcite and chalcopyrite (Plate 2-1-2), but also as fine disseminations in skarn.

Skarn at the Oro Denoro mine consists of massive reddish brown garnet and magnetite with coarse megacrystal calcite. Later chlorite and amphibole(?) veinlets can be seen replacing the garnet. Skarn is localized in limestone and possibly sharpstone conglomerate beds at a contact with Nelson granodiorite. At the north end of the main workings, endoskarn occurs in the granodiorite. Minor epidote-hematite-chlorite alteration, with bleaching of the intrusion, grades to massive garnet-epidote-chalcopyrite skarn and overprinting of original igneous textures. This type of alteration and mineralization is seen in many calcic iron skarns elsewhere in British Columbia.

The Emma deposit lies approximately 1.5 kilometres north of the Oro Denoro mine. This deposit follows the contact between the northerly striking Brooklyn limestone and underlying siltstone beds close to the margin of Cretaceous granodiorite. It is uncertain whether the skarn is genetically related to this granodiorite body or to a suite of Early Mesozoic microdiorite bodies in the area. The microdiorites grade into greenstone of the Eholt Formation and are interpreted to be feeder dykes for these volcanics. Skarn consists of reddish brown garnet, epidote and massive magnetite which is preserved in pillars in the mine area.

Plate 2-1-2. Specular hematite and chalcopyrite in quartz-calcite vein, Phoenix mine, Greenwood.

NICKEL PLATE MINE (MINFILE 092H/SE-037, 038, 062; 92H/8E)

The Hedley camp has had a long history of gold production from several skarn deposits (Camsell, 1910; Billingsley and Hume, 1941; Dolmage and Brown, 1945), but most of the production was derived from one very large deposit which was worked in the Hedley Mascot and Nickel Plate mines. Recent work by Ray *et al.* (1986, 1987, 1988) indicates that the deposits are surrounded by exceedingly large skarn envelopes, and that the auriferous mineralization represents a very small proportion of the total alteration. Mineralization in the camp is unusual in being sporadically enriched in arsenic, bismuth, nickel, tellurium and cobalt. The gold-bearing sulphide zones normally form semi-conformable tabular bodies situated less than 100 metres from the lower, outer skarn margin.

A cross-section through the Nickel Plate orebody currently being mined by Mascot Gold Mines Ltd. is shown in Figure 2-1-12. Three rock types are observed in this section: Sunnyside limestone and marble, altered Hedley intrusion sills and dykes (endoskarn), and exoskarn. Three of four drill holes bottomed in marble. The marble is white to greenish grey and commonly includes irregularly distributed lenses of silica replacement that contain disseminated pyrrhotite, arsenopyrite and pyrite. The limestone is dark grey to black, fine grained and contains small fossil fragments, abundant organic material, finely disseminated pyrite and small black euhedral amphibole crystals.

The Hedley intrusions form concordant sills and near-vertical dykes in the mine area. They are commonly altered to skarn, although complete metasomatic replacement of igneous texture is unusual. These sills and dykes are calc-alkaline I-type diorites to gabbros (Ray *et al.*, 1987, 1988). Relatively fresh diorite contains up to 15 per cent subhedral tabular plagioclase and 0.5 to 2 per cent anhedral hornblende phenocrysts in a dark, fine-grained matrix of plagioclase and amphibole. Alteration in the intrusions is highly variable in style. In the "north-45 dyke", intersected in hole MG85-229, it is limited to chlorite and epidote replacement of the plagioclase phenocrysts. Bleaching of the phenocrysts also occurs rimming a chlorite-epidote stockwork. This dyke is near vertical and strikes subparallel to the line of section, resulting in the large apparent width of dyke depicted in Figure 2-1-12. Another style of alteration forms a milky dark brown flooding of the matrix, similar in appearance to a biotite hornfels. Further chemical analyses and petrographic work are required to identify this mineralogy.

As illustrated by Section 33 + 50, essentially all country rock above the marble has been altered to skarn. Remnant lithologies are present only as thin discontinuous lenses of hornfelsed argillite and tuffaceous siltstones. Skarn development is strongly controlled by lithology and the thinly laminated, alternating zones of garnet-rich and diopside-rich skarn follow the original bedding. Minor wollastonite is generally associated with diopside adjacent to garnet stringers. Retrograde alteration of garnet and diopside to amphibole, chlorite or epidote is rare although Simpson and Ray

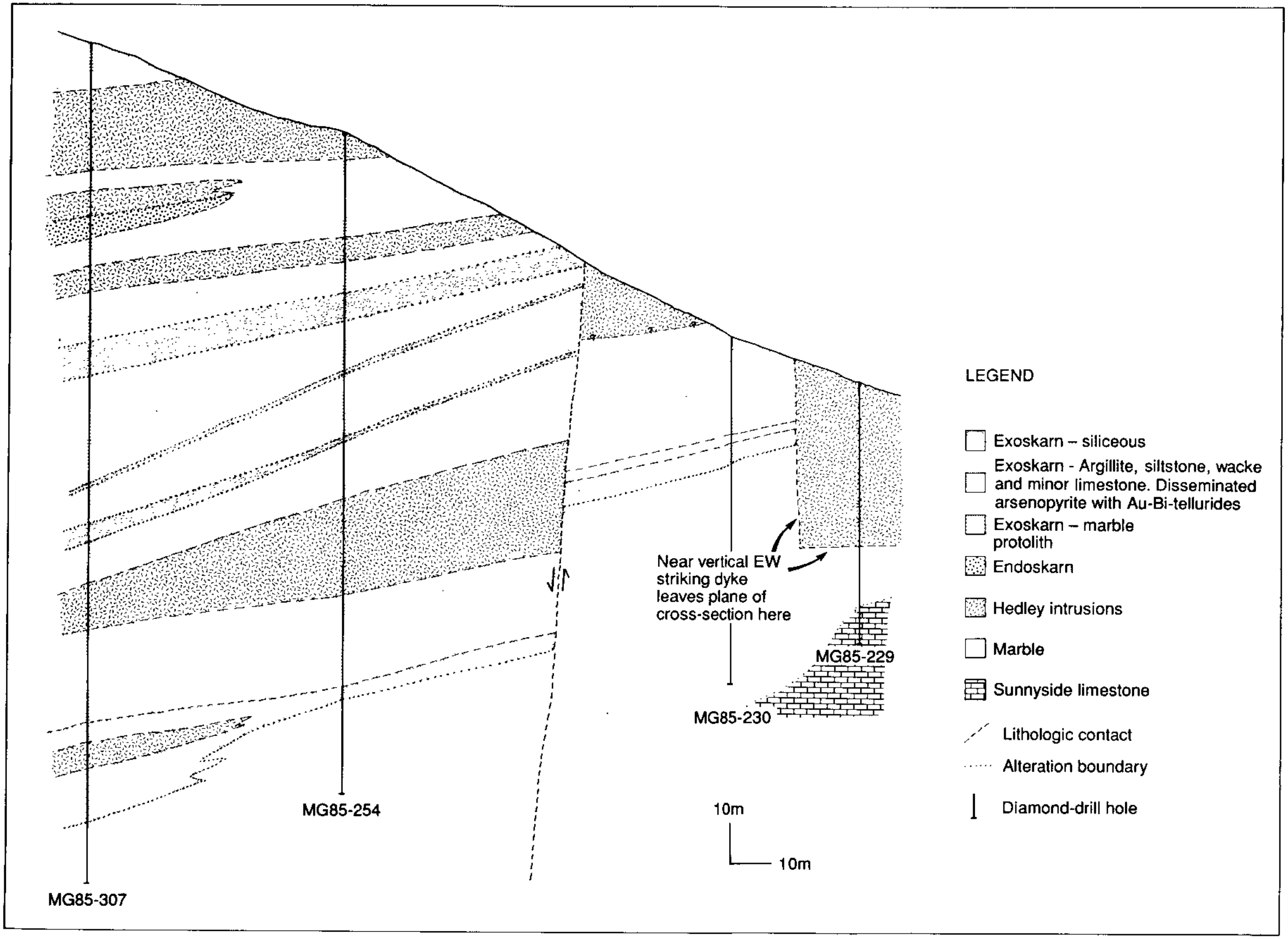

Figure 2-1-12. East-west cross-section through Nickel Plate orebody.

(1986) postulate an early and late stage of retrograde alteration replacing the prograde skarn minerals. The early stage, as described by Ray and Simpson, consists of tremolite, calcite, quartz and epidote; however, recent electron microprobe analyses indicate much of the "tremolite" is wollastonite, an unlikely retrograde product.

Gold mineralization is associated with the latest stage of alteration. Calcite, quartz and gold-bearing sulphides (*pyrrhotite, pyrite, arsenopyrite, hedleyite, native bismuth* and maldonite) were deposited near the skarn-marble boundary (Figure 2-1-12). The quartz-calcite-sulphide assemblage may result from low-temperature hydrous alteration of aluminum-poor calc-silicate minerals (granditic garnet and diopside/hedenbergite). This alteration may have occurred late in the skarn-forming process during cooling of the intrusive components and invasion of the hydrothermal system by cool meteoric fluids.

TP CLAIMS
(MINFILE 104M-048, 050; 104M/10E)

Gold and cobalt mineralization occurs in skarn on the southwest flank of Teepee Peak, 50 kilometres west of Atlin (Figure 2-1-1). The main skarn zone measures approximately 15 by 200 metres and consists of four skarn types: magnetite with minor calcite, garnet and amphibole; calc-silicate skarn with calcite, garnet and epidote; amphibole skarn; and marble-rich skarn (T.G. Schroeter, personal communication, 1987). Mineralization is hosted by pre-Triassic gneisses and schists of the Yukon Group (M. Mihalynuk, personal communication, 1987). Exploration work completed in 1983 outlined two northwesterly trending fracture zones that cut the amphibole skarn. Gold and cobalt/erythrite mineralization is primarily hosted within these fracture zones. Chip samples from trenches across the fracture zones returned composite average assays up to 15.0 grams per tonne gold and 3.91 per cent cobalt over 3.5 metres. Minor amounts of arsenopyrite are also reported.

Cobalt enrichment in skarns is seen elsewhere in British Columbia, in the Hedley district (*see* Ray *et al.*, 1988) and at the Merry Widow mine. Einaudi and Burt (1982) and Meinert (1984) report that cobalt enrichment is characteristic of calcic-iron skarns, however, cobalt is present in some other gold-enriched skarns (Cox, 1986; Cox and Theodore, 1986; Orris *et al.*, 1987) and may be a useful pathfinder element for these deposits.

CONCLUSIONS

Skarns are hosted by a variety of lithologies, but the more auriferous skarns are found in assemblages characterized by one or more of the following:

(1) Sequences of impure clastic rocks containing massive to thinly bedded limestones and calcareous pelites. The argillites and siltstones commonly have a fine tuffaceous component.

(2) Submarine volcanic flows, crystal and lapilli tuffs, and their hypabyssal equivalents in the form of dykes and sills, may be interlayered with argillites, cherts and calcareous tuffs.

(3) The host rocks have not undergone significant regional metamorphism and do not generally exhibit a strong metamorphic foliation. Hornfelsing and recrystallization of limestone are common and may result from thermal effects during intrusive emplacement.

(4) Structural deformation is manifest as one or more of the following: pre-skarn normal and reverse faults which act as fluid conduits and facilitate metasomatic alteration; microfracturing and jointing of intrusive and country rocks; post-skarn remobilization of gold and sulphide minerals into later faults and fractures; and pre or syn-skarn folding of the host rocks resulting in skarn formation in the fold hinges.

Geochemical and mineralogical signatures of gold-bearing skarns make them distinct from base metal skarns as classified by Einaudi *et al.* (1981). Many are sporadically enriched in arsenic, bismuth, tellurium, cobalt and tungsten present as arsenopyrite, hedleyite, bismuthinite, native bismuth, maldonite, hessite, tetradymite, cobaltite, erythrite and scheelite. Sulphide and oxide mineralogies are simple with pyrrhotite, pyrite, chalcopyrite, arsenopyrite and magnetite being by far the most common. Hematite may be important locally. Gold anomalies in soils above skarn zones are sometimes spectacular, with values over 10 000 ppb being reported from several deposits.

Two intrusive phases are present in some gold skarn camps, (for example, Tillicum Mountain and Hedley; *see* Ray *et al.*, 1988). The initial skarn-related intrusions are often small and dioritic or gabbroic in composition. The later phase is represented by granodiorite or quartz monzonite plutons, often of batholithic proportions. It is uncertain whether the two phases are genetically related.

Preliminary data suggest that the Nickel Plate and Tillicum Mountain deposits and the OKA occurrence are associated with calc-alkaline I-type intrusions as are the calcic iron skarns of western British Columbia (Meinert, 1984). These are distinct from certain gold-enriched copper porphyries such as Copper Mountain (Preto, 1972) and Cariboo-Bell (Simpson and Saleken, 1983) which contain some skarn-like alteration minerals including garnet, epidote, scapolite and carbonate. This skarn-like mineralization differs from the Hedley, Tillicum Mountain and Texada Island gold-bearing skarns in being associated with high-level, alkalic intrusions.

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ALASKAN-TYPE ULTRAMAFIC ROCKS IN BRITISH COLUMBIA: NEW CONCEPTS OF THE STRUCTURE OF THE TULAMEEN COMPLEX*

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KEYWORDS: Alaskan-type ultramafite, Tulameen complex, structure, cumulates, chromitite, sulphides, platinum.

INTRODUCTION

Alaskan-type ultramafic rocks in British Columbia are potential hosts for commercially exploitable deposits of platinum metals (Rublee, 1986; Evenchick *et al.*, 1986) as well as other commodities (for example, chrome, nickel, cobalt, asbestos and jade). In 1987 the British Columbia Geological Survey initiated a program designed to investigate the mineral potential of these intrusions through detailed geologic mapping and lithogeochemical sampling specifically for platinum group elements. In the first year of this project, a concerted effort is being made to more thoroughly understand one of these intrusions, the Tulameen ultramafic complex in southern British Columbia. The Tulameen complex warrants careful attention as it has been the largest producer of platinum in the province and has been taken as a typical example of a zoned Alaskan-type ultramafic intrusion (Findlay, 1963, 1969; Evenchick *et al.*, 1986).

The general structure of Alaskan-type complexes is characterized by a crudely concentric outward zonation of rock types ranging from olivine-bearing to hornblende-rich or magnetite-rich clinopyroxenites about a steeply dipping dunite core (Taylor, 1967). Lesser proportions of hornblendite and mafic pegmatite usually occur as isolated masses toward the periphery of the intrusion. Typical cumulate minerals include forsteritic olivine, diopsidic augite, chromite and magnetite; orthopyroxene is characteristically absent, indicating an alkalic affinity. Gabbroic rocks associated with the intrusion are commonly tholeiitic, and in this respect the syenogabbros and syenodiorites of the Tulameen complex are unusual (Findlay, 1969).

This report summarizes the results of geological fieldwork in the Tulameen conducted between July 1 and September 4, 1987. Our study brings out the intense deformation and structural complexity of the ultramafic complex and its host rocks; questions the mechanism of emplacement and igneous zonation previously proposed to account for the crudely concentric outcrop pattern of principal rock types; and provides evidence for mechanisms of emplacement of cumulate sequences that tend to obliterate primary layering. The structure of the complex is particularly important in further testing the potential for economic concentrations of platinum. Subsequent work will focus on a number of other Alaskan-type intrusions in northern British Columbia. The ultramafic program is funded by the Mineral Development Agreement between Canada and the Province of British Columbia, and by a British Columbia Geoscience Research Grant awarded to the junior author to defray field expenses incurred as part of Master's thesis work at Ottawa University.

LOCATION AND ACCESS

The Tulameen ultramafic complex underlies 60 square kilometres of rugged forested terrain centred 23 kilometres due west of Princeton (Figure 2-2-1). Physiographically, the region lies in a transition zone between the Cascade Mountains to the west and the Interior Plateau to the east. The project area is covered by map sheets 92H/07 and 92H/10 at a scale of 1:50 000. Paved highway connects Princeton with the communities of Coalmont and Tulameen where a network of well-maintained logging roads leads westwards into the intrusion. The Tulameen River road provides access to a complete cross-section through the intrusion, intersecting the dunite "core" approximately 10 kilometres west of the village of Tulameen.

GEOLOGIC SETTING

The Tulameen ultramafic complex is situated within the southwestern Intermontane Belt immediately west of the juncture of the Quesnellia tectonostratigraphic terrane and Mount Lytton plutonic complex (Figure 2-2-1). The project area lies within a zone of Early Tertiary "transtensional" block faulting related to regional right-lateral transform motions along the Fraser River–Straight Creek fault system (Ewing, 1980; Monger, 1985).

The general geology of the Tulameen complex is shown in Figure 2-2-2. The intrusive suite was emplaced into metasedimentary and intermediate to felsic metavolcanic lithologies that belong mainly to the western facies of the Upper Triassic (Carnian to Lower Norian) Nicola Group (Preto, 1975, 1979; Price *et al.*, 1987). Volcanic assemblages in the Nicola Group contain clinopyroxene-rich shoshonitic lavas that evolved during Late Triassic subduction (Mortimer, 1986). These rocks are possibly comagmatic with ultramafic and mafic alkalic rocks of the Tulameen suite (Findlay, 1969). The Tulameen complex and its host rocks are

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

unconformably overlain by terrigenous sedimentary and volcanic assemblages of the Early Tertiary (Eocene) Princeton Group and Miocene plateau basalts.

Regional structures trend approximately north-northwest and are characterized by a westward-dipping foliation that parallels the eastern margin of, and extends into, the southern extension of the Mount Lytton batholith, otherwise known as the Eagle plutonic complex. The Tulameen complex forms an elongate body concordant with the structural grain.

Previously published potassium-argon dates for the Tulameen complex yield a preferred estimate of 175 Ma (mid-Jurassic), but this may be too young due to subsequent loss of radiogenic argon during metamorphism (Roddick and Farrar, 1971, 1972). Published potassium-argon dates for the Eagle

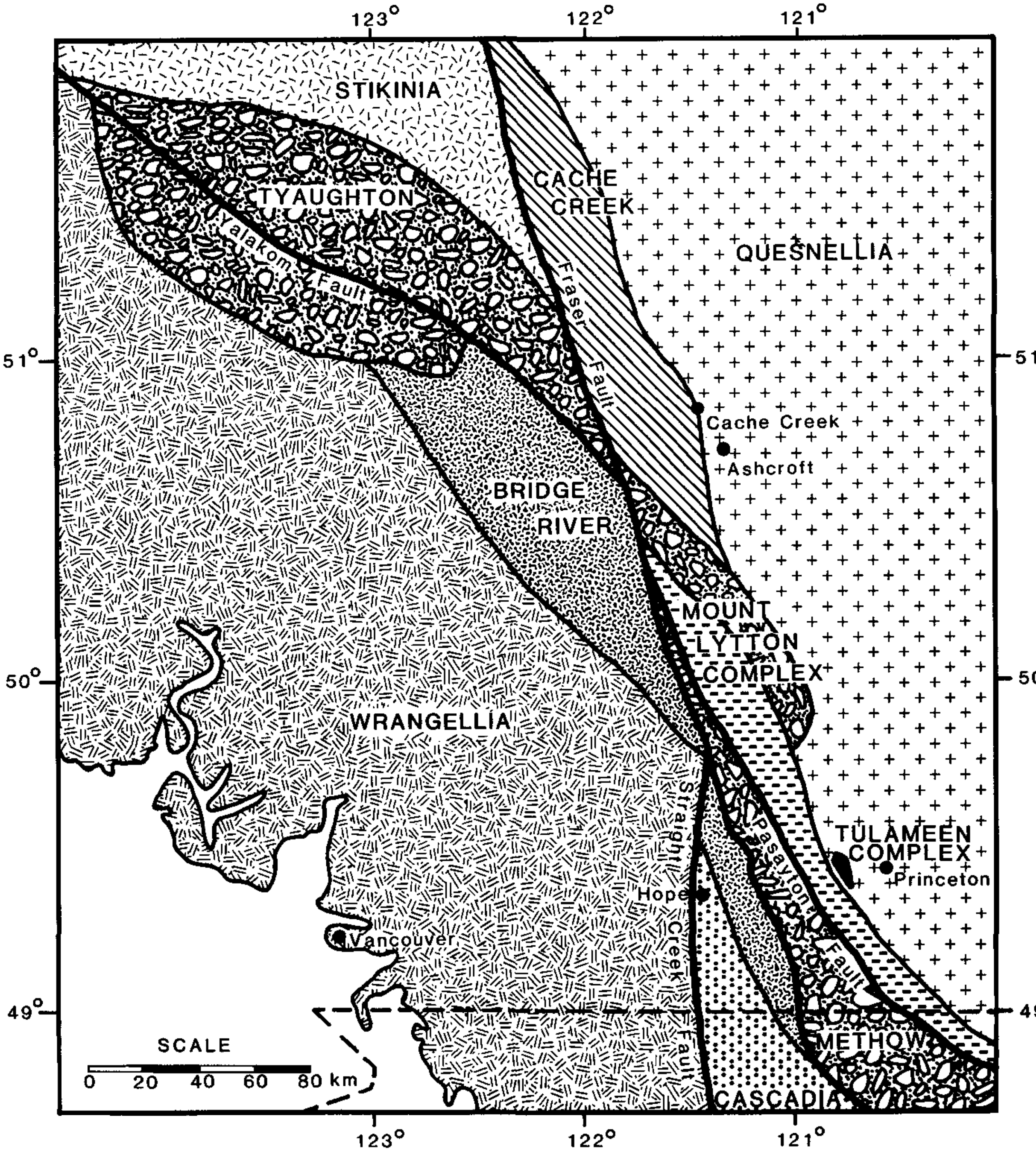

Figure 2-2-1. Geologic setting of the Tulameen ultramafic complex in relation to tectonostratigraphic terranes (modified after Kleinspehn, 1985).

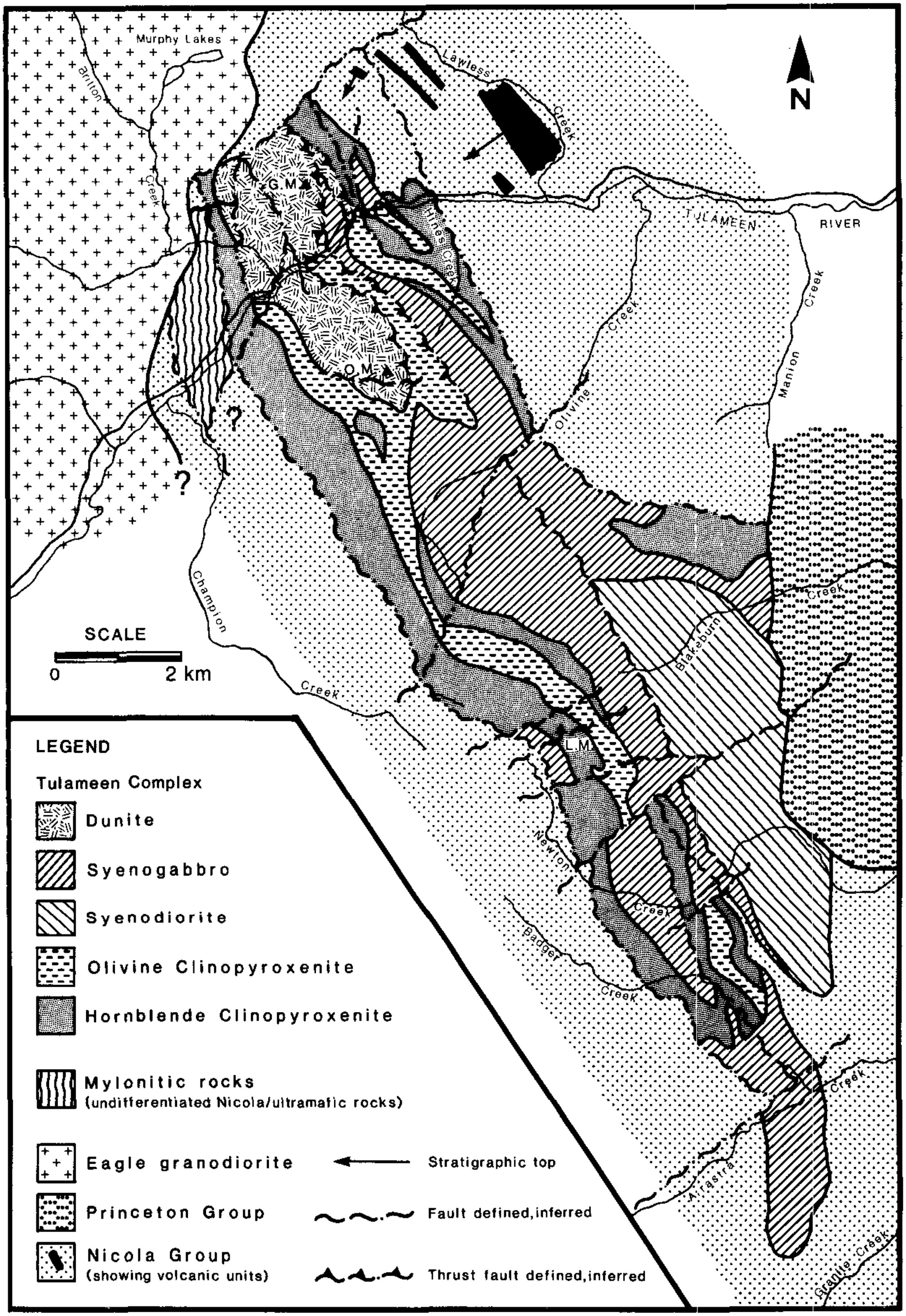

Figure 2-2-2. Generalized geologic map of the Tulameen ultramafic complex (modified after Findlay, 1963).

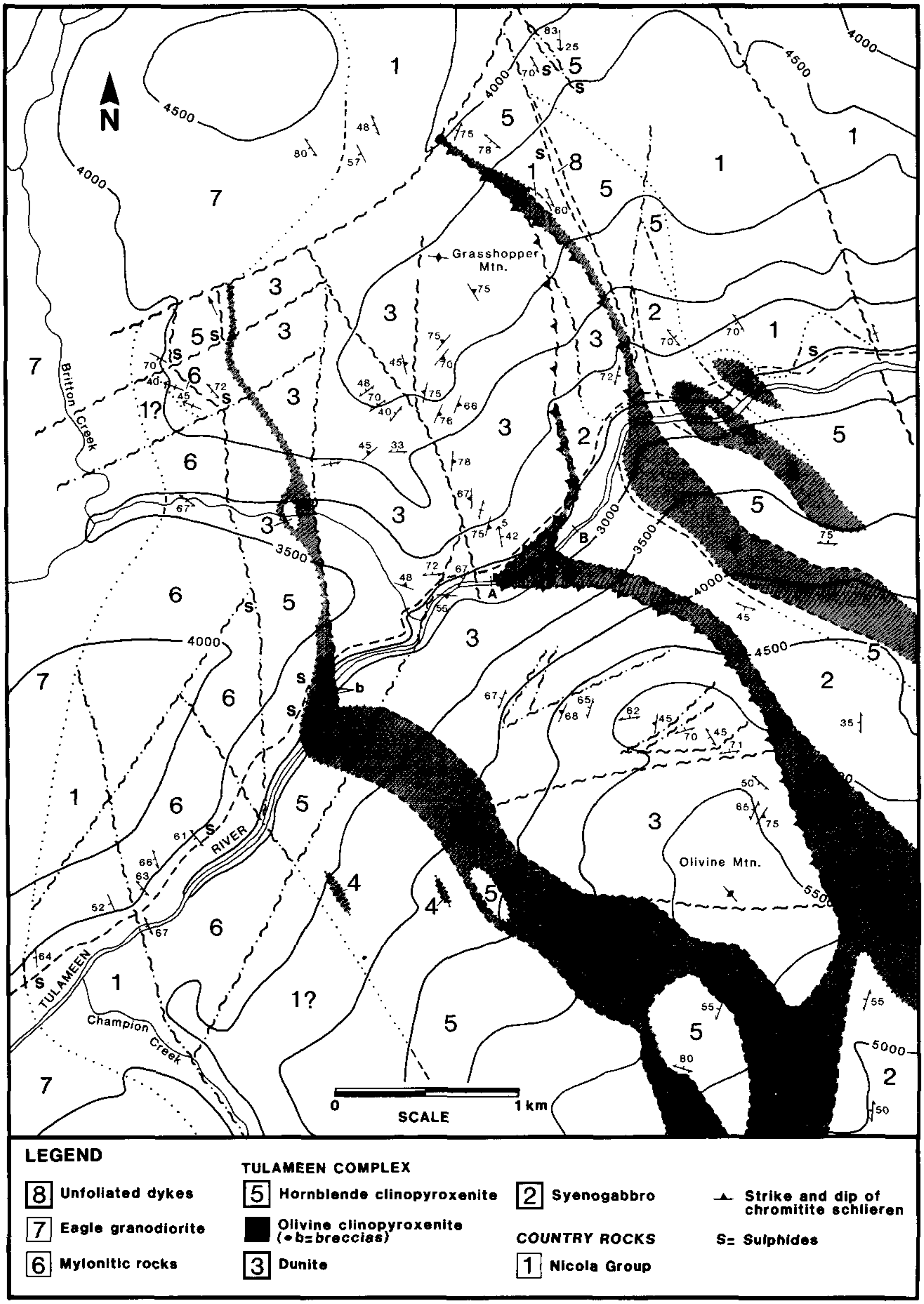

Figure 2-2-3. Detailed geologic map of the northern part of the Tulameen ultramafic complex (modified after Findlay, 1963). A-B refers to the location of the measured stratigraphic section (Figure 2-2-4).

pluton (Roddick and Farrar, 1972) and preliminary results of ongoing potassium-argon, rubidium-strontium, and uranium-lead geochronometry, suggest a probable Early to mid-Cretaceous (97 to 120 Ma) age of emplacement (C. Greig, personal communication, 1987).

COUNTRY ROCKS

NICOLA GROUP

Representatives of the Nicola Group in the Tulameen region comprise black thinly laminated argillites, green and brown tuffaceous siltstones and lapilli tuffs, dark grey-green aphyric to plagioclase-phyric pyroxene andesite and hornblende dacite flows, rare aphanitic rhyolites, cherts, chert breccias, and dark grey limestones. All lithologies are regionally metamorphosed to greenschist grade. Chlorite-muscovite schists with minor biotite are common to the west of the ultramafic complex and marbles with weakly developed skarns commonly occur adjacent to the Eagle granodiorite contact. Skarn mineralization includes traces of molybdenite, chalcopyrite, pyrite, covellite, bornite and chalcocite (?).

Beyond the northeastern margin of the intrusion, andesitic lavas preserve primary flowage features such as vesicle trains aligned within the flow foliation, chilled basal zones overlying baked sedimentary horizons, and basal flow breccias caught in "squeeze-ups". The latter two criteria indicate that these lavas are the right way up (Figure 2-2-2). A distinctive variety of porphyritic flow contains large (<4 centimetres) feldspar laths with subtrachytic texture previously referred to as "bladed feldspar porphyries" (Preto, 1975, 1979).

PRINCETON GROUP

The Princeton Group contains sub-greenschist grade lithologies of Tertiary (Eocene) age that have been deformed and rotated by block faulting (Ewing, 1980; Monger, 1985). Rock types include thinly bedded coal seams and seat earths, fissile shales yielding plant remains, arkosic sandstones and conglomerates, polymictic laharic breccias, biotite rhyolite, hornblende-phyric dacite, and locally pillowed olivine basalt flows and hyaloclastites. The Princeton Group is locally capped by subhorizontal amygdaloidal basalts of Miocene age that are unfaulted (Monger, 1985).

EAGLE GRANODIORITE

The Eagle pluton comprises a foliated to gneissic (syntectonic) granodiorite and variably deformed (syntectonic to post-tectonic) muscovite granite. Granodiorite at the western margin of the study area is a medium to coarse-grained rock containing quartz, plagioclase, potassium feldspar and biotite. The granodiorite is weakly to intensely foliated, cut by quartz veins and locally encloses amphibolitic schlieren. Near the contact with the Nicola on the Tulameen River road, numerous aplite sills (<1 metre) that are generally concordant with westward-dipping argillites and metasiltstones are probably rooted in the Eagle pluton. On Britton Creek, unfoliated biotite-hornblende granodiorite contains randomly oriented xenoliths of amphibole-biotite-chlorite schist derived from adjacent mylonitic rocks. Recent mapping has identified this granitoid stock as a post-tectonic intrusion of probable Tertiary (Eocene ?) age (C. Greig, personal communication, 1987).

TULAMEEN ULTRAMAFIC COMPLEX

Comprehensive reports of the geology and economic mineral occurrences in the Tulameen district are provided by Camsell *(1913)* and Rice *(1947)*. However, the most complete accounts of the geology and petrology of the ultramafic complex are provided by Findlay (1963, 1969). The distribution of mappable units observed during the field season is as determined by Findlay (1963). However, we have a somewhat different view of relationships among some of the major rock units and structural evolution of the complex. The principal ultramafic-mafic units comprise dunite, olivine clinopyroxenite, hornblende clinopyroxenite and gabbroic rocks (Figures 2-2-2, 2-2-3).

ULTRAMAFIC ROCKS

Dunite and Chromitite

Outcrops of dunite are restricted to the northern part of the complex at Grasshopper and Olivine mountains. The dunite is medium to dark grey where fresh, buff weathering and well jointed. The primary mineralogy consists of forsteritic olivine, accessory chromite and rare diopsidic augite. Alteration products include serpentine, carbonate, magnetite and talc. In general, the degree of serpentinization decreases from east (80 volume per cent serpentine) to west (20 per cent) where the lowest loss-on-ignition values (<2 weight per cent volatiles) are recorded (Findlay, 1963; White, 1987).

Concentrations of chrome spinel and massive chromitite appear to be distributed randomly throughout the dunite as discrete layers, nodular masses and schlieren up to 1 metre in length and 6 centimetres in width. Chromitite schlieren are commonly distinguished in outcrop by a pale alteration halo (0.1 to 1 centimetre). Associated with the chromite are microscopic grains of platinum minerals (for example, platinum-iron alloy, sperrylite), nickel-iron sulphides (for example, pentlandite, violarite, bravoite), chalcopyrite and pyrite (St. Louis *et al.*, 1986).

Olivine Clinopyroxenite

The principal outcrops of olivine clinopyroxenite envelop the dunite "core" and extend southwards along the central part of the complex. In addition, three discrete bodies of olivine clinopyroxenite that are distinctly elongate along the regional structural trend occur in the northeastern part of the intrusion. The fresh rock is medium to coarse grained and has a blotchy green and black appearance due to partially serpentinized olivine (<20 per cent serpentine) and deep green clinopyroxene. Sporadic pegmatitic masses contain crystals up to 8 centimetres across and olivine segregations locally form schlieren.

Breccias

Breccias within the olivine clinopyroxenite unit are well exposed in the banks of the Tulameen River near the western

Plate 2-2-1. Angular block of layered dunite (Du) – pyroxenite (Px) in sulphide-rich serpentinized breccia within westernmost olivine clinopyroxenite unit exposed in the Tulameen River.

margin of the dunite (Figure 2-2-3). Angular to rounded blocks (<0.5 metre) of dunite, pyroxenite and interlayered dunite-pyroxenite (Plate 2-2-1) are enclosed in a serpentinized pyroxene-rich matrix carrying calcite and disseminated sulphides (largely pyrite). On the eastern bank, the southern margin of a similar breccia is in contact with a body of dunite 8 metres thick which is succeeded southward by another breccia with clasts that are predominantly foliated (mylonitized ?) gabbro in random orientation. All observed contacts between breccias and host pyroxenite dip moderately to steeply (30 to 70 degrees) south. The cause of brecciation is not presently clear and may involve either tectonic or localized explosive activity.

Hornblende Clinopyroxenite

Hornblende clinopyroxenite generally occurs at the periphery of the complex. This unit is continuous along the western margin of the intrusion but is more irregularly distributed to the east. The fresh rock is medium to coarse grained and contains diopsidic augite, hornblende, relatively abundant magnetite, and minor biotite, apatite and disseminated sulphides; feldspathic variants are extremely rare. Medium-grained varieties commonly exhibit mineral foliations and/or hornblende lineations. Biotite locally forms coarse books (1 centimetre) and amphiboles commonly reach 1 to 3 centimetres in size. Accessory biotite and apatite are reported to occur in 6-metre-thick magnetite-rich layers that are poorly exposed in old workings on the southern slopes of Tanglewood Hill (Eastwood, 1959). Massive magnetite is also found as schlieren and podiform masses on Lodestone Mountain and is commonly associated with coarse-grained hornblende and clinopyroxene segregations. This rude igneous layering generally parallels mineral foliations developed in this region.

Minor Ultramafic Rocks

Rock types that are generally not mappable units include peridotite, clinopyroxenite, hornblende-olivine clinopyroxenite, hornblendite, "hybrid" rocks and mafic pegmatite. The latter rock exhibits large (6-centimetre) hornblende crystals with interstitial feldspar and usually passes gradationally into finer grained hornblendite. Mafic pegmatites are preferentially distributed near the margins of hornblende clinopyroxenite bodies (Findlay, 1963). "Hybrid" rocks are characterized by gabbroic xenoliths in various states of assimilation and generally occur at gabbro contacts (Findlay, *ibid.*). However, gabbroic xenoliths are also found at the summit of Lodestone Mountain.

GABBROIC ROCKS

The gabbroic rocks (or simply "gabbros") were subdivided by Findlay (1963) into syenogabbro and syenodiorite. Findlay's nomenclature is retained in this preliminary report but these rocks might equally have been named diorite, monzonite, or variants thereof, depending on the classification system used.

The main mass of gabbroic rocks is distributed eccentrically on the eastern side of the complex. In the north, gabbros are commonly in direct contact with olivine clinopyroxenite but only rarely lie against dunite. In the south, well-foliated and/or strongly lineated fine to medium-grained gabbroic rocks extend southwards across Arrastra Creek but their southern limit is poorly defined. These rocks were formerly mapped as "Badger gneiss" by Findlay (1963) who considered them to be contact-metamorphosed equivalents of the Nicola Group. The syenodiorite is confined to the southeastern margin of the intrusion where it is unconformably overlain by the Princeton Group.

Essential minerals are plagioclase (andesine), clinopyroxene, hornblende and potassium feldspar with minor biotite and opaques and accessory apatite and sphene. Syenodiorite is more leucocratic than syenogabbro and contains slightly less calcic plagioclase (Findlay, 1963, 1969). Textures range from equigranular to foliated and some rocks exhibit strong mineral elongation. Most gabbroic rocks are extensively saussuritized and appear various shades of green; fresh rocks are pale to medium grey or pinkish grey, depending on the nature and proportion of the feldspar. Sulphide-rich hornblende-bearing gabbros (described below) occur as thin units within olivine clinopyroxenite in the Tulameen river bed.

MAGMATIC STRATIGRAPHY: TULAMEEN RIVER SECTION

An almost continuous stratigraphic section (530 metres) along the Tulameen River, beginning at the eastern margin of the dunite and passing through olivine clinopyroxenite into the gabbroic rocks, is presented in Figure 2-2-4. The section is cut by unfoliated hornblende-bearing dacitic and basaltic dykes, probable feeders for Tertiary lavas in the Princeton Group and Miocene basalts, and contains major tectonic breaks at the dunite-pyroxenite and pyroxenite-gabbro contacts. Two thin gabbro units are also well exposed within the pyroxenite.

Olivine Clinopyroxenite

The olivine clinopyroxenite unit is rather massive and characterized by abundant xenoliths of dunite ranging in size

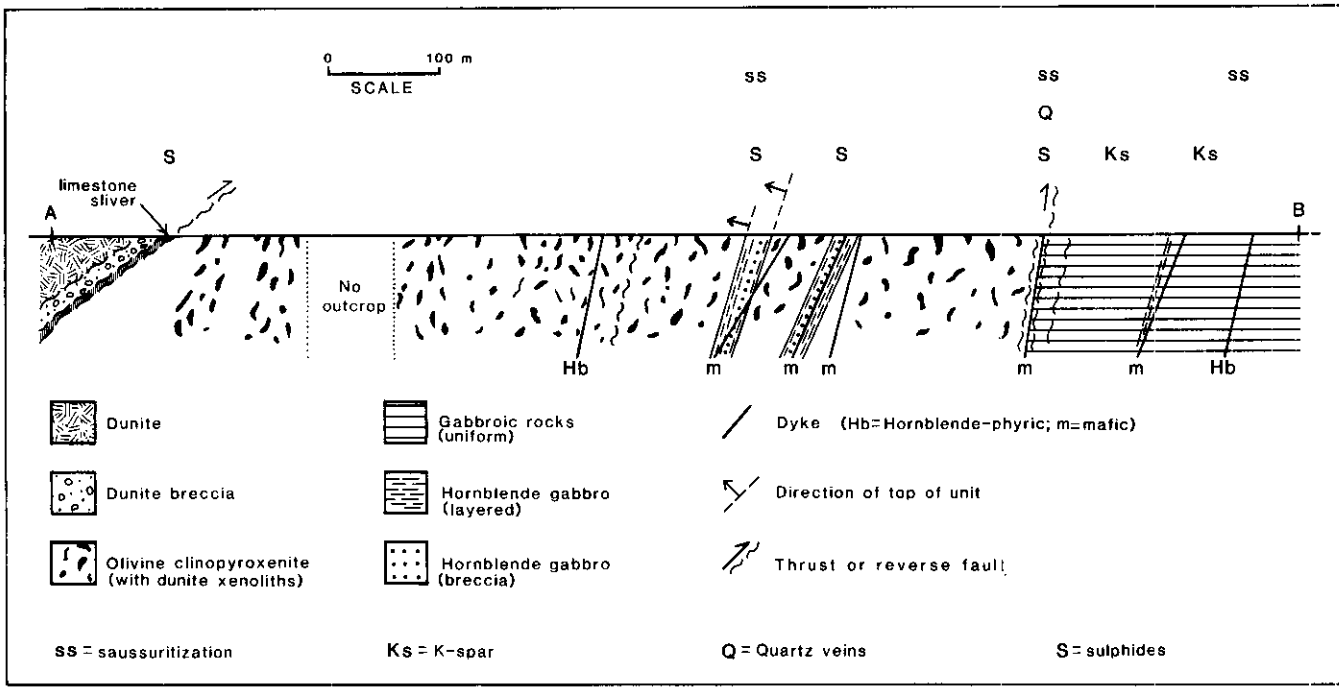

Figure 2-2-4. Stratigraphic section along the Tulameen River bed at the eastern margin of the dunite (*see* Figure 2-2-3 for location).

from a few centimetres to 10 metres or more. Xenoliths locally exhibit clinopyroxene megacrysts or crystal clots, and the larger bodies of dunite may enclose pyroxenite xenoliths that appear to have been derived from their host. Xenolith shapes are diverse: round, wispy, tabular, or distinctly elongate and contorted; and contacts with their pyroxenite host are planar to irregular or crenulate (Plate 2-2-2). Rarely, dunite and pyroxenite are interlayered and appear to have behaved as cohesive blocks within the unit. However, the majority of xenoliths preserve features that suggest that they were deformed while hot and still capable of plastic deformation. The origin of these textures is related to episodic slumping of dunite-pyroxenite layered cumulates deposited elsewhere in the intrusion and emplaced at their present location by mass flowage down the cumulate slope.

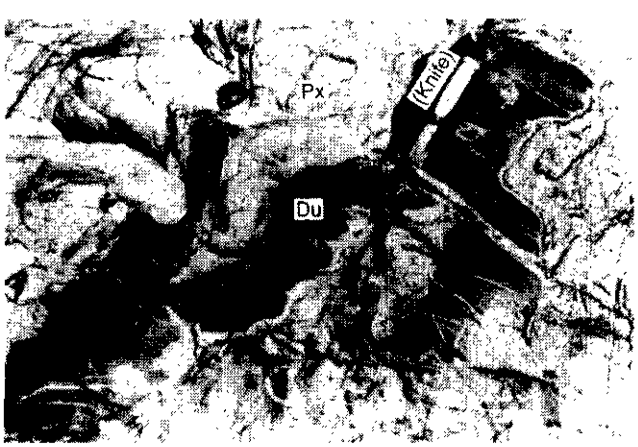

Plate 2-2-2. Intricately contorted ribbon-shaped xenolith of dunite (Du) in olivine clinopyroxenite (Px), Tulameen River section. Veins of carbonate and serpentine cut both xenolith and host.

Gabbros

Hornblende-bearing gabbro units within the olivine clinopyroxenite each contain three medium-grained subunits comprising a lower and upper layered sequence separated by gabbro breccia. Contacts with the olivine clinopyroxenite are sharp and depositional. The layered gabbros preserve a wealth of sedimentary features, including modal grading of plagioclase and ferromagnesian phenocrysts in which the density grading may be normal or reverse in different layers (Plate 2-2-3); and erosional unconformities which transect earlier layers (Plate 2-2-4). The latter features consistently indicate that stratigraphic tops face west toward the dunite

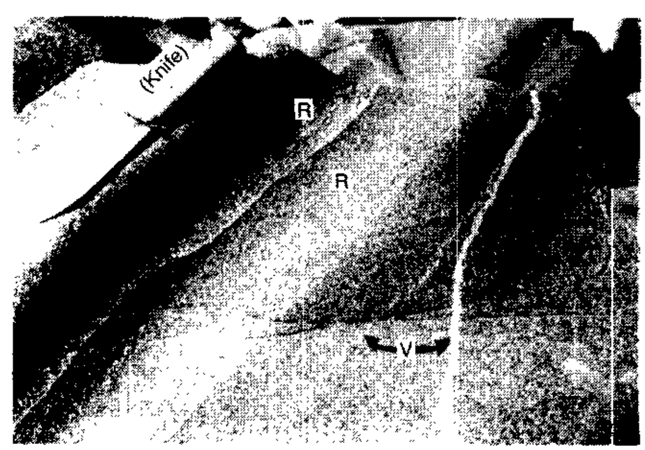

Plate 2-2-3. Reverse modal grading (R) of plagioclase and ferromagnesian cumulate crystals in layered gabbro within olivine clinopyroxenite, Tulameen River section. Leucogabbro segregation veinlets (V) are injected parallel to and across the layering.

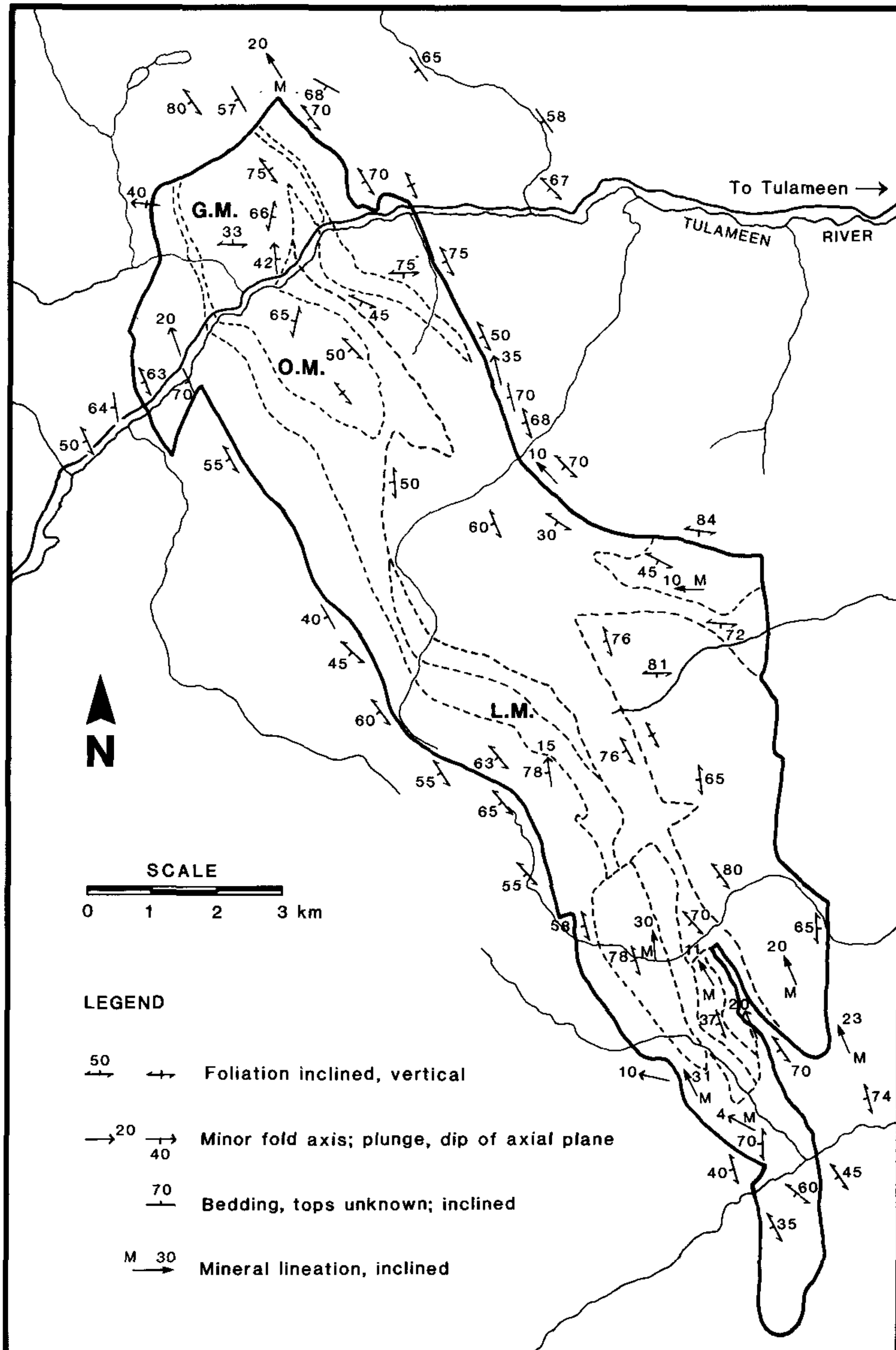

Figure 2-2-5. Representative measurements of structural fabrics in the Nicola Group and Tulameen ultramafic complex.

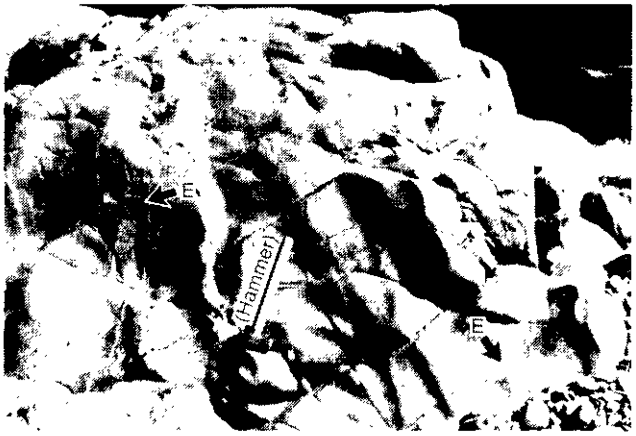

Plate 2-2-4. Layered hornblende-bearing gabbros, Tulameen River section. Note erosional truncation of layering (E) indicating stratigraphic tops face right (upstream).

Plate 2-2-5. Segregation vein (V) of leucogabbro cutting base of layered gabbro (G), underlying olivine clinopyroxenite unit (Px) and an intermediate feldspathic zone (I). Note diffuse margins of vein in gabbro and sharp contacts in pyroxenite.

"core". The brecciated layers contain rounded to angular gabbro blocks enclosed in a uniform gabbroic mesostasis that may be slightly more leucocratic or melanocratic than the majority of the blocks. Most of the above features may be related to the action of magmatic convection currents or mass wasting of previously crystallized cumulates. Both gabbro units are enriched in sulphides which appear to be concentrated in the upper layered gabbros.

A prominent feature of the gabbroic units is the presence of leucogabbro veins and stringers containing acicular "quench" amphiboles. These veins crosscut and parallel the layering for short distances, and locally transect both the upper and lower contacts with the pyroxenite. Where this occurs, many veins that have diffuse margins in the gabbro form sharp contacts with the pyroxenite (Plate 2-2-5). These textural and mineralogical features indicate that leucocratic vein material formed when trapped intercumulus liquids migrated out of gabbro cumulates. Migration of intercumulus liquids in this case may well have been promoted by rapid loading of the cumulate pile caused by sudden deposition of cumulates from dunite-pyroxenite density flows.

INTRUSIVE CONTACTS

Nicola–Ultramafic

Evidence of intrusion into the Nicola Group is rare. However, such relationships have been observed 0.5 kilometre south of Blakeburn Creek near the gabbro-ultramafic contact where rafts of Nicola metasedimentary rocks are intruded by gabbro and hornblendite; and in mafic pegmatite, exposed in logging scars on the western slopes of Grasshopper Mountain, which contains angular xenoliths (<40 centimetres across) of hornblende dacite derived from Nicola wallrocks.

Gabbro–Ultramafic

Relationships between gabbroic and ultramafic rocks are complex. Intrusive breccias with a net-veined texture comprising gabbro blocks set in a hornblende clinopyoxenite-hornblendite mesostasis were observed at several localities. In Newton Creek, thin (<15 centimetres) hornblende clinopyroxenite dykes intrude gabbro and both are crosscut by leucocratic gabbroic stringers (1 centimetre). In the Tulameen River, gabbroic rocks are interlayered with olivine clinopyroxenite and Findlay (1963) noted gabbro dykes cutting hornblende clinopyroxenite. These relationships point to more than one episode of gabbro crystallization as opposed to remobilization of previously solidified gabbros by the heat of ultramafic intrusion (Findlay, 1969).

Dunite–Olivine Clinopyroxenite

Thin (<20-centimetres) olivine clinopyroxenite dykes were observed to cut dunite on the southern flank of Olivine Mountain and north of the summit of Grasshopper Mountain near the dunite-pyroxenite contact. In addition, pyroxenite veins a few centimetres in width occur in clinopyroxene-bearing dunite exposed in the Tulameen River below the confluence with Britton Creek. These veins exhibit post-emplacement boudinage and may represent clinopyroxene-rich intercumulus liquids that segregated and migrated through hot dunite at the brittle-ductile transition.

Olivine Clinopyroxenite–Hornblende Clinopyroxenite

The only contact between hornblende clinopyroxenite and olivine clinopyroxenite examined in detail was that which crosses the Tulameen River near the western margin of the complex. Here, hornblende clinopyroxenite with pegmatitic masses of hornblende, clinopyroxene, biotite and magnetite grades into a medium to coarse-grained olivine clinopyroxenite cut locally by thin (<8 centimetres) dykes of finer grained pyroxenite.

Summary of Intrusive Relationships

Findlay (1963, 1969) concluded from contact relationships that the gabbroic and ultramafic parts of the complex represented two separate intrusions, an early gabbroic mass invaded by an ultramafic body in which dunite was the last unit emplaced. One outcrop in the Tulameen River section that was used to support intrusion of dunite into olivine clinopyroxenite has been re-interpreted in this study as representing the products of magmatic debris flows that incorporated partly consolidated dunite-pyroxenite layered cumulate sequences. These relationships, and the occurrence of pyroxenite dykes cutting dunite, suggest that the dunite crystallized prior to the pyroxenites. The main body of gabbroic rocks to the east appears to largely predate emplacement of the ultramafic rocks. However, thin sequences of gabbro cumulates interlayered with olivine clinopyroxenite and gabbro dykes cutting hornblende clinopyroxenite point to a protracted history of gabbro crystallization involving more than one influx of parental magma.

STRUCTURE

Structural data for the Tulameen ultramafic complex and its host rocks are presented in Figure 2-2-5.

REGIONAL FOLIATION

A penetrative foliation, generally striking north-northwest and dipping steeply to the west, is especially pronounced in Nicola metasedimentary rocks and is also evident in Eagle granodiorite and mafic-ultramafic units of the Tulameen complex (Figure 2-2-5). Within the Nicola Group, the foliation is parallel to bedding and axial planar to eastward-verging minor isoclinal folds in thinly laminated argillites, tuffaceous siltstones and crosscutting quartz veins. The axes of these folds plunge gently (5 to 20 degrees) to the north. Structures related to this phase of deformation are exposed on the Tulameen River road at the Nicola-Eagle contact. Apophyses of granodiorite that intrude Nicola marbles are boudinaged and folded about axes lying within the plane of the regional foliation (Plate 2-2-6).

CHROMITITE SCHLIEREN

The distribution and structural controls of chromitite in the Tulameen complex have important economic implications.

Plate 2-2-6. Boudinaged and tightly folded dykes of Eagle granodiorite (G) penetrating thinly bedded skarned marbles (M) and mica schists of the Nicola Group. Nicola schistosity is axial planar to folded dykes.

Extensive areas of dunite exhibit a weak to strong foliation that is variable in attitude but generally steeply inclined (Figure 2-2-3). Chromitite schlieren are commonly oriented within the foliation and serve as structural indicators for strain within the dunite. These schlieren are generally 0.5 to 2 centimetres in width and 5 to 25 centimetres in length. The most notable concentrations of chromitite were observed on the southern flanks of Grasshopper Mountain. Boudinaged chromitite layers and tight to isoclinal minor folds have been observed as well as peculiar "ring structures" that may represent cross-sections through domical folds (Plate 2-2-7). Whereas these structures are associated with the development of the foliation, other folds clearly postdate this fabric (Plate 2-2-8). In the latter case, the foliation is emphasized by micaceous alteration products (serpentine and talc) and serpentine veinlets have been folded. Evidently, the latter phase of ductile deformation took place at temperatures below the upper thermal stability limit of serpentine (<500 degrees centigrade).

Although data are sparse, there appears to be no concentric arrangement of either the foliation or chromitite schlieren within the dunite that might be expected during emplacement of a crystal mush (Findlay, 1963, 1969). However, there is some indication that radical changes in the attitude of the fabric are related to faulting, such as the change from north-

Plate 2-2-7. Chromitite layers (Cr) exhibiting ring structure (R) or condom fold in dunite, Grasshopper Mountain.

Plate 2-2-8. Hinge zone of minor fold in strongly foliated serpentinized dunite, Tulameen River road. Serpentine veinlets (Sp) lying within the foliation predate this folding event.

erly to predominantly easterly dipping structures across a north-trending fault bisecting Grasshopper Mountain. Despite these complexities, isoclinal folds in chromitite schlieren and the layer-parallel foliation within the dunite mimic structural elements in the country rocks. Thus, it seems reasonable to equate the penetrative fabric of the dunite with the regional foliation. Chromitite schlieren within the dunite presumably represent vestiges of formerly much more extensive cumulate layers.

THRUST FAULTS: TULAMEEN RIVER SECTION

Structures interpreted as thrust or reverse faults are well exposed in the Tulameen River section (Figure 2-2-3). The eastern margin of the dunite is faulted and contains a cataclastic breccia comprising rounded dunite fragments set in a serpentinized matrix. A dark grey unmetamorphosed pyritic limestone (2 metres thick) lies in fault contact with olivine clinopyroxenite. The fault plane dips 35 to 40 degrees west and is marked by a thin (1-centimetre) pale green gouge. The limestone was presumably derived from the Nicola Group and appears to have been emplaced by thrusting. We have therefore re-interpreted the contact between the dunite and olivine clinopyroxenite units mapped by Findlay (1963) as a thrust fault (Figure 2-2-3).

A major high-angle fault at the contact between the pyroxenite and the mappable gabbroic rocks is marked by a mylonite zone 3.5 metres wide containing sheared quartz veins and disseminated pyrite. The gabbroic rocks near the fault zone are heavily saussuritized, locally pyritic, cut by veins of potassium feldspar, and rarely preserve primary cumulate layering. Despite its steep attitude at the Tulameen River, the trace of this fault (Figure 2-2-3) lies subparallel to the thrust at the margin of the dunite and it too probably represents a thrust or reverse fault. An unfoliated mafic dyke intruding the mylonite zone suggests that the last fault movements were pre-Eocene.

SHEAR ZONES AND FAULTS

All of the contacts between the Tulameen complex and Nicola rocks observed in the field, with the few exceptions mentioned earlier, are ductily sheared or faulted. A package of strongly schistose to mylonitic rocks is distinguished at the northwestern margin of the Tulameen complex (Figure 2-2-3). Phyllites, chlorite-muscovite-biotite ± amphibole schists and mylonites characterized by well-developed flaser textures and amphibole augen are all represented. Contacts between the mylonitic rocks and Nicola Group are gradational and marked by increasing degrees of ductile strain, whereas the ultramafic contact appears more sharply defined by faults. In a logging scar on the western side of Grasshopper Mountain, foliated gabbros with intense mineral elongation, schistose layers and quartz rodding have been tightly folded about minor fold axes plunging up to 45 degrees west-northwest (Plate 2-2-9). These rocks were originally mapped as part of the Nicola by Findlay (1963) but they clearly include retrograde bodies of hornblende clinopyroxenite and gabbro. The margin of the intrusion in this area is interpreted to represent a ductile shear zone that has subsequently undergone folding and faulting. Another shear zone, with a similarly complex history, occurs in hornblende clinopyroxenite about 100 metres south of the summit of Lodestone Mountain.

At the eastern margin of the complex, northeast of Grasshopper Mountain, metre-wide pods of hornblendite are

Plate 2-2-9. Tightly folded mylonitized gabbros at the northwestern extremity of the complex, west of Grasshopper Mountain.

imbricated with Nicola volcanic breccias along heavily chloritized high-angle shear zones. The attitude of the contact and the planar fabric in rocks at this boundary commonly appear concordant with the regional foliation. Further south along the same shear zone, at Olivine Creek, the intensity of mineral elongation lineations in Nicola tuffs and gabbros increases dramatically toward the contact. In general, lineations due to rodding and mineral streaking developed at the margins and locally within the intrusion are gently to moderately plunging (10 to 35 degrees) to the northwest (Figure 2-2-5). Preliminary examination of kinematic indicators in the field suggests that major north-northwest-trending high-angle faults bounding the complex, and some fault zones within the complex, have a dextral component of motion.

Brittle deformation of the Tulameen complex is commonly related to northeasterly to easterly trending high-angle faults manifested by zones of intense brecciation, clay fault gouge, quartz and carbonate veining, and manganese-stained slickensided fault surfaces. Brecciated dunite is well exposed near the mouth of Britton Creek. Fragments are subangular to well rounded and cemented by coarsely crystalline serpentine (antigorite ?) and finely comminuted dunite. The breccia is tectonic in origin and localized by a northeast-trending fault along the Tulameen River (Figure 2-2-3). The northern termination of the complex is defined by a fault that has caused extensive brecciation of all exposed lithologies including Tertiary dykes. Slickensides along the fault plane indicate a vertical component of motion.

MINERAL POTENTIAL

Ultramafic and mafic rocks, and chromite-magnetite occurrences, are currently being analysed for platinum group elements (PGEs). According to St. Louis *et al.* (1986), PGEs occur in platinum-iron alloys associated with chromitite, except for palladium which is concentrated in hornblende clinopyroxenite and gabbroic rocks. The main structural control of chromitite schlieren is the penetrative foliation described above (Figure 2-2-3). However, the distribution of chromitite within the dunite "core" is not adequately known and deserves further attention in light of its economic importance. Similarly, the PGE potential of magnetite layers and schlieren on Lodestone Mountain and Tanglewood Hill remains to be more thoroughly evaluated.

Newly discovered and previously recognized sulphide localities are shown in Figure 2-2-3. The most notable new showings occur in thin gabbroic units within olivine clinopyroxenite in the Tulameen River section (Figure 2-2-4). Here, net-textured sulphides, predominantly pyrite, are disseminated throughout the rock and locally line fractures. The mineralogy and chemistry of these sulphide-rich gabbros are currently under investigation in view of the potential for remobilization of PGEs during serpentinization or precipitation of monosulphides directly from the melt (St. Louis *et al.*, 1986).

Companies currently investigating the mineral potential of the Tulameen complex include Newmont Exploration of Canada Ltd. and Tiffany Resources Inc. Newmont are systematically sampling chromitite occurrences on Grasshopper Mountain for platinum and palladium mineralization, and conducting bulk sample tests in an effort to evaluate the open-pit potential of the dunite. Tiffany Resources are re-assaying proven reserves of magnetite on Lodestone Mountain for their platinum group element potential. In addition, recently completed bulk testing of Tulameen dunite favour this rock as a suitable source of foundry olivine (G. White, personal communication, 1987).

DISCUSSION AND CONCLUSIONS

The Tulameen ultramafic complex exhibits a prolonged and complex history of penetrative ductile and brittle deformation. The oldest structures recognized in both the intrusive suite and Upper Triassic host rocks of the Nicola Group are a westward-dipping layer-parallel foliation and associated northwest-plunging minor isoclinal folds. In the opinion of the senior author, these data are consistent with an early [Late Jurassic (?) to Early Cretaceous] phase of eastward-verging isoclinal folding, although in the immediate vicinity of the Tulameen complex we have been unable to demonstrate any large-scale recumbent stratigraphy. Thrusting and imbrication of dunite and pyroxenite units of the complex are probably related to this phase of easterly directed tectonic transport. The junior author believes that the regional foliation and associated minor structures reflect a ductile shear deformation involving right-lateral slip in which the Tulameen complex behaved as a "mega-boudin". We both agree that major ductile shear zones or faults oriented along the strike of the complex were active prior to Early Tertiary (Eocene) intrusion of granitic stocks and dykes. Their inferred sense of dextral shear may be related to oblique compression associated with early thrusting, or early movements along the Fraser–Straight Creek fault system (Monger, 1985) which may have created new faults in the Tulameen region or reactivated existing reverse faults. Northeasterly and easterly trending cross faults are related to a Tertiary "transtensional" structural regime prevalent at this time in the southwestern Intermontane Belt.

Evidence for folding and thrusting of the Nicola Group by mid-Cretaceous time is found in the Cache Creek–Ashcroft area. Here, Travers (1978, 1982) documented structural elements in Nicola and Ashcroft strata that are remarkably similar to those described above in the Tulameen region. Furthermore, he demonstrated the presence of large-scale recumbent folding and easterly directed thrusting in response to eastward overthrusting of Cache Creek terrane on Quesnellia (*see* Figure 2-2-1). Using these data, Monger (1985) speculatively linked the eastern boundary of the southern Mount Lytton plutonic complex (Eagle plutonic complex) with its southwestern dipping gneissosity and adjacent concordant schist belt (Nicola Group) with the eastward-verging structures near Ashcroft. The senior author's interpretation of the structure of the Tulameen complex and Nicola host rocks lends support to his speculation that the two regions represent different structural levels of the same fold and thrust package.

Findlay (1963, 1969) interpreted ultramafic rocks of the Tulameen complex as reflecting an original igneous zonation formed in a "proto-stratiform" laccolith-like body in the order dunite, olivine clinopyroxenite, hornblende clinopyroxenite. The zonal configuration of units expressed in outcrop was formed subsequently during forcible emplacement of the dunite layer (or "core"), intruded as a partly consolidated crystal mush into overlying pyroxenites (or "shell"). The dunite provided a "piston-like" locus of stress for deformation and tilting of overlying gabbroic and surrounding country rocks. Crystallization and emplacement were regarded as partly synchronous with regional deformation of Upper Triassic Nicola rocks in order to explain the lack of well-developed cumulate layering within the complex.

In this study, it has been argued that the transgressive character of the main dunite body in relation to its pyroxenite "shell" is a consequence of thrusting during the development of Late Jurassic (?) to Early or mid-Cretaceous eastward-verging regional structures. At least one other thrust or reverse fault separates olivine clinopyroxenites from gabbros in the Tulameen River section and imbrication by thrusting or infolding may partly explain the intricate repetition of pyroxenite and gabbro units in the eastern and southern parts of the complex. The elongate outcrop pattern of the intrusion reflects not only this deformation but high-angle strike-slip faulting with an inferred sense of right-lateral displacement of unknown magnitude.

The structural evolution of the Tulameen complex inferred above precludes any firm assessment of original intrusion geometry. However, gradational contacts among pyroxenite units (especially in the western half of the complex), interlayered dunite-pyroxenite cumulates, and evidence for a common petrogenetic affiliation (Findlay, 1969) support Findlay's concept of a single differentiated intrusive body. Given a sill-like geometry, deeper stratigraphic levels appear to be exposed by thrusting in the northern part of the complex.

Emplacement of ultramafic units as a crystal mush is unlikely to preserve delicate sedimentary structures such as those observed in thin gabbroic units within olivine clinopyroxenite. The general lack of magmatic layering is at least partly attributable to periodic remobilization and slumping of cumulate sequences penecontemporaneous with deposition; and tectonic reworking of cumulate stratigraphy (for example, disruption of chromitite layers in dunite by flowage during regional deformation). The contemporaneity of intrusion and regional tectonism will no doubt be elucidated by detailed petrofabric studies and further age dating now in progress. However, there is nothing in the existing data that precludes deformation and thrust emplacement of the Tulameen ultramafic complex in an essentially cold, completely solidified state.

ACKNOWLEDGMENTS

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GEOLOGY OF THE MAGGIE PROPERTY, INDIAN RIVER AREA, SOUTHWESTERN BRITISH COLUMBIA* (92G/11E)

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KEYWORDS: Economic geology, Indian River, Stawamus River, Slumach gold zone, Gambier Group, Goat Mountain formation, quartz veins, vent zone, volcanogenic sulphides.

INTRODUCTION

The Indian River project is a continuation of mapping by the senior author on the Maggie property (formerly known as the Hopkins property) centred at approximately latitude 49°38′ north, longitude 123°02′ west (Figure 2-3-1) around the headwaters of the Indian and Stawamus rivers. Access from Squamish is by 10 kilometres of logging road that parallels the Stawamus River.

The property consists of 84 units in 11 claims, staked in 1976 by H. Hopkins after finding copper-lead-zinc mineralization (Clendenan and Pentland, 1979). Since 1977, work by International Maggie Mines Ltd. and Placer Development Limited (now Placer Dome Inc.) has included mapping, trenching, 78 drill holes totalling 8005 metres, and two short adits with drifts following mineralization (Drummond and Howard, 1985). A detailed history of the property is given in Reddy *et al.* (1987). Minnova Inc. has recently optioned the property and has completed grid mapping and geochemical studies concentrated on the Mar and War Eagle claims.

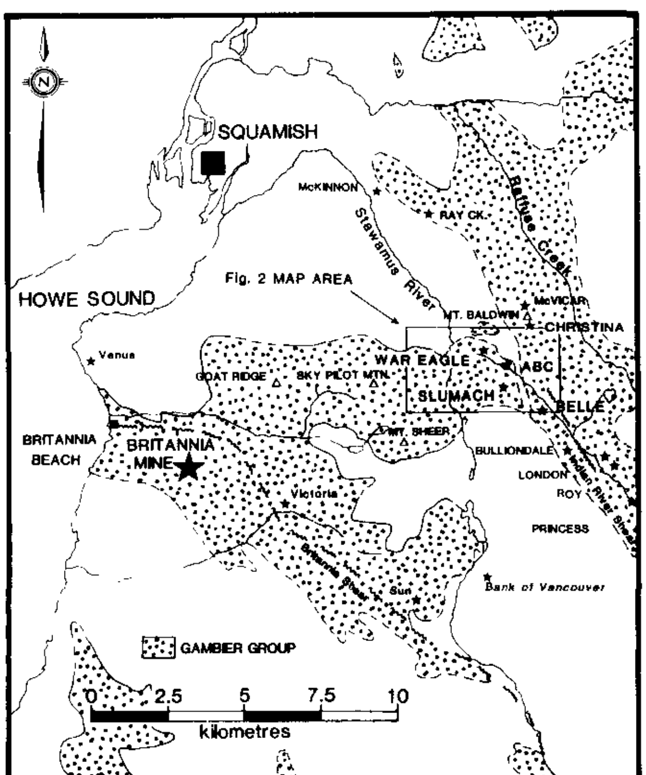

Figure 2-3-1. Location of the map area and mineral prospects in the Britannia–Indian River pendant, southwestern British Columbia.

The Maggie property is on the eastern edge of the Britannia–Indian River pendant that hosts the volcanogenic deposits of the abandoned Britannia camp and several prospects along the Indian River valley (Figure 2-3-1). This study is directed toward gaining an understanding of the relative structural and stratigraphic location of the Indian River prospects with respect to the Britannia orebodies.

The Slumach gold zone on the Mar claim of the Maggie property (south-central part of the map area, Figure 2-3-2) consists of two parallel quartz-chlorite veins carrying sulphides and anomalous gold and silver values. These veins cut an intensely hornfelsed zone characterized by pervasive biotitization, local silicification and development of chlorite and cordierite.

REGIONAL GEOLOGY

The Britannia–Indian River pendant is mainly a calc-alkaline, subaqueous volcanic and sedimentary sequence of felsic to intermediate pyroclastics, flows, cherts, argillites and greywackes. Schofield (1926) named the strata of Goat Ridge, adjacent and west of the project area, the Goat Mountain formation. He described it as a monoclinal succession dipping moderately to the southwest with the Britannia formation being stratigraphically higher. The Indian River area was described as Lower and Middle Goat Mountain formation by James (1929). He felt that the Britannia formation, host to the Britannia orebodies, was older than the Goat Mountain formation, and therefore had been thrust over it.

More recently the entire pendant has been classified as the Gambier Group of Late Jurassic to Early Cretaceous age (Armstrong, 1953). Correlations between Gambier Group and the Britannia and Goat Mountain formations suggest that the Lower Goat Mountain formation is equivalent to lower Gambier Group, and that the Britannia formation has not been thrust over the Goat Mountain formation (*compare*

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

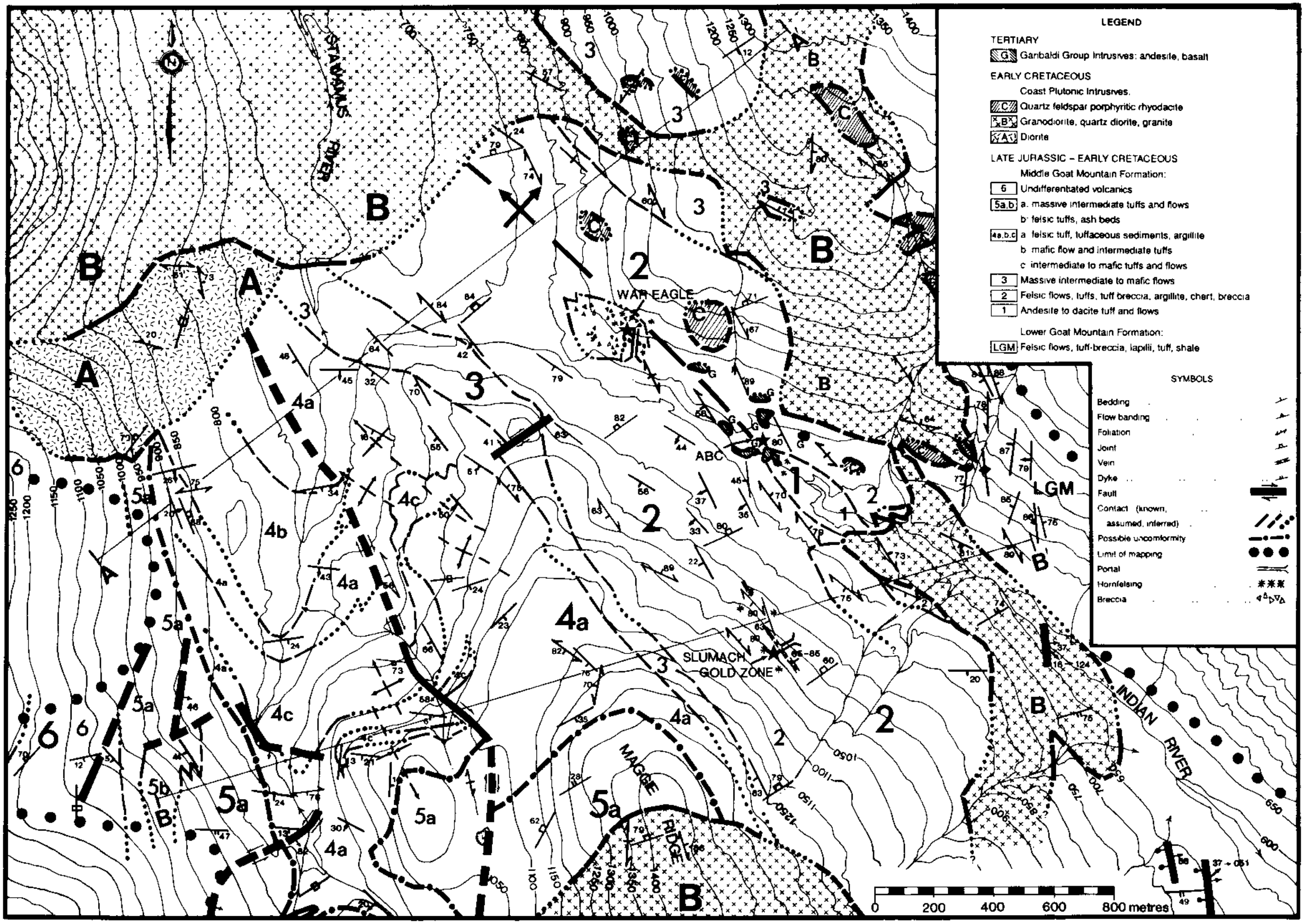

Figure 2-3-2. Geology map of the Maggie property at the headwaters of the Indian and Stawamus rivers, Britannia–Indian River pendant, southwestern British Columbia.

McColl, 1987). Therefore the project area is probably within the Lower and Middle Goat Mountain formation or lower Gambier Group.

Pelecypods (as yet of undetermined age) found in the northeast corner of the map area may help constrain the age of the Goat Mountain formation.

The Coast plutonic intrusives surround portions of the stratified rocks creating screens or pendants. These bodies are oriented northwesterly throughout the Coast Complex. Late Garibaldi Group basaltic dykes and sills intrude both the pendant and the plutonic rocks.

LOCAL GEOLOGY

James (1929) used the granodiorite apophysis that cuts across the Indian River valley to partition the Lower from the Middle Goat Mountain formation (Figure 2-3-2). Units on both sides of the intrusion are characterized by abundant felsic volcanics and appear similar. However, the structural orientations are different on opposite sides of the intrusion, and flows dominate over pyroclastic rocks to the east. Lower and Middle Goat Mountain formation, the surrounding Coast plutonic intrusives and dykes and sills of the Garibaldi Group are described in the following sections.

LOWER GOAT MOUNTAIN FORMATION

This north-striking succession of felsic flows, interbedded with shale, fragmental tuff-breccia and lapilli tuff, is at least 350 metres thick. Dips are steeply west and east, with tops to the west. The bottom of the formation is not exposed here and exposures continue to the southeastern part of the map area. The upper part of the formation is truncated by granodiorite.

MIDDLE GOAT MOUNTAIN FORMATION

Six major units form a continuous stratigraphic succession from the Indian River valley to the lower slopes of Sky Pilot Mountain. The section, at least 2.5 kilometres thick within the map area, continues to Goat Ridge to the west. It dips moderately south-southwest. The six units are described below, from oldest to youngest (Figures 2-3-2 and 2-3-3).

Lower intermediate tuffs and flows (Unit 1) comprise dark green, massive andesitic to dacitic tuffs with minor intermediate flows. This unit crops out in the bottom of the Indian River valley and has a minimum thickness of 25 metres. The tuffs vary from fine-grained ash and crystal tuffs to lapilli tuffs with a few large fragments up to 15 centimetres across. Flows are feldspar porphyritic and sometimes contain chloritic amygdules. The flows are also marked by ubiquitous development of chlorite and epidote; local hornfelsing by contact metamorphism destroys many textures and makes the upper contact of this unit indistinct.

Felsic tuffs, flows and sedimentary interbeds (Unit 2), lying conformably above Unit 1, consist of a 750-metre-thick felsic tuffaceous succession with numerous argillite and chert beds. (This unit includes packages II, III and IV of Reddy *et al.*, 1987). Numerous cycles of explosive volcanism are indicated by the repeated layers of coarse tuff-breccia with fragments up to tens of centimetres across. The middle of this unit is dominated by numerous shale and tuffaceous chert horizons. Individual beds are commonly 1 centimetre thick; massive cherty beds up to 2 metres thick occur locally. Bedding is well developed and faces upwards. The breccia at War Eagle adit (Figure 2-3-2) is at the stratigraphic top of the sediments and probably represents the start of a new eruptive cycle.

The hornfelsed upper part of Unit 2 hosts the Slumach gold zone. Lithologies that host the veins are probably felsic

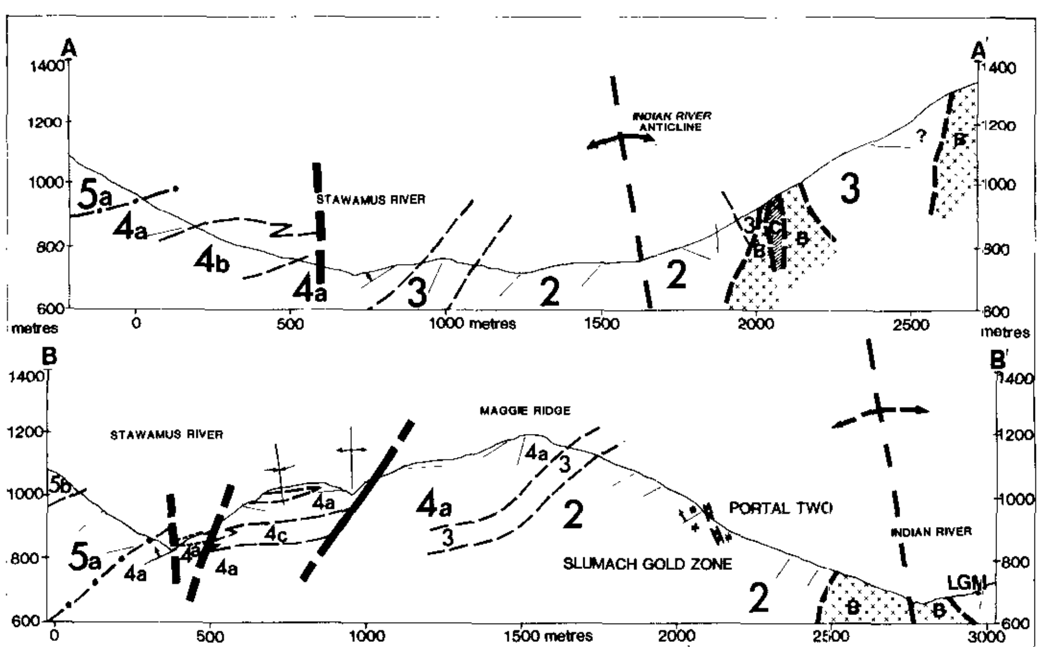

Figure 2-3-3. Cross sections A-A′ and B-B′ of the Maggie property. The section lines are shown in Figure 2-3-2.

lapilli tuffs, as suggested by rocks on strike with the hornfelsed mineralized zone. Near the upper contact, good shale marker beds show that Unit 2 is conformable with Unit 3.

Massive intermediate to mafic flows (Unit 3) form resistant bluffs at the north end and east side of Maggie Ridge. They are massive, dark green intermediate flows that total about 150 metres in thickness. Locally layers of epidotized fragments give an orientation suggesting flow parallel to bounding units. Whole rock analyses indicate intermediate to mafic compositions (C. Burge, personal communication, 1987).

Felsic tuffs, sediments and intermediate interbeds (Unit 4) conformably overlie the massive flows of Unit 3. Unit 4a consists of a thick felsic tuffaceous sediment series with several intermediate interbeds. The total thickness varies from 150 metres minimum at the top of Maggie Ridge to over 650 metres in the Stawamus River valley (Figure 2-3-2). The lithology consists generally of thin to massive beds of ash to lapilli tuff, and rarely tuff-breccia, interlayered with thin shale or greywacke beds. Beds always face up.

Units 4b and 4c are extensive intermediate to mafic volcanic units that interfinger with the felsic sediments of Unit 4a. Most of Unit 4b appears to be a thick hornblende and pyroxene porphyritic mafic flow with numerous epidote-rich layers. Unit 4c is poorly stratified in part, but resembles 4b in the more massive parts of the outcrop.

Massive intermediate volcanics (Unit 5) form a set of bluffs rimming the west side of the Stawamus River valley. It consists of intermediate tuffs and flows (5a) and interbedded felsic tuffs and fine ash beds (5b) that are characterized by accretionary lapilli. Several faults disrupt the outcrop patterns on the west side of the Stawamus River valley. The drastic thinning of Unit 4, and irregular contacts with Unit 5, possibly reflect a paleotopographic surface developed on Unit 4.

Upper felsic tuffs and overlying undifferentiated units (Unit 6) conformably overlie Unit 5. The unit was not mapped in detail, but a continuous bimodal succession of felsic and intermediate to mafic rocks continues off the map area (*see* Heah *et al.*, 1986).

COAST PLUTONIC INTRUSIVES

Three major types of intrusive bodies are found in the map area: a diorite pluton (Unit A), granitoid plutons (Unit B) and several small quartz feldspar porphyritic rhyodacite bodies (Unit C). Heah *et al.* (1986) used a two-point rubidium-strontium isochron to date the Squamish granodiorite pluton in the northwest corner of the map as Early Cretaceous (114 ± 40 Ma). Mid-Cretaceous metamorphism is associated with the emplacement of the Squamish granodiorite (Heah *et al.*, 1986; *see* "Metamorphism" below).

Diorite (Unit A) in the northwest corner of the map, has distinctively white-weathering coarse-grained feldspar phenocrysts (up to 60 per cent) in a strongly chloritized green groundmass (30 to 60 per cent). Magnetite and bright red hematite blebs (5 per cent) are interstitial to the coarse feldspars. Locally the diorite is strongly foliated and metamorphism up to the lower amphibolite facies is observed near the contact with the granodiorite.

Granodiorite (Unit B) often has faulted contacts where the Squamish pluton intrudes the earlier diorite and sediments. Composition varies from granite to diorite with granodiorite being most common. The pale grey, coarse-grained bodies are made up of quartz (35 per cent), plagioclase (45 per cent), potassic feldspar (10 per cent) and mafic minerals (10 per cent). On the east and west sides of the map, plutons are granodiorite to quartz diorite with biotite as the major mafic mineral. In the Indian River intrusion the lithology is granite with obvious potassic feldspars, quartz and biotite. On Maggie Ridge the mafic minerals are biotite and hornblende up to 25 per cent and this latter body has a chilled margin 75 metres wide along its northern contact. A myrmekitic texture of quartz and plagioclase is observed in thin sections from this chilled zone.

Quartz feldspar porphyritic rhyodacite (Unit C) intrusives are small massive dykes and bodies that intrude the sediments and plutons. They are found only on the eastern side of the Indian River valley and are sporadically distributed for several kilometres southeast of the map area. The intrusives are plagiophyric with crystals 5 millimetres long that average up to 10 per cent of the rock. Quartz eyes are usually 3 millimetres long and comprise 8 per cent of the rock.

Garibaldi Group intrusives (Unit G) intrude the stratified units and plutonic bodies throughout the map area. Light brown or dark green dykes (up to 3 metres in thickness) often exhibit columnar jointing. Phenocrysts are plagioclase and/or euhedral hornblende. Many dykes are vesicular and locally have calcite amygdules. Vesicles in a large basalt dyke in the east-central part of the map area contain chabazite in radiating groups of acicular rhombs up to 3 centimetres across. These intrusives are fresh-looking andesite and basalt dykes of probable Tertiary age.

STRUCTURE

The project area has three main structural elements: (1) east of the Indian River and the granodiorite apophysis; (2) between the Indian River and Stawamus River; and (3) along the Stawamus River.

East of the Indian River bedding, S_0, strikes north and dips steeply west or east (Figure 2-3-2). This series of felsic flows and interbedded sediments appears structurally different from felsic units to the west. Tops show the sequence faces consistently west and is therefore overturned.

Between the Indian River and Stawamus River beds generally strike northwest and dip moderately to the southwest. Excellent tops indicate that the sequence is upright. A major anticlinal structure, with its axial trace parallel to the Indian River, is indicated by predominantly northwest-striking, nearly vertical axial-planar cleavage, S_1 (Figures 2-3-2 and 2-3-3). The gradual change in attitude from moderately southwest-dipping beds near Portal Two, through shallow dips east of Portal Two, to vertical beds east of the War Eagle adit indicates that the asymmetrical antiform might be overturned to the northeast. A few minor fold axes indicate a shallow fold axis that plunges northwest, north of the Indian River–Stawamus River pass, and southeast to the south. James (1929) and Roddick (1965) recognized this antiform and drilling results support their interpretation (Drummond and Howard, 1985).

East of Maggie Ridge, a second locally developed cleavage (S_2), strikes north and dips moderately to the west. S_2 is axial planar to minor folds with steep northwesterly plunging axes.

Along the Stawamus River beds strike easterly and dip moderately to the south. The change in bedding orientation and the rapid thinning of intermediate dome-like interbeds of Units 4b and 4c are possibly indicative of a low-angle unconformity with an irregular paleotopography between Units 4 and 5. Higher up, in the Sky Pilot bowl, thick-bedded sequences dip shallowly to the southwest (Heah *et al.*, 1986).

Poorly expressed broad, open anticline-syncline pairs are evident in changes of bedding attitude just east of the Stawamus River. The folds have a consistent moderate northwest plunge and steep southwest-dipping axial planes. The fold axis of one very open syncline appears to plunge gently southeast.

Numerous late north to northwest-striking faults are subparallel to the S_1 cleavage. Several northeast-striking faults were noted near Portal Two and parallel to creeks east of the Indian River.

METAMORPHISM

The entire pendant exhibits lower greenschist facies regional metamorphism that has little affect on the felsic units, but renders the units of intermediate composition massive and difficult to distinguish as tuffs or flows. A common alteration mineral assemblage includes chlorite-epidote-quartz-sericite ± zeolites. Potassium-argon dates obtained by McColl (1987) in the Britannia Ridge area were Late Cretaceous (90.5±3.2 Ma and 81.4±3 Ma). Lower amphibolite grade metamorphism within the diorite pluton (Unit A), peripheral to the Squamish granodiorite (Unit B), has been dated by potassium-argon as Late Cretaceous (101±4 Ma and 95.1±3.3 Ma) by Heah *et al.* (1986).

Contact metamorphic hornfels is widespread in mineralized areas peripheral to the plutons. Pervasive purplish brown secondary biotite development is often accompanied by silicification and chloritization. The hornfels is easily distinguished in hand specimen by pale brown, ovoid, 5 to 10-millimetre porphyroblasts (cordierite with quartz) within a dark brown biotitic groundmass.

MINERALIZATION

The Maggie property has five main mineralized zones that have been explored since the early 1900s. The five prospects are: (1) Belle, (2) ABC, (3) Christina, (4) War Eagle and (5) Slumach. Other properties along the Indian River valley include the Roy, London, Bulliondale and McVicar (Figures 2-3-1 and 2-3-2). These prospects are all on or close to the Indian River shear zone, a discontinuous zone of shearing that trends northwest along the Indian River valley.

Camsell (1917) and Brewer (1918) describe the Belle (Irish Molly or W.C., MINFILE 092G/NW-014) prospect just south of the southeast corner of the map on the Bob claim. Pyrite and chalcopyrite occur in a 3.1-metre-wide zone of "schistose gangue" trending northwest and dipping about 65 degrees to the southwest (Brewer, 1918). Mineralization is localized along the contacts of a granodiorite porphyry dyke and associated with biotitization and later silicification. Brewer (1918) sampled a 25-foot-wide (7.6-metre) zone that assayed trace gold, 68.6 grams per tonne silver and 5.3 per cent copper. Three other possibly related exposures upslope from this zone are probably along strike. A 31-metre adit was driven prior to 1917 to intersect the lower zone, but reportedly did not reach it.

The ABC prospect (MINFILE 092G/NW-028), described by Brewer in 1918, is located on the most northerly tributary of the Indian River, on the War Eagle claim. The workings probably lie within the area of disseminated pyrite, chalcopyrite and sphalerite mineralization (up to 4 per cent sulphides) associated with the intensely hornfelsed and silicified zone in the centre of the map area. Numerous faults and a pervasive S_1 cleavage were also noted in this area. An adit driven 9.1 metres into the banks of the creek has since caved (H. Hopkins, personal communication, 1986).

The Christina prospect (MINFILE 092G/NW-041) is a scattered series of outcrops of pyrite and sphalerite in sheared felsic volcanic rocks just covered by the legend of Figure 2-3-2 in the northeastern corner of the map area (Seraphim, 1977). This is probably a southern extension of widespread pyrite-chalcopyrite-sphalerite-galena mineralization exposed on the McVicar claims on Mount Baldwin.

Exploration on the War Eagle claim (MINFILE 092G/NW-042) has been concentrated around Portal One. The close proximity of a breccia and vent zone (Clendenan and Pentland, 1979) suggests a volcanogenic style of mineralization. An adit has been driven along quartz-sulphide "stringer" mineralization in a sheared zone (Archibald, 1981). The stringer sulphides are possibly remobilized from two flat-lying volcaniclastic horizons hosting subeconomic mineralization encountered at depth (Archibald, 1981). Although high-grade zones of anastomosing veins are reported locally underground, the sampling returned an average grade of 0.50 per cent copper, 0.35 per cent zinc and 0.20 per cent lead (Clendenan and Pentland, 1979). The portal is now buried, but examination of the dump material shows that the dominant sulphides are pyrite, chalcopyrite, sphalerite, pyrrhotite and minor galena, in a silicified, rebrecciated, intensely altered and biotitized gangue.

Work on the Slumach gold zone has been focused on two quartz veins near Portal Two on the Mar claim. The Main and East veins trend northwest and dip steeply northeast. They carry up to 15 per cent sulphides, primarily pyrite, sphalerite, chalcopyrite and traces of galena in a brecciated and silicified wallrock gangue. The sulphides appear to have been rebrecciated and cemented by quartz. Fragments of wallrock within the vein are totally biotitized or chloritized and have cockscomb quartz envelopes. Both veins consist of a higher grade (gold-silver) vein approximately 1 metre wide, with lower grade, altered hanging and footwalls (Drummond and Howard, 1985). The wallrocks are intensely hornfelsed tuffaceous sediments of Unit 2. Numerous late, dark green andesitic dykes cut the zone at varying angles.

The Main vein varies from 30 to 70 centimetres wide over its 70 metres known length and averages 65.5 grams per tonne gold over a 31-centimetre width (Drummond and Howard, 1985, based on nine channel samples from the Portal Two subdrift, the range is 19.7 to 109.4 grams per tonne). Free gold has been reported (H. Hopkins, personal communication, 1987; Blundell, 1984) and an association of gold within pyrite has been determined (Blundell, 1984). The East vein, 9 metres east of the Main vein, is at least 20 metres long and varies from 30 to 200 centimetres in width (Drummond and Howard, 1985).

A second zone of quartz with galena, sphalerite, pyrite and coarse euhedral barite lies above the Slumach zone, but its extent is not known.

CONCLUSIONS

The Maggie property in the Britannia–Indian River pendant is underlain by dominantly subaqueous, calcalkaline intermediate and felsic volcanic rocks with minor sediments that are probably part of the Late Jurassic or Early Cretaceous Lower and Middle Goat Mountain formation of the lower Gambier Group. Northwest-striking units in the Indian River area are folded into a broad northwesterly trending anticline. Westerly trending orientations in the Stawamus River valley suggest that an unconformity or structural break exists above or within a thick felsic tuffaceous unit (Unit 4). Late Cretaceous lower greenschist facies metamorphism is related to emplacement of Coast plutonic intrusives. Mineralization is associated with contact metamorphism in the Slumach gold zone, a quartz-chlorite vein with anomalous gold values. Other mineralization such as that on the War Eagle claim, represents a low-grade volcanogenic sulphide system with remobilized sulphides in higher grade "stringer" zones.

ACKNOWLEDGMENTS

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ISOTOPIC AGES, WALLROCK CHEMISTRY AND FLUID INCLUSION DATA FROM THE BRALORNE GOLD VEIN DEPOSIT* (92J/15W)

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KEYWORDS: Economic geology, Bralorne, gold veins, fluid inclusions, geochronology, galena lead isotopes, sulphur isotopes, wallrock alteration.

INTRODUCTION

Work aimed at understanding the nature of the ore-forming processes at the Bralorne gold vein deposit continued in 1987. A few days were spent in the Bridge River camp examining key outcrops to assess questions raised by the isotopic age determinations at Bralorne. One further isotopic date, on sericite from the Lucky Gem property in Eldorado Basin north of Gold Bridge (Figure 2-4-1, Table 2-4-1), is in progress. Galena lead isotope data for previous and recently obtained samples from the Bridge River camp have been compiled and interpreted.

Further petrographic and chemical analysis of the rocks immediately surrounding the Bralorne mine suggests that the Pioneer volcanics of the Cadwallader Group are basalts of probable island-arc tholeiite affinity. Detailed chemical analyses of the altered intrusive rocks adjacent to major vein systems were also completed. Gains and losses of mobile elements have been corrected for volume changes accompanying alteration by the methods of Gresens (1967). The ore-forming fluids are further characterized by fluid inclusion studies at several levels from surface to 2000 metres depth in the deposit. Results from sulphur isotope studies confirm the mesothermal character of the mineralization.

GEOCHRONOLOGY OF THE BRIDGE RIVER CAMP

Mineralization at the Bralorne mesothermal gold vein deposit is closely related to a suite of Late Cretaceous or Early Tertiary dykes. Pre-mineral albitite dykes dated at 91.4 ± 1.4 Ma by uranium-lead determinations on zircons, and post-mineral lamprophyre dykes dated at 43.7 ± 1.5 Ma by potassium-argon on biotite, set limits on the time of mineralization. An intra to postmineral green hornblende porphyry dyke set, which forms a transitional series to the albitites, dates at 85.7 ± 3.0 Ma and may restrict the age further. Thus mineralization occurred long after and is genetically unrelated to emplacement of the host Bralorne intrusives, which have been dated as Early Permian by uranium-lead on zircons (minimum age of 270 ± 5 Ma) and by potassium-argon on hornblende (284 ± 10 Ma). Further support for the Early Permian age comes from lithologically similar intrusives 20 kilometres to the north at Gold Bridge, which gave 287 ± 20 Ma by potassium-argon on hornblende, and 320 ± 80 Ma by rubidium-strontium for a whole-rock isochron (Leitch, Van der Heyden, Armstrong, Godwin and Harakal, in preparation).

The Early Permian age of 270 Ma implied by the present work for at least parts of the Cadwallader and Bridge River groups is in conflict with Middle Triassic stratigraphic ages

TABLE 2-4-1
FORMATIONS IN THE BRIDGE RIVER AREA, SOUTHWESTERN BRITISH COLUMBIA
(Figure 2-4-1 shows distribution of units)

UNIT NO.	MAP SYMBOL	DESCRIPTION
EOCENE		
7		Rexmount porphyry
CRETACEOUS–TERTIARY		
6	+ + +	Coast plutonic complex (and satellite plutons)
JURASSIC–CRETACEOUS		
5		Relay Mountain and Tyaughton Groups
EARLY PREMIAN (OR EARLIER)		
4	× × ×	Bralorne intrusions
3		Cadwallader Group
2		Bridge River (Fergusson) Group
1		Ultramafic rocks
		Geological contact
		Fault
	hk 287	Radiometric date (Ma): h = hornblende; b = biotite; z = zircon; w = whole rock. k = K-Ar, r = Rb-Sr, u = U-Pb.

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

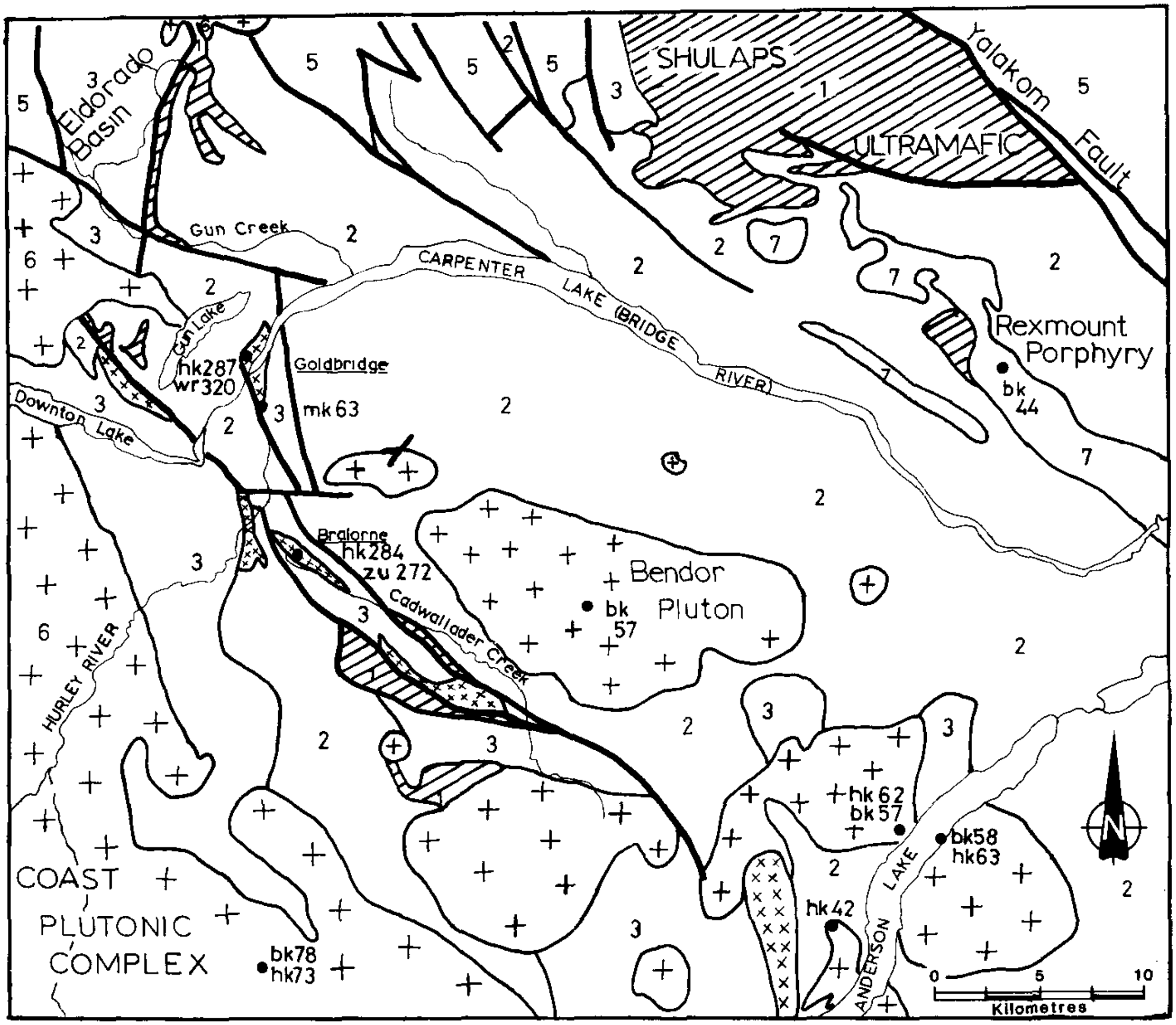


Figure 2-4-1. Regional geology and radiometric ages of the Bridge River area, from Woodsworth (1977), modifed after Church (1987) and the results of this study. Units and symbols are defined in Table 2-4-1.

(225 Ma) assigned elsewhere on the basis of paleontologic evidence. This issue is addressed in more detail later in this paper. However, the 45-Ma discrepancy might be explained by combined uncertainty in the isotopic and paleontologic data. Alternatively, rocks of the Cadwallader Group in the Bralorne area could be distinct from and older than the lithologic equivalents 20 to 30 kilometres to the north, or the contact between Bralorne intrusives and stratified rocks might be everywhere faulted.

Geochronology, combined with the lead isotope and fluid inclusion data of this study and stable isotope plus fluid inclusion studies of other workers (Maheux *et al.*, 1987), suggest that there were several pulses of mineralizing activity in the Intermontane Belt adjacent to the Coast plutonic complex. A trend of decreasing temperatures and younger age of mineralization is evident with increasing distance from the Coast plutonic complex, implying that it was the main heat source responsible for mineralization. The main pulses seem to become progressively younger to the east, from about 90 Ma for relatively high-temperature mesothermal $Au + Ag + As \pm W \pm Mo$ mineralization at Bralorne near the Coast plutonic complex, to 65 Ma for $Ag + Au + Sb + As \pm Hg$ mineralization at the Minto and Congress deposits just north of Gold Bridge (Figure 2-4-1), to about 45 Ma (Faulkner, 1986) for gold-silver epithermal mineralization at the Blackdome deposit (92O/8W), 100 kilometres east of the Coast plutonic complex.

GALENA LEAD ISOTOPE DATA

A compilation of previous and recently obtained lead isotope ratios for the Bridge River camp (Leitch, Dawson and Godwin, in preparation) shows a distinct clustering of data from 17 widespread and apparently diverse deposits that is interpreted to be the expression of a single, protracted but episodic mineralizing event coinciding with emplacement of the Coast plutonic complex during Late Cretaceous to Early Tertiary time (90 to 45 Ma). This, and the geochronological data presented above, supports the district-wide zoning model proposed by Woodsworth *et al.* (1977).

The tightly clustered lead isotope data define a linear trend that falls between upper crustal model curves and a mantle curve. This trend is interpreted to be a "mixing line isochron" (compare Andrew *et al.*, 1984) that represents the mixing of primitive mantle-type lead and more radiogenic lead (modeled respectively by the "mantle" and "upper crustal" curves of Doe and Zartman, 1979). Such mixing could be between either: (1) two groups of rocks (oceanic volcanics, such as the Bridge River Group basalts, and upper crustal volcanic arc/clastic rocks, such as the Cadwallader Group) by a meteoric thermal system generated by the emplacement of the Coast plutonic complex, or (2) the Bridge River Group primitive oceanic volcanics and introduced fluids with a more radiogenic signature. Lead from cratonal sediments, represented by Godwin and Sinclair's (1982) "shale curve" for lead evolution in Cordilleran miogeoclinal shale-hosted stratiform deposits, apparently is not involved in the proposed mixing model, confirming the allochthonous nature of the host oceanic and arc terranes.

REGIONAL GEOLOGY

Fieldwork tried to resolve the differences between isotopic and paleontologic ages of the Cadwallader and Bridge River groups referred to above. Detailed work involved the logging of drill core from surface holes on the Bralorne property. This has resulted in revision of the surface geology plan published earlier (Leitch and Godwin, 1986).

AGE OF THE CADWALLADER GROUP

The Early Permian age of 270±5 Ma implied by the present work for those parts of the Cadwallader and Bridge River groups in the Bralorne block is in conflict with Middle Triassic stratigraphic ages (225 Ma) assigned elsewhere on the basis of paleontologic evidence. The Bralorne block is the area bounded by the Fergusson and Cadwallader faults (Figure 2-4-2, Table 2-4-2); stratified rocks within it show lithological similarities to rocks of the Cadwallader Group mapped by Rusmore (1985) in the Eldorado basin 20 kilometres to the northwest (Figure 2-4-1). The age conflict hinges on several key points:

(1) Paleontologic evidence, all from outside the Bralorne block, dates the Cadwallader and Bridge River groups as younger than the Bralorne intrusives.

(2) The rocks mapped as Cadwallader and Bridge River within the Bralorne block are lithologically and chemically similar to those mapped elsewhere.

(3) The Cadwallader and Bridge River rocks appear to be intruded by, not laid on top of, the Bralorne intrusives; however, some contacts are faulted.

(4) Cadwallader sediments include a conglomerate which contains clasts that resemble soda granite, implying that the soda granite is older than the conglomerate.

TABLE 2-4-2
FORMATIONS IN THE BRALORNE-PIONEER CAMP
(Figure 2-4-2 shows distribution of units)

UNIT NO.	MAP SYMBOL	DESCRIPTION
EOCENE		
10		Lamprophyre dykes
UPPER CRETACEOUS		
9		Green hornblende porphyry dykes
	'77'	Major quartz veins (named)
8		Albitite dykes
8a	....	Grey plagioclase porphyry dykes
EARLY PERMIAN BRALORNE INTRUSIVES		
7		Soda granite
6		Diorite
6a		Hornblendite
5		President ultramafics (serpentinite)
PERMO-TRIASSIC (?) CADWALLADER GROUP		
4		Hurley Formation (turbidites, volcaniclastic sediments)
3		Pioneer Formation (basalts, aquagene breccias)
PERMO-JURASSIC (?) BRIDGE RIVER (FERGUSSON) GROUP		
2		Sediments (ribbon chert, argillite)
1		Pillow basalts

(5) Although the paleontologic dates in the Cadwallader rocks come from a sedimentary unit overlying the basal volcanic unit, the lower parts of the sedimentary unit contain intercalations of volcanics lithologically similar to those of the underlying unit.

The paleontologic age of the Cadwallader Group is limited to the Late Triassic Karnian-Norian boundary at about 230 to 220 Ma, by conodonts found in exposures in the Eldorado basin by Rusmore (1985). Her mapping led her to propose a new subdivision of the Cadwallader Group. She distinguished a lower volcanic unit equivalent to the Pioneer Formation, an upper sedimentary unit equivalent to the Hurley Formation, and a unit transitional between the two. She could find no justification for the formerly defined Noel Formation at the base of the Cadwallader Group and proposed that it be abandoned. On the other hand, Church (1987) in mapping of the Bralorne sheet (92J/15W) retained the threefold division of the Cadwallader Group. However, he put most of the basaltic volcanics in the area into the Pioneer Formation, including those formerly considered (Cairnes, 1937; Stevenson, 1958) as part of the underlying Fergusson (Bridge River) Group.

Conodonts and radiolaria of similar age to those in the Cadwallader Group have also been found in the Bridge River Group sediments at several locations to the north of Bralorne (Cameron and Monger, 1971). Here the paleontologic ages range from Middle Triassic to Early Jurassic (Potter, 1983).

Volcanic and sedimentary rocks in the Bralorne block have long been considered to belong to the Bridge River and Cadwallader groups, and to be intruded by the Bralorne intrusives (Cairnes, 1937; Stevenson, 1958; Joubin, 1948). In the mine area, both drill core and underground workings show Bralorne intrusives with abundant xenoliths, apparently of Cadwallader rocks, implying an intrusive relationship. A similar complex interfingering relationship between the Cadwallader volcanics and the Bralorne intrusives has been described 5 kilometres north of the mine by Cairnes (1937), who further suggested that the volcanics and intrusives were comagmatic and therefore roughly coeval.

The following evidence suggests that Cadwallader Group rocks are intruded by the Bralorne intrusives:

(1) From 5 to 20 metres of baking or bleaching of the Cadwallader rocks, that appears to be the product of hornfelsing, occurs in drill holes crossing the northeast contact of the Bralorne intrusive mass, where it is composed mainly of soda granite (Figure 2-4-2). This linear contact is, however, marked by a strong zone of shearing, and is probably an intrusive contact that was later faulted. Such hornfelsing is also evident on the Wayside property 5 kilometres north of Gold Bridge, where the adjacent intrusive, although devoid of the network of quartz-epidote fractures characteristic of the Bralorne diorite, is seen in thin section to be a soda granite, with distinctive symplectic quartz-albite intergrowths identical to those seen in the soda granite at Bralorne and described below.

(2) Complex interfingering of Bralorne diorite and greenstone occurs on the southwest flank of the intrusive mass. If these greenstones belong to the Cadwallader Group then it would be difficult to propose that each of these small greenstone bodies is in fault contact with the Bralorne diorite. The alternative is that the greenstone bodies are unrelated to the Cadwallader rocks and are simply fragments of an older greenstone terrane. This seems unlikely because the section at Bralorne is lithologically similar to the Cadwallader section established by Rusmore (1985). Both contain volcanic and volcaniclastic rocks and turbidite sequences composed of volcanic detritus.

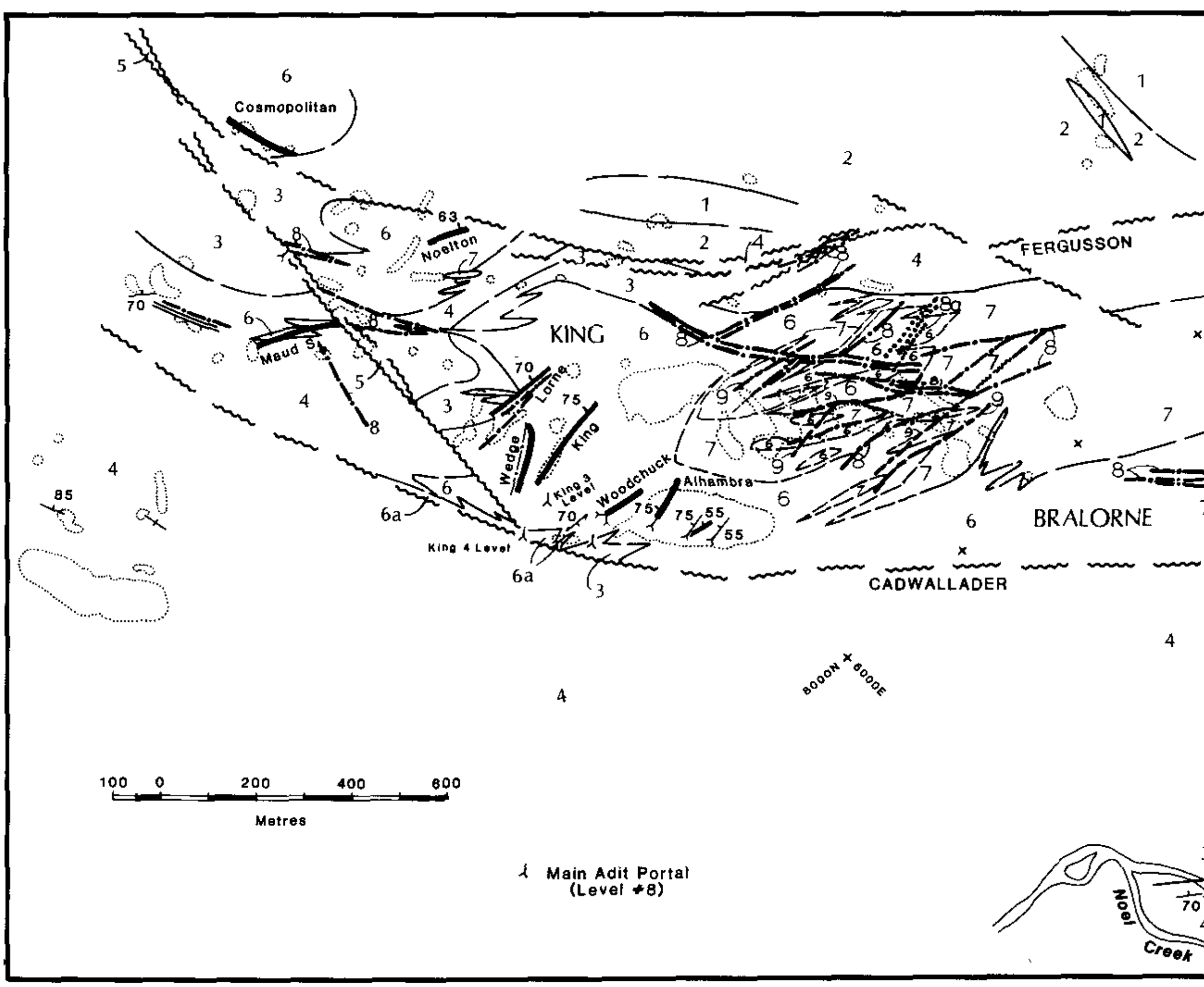


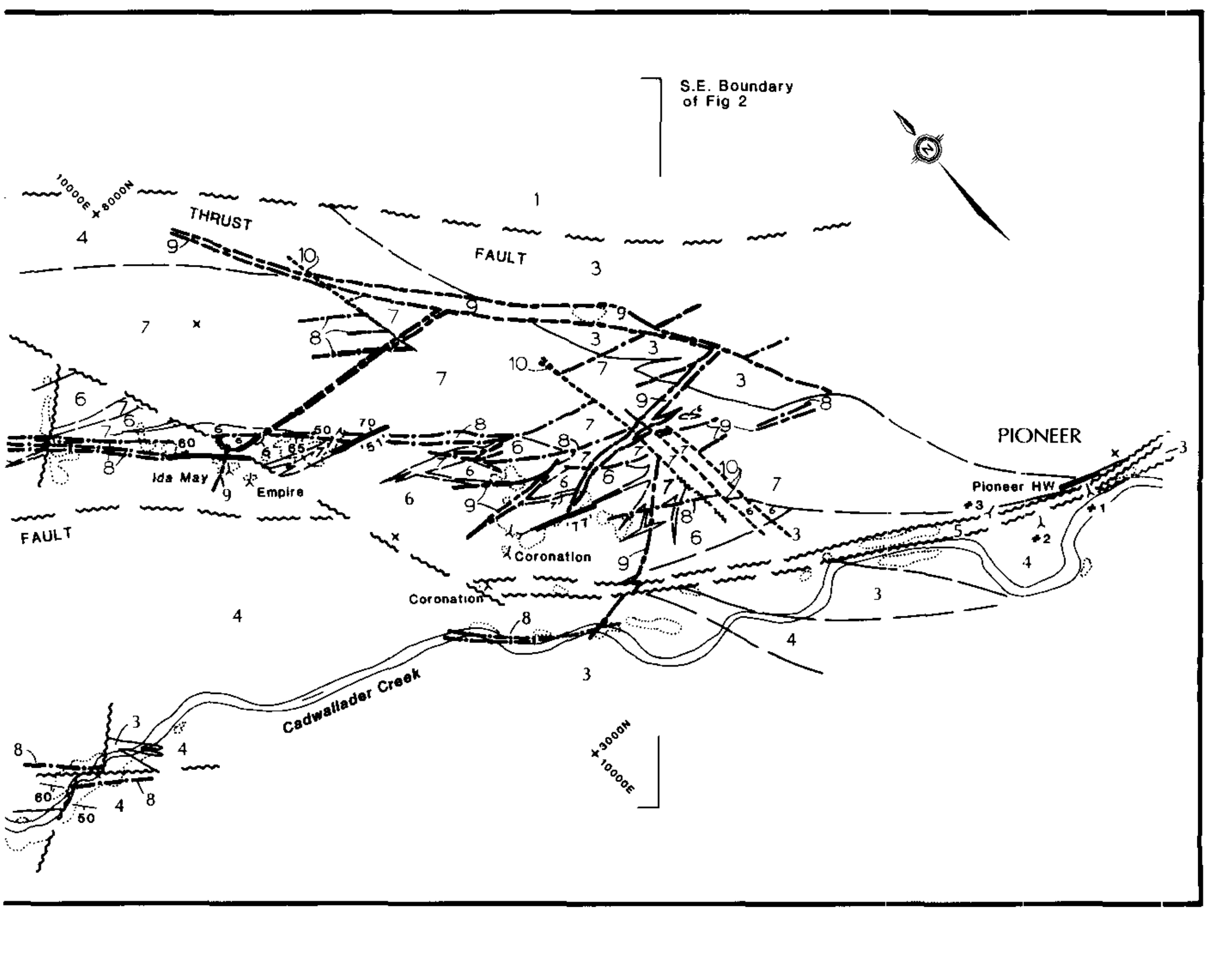
Figure 2-4-2. Surface geology of the Bralorne-Pioneer gold-quartz vein system. Units are defined in Table 2-4-2 (continued on facing page).

Cadwallader Group sediments at several locations (Wayside property and Eldorado basin) outside the Bralorne block include a conglomerate unit which contains clasts that resemble soda granite in both hand specimen and thin section. One possible interpretation of this relationship is that the transitional and sedimentary units of the Cadwallader are younger than the Bralorne intrusives, while the underlying volcanic unit is older. Unfortunately, both the volcanic and sedimentary parts of the Bralorne section appear to be hornfelsed by the Bralorne intrusives. Also, if the volcanic unit is older than the Bralorne intrusives (that is, >270 Ma), and the sedimentary unit is younger, it implies a volcanic event spanning 40 Ma, since the lower portion of the sedimentary unit contains intercalations of the same volcanics.

OTHER REGIONAL OBSERVATIONS

At the Gold Bridge quarry, Bralorne diorite and soda granite are cut by dykes identical to the albitite dykes in the Bralorne mine. The Lucky Gem prospect in Eldorado basin (Figure 2-4-1), and the Lucky Strike in Taylor basin adjoining to the east, were also visited. Rocks at the Lucky Strike bear a striking resemblance to those at Bralorne. An outcrop of foliated Bralorne diorite is cut by a felsic dyke similar to albitite (Leitch and Godwin. 1986), and mineralization in the adit is associated with an intensely quartz-carbonate-sericite-altered albitite dyke. Further north and west, however, the abundant felsic dykes are not albitites; instead, they are very similar to Bendor dykes (described below).

Several lines of evidence indicate that the major intrusives hosting the Bralorne deposit could have been emplaced below the sea floor in a zone transitional between an arc and a back-arc basin. First, the petrology of the intrusive suite, which includes serpentinized ultramafite, hornblende diorite and trondjemite or "soda granite" are typical of an ophiolite association. Also, the chemistry of both the Cadwallader and Bridge River basalts is transitional between island-arc tholeiite and mid-ocean-ridge basalts (Rusmore, 1985; Potter, 1983; this study). Secondly, the gradational contact relationships between the hornblende diorite and the intruded Cadwallader Group volcanics suggest that the diorite intruded its own volcanic products. Finally, intrusive contacts of the diorite into the elongate ultramafic bodies seen at Wayside and Bralorne imply that the ultramafics are of Permian or older age and had themselves been emplaced into a higher structural level (that is, thrust up out of their initial mantle environment, by the time of diorite intrusion).



DETAILED GEOLOGY — BRALORNE AREA

Petrography and chemistry of the major units in the Bralorne block have been reported in Leitch and Godwin (1987). Further petrographic and chemical analyses have now been completed to characterize these major units, investigate minor units, and compare the supposed Pioneer volcanics of the Cadwallader Group in the Bralorne block to volcanics mapped elsewhere as Cadwallader by Rusmore (1985) and Bridge River by Potter (1983).

PIONEER VOLCANICS

Six samples of Pioneer volcanics (Table 2-4-3) were selected to show as great a range of composition as possible for chemical analysis and rubidium-strontium dating. They range from intermediate to felsic in appearance, but thin

TABLE 2-4-3
CHEMISTRY OF PIONEER VOLCANICS

Location	Bralorne Block						Bonanza Basin	Carpenter Lake	Average Basalts (Hughes, 1982)			
Sample No.	C095	C096A	C096B	C096C	C098A	C098D	AVGCAD[1]	AVBRIV[2]	CALK	MORB	OIB	IAT
(N)	(4)	(1)	(1)	(5)	(1)	(1)	(3;10)[3]	(3)	(>3)	(100)	(>14)	(10)
Major Elements (%)												
SiO_2	47.34	44.8	45.9	63.96	48.6	52.9	50.64	48.4	51.0	49.3	50.0	51.2
A_2O_3	13.71	11.0	14.8	13.49	14.8	14.2	15.26	13.6	18.7	16.5	13	18.1
TiO_2	1.01	0.15	0.72	0.33	1.38	0.50	(1.22)	2.05	0.90	1.5	2.7	0.8
Fe_2O_3	10.32	8.40	11.5	4.46	10.9	7.8	12.17	11.1	8.9	10.0	11.5	10.1
MgO	12.41	14.7	15.5	8.07	10.1	11.7	5.57	5.20	4.8	7.5	10	6.2
CaO	9.03	9.0	5.9	3.13	6.8	6.0	6.24	10.7	10.7	11.0	10	11.0
Na_2O	1.50	0.00	0.59	3.57	3.6	4.1	4.90	3.31	2.9	2.8	2.5	2.0
K_2O	0.04	0.00	0.03	0.05	0.59	0.24	(0.71)	0.36	0.6	0.2	0.5	0.3
MnO	0.26	0.15	0.25	0.11	0.18	0.16	(0.16)	0.15	0.17	0.18	0.18	0.2
P_2O_5	0.11	0.03	0.06	0.06	0.20	0.05	(0.17)	0.31	0.13	0.10	0.3	0.1
LOI	4.58	11.92	4.90	3.16	2.88	2.50	2.58	4.60	1.0	—	0.5	0.7
TOTAL	100.31	(100)	(100)	100.39	(100)	(100)	99.65	99.8	99.80	99.1	101.2	100.4
Specific Gravity	2.90	2.72	2.83	2.74	2.87	2.84						
Minor Elements (ppm)												
As	14	15	4	0	0	0						
Ba	50	52	53	62	72	83	220		160	14	200	75
Cl	26	—	—	—	—	—	—					
Co	30	64	54	25	46	52	39			55		
Cr[4]	275	1185	495	117	191	348	115	130	90	330	140	50
Cu	75	58	135	8	2	4	95					
Mo	1	—	—	—	—	—	(Li = 22)					
Nb	3	3	3	1	8	1	<10	20				
Ni	70	465	195	34	75	135	61		70	175	75	30
Pb	6	15	8	11	18	12	—					
Rb	2	0.0	0.5	0.1	5.0	1.9	—	10	12	3	5	5
S	745	305	530	220	575	540						
Sb	3	0	4	2	0	0	(Sc = 37)					
Sr	270	50	196	240	163	110	310	210	400	150	400	200
V[4]	270	54	235	57	395	140	340	340	255			270
Y	22	8	25	12	35	16	24	33		45		
Zn	105	61	200	66	91	83	91					
Zr	63	41	48	65	139	52	49	150	65	110	100	
Normative Minerals (%)												
Quartz		1.1		23.4				2.0	1.3		1.0	3.4
Corundum				2.2								
Orthoclase	0.2		0.2	0.3	3.6	1.5	3.2	2.1	3.5	1.2	3.0	1.8
Albite	13.8		5.3	30.4	32.1	36.5	43.1	29.5	24.5	23.5	19.0	16.9
Anorthite	35.6	34.5	31.2	15.8	23.5	20.0	18.8	25.0	31.2	32.4	24.0	39.5
Diopside	7.0	12.9			8.7	8.8	9.9	23.5	13.1	19.2	20.6	11.8
Hypersthene	29.4	49.4	54.4	26.2	4.2	15.8	5.8	8.0	14.8	10.3	22.0	21.8
Olivine	9.3		1.7		22.5	14.7	12.4	2.5		7.1	4.0	
Magnetite	2.2	1.9	2.4	0.9	2.2	1.6	2.8	3.5	3.2	3.0	2.8	3.9
Ilmenite	2.2	0.3	1.5	0.7	2.7	1.0	3.1	2.8	1.7	2.9	4.9	1.5
Apatite	0.3	0.05	0.1	0.1	0.5	0.1	0.5	0.7	0.3	0.3	0.6	0.3
Diff'n Index	14	1	5	54	36	38	37	25	29	25	27	22
Modes (Estimated Volume %)												
Quartz	10	8	10	10		5	2					
Albite (andesine)	(40)	(44)	(30)	68	(50)	(40)	(60)	(75)				
Mafic: H'blende (Cpyrox)	(55)	(46)				(54)	(35)	(20)				
Ilmenite (Rut), Sph	(3)	(2)	2		5	(1)	(3)	(5)				
Pyrite (Py/Po)	2	tr										
(No. of Samples)	(1)	(1)	(1)			(1)	(3)	(3)				

1 – Rusmore, 1985; 2 – Potter, 1983; 3 – bracketted figures are averages of 10 analyses; 4 – adjusted to allow for known contamination due to grinding in Cr-steel Teel Tema mill, by comparison to same samples ground in W-carbide mill.

section and chemical analyses show that they are, with one exception, basalts composed principally of relict plagioclase (albite, An_{0-5}, replacing andesine, An_{30}), and hornblende or clinopyroxene phenocrysts in a felted mat of plagioclase microlites and interstitial chlorite and actinolite. Small but significant amounts of quartz, iron and titanium oxides and sphene are present, and quartz-epidote-chlorite amygdules are common. Magnesia contents (8 to 15 per cent) are unusually high – enough to justify calling them high-magnesia basalts (Hughes, 1982). Potash contents range from not detectable to average (0.6 per cent) as is typical of all the volcanics in the Bridge River district that were analysed in this study or by Rusmore (1985) or Potter (1983). Soda contents fall into two categories with either normal low (0 to 1.5 per cent) or high (3.5 to 4 per cent) values that are characteristic of spilitized basalts produced by low-grade alteration on the sea floor (Carmichael *et al.*, 1974). Titania values are low to very low compared to average basalts. Less mobile trace elements (vanadium, titanium, yttrium, niobium, zirconium, chromium) in diagrams proposed by Pearce and Norry (1979), Shervais (1982), and Garcia (1978) indicate that these Pioneer volcanics are transitional between island-arc tholeiites and mid-ocean-ridge basalts. A similar conclusion was reached by Rusmore (1985) for the volcanics of the Eldorado basin.

The one sample at Bralorne that is not a basalt is C096C (Table 2-4-3, 64 per cent SiO_2, 3.6 per cent Na_2O). This rock is a quartz keratophyre (Carmichael *et al.*, 1974), which is commonly associated with spilitized basalts.

MINOR UNITS

Further analysis of minor units (Table 2-4-4) was carried out on the dykes at Bralorne because isotopic dating had shown that mineralization was closely related to them spatially and temporally. The dyke sets, from oldest to youngest are: aplite, grey plagioclase porphyry, albitite, green hornblende porphry, Bendor porphyry and lamprophyre.

Aplite dykes are merely fine-grained equivalents of the soda granites. They lack the porphyritic character and aphanitic groundmass that characterize all the following dykes. They are probably final differentiates of the diorite – soda granite system and as such are Early Permian in age (no radiometric dating or chemical analyses are available).

Grey plagioclase porphyry dykes contain striking symplectic quartz-albite intergrowths which are also present in highly altered "quartz core" areas of the soda granite and albitite dykes. The grey plagioclase porphyry may be more closely related to the time of mineralization, and essentially a precursor to the albitites. Chemically it is very similar to the albitite dykes (Table 2-4-4) in all respects except the soda, barium and strontium contents, which are closer to those of the soda granite.

Albitite and green hornblende porphyry dykes appear to form a spectrum which spans the pre to post-mineral range (91 to 86 Ma). They are characterized by varying proportions of quartz, plagioclase and hornblende phenocrysts. Albite and quartz phenocrysts with rare hornblende are typical of the albitites, while the other end-member, green hornblende porphyry, is typified by lesser albite, major hornblende and a lack of quartz phenocrysts. As the name albitite implies, these rocks are rich in soda (7 per cent). They would be classified as extremely fractionated (differentiation indexes are 75 to 90; Hughes, 1982), calcalkaline dacites to rhyolites of potash-deficient subalkaline character (Irvine and Baragar, 1971). The other end-member, green hornblende porphyry, is much less differentiated (differentiation index is 30) and far more mafic (Table 2-4-4).

Bendor dykes are not well represented at Bralorne, but are more common throughout the Bridge River camp. Although initially mapped as albitite, these dykes have several distinctive petrographic features that set them apart. As these features are also found in the nearby Bendor batholith (Cairnes 1937), it seems appropriate to call them Bendor dykes. These rocks are characterized by hornblende with relict augite cores, and calcic plagioclase with sharp oscillatory zonating. This zoning (oligoclase, An_{17}, to andesine, An_{42}), and the more calcic composition are not observed in any of the earlier intrusive rocks; zoning presumably has been obliterated by the homogenizing effects of greenschist metamorphism associated with intrusion of the Coast Complex. Available isotopic dates support this conclusion, as the earlier dykes (90 to 85 Ma) pre-date the bulk of Coast Complex intrusion at 85 to 70 Ma (Woodsworth, 1977), and the Bendor plutons are younger than the Coast plutonic complex at 63 to 57 Ma (Wanless *et al.*, 1977). Dykes at the Congress mine, 15 kilometres north of Bralorne, are also younger than the Coast Complex at 67 Ma (Harrop and Sinclair, 1986). They contain 30 per cent oscillatory zoned intermediate plagioclase, and similar amounts of chloritized hornblende phenocrysts, as in the Bendor dykes.

Lamprophyre dykes (43.7 ± 1.5 Ma), dated in this study by potassium-argon on biotite, distinctly crosscut mineralized veins and are oriented roughly perpendicular to the veins and earlier dykes. They are ultramafic rocks, classed as kersantites (Hughes, 1982) that contain biotite, clinopyroxene and apatite phenocrysts in a finer grained groundmass of the same minerals plus glass. They are distinct chemically from all other intrusive rocks in the area, containing more abundant barium, strontium, phosphorus pentoxide, potash and titania (Table 2-4-4). They are the same age as the Rexmount porphyry (Figure 2-4-1; Woodsworth, 1977), and perhaps the same age as mineralization at Blackdome (Faulkner, 1986).

Restites, or dark-coloured masses, in the Bralorne intrusives suggest that at the present level of exposure the Bralorne soda granite may have been derived from the diorite by partial melting, as the two show migmatitic contact relationships (compare Leitch and Godwin, 1987). To test this hypothesis, areas of darker coloured material in the migmatite (the restite or neosome) presumably derived from diorite by extraction of the felsic material that formed the lighter coloured soda granite (leucosome) were analysed (C043 and C085 in Table 2-4-4). These analyses do not correspond well with the calculated restite compositions (Leitch and Godwin, 1987; reproduced here as RESTI, Table 2-4-4). They are depleted in silica and considerably enriched in alumina, titania and iron compared to the calculated restite composition. They also have normative olivine, which the calculated restite does not. Except for higher iron they correspond most closely to analyses of Pioneer basalts (C095, C096, C098, Table 2-4-3) which supports field observations that suggest the restites are merely xenoliths of the volcanics initially intruded by the diorite and then both intruded by the soda granite.

Hornblendite at Bralorne (Unit 6a on Figure 2-4-2) is probably an ultramafic derivative, formed by intrusion of the diorite into ultramafite as described in Leitch and Godwin (1987). The texture of the original ultramafic rock is strongly modified to a net of coarse dark hornblendes poikilitically enclosing pyroxene remnants. This is also seen on the Wayside property, again on the west flank of the diorite where it is in contact with the ultramafite. One analysis (Table 2-4-4) shows the low alumina, titania, soda, potash, phosphorus, and higher magnesia and lime contents expected of an ultramafic derivative. A comparison of the analyses of the hornblendite and the President ultramafics (Cairnes, 1937) also shows this strong modification, with the peridotite or serpentinite containing much higher magnesia and much lower silica and alumina than the hornblendite.

TABLE 2-4-4
CHEMISTRY OF MINOR UNITS

Description	Grey dyke	Albitite Dykes			Green dyke	Lamp. dyke	Restites			Hornblendite
Sample No.	C193	C038	C022	C4141	C083	C1033	C043	C085	RESTI	UM/HBITE
(No. of Analyses)	(2)	(4)	(2)	(2)	(5)	(2)	(2)	(2)	(Calculated)	(2)
Major Elements (%)										
SiO_2	70.9	63.31	65.5	73.2	51.40	50.7	49.5	48.4	56.1	54.6
Al_2O_3	12.7	16.76	16.5	13.2	14.76	14.0	15.2	14.7	10.6	4.84
TiO_2	.24	0.40	0.25	0.16	0.80	2.40	0.97	0.72	0.3	0.22
Fe_2O_3 (Total Fe)	2.7	4.00	2.85	1.65	10.24	7.10	13.6	13.2	9.0	7.20
MgO	1.35	1.47	1.32	0.64	6.48	5.82	7.04	9.22	10.2	15.9
CaO	2.64	3.47	2.70	1.65	8.47	7.81	7.25	8.81	8.4	14.9
Na_2O	5.72	7.08	6.50	6.95	3.10	2.84	4.08	2.82	3.4	0.58
K_2O	0.32	0.86	0.62	0.38	0.25	3.55	0.19	0.05	0.0	0.04
MnO	0.07	0.09	0.09	0.06	0.18	0.09	0.20	0.24	0.2	0.18
P_2O_5	0.06	0.17	0.13	0.10	0.19	1.25	0.08	0.05	0.0	0.02
LOI	3.24	2.71	3.54	2.03	2.72	4.57	1.97	2.54	1.8	1.55
TOTAL	(100)	100.32	(100)	(100)	99.50	(100)	(100)	(100)	100	(100)
Specific Gravity	2.68	2.63	2.67	2.62	2.91	2.62	2.84	2.96	—	3.01
Minor Elements (ppm)										
As	ND	ND	1	2	3	15	ND	ND		26
Ba	60	275	260	140	245	2200	75	60		70
Co	34	14	12	52	35	34	41	38		75
Cr(*)	11	7	7	15	135	100	90	160		3800
Cu	4	6	4	1	36	130	10	3		55
Nb	2	4	2	2	1	17	2	4		ND
Ni	4	7	2	3	36	110	55	77		195
Pb	12	12	14	15	4	27	11	10		35
Rb	8	16	14	9	5	47	3	ND		ND
S	2000	3700	1400	570	310	6800	320	180		360
Sb	ND	ND	ND	4	1	6	ND	3		ND
Sr	88	280	200	205	350	3200	300	300		25
V(*)	27	55	25	12	230	300	290	210		80
Y	15	24	13	9	22	19	25	25		10
Zn	36	70	57	53	100	130	78	120		52
Zr	91	110	84	120	61	430	42	21		18
Normative Minerals										
Quartz	29.6	7.3	17.9	29.0	4.5	0.3			5.4	4.3
Orthoclase	2.0	5.3	3.7	2.1	1.5	21.3	1.1	0.3		0.2
Albite	49.7	63.6	56.0	58.5	26.2	26.0	35.5	25.3	28.8	5.0
Anorthite	8.6	8.7	13.3	4.6	25.8	15.5	23.5	27.3	13.6	10.5
Diopside	4.0	8.7		2.8	13.1	13.4	10.9	15.0	22.4	51.7
Hypersthene	4.8	4.4	7.1	2.1	19.6	14.0	11.5	15.0	23.1	26.3
Olivine							12.8	13.0		
Magnetite	0.6	0.8	0.6	0.3	4.3	1.5	2.7	2.6	4.3	1.5
Ilmenite	0.5	0.7	0.5	0.3	1.5	4.7	1.9	1.4	0.6	0.4
Apatite	0.1	0.4	0.3	0.2	0.5	3.3	0.2	0.1	0.02	0.05
Diff'n Index	81	76	78	90	32	48	37	26	34	10
Modes (Estimated Volume %)										
Quartz	34	15	20	10	8	(Glass 15)		3		1
Albite (Andesine)	56	60	70	85	54		35	40		20
Mafic: Hornblende	10	19	7	5	36	(Biotite 33)	60	53		62
Clinopyx						45			15	
Ilmenite (Rutile)	tr	3	1	tr		2	5	3		2
Sulphide (Py/Po)	tr	3	2	tr	2	(Apatite 5)		1		1
(No. of Thin Sections)	(2)	(1)	(1)	(1)	(8)	(1)	(1)	(2)	(6)	

Totals in brackets (100) indicate pressed powder analysis, normalized to 100%. Otherwise analysis is by fused disk.
* Cr, V contents are adjusted for known contamination introduced during grinding in Cr-steel ring mill.

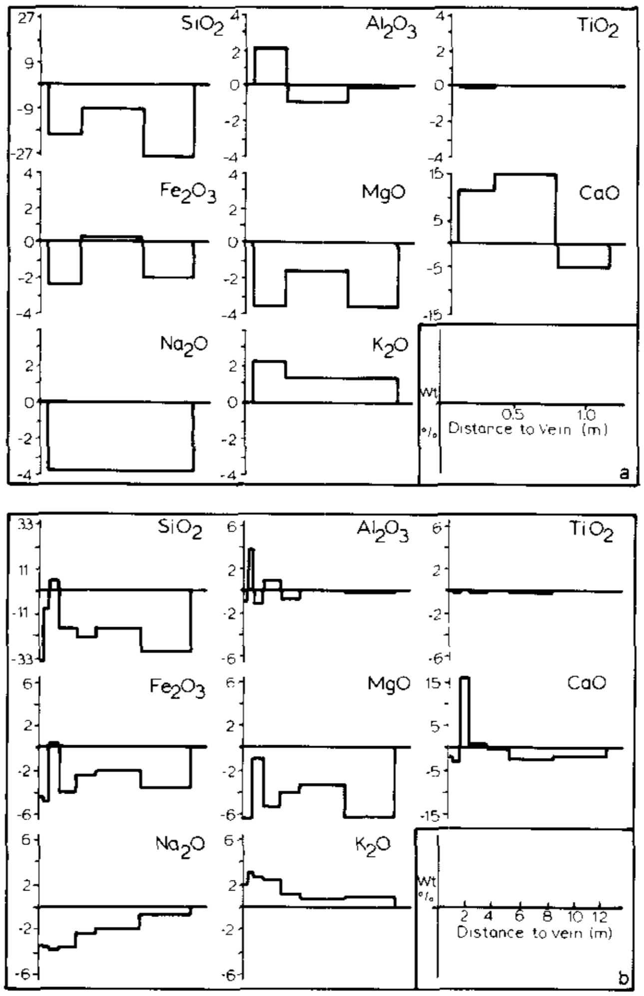


Figure 2-4-3. (a) Gresens plot of weight per cent loss/gain of oxides, plotted versus distance from the vein. Hangingwall of 51 vein, 8 level, near Empire shaft, Bralorne mine, compared to sample C093, the least altered diorite host, from DDH UB-81-17 at 350-400′. Volume factor based on Al_2O_3 and TiO_2. (b) Same details as (a) but in footwall of 51 vein, 15 level, near Crown shaft, Bralorne mine.

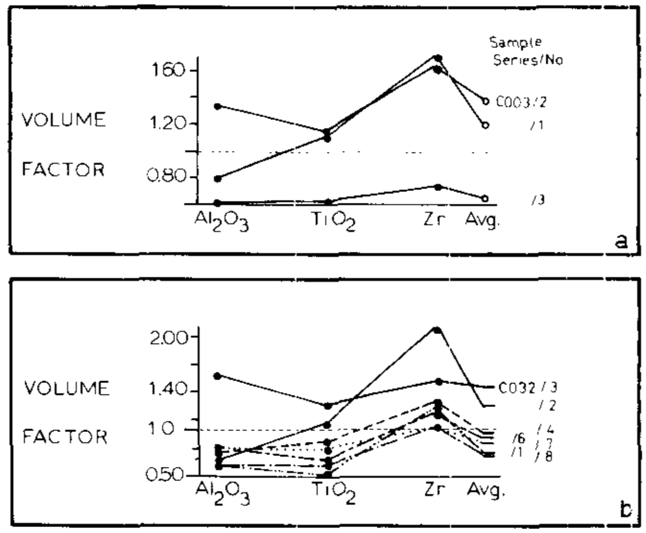


Figure 2-4-4. (a) Volume factor plot for the sample series in Figure 2-4-3(a). (b) Volume factor plot for the sample series in Figure 2-4-3(b).

WALLROCK ALTERATION

PETROGRAPHY

Detailed thin-section examination of altered wallrocks at Bralorne has been completed. The common arrangement of alteration minerals around a vein is from an outer green chlorite-epidote zone through a buff carbonate-albite zone to a foliated cream quartz-sericite ± carbonate zone.

Biotite alteration distributed along fractures, and therefore hydrothermal, has also now been recognized at Bralorne. It occurs both near the surface around the 51 vein and at depth around the 77 vein (*see* Figure 2-4-2 for locations). It is much more common to the southeast on the Pioneer (Joubin, 1948) and P.E. Gold (Nordine, 1983) properties. The Pioneer greenstones on these two properties seem to alter more readily to biotite, as do the green hornblende porphyry dykes near the 51 vein on 4 level at Bralorne. Otherwise, biotite is only seen below 40 level (1700-metre depth) at Bralorne when the altered host rock is diorite. This may be similar to the Sigma mine in Quebec (Robert and Brown, 1986) where biotite only becomes prominent as an alteration mineral in the lower levels, suggesting that the Pioneer and P.E. Gold properties expose deeper levels of the vein system than seen at Bralorne. Unfortunately the biotite is always intimately intergrown with chlorite and sericite and is not suitable for isotopic dating.

Cream-coloured carbonate alteration at Bralorne is almost always iron-calcite close to the veins, with calcite away from the veins. The iron-calcite does not react to cold dilute hydrochloric acid, and because of its characteristic orangey brown weathering, it has often been misidentified as ankerite. However, even in rocks showing strong carbonate alteration, X-ray diffraction peaks for ankerite and dolomite are very weak or completely absent. This implies a lack of magnesium in the hydrothermal system, which is borne out by the results of chemical analysis (*see* below).

Two other unusual alteration facies in Pioneer volcanics were found in specimens collected from the Pioneer mine by Joubin, which are now in The University of British Columbia Economic Geology Collection. These are garnet-quartz-calcite-pyrite and quartz-tourmaline (schorl) facies. Neither is common, but the presence of borosilicate is significant; it is common in analagous systems in the Precambrian Shield, (for example, Sigma; Robert and Brown, 1986), but apparently rare at Bralorne.

Albite alteration around the Bralorne veins is stronger and much more widespread than was previously reported (Leitch and Godwin, 1987). It is difficult to recognize due to its superposition on a background of albite from greenschist metamorphism, and the ubiquitous presence of albite in soda granite and albitite dykes. However when examined carefully in thin section it becomes clear that much of the original albite, even in these sodic rocks, has been pervasively altered to "patchwork", "chessboard" and "irregular" albite (Battey, 1951; Leitch, 1981) in proximity to major vein

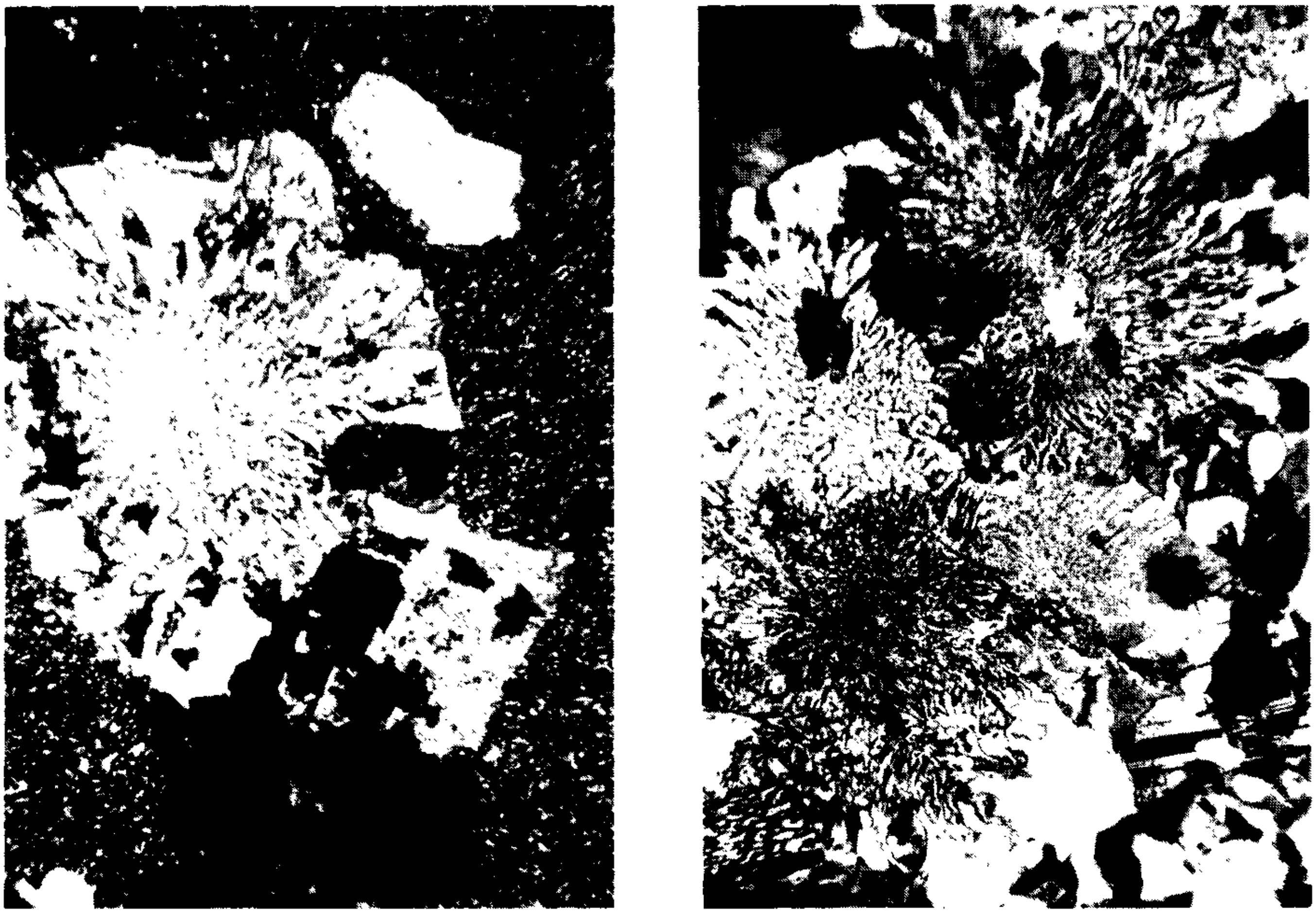


Plate 2-4-1(a). Primary igneous phenocryst of plagioclase in a grey plagioclase porphyry being replaced by a symplectic overgrowth of quartz and albite. (b) Primary texture of soda granite being replaced by symplectic overgrowths of quartz and albite in a radiating psuedohexagonal pattern.

systems. The textural evidence thus supports a hydrothermal origin for the albite found in veinlets, as well as much of that in envelopes surrounding larger quartz veins.

Silica flooding forms an unusual alteration facies and is found in the central portions of the large dyke-like mass of soda granite lying northeast of the diorite (Figure 2-4-2). These sections are exposed in diamond-drill core, in which the typical silica crackling or stockworking by hairline quartz-pyrite veinlets in the soda granite becomes increasingly strong. This leads eventually to a rock composed almost entirely of quartz and albite, with some sericite developed after albite, and pyrite after mafics. In thin section, this intense silicification takes several forms, the most striking being a symplectic intergrowth of quartz and albite that locally completely replaces primary igneous textures (Plate 2-4-1). The texture nucleates in clots which have a radial pattern and psuedohexagonal outline, implying quartz grains growing outwards. These textures are restricted to the the most siliceous intrusive phases: soda granite, albitite dykes, and the grey plagioclase porphyry dykes.

A distinctive black calcium carbonate alteration is occasionally present; it also develops along hairline fractures and eventually replaces the whole rock, turning it black and almost opaque in thin section. The black coloration is caused by myriads of extremely fine (1 to 2 microns) opaque inclusions which may be carbon or, more likely, pyrrhotite. This alteration crosscuts, and is clearly later than, the main-stage alteration associated with mineralization.

ALTERATION CHEMISTRY

A preliminary report in Leitch and Godwin (1987) outlined general trends in alteration chemistry. Further chemical analyses of 10 detailed traverses across altered foot and hangingwall rocks of major veins are in Table 2-4-5. Traverses in diorite host rock cover a vertical range of 1200 metres from surface down to 26 level on the 51 vein system, and 2000 metres from surface down to 44 level on the related 77 and 79 vein systems. In soda granite, which is a less important ore host (Campbell, undated; James and Weeks, 1961), only two traverses were sampled, at 8 and 26 levels on the 51 vein system. All chemical data were reduced to per cent losses and gains relative to the appropriate fresh host rock. Volume changes were corrected for by the method of Gresens (1967), as modified by Sketchley and Sinclair (1987), with a computer program developed for the purpose (Leitch and Day, in preparation).

TABLE 2-4-5
CHEMISTRY OF ALTERED HOST ROCKS, BRALORNE MINE

Location	**Surface: FW**		**-51 Vein (in diorite) HW**		**-77 Vein (granite)**	
Sample No.	C1027F1	WC1027F1	C1027H1	C1027H2	C1027H3	C048HW
Distance to Vein (m)	0.1	0.2	0.1	0.3	2.3	1.0
(No. of Analyses)	(2)	(2)	(2)	(2)	(2)	(2)
Major Elements (%)						
SiO_2	59.5	57.4	52.6	41.6	50.4	70.0
Al_2O_3	13.4	12.5	19.1	19 6	15.1	12.9
TiO_2	0.23	0.22	0.36	0 58	0.48	0.26
Fe_2O_3 (Total Fe)	7.42	6.52	8.21	9 52	11.2	3.22
MgO	2.72	3.29	3.69	4.80	5.59	1.77
CaO	4.60	6.36	6.29	11.3	8.51	3.28
Na_2O	0.65	0.70	0.21	0.50	1.71	4.00
K_2O	2.40	2.14	3.32	2.90	0.65	[illegible].10
MnO	0.13	0.13	0.11	0.17	0.14	0.07
P_2O_5	0.03	0.03	0.05	0.04	0.04	0.12
LOI	9.05	10.74	6.07	9.08	6.31	3.65
TOTAL	(100)	(100)	(100)	(100)	(100)	(100)
Specific Gravity	2.59	—	2.81	2.83	2.80	2.65
Minor Elements (ppm)						
As	180	100	410	1610	19	4
Ba	220	185	265	240	95	350
Co	38	50	24	33	32	10
Cr	210	90	96	25	103	13
Cu	53	47	80	140	39	12
Nb	0	0	2	2	2	ND
Ni	60	42	3	8	16	6
Pb	17	14	10	10	11	20
Rb	45	37	62	60	16	12
S	665	670	2.76%	2.37%	2080	620
Sb	7	12	0	0	0	ND
Sr	90	110	100	150	280	90
V	76	66	80	150	220	30
Y	16	13	7	14	16	6
Zn	72	60	43	72	60	32
Zr	65	57	65	21	48	27

NOTE: Alteration types for Table 2-4-5 are as follows: Q = quartz, A = albite, S = sericite, C = carbonate, X = chlorite, E = epidote, F = fuchsite, Sx = sulfide, B = biotite. Totals given to 2 decimal places include at least one analysis by fused glass disk. All others, listed as (100), are by pressed powder pellet only and have no significance, having been normalized to 100%.

Location	**8 Level -51 Vein (in diorite)**						
		FW				**HW**	
Sample No.	COO2F1	C002F2	WC002F3	C002F4	C003H1	C003H2	C003H3
Distance to Vein (m)	0.1	0.4	1.5	3.5	0.1	0.5	1.0
(No. of Analyses)	(2)	(3)	(2)	(2)	(2)	(1)	(2)
Major Elements (%)							
SiO_2	49.7	54.0	54.8	53.0	42.6	40.6	51.7
Al_2O_3	6.5	14.8	14.6	14.9	14.1	8.3	18.0
TiO_2	0.12	0.21	0.24	0.20	0.21	0.21	0.39
Fe_2O_3 (Total Fe)	4.3	6.7	5.9	6.1	5.7	6.6	9.6
MgO	4.6	3.0	3.3	4.8	2.2	5.0	5.9
CaO	16.7	10.0	9.0	7.8	19.5	17.7	4.0
Na_2O	0.09	0.29	1.88	1.36	0.13	0.08	0.38
K_2O	1.35	2.85	1.70	1.59	2.49	1.16	2.37
MnO	0.18	0.11	0.12	0.10	0.20	0.26	0.11
P_2O_5	0.02	0.02	0.05	0.01	0.04	0.02	0.02
LOI	16.41	8.07	8.38	10.18	12.79	19.89	7.65
TOTAL	(100)	(100)	(100)	(100)	(100)	(100)	(100)

TABLE 2-4-5: CONTINUED

Sample No.	COO2F1	C002F2	WC002F3	C002F4	C003H1	C003H2	C003H3
Specific Gravity	2.80	2.88	2.70	2.73	2.82	2.84	2.77
Minor Elements (ppm)							
As	4000	1835	17	47	4950	21	28
Ba	120	160	145	170	150	140	200
Co	15	37	32	31	29	15	27
Cr	360	160	21	110	17	140	62
Cu	8	28	26	5	7	15	32
Nb	0	0	0	1	1	2	1
Ni	88	60	11	38	12	24	21
Pb	9	8	9	7	7	14	12
Rb	27	89	39	33	47	25	45
S	1.05%	2.75%	4780	1340	2.03%	1050	875
Sb	14	4	0	0	25	20	0
Sr	195	185	110	140	135	200	46
V	35	90	80	80	75	70	170
Y	10	14	11	12	15	34	13
Zn	47	47	50	56	29	46	95
Zr	30	120	93	48	29	29	67

Location	**8 Level - 51B FW Vein (in soda granite)**					
	FW				**HW**	
Sample No.	C111-1	C111-2/3	C111-4/8	C111-29	C111-30	C111-31
Distance to Vein (m)	1.0	0.3	0.1	0.5	1.0	3.5
(No. of Analyses)	(2)	(2)	(2)	(2)	(2)	(2)
Major Elements (%)						
SiO_2	72.5	73.1	68.5	71.8	75.2	73.6
Al_2O_3	13.4	14.5	17.7	17.9	15.4	13.6
TiO_2	0.19	0.16	0.16	0.21	0.17	0.13
Fe_2O_3 (Total Fe)	2.56	1.56	2.20	1.48	1.38	2.33
MgO	1.17	0.54	0.49	0.60	0.45	0.87
CaO	2.47	3.18	4.04	0.62	0.91	2.39
Na_2O	1.69	0.53	0.27	0.32	0.23	2.41
K_2O	2.49	2.87	3.37	3.72	3.22	1.80
MnO	0.09	0.04	0.04	0.01	0.01	0.09
P_2O_5	0.04	0.05	0.04	0.04	0.03	0.03
LOI	3.31	3.48	3.17	3.35	2.98	2.74
TOTAL	(100)	(100)	(100)	(100)	(100)	(100)
Specific Gravity	2.70	2.70	2.74	2.71	2.73	2.70
Minor Elements (ppm)						
As	20	1500	1940	2100	3280	9
Ba	185	190	225	255	220	170
Co	3	42	55	4	5	5
Cr	12	11	11	12	13	13
Cu	65	18	4	2	5	125
Nb	3	2	2	2	1	5
Ni	5	3	2	4	3	4
Pb	15	12	13	12	10	14
Rb	40	47	52	63	54	32
S	5020	7940	1.67%	8960	7560	3380
Sb	12	2	13	14	13	4
Sr	55	49	76	22	18	64
V	34	27	30	40	23	29
Y	18	15	13	17	13	27
Zn	300	220	170	100	130	340
Zr	98	70	84	102	75	110
Alteration Type	A-Q-C	Q-S-A-C	Q-C-S	Q-S-C	Q-S-C	Q-A-X
Modal Mineralogy (% Estimated from thin section)						
Quartz	37	50	50	47	60	45
Albite	40	17		6		40
Sericite	7	20	15	35	30	4
Calcite	10	7	25	7	7	3
Ankerite (Fe-carbonate)		2	5			
Chlorite	3					6
Sulphides	py	py,po,as3	py,sl,as5	py,as3	py,sl,as3	po1
Oxides	ru1	ru1	ru<1	ru2	ru<1	ru2

TABLE 2-4-5 : CONTINUED

Location	15 Level - 51 Vein (in diorite) FOOTWALL						
Sample No.	C032-1	C032-2	C032-3	C032-4	C032-5/6	C032-7	C032-8
Distance fron Vein (m)	0.1	0.5	1.0	2.0	3.5	5.0	10.0
(No. of Analyses)	(1)	(1)	(1)	(1)	(1)	(1)	(2)
Major Elements (%)							
SiO_2	45.15	60.15	45.25	53.01	49.02	53.66	48.38
Al_2O_3	18.85	17.75	7.06	15.47	14.12	14.66	18.20
TiO_2	0.46	0.22	0.18	0.27	0.34	0.30	0.33
Fe_2O_3 (Total Fe)	6.14	3.46	5.72	4.93	7.15	7.65	7.11
MgO	3.24	2.07	5.03	3.51	5.57	6.33	3.35
CaO	9.22	4.93	16.26	9.82	8.97	6.13	8.49
Na_2O	0.76	0.24	0.03	0.24	2.21	2.57	5.04
K_2O	3.69	3.70	1.80	3.01	1.73	1.14	1.56
MnO	0.12	0.08	0.19	0.12	0.14	0.14	0.08
P_2O_5	0.04	0.06	0.05	0.04	0.04	0.05	0.02
LOI	12.26	7.55	18.82	10.04	11.01	7.28	6.39
TOTAL	99.94	100.21	100.38	100.46	100.29	99.89	99.00
Specific Gravity	2.76	2.75	2.82	2.74	2.75	2.73	2.72
Minor Elements							
Ag	ND	ND	ND	ND	ND	ND	ND
As	4700	150	714	673	45	23	8
Ba	240	200	81	179	132	106	137
Cl	26	31	45	75	50	30	31
Co	20	ND	31	14	16	25	15
Cr	60	154	1835	165	74	86	35
Cu	25	36	35	30	43	29	47
Mo	2	2	1	1	1	1	1
Nb	ND	ND	1	ND	ND	ND	2
Ni	17	6	494	33	38	20	8
Pb	4	3	1	10	5	4	5
Rb	50	48	25	43	25	20	27
S	1.43%	4550	4971	6844	1292	336	3166
Sb	22	8	27	18	4	3	ND
Sr	170	78	157	113	83	125	68
V	110	43	79	140	151	167	272
W	12	5	ND	ND	4	ND	ND
Y	13	8	7	8	14	12	6
Zn	75	31	43	38	44	50	30
Zr	41	24	32	38	43	49	49
Alteration Type	C-S-A (Bxa)	Q-C-S (Schist)	C-S-Q (Schist)	C-A-Q-S	A-S-X-C	A-C-X-S	A-X-C
Modal Mineralogy (% Estimated from thin section)							
Quartz	5	40	13	20	7	10	2
Albite	10			25	43	25	55
Sericite (+ Fuchsite)	35	24	20	13	18	20	
Calcite	40	20	65	35	12	25	15
Ankerite (Fe-carbonate)	5	15			5		
Chlorite				5	13	20	25
Sulphides	py,as3	py1	po1	py1	py1	po,py1	
Oxides	ru2		ct1	ru1	ru1	ru<1	ru2

Location	15 Level - 51 Vein (in diorite) HANGING WALL						
Sample No.	C033/1-2	C033/3-4	C033/5-6	C033/7	C033/8	C033/9	C033/10
Distance to Vein (m)	0.3	1.5	3.5	5.0	8.0	9.0	10.0
(No. of Analyses)	(2)	(1)	(2)	(1)	(1)	(1)	(3)
Major Elements (%)							
SiO_2	63.66	57.56	54.81	50.58	55.52	57.03	51.71
Al_2O_3	6.89	14.54	17.23	15.02	13.12	9.29	15.19
TiO_2	0.12	0.22	0.31	0.34	0.28	0.19	0.49
Fe_2O_3 (Total Fe)	3.34	4.79	7.71	9.56	6.96	7.53	10.54
MgO	2.72	2.83	3.85	5.01	3.46	11.12	6.40
CaO	11.59	7.67	4.97	6.54	9.95	8.14	7.51
Na_2O	0.13	0.60	1.07	2.86	2.97	2.09	3.04
K_2O	1.38	2.69	2.51	1.18	0.21	0.04	0.03
MnO	0.10	0.11	0.09	0.17	0.14	0.19	0.20
P_2O_5	0.03	0.05	0.04	0.03	0.02	0.02	0.07
LOI	10.46	9.34	7.62	8.60	6.43	4.14	3.14
TOTAL	100.42	100.39	100.21	99.89	99.07	99.78	98.33

TABLE 2-4-5: CONTINUED

Sample No.	C033/1-2	C033/3-4	C033/5-6	C033/7	C033/8	C033/9	C033/10
Specific Gravity	2.83	2.74	2.78	2.76	2.80	2.92	2.84
Minor Elements (ppm)							
Ag	ND	ND	ND	ND	ND	ND	ND
As	4340	86	1310	34	12	9	18
Ba	62	179	207	141	58	26	51
Cl	53	24	17	25	26	65	50
Co	33	10	26	32	20	35	30
Cr	972	95	52	10	25	620	50
Cu	26	24	80	128	56	20	70
Mo	2	2	ND	ND	2	ND	ND
Nb	1	ND	1	1	ND	ND	1
Ni	312	7	22	15	11	69	17
Pb	10	8	7	6	4	6	6
Rb	20	40	40	19	7	2	3
S	9580	6123	5625	2095	2497	217	6520
Sb	71	8	9	2	6	9	1
Sr	130	120	81	101	192	58	109
V	63	80	263	324	186	129	236
W	ND	2	ND	ND	ND	ND	ND
Y	6	9	10	13	13	17	17
Zn	45	41	55	54	46	55	80
Zr	27	73	33	42	35	28	43
Alteration Type	Q-C-S-F (Schist)	Q-C-S (Schist)	C-Q-S-A-X	A-X-C-Q	A-X-C	FRESH	A-E
Modal Mineralogy (% Estimated from thin section)							
Quartz	40	25	15	10	8	5	5
Albite		8	20	40	45	35	50
Sericite (+ Fuchsite)	8	25	20	8	3		
Calcite	35	15	27	15	10	3	4
Ankerite (Fe-carbonate)	5	20					
Epidote (+ Zoisite)					2	5	33
Chlorite		5	16	25	30	2	5
Hornblende (+ Actinolite)						50	
Sulphides	py,as1 1	py,po2	po2	py2	py1		po2
Oxides	ct1				ru1	ru<1	ru1

Location	19 Level -51 Vein (in diorite)					
	FW				HW	
Sample No.	1951F1	1951F2	1951F3	1951F4	1951H1	1951H2
Distance from Vein (m)	0.1	0.8	1.5	3.0	0.1	0.5
(No. of Analyses)	(3)	(1)	(2)	(2)	(1)	(1)
Major Elements (%)						
SiO_2	50.11	68.5	45.0	56.9	49.8	53.7
Al_2O_3	13.05	11.9	15.3	13.7	13.6	14.5
TiO_2	0.15	0.20	0.32	0.39	0.23	0.38
Fe_2O_3 (Total Fe)	3.59	1.83	9.90	9.25	5.46	7.77
MgO	2.98	1.40	6.82	7.39	6.02	6.55
CaO	12.85	6.63	9.63	6.63	12.6	7.05
Na_2O	0.53	1.33	2.04	2.46	0.30	1.03
K_2O	2.86	2.28	1.08	0.04	2.25	1.81
MnO	0.13	0.04	0.14	0.15	0.10	0.11
P_2O_5	0.04	0.03	0.02	0.02	0.03	0.14
LOI	13.94	5.84	9.83	3.19	9.70	7.08
TOTAL	100.23	(100)	(100)	(100)	(100)	(100)

TABLE 2-4-5: CONTINUED

Sample No.	1951F1	1951F2	1951F3	1951F4	1951H1	1951H2
Specific Gravity	2.77	2.71	2.76	2.84	2.77	2.75
Minor Elements (ppm)						
As	1200	19	31	9	55	ND
Ba	240	160	100	60	180	150
Co	4	4	38	45	34	35
Cr(*)	120	200	42	75	160	48
Cu	10	ND	70	62	47	48
Nb	ND	ND	2	1	2	3
Ni	18	2	26	18	49	23
Pb	22	8	9	11	6	12
Rb	71	46	23	ND	48	36
S	8000	7400	4300	7900	8800	9500
Sb	ND	ND	5	ND	ND	ND
Sr	400	80	75	62	90	45
V(*)	50	30	120	150	70	130
Y	7	4	9	16	14	15
Zn	47	26	76	77	52	61
Zr	9	16	27	29	46	39
Alteration Type	Q-S-C-A	Q-S-C-A	C-A-X-S	A-C-E-X	Q-C-S-X	Q-C-A-X
Modal Mineralogy (% Estimated from thin section)						
Quartz	30	55	10	5	35	30
Albite	20	10	25	50	5	25
Sericite	20	18	15		15	8
Calcite	20	12	27	5	30	25
Epidote (+ Zoisite)				5		
Chlorite		1	20	3	12	10
Hornblende (+ Actinolite)				30		
Sulphides	as2,py3	py4	py1	po2	py3	po2
Oxides		ru<1	ru2	rutr		

Location	20 Level - 77 Vein							
	FW				HW			
Sample No.	W2077F0	2077F1	2077F2	2077H3	2077H5	2077H1	2077H2	2077H4
Distance to Vein (m)	0.1	0.2	0.5	0.1	0.5	1.0	2.0	5.0
(No. of Analyses)	(1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Major Elements (%)								
SiO_2	50.8	46.7	53.1	42.0	41.6	46.7	42.2	40.3
Al_2O_3	22.3	17.0	15.2	18.0	16.9	17.6	16.0	15.7
TiO_2	0.45	0.79	0.97	0.27	0.46	0.44	0.54	0.45
Fe_2O_3 (Total Fe)	7.06	6.50	7.31	9.33	14.4	11.0	14.8	11.6
MgO	1.65	5.35	8.07	6.97	7.55	6.05	7.30	10.5
CaO	6.69	9.13	6.43	9.15	7.90	5.87	7.51	8.65
Na_2O	0.18	0.48	2.94	1.03	1.44	2.02	2.24	1.88
K_2O	3.77	2.51	0.18	1.97	1.01	0.63	0.29	0.13
MnO	0.07	0.11	0.10	0.12	0.15	0.13	0.15	0.15
P_2O_5	0.05	0.16	0.18	0.01	0.04	0.02	0.02	0.01
LOI	7.03	11.67	5.61	11.63	9.14	9.89	9.10	0.61
TOTAL	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Specific Gravity	2.89	2.78	2.79	2.81	2.68	2.79	2.81	2.78
Minor Elements (ppm)								
As	5900	1120	ND	64	30	71	40	48
Ba	450	350	160	450	120	220	130	60
Co	45	37	40	45	53	52	57	52
Cr (*)	20	140	130	40	35	25	30	220
Cu	71	46	67	26	100	81	110	90
Nb	ND	1	2	ND	ND	ND	ND	1
Ni	14	35	45	27	23	24	21	70
Pb	15	16	16	11	13	20	12	10
Rb	71	62	ND	43	19	17	5	2
S	2.13%	3800	940	2500	3300	2500	3400	910
Sb	15	ND	3	ND	ND	2	ND	ND
Sr	125	170	600	150	125	160	320	160
V (*)	210	190	220	150	250	200	260	170
Y	13	16	17	7	4	9	10	8
Zn	75	93	100	56	75	68	73	83
Zr	41	80	78	14	19	20	15	19

TABLE 2-4-5: CONTINUED

Location	26 Level - 85 Vein (soda granite)				32 Level - 79 Vein (diorite)			
	FW		HW		FW		HW	
Sample No.	C118/1-4	C118	C118/16	C118/17	WC117/1	WC117	C117/9	C117/11
Distance to Vein (m)	0.7	3.0	1.5	3.0	0.1	1.2	0.1	1.2
(No. of Analyses)	(1)	(2)	(1)	(1)	(5)	(2)	(2)	(2)
Major Elements (%)								
SiO_2	75.2	76.7	74.6	75.1	40.04	45.6	45.4	40.1
Al_2O_3	14.5	12.1	12.6	11.9	16.69	12.2	14.1	15.3
TiO_2	0.15	0.18	0.21	0.22	0.82	0.75	0.75	1.20
Fe_2O_3 (Total Fe)	2.14	2.03	2.30	2.11	16.97	14.2	12.9	19.0
MgO	0.43	0.57	0.66	0.36	8.82	10.1	11.2	8.55
CaO	1.37	1.41	2.14	2.42	7.26	11.1	8.50	11.7
Na_2O	2.03	4.39	4.55	4.50	1.60	2.25	1.55	1.31
K_2O	2.17	1.04	0.87	0.80	0.25	0.13	0.22	0.08
MnO	0.02	0.03	0.05	0.04	0.18	0.19	0.13	0.17
P_2O_5	0.02	0.01	0.03	0.07	0.02	0.02	0.05	0.04
LOI	1.95	1.44	2.06	2.47	7.97	3.47	5.35	3.62
TOTAL	(100)	(100)	(100)	(100)	100.62	(100)	(100)	(100)
Specific Gravity	2.68	2.67	2.59	2.67	2.91	3.02	2.91	3.15
Minor Elements (ppm)								
As	1300	16	ND	1	23	13	17	ND
Ba	190	120	88	94	100	90	77	27
Co	3	4	37	9	50	60	56	49
Cr	20	18	12	19	43	65	470	200
Cu	43	5	54	67	82	54	38	22
Nb	3	ND	2	3	ND	1	1	2
Ni	6	3	3	7	12	50	190	65
Pb	15	12	8	12	11	15	15	14
Rb	41	20	16	16	2	3	3	ND
S	6700	6300	3100	1800	2050	320	260	1800
Sb	7	ND	4	ND	6	ND	3	2
Sr	63	65	72	75	210	170	180	150
V	30	35	40	45	350	280	250	200
Y	31	5	7	23	8	28	17	11
Zn	19	31	31	31	100	67	59	75
Zr	185	210	130	30	11	22	21	18
Alteration Type	Q-S-A	Q-A-S	Q-A-S	A-Q-X	C-X-A-E	A-E-C	C-X-E-A	A-X-E-C
Modal Mineralogy (Estimated from thin section, %)								
Quartz	50	40	50	40	5	tr	3	tr
Albite	15	40	35	45	10	30	10	40
Sericite	25	10	5	2				
Calcite		5	4	3	35	5	5	10
Ankerite	5		1				25	
Epidote (+ Zoisite)					10	10	15	10
Chlorite	2	2	3	8	30	tr	20	10
Clinopyroxene						20		10
Hornblende (+ Actinolite)					5	35	20	10
Sulphide (Py,Po)	3	3	2	1	<1			
Rutile	<1	<1	<1	1	5	<1	2	10

Location	41 Level - 79 Vein (in diorite)						
	FW	HW					
Sample No.	C116	C116/18	C116/19	C116/20	C116/21	C116/22	C116/23
Distance to Vein (m)	0.1	0.3	1.0	2.0	3.0	5.0	10.0
(No. of Analyses)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Major Elements (%)							
SiO_2	38.0	44.7	50.5	41.1	37.1	46.4	39.0
Al_2O_3	17.2	20.4	20.7	15.3	13.7	20.8	15.6
TiO_2	0.75	1.55	0.23	0.78	0.97	1.18	0.76
Fe_2O_3 (Total Fe)	12.8	12.4	5.13	11.1	16.3	12.8	14.5
MgO	7.95	5.93	3.69	7.70	7.30	7.07	8.48
CaO	13.1	5.29	6.40	10.2	12.5	3.30	9.79
Na_2O	0.34	2.52	2.35	0.30	1.05	0.94	1.31
K_2O	1.93	1.71	3.05	1.51	0.56	2.32	0.07
MnO	0.18	0.11	0.22	0.17	0.17	0.11	0.22
P_2O_5	0.04	0.17	0.11	0.06	0.07	0.13	0.25
LOI	8.32	4.77	7.66	11.96	10.29	5.09	10.19
TOTAL	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Specific Gravity	2.88	2.83	2.76	2.80	2.84	2.80	2.84

TABLE 2-4-5: CONTINUED

Sample No.	C116	C116/18	C116/19	C116/20	C116/21	C116/22	C116/23
Minor Elements (ppm)							
As	5400	6100	39	37	57	66	2
Ba	230	200	450	220	120	230	61
Co	39	34	18	34	92	23	33
Cr	100	25	40	95	30	80	40
Cu	220	38	ND	ND	190	39	2
Nb	ND	1	ND	4	1	2	ND
Ni	24	18	15	64	47	46	67
Pb	20	21	12	17	20	16	15
Rb	37	31	61	30	14	46	ND
S	2.12%	2.05%	1800	245	1.27%	9500	230
Sb	43	2	ND	ND	ND	ND	ND
Sr	230	190	200	105	130	120	230
V	260	340	70	250	280	290	200
Y	14	16	8	27	26	21	15
Zn	100	90	40	66	80	75	86
Zr	13	24	11	24	42	18	15
Alteration Type	C-Q-S-Sx	C-S-A-X	C-S-X-Q	C-S-X-E	C-A-S-X	S-X-C-Q	A-X-C-S
Modal Mineralogy (% Estimated from thin section)							
Quartz	10	2	10	tr	2	15	5
Albite		15	7		30	5	40
Sericite	10	30	25	25	10	40	10
Calcite	40	30	30	30	35	10	20
Ankerite (Fe-carbonate)		5	5		3	5	
Epidote				20			
Chlorite	30	12	20	20	10	20	23
Sulphides	po6,as2	as4,po1	py,po1		po6,cp1	po3	
Oxides, Phosphates	ru2	ru1	ru2	ap3,ru2	ru3	ru2	ru2

Location	**44 Level - 77 Vein (in diorite)**								
	FW					**HW**			
Sample No.	C128/21	C128/23	C128/24	C128/5	C128/4	C128/3	C128/2	C128/1	WC128
Distance to Vein (m)	0.1	1.0	2.0	0.1	1.0	2.0	3.0	4.0	6.0
(No. of Analyses)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Major Elements (%)									
SiO_2	28.5	56.2	55.8	41.1	42.1	39.1	42.3	40.7	39.6
Al_2O_3	9.28	17.1	16.2	16.5	18.6	18.3	20.6	19.5	14.7
TiO_2	0.38	0.68	0.66	0.78	0.75	0.74	0.70	0.60	0.72
Fe_2O_3 (Total Fe)	6.63	7.91	8.76	12.4	16.7	16.3	14.0	13.8	12.0
MgO	9.24	5.80	5.17	8.82	10.1	9.21	6.08	6.90	10.4
CaO	24.8	2.91	4.67	8.63	4.40	6.43	5.71	9.38	12.2
Na_2O	0.16	3.80	4.88	1.41	1.85	1.17	2.63	2.13	1.44
K_2O	0.42	1.13	0.15	0.78	0.38	0.27	1.55	0.20	0.17
MnO	0.14	0.10	0.16	0.16	0.18	0.19	0.14	0.23	0.17
P_2O_5	0.03	0.21	0.22	0.08	0.03	0.02	0.20	0.23	0.03
LOI	20.97	4.31	3.33	9.43	4.74	8.35	6.08	6.39	9.31
TOTAL	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Specific Gravity	2.77	2.74	2.80	2.80	2.89	2.84	2.84	2.88	2.88
Minor Elements (ppm)									
As	425	3	ND	14	ND	1	110	ND	3
Ba	110	240	110	190	80	68	200	70	75
Co	49	32	35	44	45	32	35	23	23
Cr	600	31	58	150	36	34	61	22	220
Cu	33	20	58	65	130	120	140	120	26
Nb	ND	3	4	2	ND	ND	1	ND	1
Ni	170	11	11	39	14	12	28	11	105
Pb	14	9	12	15	13	9	20	18	17
Rb	6	21	3	17	12	9	38	4	5
S	2800	5100	2000	2200	1.06%	3200	1.04%	1170	840
Sb	1	ND	ND	ND	ND	9	6	ND	ND
Sr	200	250	360	125	270	230	190	400	260
V	140	160	155	260	310	230	230	200	220
Y	17	23	23	13	6	7	8	7	12
Zn	56	110	100	110	95	60	51	70	90
Zr	10	81	79	34	5	9	8	5	9
Alteration Type	X-C-A	A-C-X	A-C-X-E	X-A-S-C	A-X-B	X-A-E-C	S-X-A-C	A-X-C-E	E-C-X-A

TABLE 2-4-5: CONTINUED

Sample No.	C128/21	C128/23	C128/24	C128/5	C128/4	C128/3	C128/2	C128/1	WC128
Modal Mineralogy (% Estimated from thin section)									
Quartz	tr	tr	5	4		5	5		3
Albite	10	50	60	25	40	20	15	30	10
Sericite		10	1	17	5	3	40	5	
Calcite	25	20	10	10	5	15	10	20	20
Ankerite (Fe-carbonate)				8					
Epidote (+ Zoisite)			10	2		20		20	40
Chlorite	55	15	10	27	25	25	20	20	15
Biotite					15	5			
Hornblende (+ Actinolite)									10
Sulphides	po3,cp1,as	po,cp2	po1	po,py,as,cp2	po4,cp1	py<1	po2,cp1	po1	po<1
Oxides	ru6,ap1	ru3	ru3	ru5	ru5	ru7	ru7	ru4	ru2

A few representative examples of the chemical changes adjacent to the major veins are provided in Figure 2-4-3 (a and b). The more obvious changes on approaching the vein, with mineralogical explanations, are:

(1) Loss of Na_2O and increase in K_2O, due to destruction of albite and replacement by sericite.

(2) Loss of MgO and Fe_2O_3, due to destruction of mafic minerals (hornblende) and replacement by sericite and carbonate.

(3) Increase in loss on ignition (LOI) and calcium content due to development of carbonate (calcite and iron-calcite or ankerite). This is variable, depending on composition of the original host rock. Often, even where strong carbonate replacement is seen in thin section, there is a net loss of calcium because quartz and sericite become prominent near the vein and calcite is replaced by iron-calcite or ankeritic carbonate.

(4) There is a net loss of SiO_2 in the vein envelope that is variable due to the inclusion of thin quartz veinlets in some samples near the vein.

There is no major change in alteration chemistry from the surface to the 2000-metre depth; thin-section examination indicates that similar alteration assemblages (with the possible exception of biotite) are present on 44 level and at surface. Differences between the way diorite and soda granite react to alteration are slight. There is a less noticeable loss of Fe_2O_3 and MgO in the altered soda granite, as there are only minor mafics to destroy; there is a greater loss of Na_2O, as albite is more abundant. Changes in calcium are often less noticeable, again as most of the calcium is in mafic minerals in both soda granite and diorite, and the soda granite is considerably less mafic.

The diagrams of losses and gains (Figure 2-4-3) show relatively little change in Al_2O_3 and TiO_2, since these components and zirconium are used as approximations to immobility in order to estimate volume changes. Of course, per cent changes in Al_2O_3 are larger than those in TiO_2 as alumina is far more abundant in unaltered rocks. An example of the volume changes or volume factor involved in alteration is given in Figure 2-4-4a. In this case there is an initial volume decrease (C003/3), possibly due to destruction of albite and hornblende. This is followed by an increase in volume (C003/1, 2) immediately adjacent to the vein, caused by strong carbonate alteration as shown by the correlated increases in LOI and calcium content (Table 2-4-5). Also shown in Figure 2-4-4b is the typical agreement between Al_2O_3 and TiO_2 in estimation of the volume factor, and strong over estimation of volume factor by zirconium. In this case, zircon was rejected from the computation of the average volume factor used in making the profiles of loss/gain.

FLUID INCLUSIONS

Vein quartz at Bralorne is full of both primary and secondary fluid inclusions. Indisputably primary inclusions are abundant and arranged in prominent growth zones conforming to the crystal outlines, but they are all too small for inclusion studies. The rest of the inclusions may be divided into two main groups, or possibly three, on the basis of their homogenization temperatures.

Inclusions of the first group are often in clusters not obviously related to any fracture plane or growth zone. They may be primary (Roedder, 1984) and are so labelled in Table 2-4-6 and Figures 2-4-5 to 2-4-7. Some of them are visibly three-phase; they have an aqueous liquid phase, an inner carbon dioxide liquid phase and an innermost carbon dioxide vapour bubble. The presence of another component, probably methane, is indicated by the depression of the melting point of carbon dioxide by about 0.5 to 1.0°C from − 56.6°C. Historically this is supported by a methane explosion in 1947 (Patterson, 1979) on the P.E. Gold property. Most, however, appear to be simple two-phase inclusions of aqueous liquid with a vapour bubble with no detectable carbon dioxide component. It is possible that these inclusions do contain a small amount of carbon dioxide rimming the vapour bubble, that is simply too small to see. They are grouped with the primary inclusions because of their similar homogenization temperatures.

The second group of inclusions are probably secondary (Roedder, 1984). They are arranged along myriads of tiny fractures that criss-cross the quartz grains with a brush or wispy texture which, together with the presence of the primary three-phase inclusions, indicates a mesothermal environment (J.T. Reynolds, personal communication, 1987). Many of this second group may be psuedosecondary inclusions (Roedder, 1984) as the fractures containing them do not cross some grain boundaries. They are referred to as secondary for simplicity in the discussion that follows.

Data from fluid inclusions are summarized in Table 2-4-6 and Figures 2-4-5, 2-4-6 and 2-4-7. Given the equipment limitations (the instrument used was a Chaixmeca stage on a Leitz Laborlux microscope with poor optics compared to current models), the approach followed was to gather as

TABLE 2-4-6
SUMMARY OF FLUID INCLUSION DATA, BRALORNE GOLD-QUARTZ VEIN SYSTEM
(Summarized from Figures 2-4-5 and 2-4-6)

Level (vein) Depth (m)	Sample No.	Tm (ice) Primary	Tm (ice) Psuedosec	Tm (ice) Secondary	Th Primary	Th Psuedosec	Th Secondary
Surface (Lorne)	C1018		-2.0		295+15	230+30	
(Cosmopolitan) 0	C1002				280+20		
3 (Woodchuck) 130	C1024		-1.5		235+25	195+25	
8 (51B FW)	8-51B(FW)		-2.0				140+20
(51B Bxa) 270	8-51B	-7.0	-2.5		310+60	225+15	
15 (51) 580	15-51(C)		-2.5		260+20	190+20	
16 (51) 630	16-51FW(E)		-2.5 (-1.5)	-0.5	225+10	190+20 (215+25)	160+20
Additional Data: Te = -21 (-26)							
26 (85) 1100	C118-11		-1.6+0.6		290+40	225+25	
Additional Data: Tmc = +11.5 + 0.5; Te = -22.5 + 1							
32 (79) 1400	C117-7	-4.0+1	-1.5 (-2.0+1)		350+80	190+30 (205+35)	
Additional Data: Te = -20.5 (-24)							
	C117-5	-3.5	-1.5		270+40	180+30	
Additional Data: Tmc = +8.7 + 2.0; Te = (-21.5 + 0.5)							
41 (79) 1800	C116-14	-3.5		-0.5	?265+15	215+20	?150
44 (77)	C128-20	-5.0	-1.5		280+50	190+40	
2000	C128-19	-5.0	-1.5		330+60	200+40	

Figures given in brackets are measured in calcite; all others from quartz. Tm ice (melting point of ice) figures can only be regarded as crude (order of magnitude) estimates. Th = homogenization temperatures; Tmc = melting point of clathrates; Te = eutectic point (first melting temperature).

much data as possible and plot histograms to illustrate salient features. The clustering of homogenization temperatures, coupled with relatively constant liquid/volume ratios (about 15±5 per cent) within groups of inclusions in a single sample, and even from sample to sample, implies that necking has not been a serious problem. The primary/secondary separation, made largely on the dual populations seen in the histograms, appears to be valid, but further work is required to verify this.

The few fluid inclusions that were measured in calcite were generally three-phase (carbon dioxide bearing), as would be expected. It was impossible to determine if they were primary or secondary, but their homogenization temperatures are similar to the secondary inclusions in quartz. As the calcite is always paragenetically late, it is reasonable to postulate that the inclusions in calcite and the secondary inclusions in quartz both represent a phase of later, lower temperature fluids.

HOMOGENIZATION TEMPERATURES

Primary inclusions of the first group have optically determined final homogenization temperatures that increase with depth in the deposit, with a maximum range from 120 to 440°C (Figure 2-4-5). Homogenization temperatures for carbon dioxide range from 6 to 27°C. Most inclusions homogenize to the liquid phase, but a few homogenize to the vapour phase. Although this may be due to necking down, this seems unlikely because the temperatures for homogenization to both liquid and to vapour are similar. This was hard to measure with certainty because the carbon dioxide bearing inclusions commonly decrepitated.

Decrepitation studies on samples submitted to Mitsubishi Metal Corporation in Japan (Sugiyama, 1986) provide a better indication of an increase in homogenization temperature with depth (Figure 2-4-7). The decrepitation method suffers from difficulties relating data to specific fluid inclusion types, significant overshoot of homogenization temperature to produce decrepitation, and variable overshoot depending on size of inclusions (small inclusions may be able to withstand much higher pressures). However the advantages are that data may be obtained from inclusions too small to measure optically and more rapidly than by optical means. In the present study a suite of samples from surface to 2000 metres, which had been studied optically, shows general agreement between decrepitation temperatures and the optically determined data. The gradient suggested by the decrepitation data is about 30°C per kilometre, which corresponds to a reasonable geothermal gradient. So far, this is the most pronounced vertical zonation found in the deposit.

It may be significant that the lower temperature group of fluid inclusions (psuedosecondary or secondary) shows little or no increase in temperature with depth. This suggests that they represent late fluids circulating after the deposit had

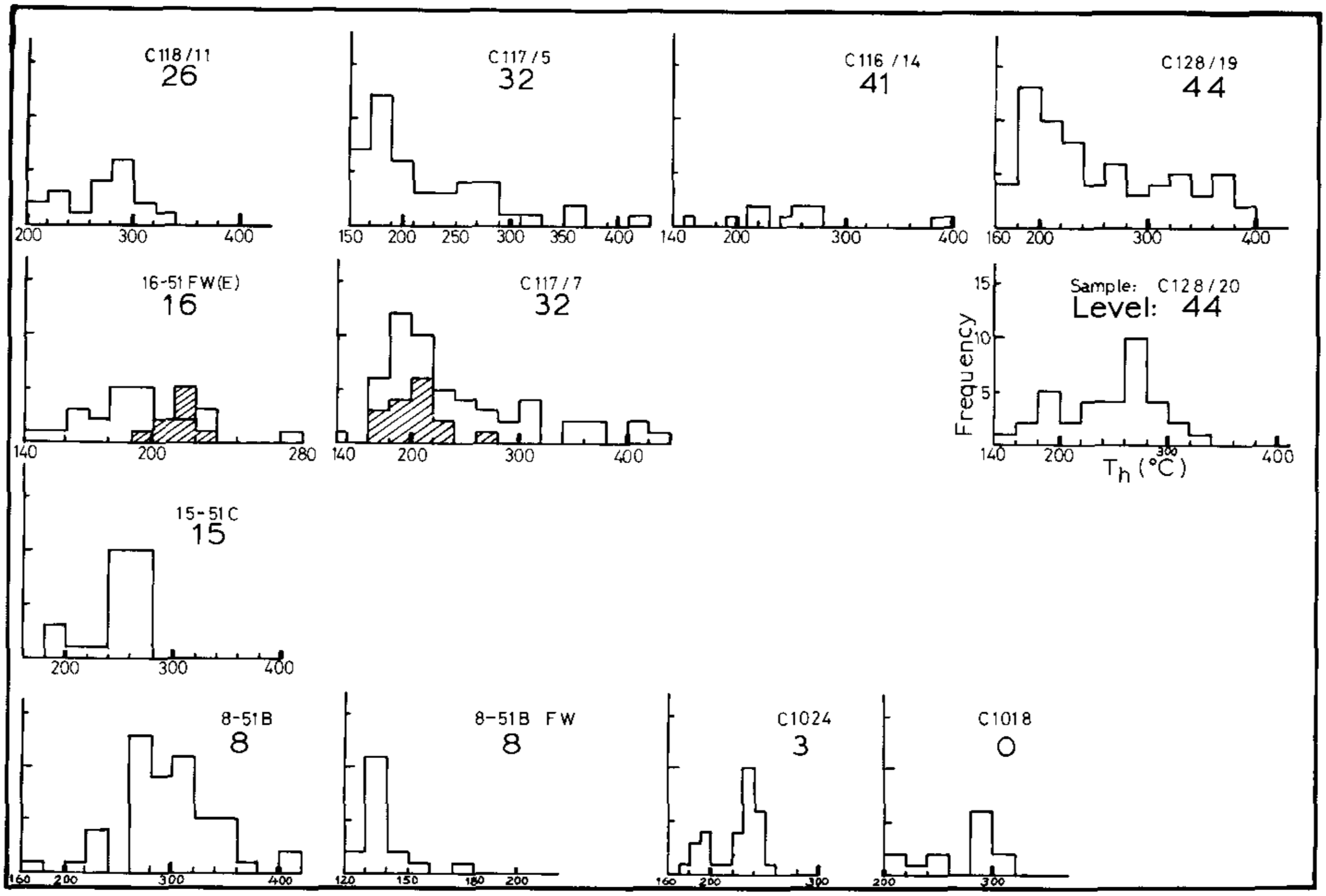


Figure 2-4-5. Histograms of homogenization temperatures (Th) for various levels in the Bralorne mine. Mean values are summarized in Table 2-4-6 and plotted on Figure 2-4-7. All inclusions measured in quartz except those shown hachured, which are in calcite.

TABLE 2-4-7
SULPHUR ISOTOPE DATA FOR SEVERAL DEPOSITS OF THE BRIDGE RIVER CAMP

DEPOSIT	Measured d34S for minerals:						Delta	T (C)
(Sample No.)	gn	sl	tt	py	cp	po	sl-gn	
Bralorne-Pioneer (E73.004.048)	+2.35	+4.13	+2.15				1.78	370
Bralorne Mines (Suite #60)	-6.48 (-6.32)	-3.35					3.03	260
Bralorne (41 Level, 79 Vein) (C116-14)	+5.95	+4.68		+8.99	+6.42	+4.17	reversed	—
Bralorne (Surface, Ida May) (E73.004.047)	+2.36		+4.53				—	—
Pioneer (14th Level) (E3519)	-5.30	-2.63					2.67	295
Pioneer (5th Level) (Joubin)	+1.94	+1.00 (+1.14)					reversed	—
P.E. Gold (P-85-03/450.5 m)	-0.08	+1.78 (+1.78)		+2.85	+2.02		1.86	360
BRX Arizona (unlocated)	-7.50	-4.22		-4.92	-5.76		3.28	240
Blackdome (unlocated)	+0.64						—	—

Legend: gn = galena, sl = sphalerite, tt = tetrahedrite, py = pyrite, cp = chalcopyrite, po = pyrrhotite.
Figures in brackets are repeat measurements. Sulphur isotope ratios and temperature estimates by H. Roy Krouse, Department of Physics, University of Calgary.

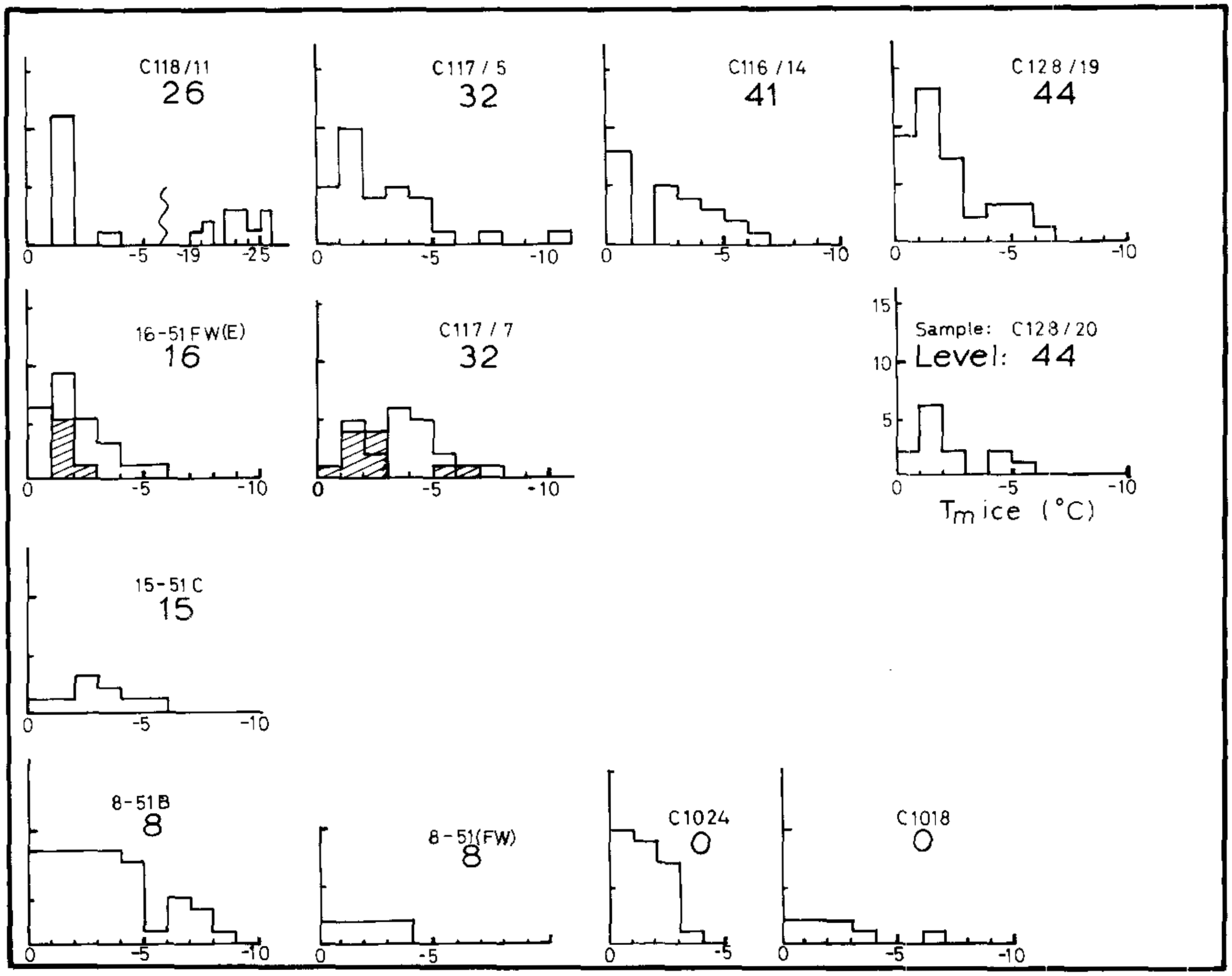


Figure 2-4-6. Histograms of ice melting temperatures (Tm) for various levels in the Bralorne mine. Mean values are summarized in Table 2-4-6. All inclusions measured in quartz except those shown hachured, which are in calcite.

been partially unroofed and the temperature gradients had been reduced.

Pressure corrections to temperature data to obtain trapping temperatures can be estimated by comparison of fluid inclusion homogenization temperatures to temperatures estimated from sulphur isotope equilibrium pairs. Sulphur isotope temperatures (*see* below) fall into two groups at around 250 and 350°C, which, if assumed to be trapping temperatures, may correspond to the two groups of homogenization temperatures at 200 and 280°C. If so, the pressure correction would be about 70°C for primary fluid inclusions and about 50°C for secondary inclusions. These would indicate pressures of approximately 1.0 kilobar for primary fluids and 0.5 kilobar for later fluids (Roedder, 1984, page 262), or depths of about 4 kilometres and 2 kilometres respectively, if lithostatic load conditions applied.

SALINITIES

Salinities of fluid inclusions are usually estimated by observing the last melting point of ice crystals after supercooling. This method can only be confidently applied to the two-phase secondary inclusions at Bralorne, which show last melting of around −0.5 to −1°C. This is because the presence of carbon dioxide in the primary inclusions causes the formation of clathrate (CO_2 hydrate) compounds that do not melt until +8 to +12°C and thus obscure the melting of ice; the presence of methane in the carbon dioxide bearing inclusions has the opposite effect (Collins, 1979). Thus it is impossible to estimate the salinities of the Bralorne inclusions by using the last melting point of clathrate compounds. Nevertheless the last melting of ice in inclusions with no observable carbon dioxide appears to fall in the range −2 to −5°C (Figure 2-4-6). Because of these complications, all that can reliably be said about the salinities at Bralorne is that the ore fluids were dilute, certainly less than 10 weight per cent and probably less than 5 weight per cent NaCl equivalent. This is typical of gold quartz veins of mesothermal character (Taylor, 1987) and has also been observed in Bralorne samples by Maheux *et al.* (1987).

Vaguely detectable eutectic temperatures of about −20.5 to −22.5°C in some samples indicate that the dissolved salts

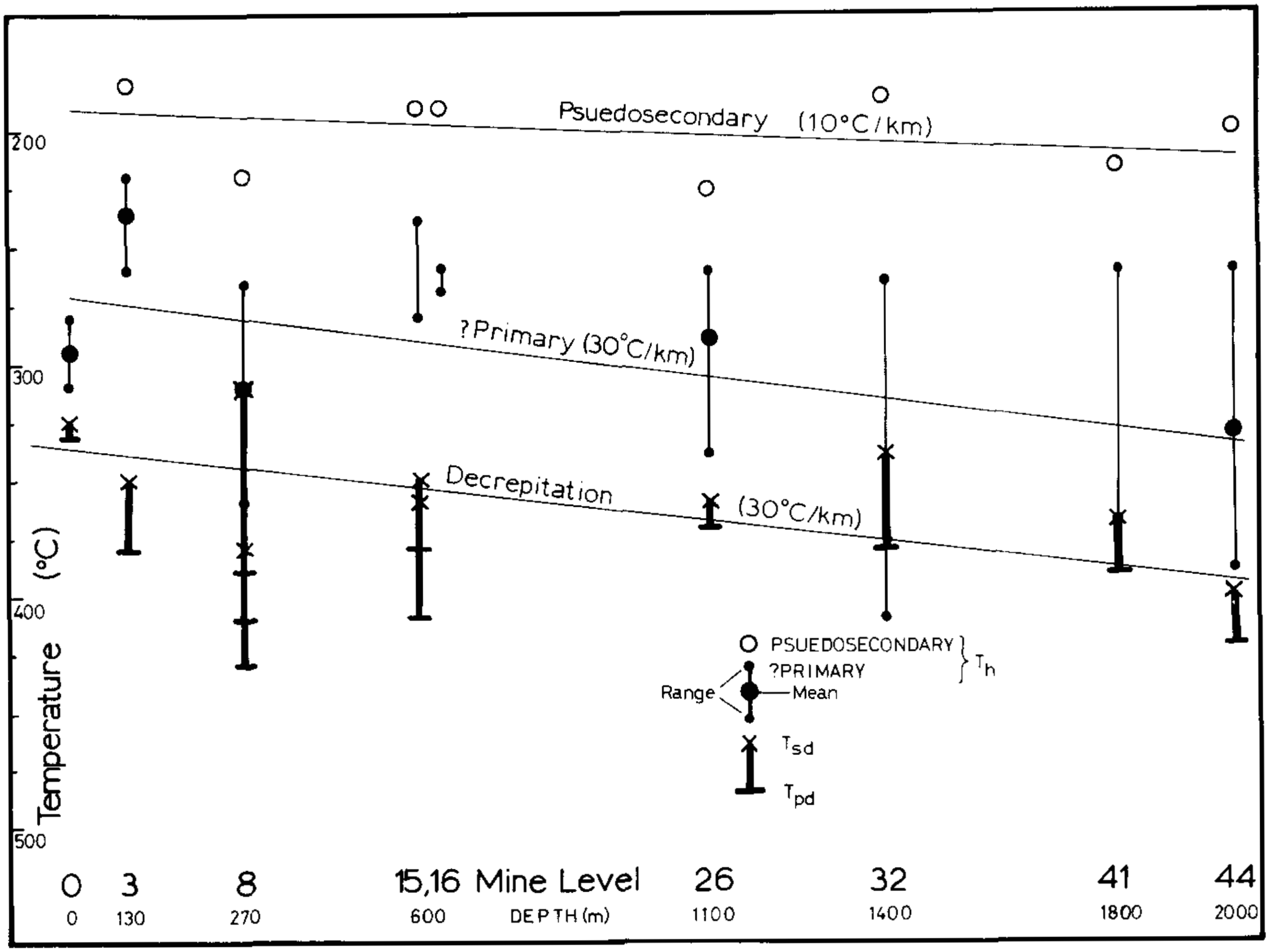


Figure 2-4-7. Plot of variation with depth for optically determined homogenization temperatures (Th), for presumed psuedosecondary and primary fluid inclusions. Also shown are decrepitation temperatures versus depth in the mine (Tsd = start of decrepitation, Tpd = peak of decrepitation). Note the two populations of temperatures for samples from 8 and 15 levels. All inclusions measured in quartz.

are probably mostly NaCl and KCl (Roedder, 1984). The destruction of albite and its replacement by sericite in wallrock alteration envelopes indicates that KCl may be dominant. In some calcite specimens, however, a lower eutectic temperature of −24 to −26°C may indicate the presence of some other salt.

SULPHUR ISOTOPES

Sulphur isotopes were analysed in hand-picked (99 per cent pure) galena, spalerite, pyrite, pyrrhotite, chalcopyrite and tetrahedrite from samples at different levels of the mine, and from nearby deposits in the Bralorne area (Pioneer, P.E. Gold, BRX). Table 2-4-7 gives the isotopic data and the temperatures calculated from them using formulae from Ohmoto and Rye (1979). Temperatures calculated using data from minerals other than galena and sphalerite are erratic and unrealistically high. This is common (Godwin *et al.*, 1986) as pyrite typically does not equilibriate as well as galena and sphalerite. Furthermore pyrrhotite, chalcopyrite and pyrite have a much more widespread distribution than sphalerite and galena and probably represent several phases of ore formation. Tetrahedrite is much more limited in distribution and appears to be in equilibrium with sphalerite and galena, but no experimental curves for tetrahedrite are available. Sphalerite and galena, on the other hand, appear to have formed contemporaneously and are therefore probably generally in equilibrium.

The sphalerite and galena pairs give temperatures of formation ranging from 240 to 370°C. Unfortunately this cannot be compared directly with fluid inclusion homogenization data as the only sample for which sulphur isotope and fluid inclusion data has been determined (C116-14) shows reversed $\delta^{34}S$ values indicating the galena and sphalerite could not have equilibrated in this case. However, two polarities are apparent in the data, one around 250°C and the other near 350°C. If these two clusters correspond to the secondary or lower temperature and primary or higher temperature groups of fluid inclusions, then substantial pressure corrections need to be applied to the homogenization temperatures.

CONCLUSIONS

The inferences that can be drawn about Bralorne ore fluids are as follows: primary fluids, presumed to be responsible for gold mineralization, were dilute solutions containing 5 weight per cent KCl ± NaCl, 10 per cent carbon dioxide and minor methane at temperatures of around 350°C and pressures of 1 kilobar. Later secondary fluids were perhaps even more dilute, 1 to 3 weight per cent NaCl ± KCl but without detectable carbon dioxide or methane, at temperatures of about 250°C and pressures of 0.5 kilobar. Sulphur isotopic ratios of sulphides associated with the gold mineralization cluster around 0 parts per mil, with a range of −7 to +9.

Neither the primary nor secondary inclusions show any direct observable relationship to gold mineralization, so it is equally possible that the gold-bearing fluids were the early high-temperature or the later lower temperature type. Microscopically, gold occurrence is restricted to sulphides which occur only with patches of alteration minerals in altered wallrock slivers included in the veins, never in the quartz itself.

Earlier workers (Dolmage, 1934; Cairnes, 1937) have stressed the paragenetically late occurrence of gold, which fills fractures in sulphides. However, this could easily be the result of remobilization of the relatively soft gold into fractures in brittle minerals such as pyrite and arsenopyrite. Macroscopically, visible gold is usually present as fine smears or paint on slickensided surfaces, where it is accompanied by pyrite. These layers are part of the thin dark septae of altered rock that give the Bralorne veins their ribboned appearance.

The available evidence suggests that gold was deposited with sulphides wherever reactive host rock was present, principally inside the vein conduit. Low gold values are reported in the wallrock, dropping off rapidly to background values over less than a metre (Bellamy and Saleken, 1983). Also, there is no gold associated with the calcite veining, which has homogenization temperatures similar to the secondary inclusions. Thus deposition was probably from the earlier higher temperature fluids of which the primary fluid inclusions reported here are the most representative.

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THE RELIANCE GOLD PROSPECT, BRIDGE RIVER MINING CAMP (92J/15)

By M. J. Hanna, D. A. R. James and B. N. Church

KEYWORDS: Economic geology, Bridge River, Reliance, stibnite, gold, quartz veins.

INTRODUCTION

The Reliance property (092J/NE-033, 136) is located at latitude 50°52′ north, longitude 122°47′ west, on the south side of Carpenter Lake, roughly opposite the mouth of Gun Creek. Access is by all-weather gravel road 5 kilometres northeast of the town of Gold Bridge (Figure 2-5-1).

The property consists of 17 Crown-granted mineral claims and fractions including the Nemo, Omen and Eros claim groups. Current exploration is focused on the western part of the property.

The writers visited the property on several occasions in July and August 1987, for survey and sampling and to check on the progress of exploration. In this regard, many thanks are owing officers of Menika Mining Co. Ltd., especially Messrs. Charles Boitard and Lawrence Sookochoff, for their courtesy and cooperation.

HISTORY

The early history of this property was noted by Cairnes (1943): "The Reliance is one of the older properties and has been known from the beginning as an antimony prospect. The original group of four claims was staked in 1910 by Mr. F.A. Brewer, who relocated the property in 1915. By September 1915, it is reported, 4 tons of ore had been bagged for shipment, and the richest carried up to ½ ounce in gold a ton."

In 1917 there was a shipment of hand-cobbed gold-bearing stibnite; no further records are available for this period.

The property was re-organized by Reliance Gold Mines Ltd. in 1933 and development work continued until 1937. This included underground work on several adits and installation of a compressor plant. The mine workings comprised the Old Reliance adit at an elevation of 1100 metres on the Nemo 7 Crown-granted claim, the Fergusson adit (elevation 1023 metres) also on Nemo 7, the Turner adit (elevation 830 metres) on Omen 1 Crown grant, the River adit (elevation 663 metres) on Omen 2 Crown grant, and the Senator adit (elevation approximately 790 metres) on Nemo 1 Crown grant. Short intervals of heavy stibnite mineralization in narrow quartz veins were encountered in the adits.

In 1971, Tri Con Exploration Surveys Ltd. carried out several geotechnical surveys and outlined electromagnetic conductors coincident with a prominent southeast-trending arsenic-antimony geochemical anomaly traversing the western part of the property, including the Senator workings. There appears to have been no immediate follow-up investigation.

In 1984 the property was acquired by Charles Boitard of Menika Mining Co. Ltd., by option agreement from Karl Otting of Lillooet. Subsequent work has been directed toward confirmation of the Tri Con discoveries and further testing for gold. By November 1987, a total of 38 diamond-drill holes had been completed by Menika Mining Co. Ltd.

GEOLOGY AND MINERALIZATION

The geology of the Reliance claims is relatively simple, consisting mostly of greenstones and small infaulted blocks of chert. The greenstones comprise thick and massive pillow lavas and breccias, feeder dykes and sills. The rocks are similar to the Pioneer Formation exposed on the Congress property on the north side of Carpenter Lake. The chert beds are intercalated with phyllite locally and are deformed, as is typical of the Fergusson Group. Generally, bedding laminations dip steeply to the southwest.

On the east side of the property, a northerly striking belt of ribbon chert, about 100 metres wide, traverses the area of the mine workings. The various tunnels follow well-defined shear zones in the intervening greenstones. According to Cairnes (1943): "These zones each carry one or more veins of nearly solid, fine to coarsely crystalline stibnite associated with more or less quartz and calcite gangues."

The Old Reliance adit, the uppermost working, follows a southeasterly striking shear in purplish volcanic rocks, the apparent target being several stringers of stibnite, 2 to 5 centimetres wide, which are exposed in a trench above the tunnel.

Cairnes (1943) also reports on the Fergusson adit which is located below and about 200 metres northwest of the Old Reliance adit: "It runs east-northeast for 80 feet (24 metres) in greenstone along a mineralized shear zone 4 feet (1.2 metres) wide to a mineralized fault fissure which offsets the first shear 13 feet (4 metres) to the southeast. Beyond this offset the drift follows the main shear about 25 feet (7.6 metres) to the face. Between the portal and the fault the shear carries a vein of stibnite up to 6 inches (15 centimetres) wide with some quartz. Beyond the fault the stibnite vein is 3 to 4 inches (7 to 10 centimetres) wide and runs off into the footwall a few feet from the face of the adit, where, however, other small stringers of stibnite were seen. Above the adit the shear zone has been investigated by a long trench from which a shipment of hand-sorted stibnite is reported to have been extracted in 1917."

The Turner adit is about 375 metres northwest of the Fergusson adit. Cairnes elaborates: "This runs southeast in green and purple volcanic rocks for 85 feet [26 metres] to a mineralized shear zone several feet wide striking east-northeast and dipping steeply northwest. This was driven on northeasterly for 55 feet [17 metres] and contains veinlets of stibnite in altered and pyritized greenstone. In the opposite direction the shear was followed for only a few feet to a fault striking southeasterly and dipping 50 degrees northeast. Where cut off, the shear zone contained a vein of stibnite several inches wide. Its probable continuation across the fault appears 6 feet [1.8 metres] to the northwest. Such a displacement is similar to that of the fault in the Fergusson adit."

The River adit is a crosscut to explore the downward projection of the mineralized zones described above.

On the western part of the Reliance property the Senator workings, located about 1100 metres west of the Fergusson adit, are the only remains of the former development. This is the general area of current exploration.

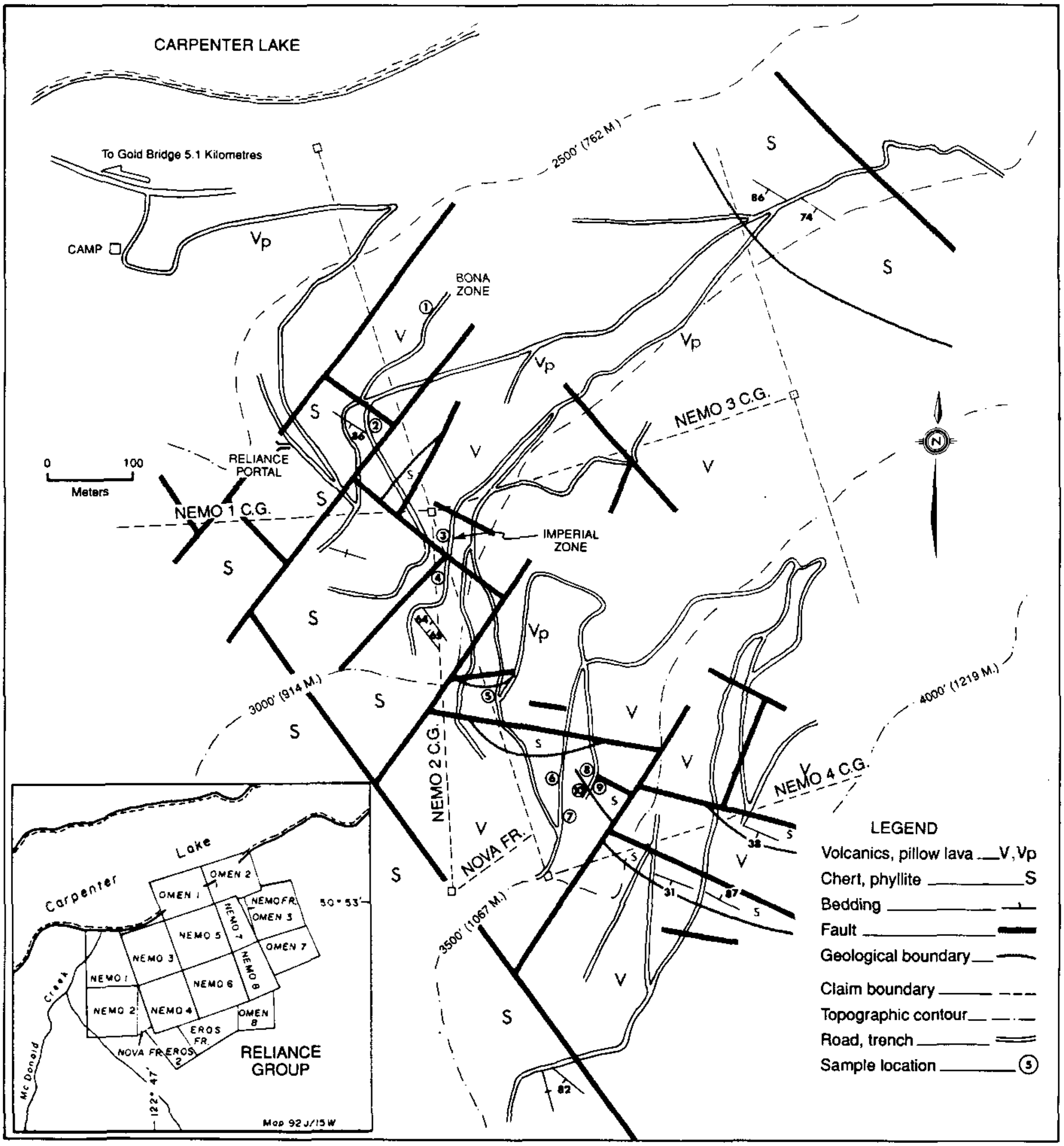

Figure 2-5-1. Geology of the Reliance property, Menika Mining Co. Ltd. (by M.J. Hanna, D.A.R. James and B.N. Church).

TABLE 2-5-1
ANALYTICAL RESULTS*

Station No.	Sample Width (m)	Au ppm	Ag ppm	Cu ppm	Pb ppm	Zn ppm	As ppm	Sb ppm
1	3	12.8	2.0	85	10	127	424	108
2	3	1.1	1.0	83	8	267	935	73
3	grab	13.0	11.0	123	8	400	9500	8000
4	3	1.2	2.0	119	17	198	1400	3400
5	3	0.06	0.5	84	17	204	40	144
6	4	6.4	2.0	76	3	110	11300	185
7	grab	0.03	<0.5	29	3	67	232	44
8	grab	11.0	1.0	57	7	102	24000	455
9	3	0.04	1.0	85	13	180	80	15
10	3	0.15	1.0	94	18	148	176	68

* Analyses by Analytical Laboratory, Geological Survey Branch, B.C. Ministry of Energy, Mines and Petroleum Resources.

The Senator vein is in a northeast-trending shear zone in pyritized and silicified volcanics and ribbon cherts of the Fergusson Group. It contains stibnite in quartz-carbonate yielding assay results in gold to 5.48 grams per tonne and silver to 8.57 grams per tonne.

The Imperial zone, located 200 metres southeast of the Senator portal, is a new discovery. This is an area of northeast-trending stibnite-bearing quartz veins cutting carbonated greenstones and limonitic silicified metasediments. Company assays report 6.34 grams of gold per tonne over 0.3 metre on individual veins and 2.74 grams of gold per tonne across the whole 12 metres of alteration. An east-west fence of recent diamond-drill holes proves similar mineralization to a depth of more than 100 metres. A single grab sample collected by the authors from the north part of the zone (Figure 2-5-1, No. 3) yields gold, 13 grams per tonne; silver, 11 grams per tonne; arsenic, 0.95 per cent and antimony 0.80 per cent.

The Bona zone, located 200 metres northwest of the Senator portal, is another area of limonitic alteration. Sampling by the authors along a 3-metre length of roadcut (Table 2-5-1, No. 1) yielded gold, 12.8 grams per tonne and silver, 2 grams per tonne.

Other interesting zones of alteration and mineralization in this vicinity occur sporadically along the course of the steep northwesterly trending draw located southwest of the Imperial zone, over an elevation interval of several hundred metres.

Control of the mineralization on the Reliance property is governed largely by fractures in the country rocks. Near the old workings on the east part of the property, Cairnes (1943) records: "Two sets of shear zones may be recognized, one striking southeast with steep dips to the southeast and the other trending east-northeast, with steep dips to the northwest. Most of the exploratory work has been done on the latter set."

The same pattern appears to exist in the new exploration area on the west side of the property (Figure 2-5-1). The steep draw passing west of the Senator portal and the Imperial zone is evidently a southeasterly trending fault lineament separating mainly ribbon chert to the west and alternating chert and greenstone panels to the east. A series of subparallel tensional feather-fractures, striking northeast off this fault zone, separates the panels and hosts much of the mineralization.

Dykes intruded into the fracture system are mostly premineralization as evidenced by their usual heavily altered condition — no doubt caused by the same migrating hydrothermal solutions which are responsible for the ore.

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THE ELIZABETH-YALAKOM GOLD PROSPECT, BRIDGE RIVER MINING CAMP (92O/02)

By R. G. Gaba, M. J. Hanna and B. N. Church

KEYWORDS: Economic geology, Bridge River, Elizabeth-Yalakom, gold, quartz veins, porphyritic quartz diorite.

INTRODUCTION

The Elizabeth-Yalakom property (MINFILE 0920-012) is centred at approximately latitude 51°02′ north, longitude 122°35′ west, 6.7 kilometres west of the junction of Blue Creek and the Yalakom River in the Shulaps Range (Figure 2-6-1). A gravel road links the property to the Yalakom River road at a point approximately 23 kilometres north of the Carpenter Lake (Bridge River) all-weather highway; the junction of the Yalakom River and Carpenter Lake roads is

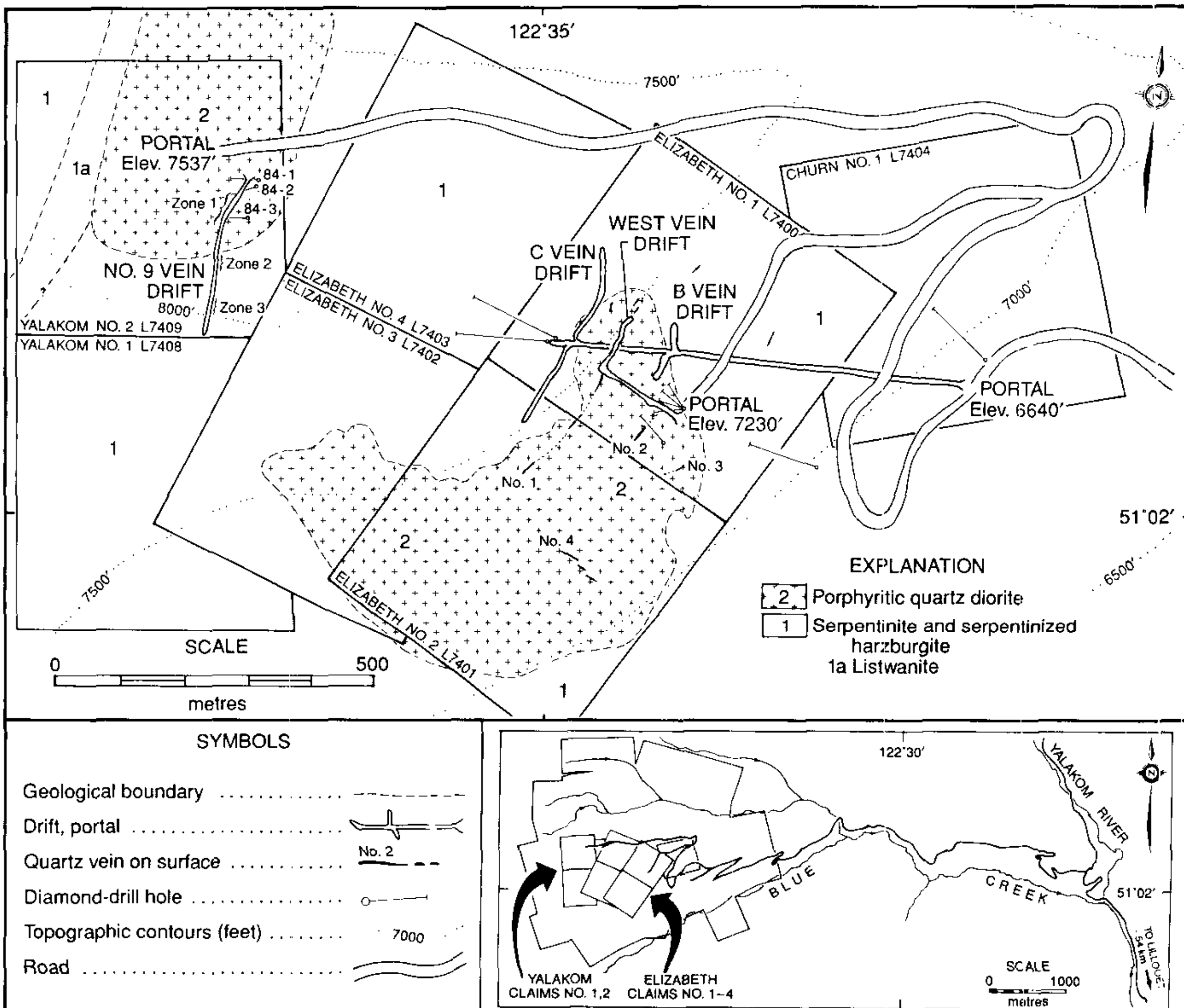

Figure 2-6-1. Location and geology of the Elizabeth-Yalakom prospect [includes information from Bralorne Mines Ltd. (1953), Leech (1948), McCammon (1946b), and Thompson (1957a, b)].

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

approximately 18.5 kilometres west of Lillooet. All workings are at or above treeline (1980 metres elevation).

EXPLORATION AND DEVELOPMENT HISTORY

Auriferous quartz veins were first discovered in 1934 (Hedley, 1941) and subsequently rediscovered and staked in 1940 and 1941 as the Crown-granted Elizabeth mineral claims. Surrounding claims staked at this time include the Yalakom, Churn and Plateau claims. Bralorne Mines Limited optioned the Elizabeth and adjoining claims and staked additional claims in the vicinity. A total of 232 metres of diamond drilling at five sites and 534 metres of surface stripping was completed, to explore four quartz veins (the Nos. 1, 2, 3 and 4 veins) exposed on the Elizabeth 1 and 2 claims (*Minister of Mines, B.C.*, Annual Report, 1941).

Wartime conditions delayed further work until 1947, at which time a portal was collared on the Churn 1 claim at 2025 metres elevation (6640 feet). A crosscut was driven nearly due west toward the Elizabeth 1 claim, to test the downward extension of the No. 1 vein (also later known as the High-grade or West vein) 230 metres below its surface exposure (Peck, 1948). By 1948, this main crosscut was extended a total length of 672 metres. Two quartz veins, the B and C veins, were intersected 490 metres and 641 metres respectively from the portal. In addition to 266 metres of diamond drilling, drifts were put in to follow these veins (Figure 2-6-1; Merrett, 1948). The B and C veins are not exposed on surface and their relationship to No. 1 vein, the intended target, is not known.

The following year a raise was driven up a 1.2-metre section of the B vein to a point 82.5 metres above the level. In addition, a raise was driven 23 metres up the C vein. No significant gold concentrations were encountered during this work. At this time, surface work on the Yalakom 2 claim uncovered a quartz vein 0.6 to 0.9 metre thick and continuous for more than 61 metres, known as the No. 9 vein (Merrett and Stephenson, 1950).

During 1951 and 1952 a drift was excavated from a portal collared on the Yalakom 2 claim at an elevation of 2299 metres (7537 feet) southward along the No. 9 vein for a distance of 246 metres. Gold content of the vein is variable; assays as high as 17.5 grams per tonne gold over a length of 8.5 metres and a thickness of 0.6 metre, and 15.4 grams per tonne gold over a length of 19.8 metres and thickness of 0.8 metre were reported (National Mineral Inventory 920/2-AU2). Surface trenches exposed the No. 9 vein in two cuts north of and below the portal. Overall, the thickness of the auriferous quartz vein was considered to be too narrow and the gold distribution too erratic to constitute ore (Merrett 1952, 1953). Bralorne Mines Limited subsequently abandoned the option and its adjacent claims in 1953 (Merrett, 1954).

Work was resumed by the owners (T.W. Illidge and W. White) in 1956 and a crosscut collared on the Elizabeth 1 claim at an elevation of 2205 metres (7230 feet) was driven at azimuth 110 degrees for 142 metres, to further explore quartz veins exposed on surface. The Main vein and West vein (No. 1 vein) were intersected at 33.5 metres and 138.8 metres from the portal respectively (Patterson, 1956; Figure 2-6-1). The following year the West vein was followed an additional 97.6 metres (King, 1957). During this time a geological study of surface and underground workings was carried out by R. Thompson (Thompson, 1957a, b). Nine tons (8.2 tonnes) of rock excavated from the West vein drift was custom processed at Trail, British Columbia and yielded 155 grams gold, 155 grams silver, 24 kilograms lead and 8 kilograms zinc (King, 1959). No further work has been done on the Elizabeth claims and the portals have subsequently caved.

The claims remained dormant until 1978 when Southern Lights Resources Ltd. acquired the Yalakom claims and did additional staking in the area. In 1983 an option to earn a 40-per-cent interest was given to Cal-Denver Resources Ltd. and the same year the No. 9 vein drift was rehabilitated, sampled and subsequently drilled. Both drift sampling and drilling yielded encouraging results (George Cross News Letter, August 26, 1984; Culbert and Leighton, 1986). During the summer of 1987 a total of 600 metres of diamond-drill core was recovered from four holes drilled from surface to test the down-dip extension of the veins (Vancouver Stockwatch, 1987a). During a visit by the authors, the No. 9 vein portal (Plate 2-6-1) was being de-iced as a prerequisite for further underground exploration planned for the fall of 1987 in conjunction with Vanguard Mining Exploration Ltd. (Vancouver Stockwatch, 1987b).

Plate 2-6-1. The No. 9 portal, 2297-metre (7537-foot) elevation, Yalakom 2 claim.

GEOLOGICAL SETTING

The Shulaps Range in the area of the Elizabeth-Yalakom gold prospect is composed of ultramafic rocks, specifically serpentinite and serpentinized harzburgite, with porphyritic quartz diorite intrusions. The geology of the area has previously been described by McCammon (1947) and Leech (1953).

The two largest outcrop areas of porphyritic quartz diorite [refered to as the Blue Creek porphyry by Leech (1953)] are on the Elizabeth 1, 2 and 3 claims and on the Yalakom 2 claim on the southeast and north slopes of the ridge that forms the main topographic feature in the area (Figure 2-6-1). The porphyritic quartz diorite is typically grey, with plagioclase (2 to 5-millimetre) and hornblende (2 to 3-millimetre) phenocrysts in a finer grained groundmass of plagioclase, hornblende, quartz and some biotite; altered porphyritic quartz diorite also contains epidote as well as hornblende partly occupied by biotite to completely pseudomorphed by chlorite.

The outline of the porphyritic quartz diorite bodies is more complex than as shown in Figure 2-6-1. Peripheral areas contain irregular offshoots and satellitic bodies of intrusive rocks similar in appearance to the main masses but variable (in texture and composition) from porphyritic to equigranular diorite to quartz-rich diorite. Abundant white aplite veinlets occupy irregular fractures in porphyritic quartz diorite on the northwest part of the Elizabeth 1 claim.

Serpentinized ultramafic rocks, typical of the Shulaps ultramafic body, surround the porphyritic quartz diorite. Glacial debris consists predominantly of unlayered to slightly layered yellow rusty surfaced serpentinized harzburgite and dark green serpentinite, and obscures much of the ultramafic bedrock exposure. Ultramafic rocks adjacent to porphyritic quartz diorite are well-foliated serpentinite.

The porphyritic quartz diorite contact along the west side of the Yalakom 2 claim is occupied by rusty coloured carbonate, talc, quartz, green mica rocks or listwanite (Boyle, 1979, page 210). These rocks resemble harzburgite on weathered surface but are more physically resistant and form a 9 to 21-metre-thick rib along the northwest slope of the main ridge (previously referred to as the Bralorne dyke by Leech, 1953). These rocks are most likely the hydrothermally altered equivalent of surrounding serpentinized harzburgite.

AURIFEROUS QUARTZ VEINS

The important gold-bearing quartz veins at the Elizabeth-Yalakom prospect are confined to porphyritic quartz diorite (McCammon, 1947), although some are along or adjacent to contacts with ultramafic rocks (Leech, 1953; Thompson, 1957b).

Alteration of porphyritic quartz diorite along vein margins is slight; plagioclase phenocrysts, originally andesine, contain albite-oligoclase, sericite, epidote, clinozoisite and clay-like material. A greater pyrite and quartz content is also noted (Leech, 1953).

Auriferous quartz veins on the Elizabeth-Yalakom prospect include: the Nos. 1, 2, 3 and 4 veins and the B and C veins on the Elizabeth 1 and 2 claims and the No. 9 vein on the Yalakom 2 claim (Table 2-6-1). Surface and underground

TABLE 2-6-1
AURIFEROUS QUARTZ VEINS OF THE ELIZABETH-YALAKOW PROSPECT

Vein Name	Claim	*Dimensions (approx.)* Length (max.) (m)	Width (cm)	Attitude	Exposure and/or Access	References
No. 1 vein (also High-grade vein, West vein)	Elizabeth 1, 2	183	117	030/vertical	Exposed in trenches; access at depth in West vein drift via 2200-m (7230-ft.) elevation portal	McCammon (1945a) Thompson (1957a)
No. 2 vein	Elizabeth 1	73	61	038/70 NW	Exposed in trenches; access at depth in drift via 220-m (7230-ft.) elevation portal	McCammon (1946a)
No. 3 vein	Elizabeth 1	28	94 to 107	070/79 S	Exposed in trenches	McCammon (1946a)
No. 4 vein	Elizabeth 2	75	7.5 to 19	120/65 NE	Exposed in trenches	McCammon (1946a)
B vein	Elizabeth 1	76	up to 122	000/015	Access at depth in B-vein drift via 2020-m (6640-ft.) elevation portal	Merrett (1948) Merrett and Stephenson (1949)
C vein	Elizabeth 1, 2	275	?	000/025	Access at depth in C-vein drift via 2020-m (6640-ft.) elevation portal	Merrett (1948) Merrett and Stephenson (1949)
No. 9 vein	Yalakom 2	245	60 to 90	000/70 W	Exposed on surface in trenches; accessed by No. 9 drift via 2300-m (7537-ft.) elevation portal	Merrett and Stephenson (1949) Merrett (1952)

exploration of veins on the Elizabeth claims has resulted in the delineation of gold concentrations considered too erratic and vein widths too narrow to constitute ore. At present, the No. 9 vein is the only vein with underground workings that are accessible and is being actively explored.

THE NO. 9 VEIN

The No. 9 vein is within the porphyritic quartz diorite body northwest of the main body that contains the Elizabeth veins; it is not known whether the diorite is continuous between the two areas beneath the surface. The No. 9 vein is exposed at depth along much of the length of the No. 9 drift. It is generally less than 0.5 metre wide although continuous for more than 245 metres and is actually a system of parallel veins rather than a single vein.

Vein quartz is massive and milky white and contains a variable amount of calcite and ankerite with disseminated sulphide minerals (as observed in vein material on the dump). However, much of the vein quartz is ribboned with laminations and styolitic partings of chlorite and carbonaceous material. Metallic mineral concentrations tend to coincide along the ribbons (Plate 2-6-2). Small fragments of what appears to be altered porphyritic quartz diorite are common within ribboned domains. Ribbons are generally parallel to vein walls and separate massive to fractured, partly rusty, milky white quartz that contains only sparsely disseminated metallic minerals and a variable calcite and ankerite content.

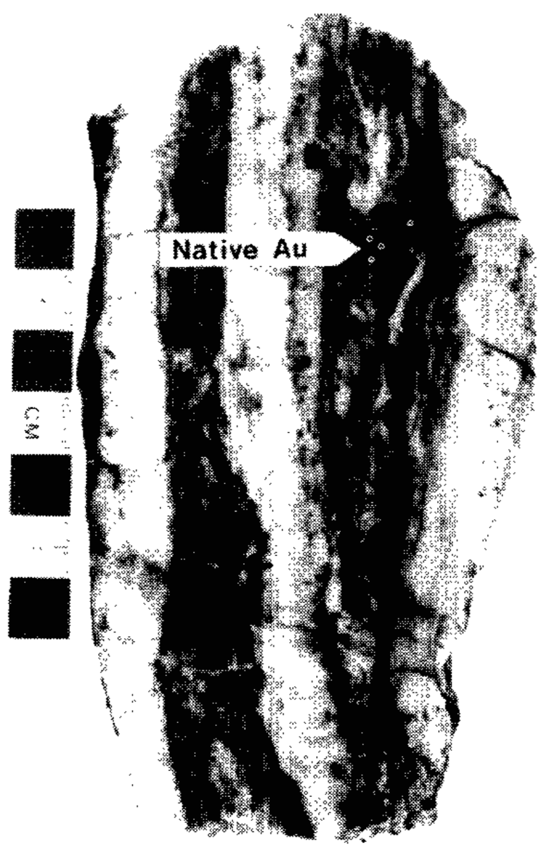

Plate 2-6-2. Ribboned quartz from the No. 9 vein. Note concentration of metallic minerals and native gold along ribbons.

Metallic minerals are mostly arsenopyrite, pyrite and chalcopyrite (accompanied by malachite and azurite), with lesser galena, sphalerite, pyrrhotite, magnetite and molybdenite. Native gold occurs as visible blebs within and as thin surface coatings along chloritic carbonaceous ribbons (Plate 2-6-2) and only rarely as isolated visible blebs within inter-ribbon quartz. Total metallic mineral content of the veins rarely exceeds a few per cent.

An underground sampling program carried out in 1983 by Southern Lights Resources Ltd. (Balsam Resources Inc. as of March 1987) along the length of the No. 9 drift delineated three auriferous zones (Figure 2-6-1; Table 2-6-2). Three diamond-drill holes were subsequently drilled to test the continuity of the auriferous zones and intersected numerous auriferous quartz veins adjacent to the No. 9 vein (Table 2-6-3). Combined drift sampling and diamond drilling results indicate reserves to be approximately 3850 tonnes with a mean gold content of 41.1 grams per tonne (George Cross News Letter, August 26, 1984).

Four additional diamond-drill holes completed in 1987 and totalling 600 metres, yielded gold concentrations of 4.94, 4.18 and 3.57 grams per tonne over unknown thicknesses. Grab samples taken from the rock dump outside the No. 9 portal contain up to 24.5 grams per tonne (Vancouver Stockwatch, 1987a).

DISCUSSION

Auriferous quartz veins at the Elizabeth-Yalakom prospect are essentially confined to porphyritic quartz diorite and generally strike north or slightly east of north with a steep dip. The location of auriferous quartz veins indicates that,

TABLE 2-6-2

AURIFEROUS ZONES ALONG NO. 9 DRIFT (1983 SAMPLING PROGRAM)

Zone	Distance from Portal (m)	Length (m)	Average Width (cm)	Uncut g/t Au	Diluted* g/t Au/ width
1	32-81	49	27.2	69.2	44.4/42.5 cm
2	111-127	16	46.7	33.7	25.4/61.9 cm
3	183-194	11	28.4	31.7	20.6/43.5 cm

* Addition of 7.6 centimetres on either side of sample width.
See Figure 2-6-1 for zone locations.
Information from Culbert and Leighton (1986); Vancouver Stockwatch (1987a).

TABLE 2-6-3

DIAMOND-DRILL CORE GOLD ASSAYS (1984 DRILLING PROGRAM)

Hole No.	Vein Intersection (m)	Vein Width (cm)	Au (g/t)/ Width
84-1	95.5	21	37.4/21 cm
84-2	88.5-89.1	60	7.1/60 cm
84-3	76.3-76.9	60	0.2/60 cm

See Figure 2-6-1 for hole locations.
Information from Culbert and Leighton (1986).

under stress, the porphyritic quartz diorite acted as a competent medium and was brittley deformed, in contrast to surrounding incompetent ultramafic rocks which behaved in a ductile manner. As a consequence, diorite-ultramafic contacts are mostly well foliated and yield little information on relative age relationships.

The ribboned texture of the quartz veins suggests repeated fracturing during emplacement and vein growth. The concentration of metallic minerals (including native gold) along chloritic carbonaceous ribbons may have resulted from fluid penetration and metal precipitation during vein-fracturing episodes. Inclusions of altered wallrock within ribboned quartz suggest stoping and partial consumption of adjacent wallrock during fracturing and vein growth.

Surrounding serpentinite may have acted as an important impervious barrier, restricting fluid movement and circulation to within the porphyritic quartz diorite.

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ALTERATION OF FRAGMENTAL BASALTIC ROCKS: THE QUESNEL RIVER GOLD DEPOSIT, CENTRAL BRITISH COLUMBIA (93A/12W)

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KEYWORDS: Economic geology, QR gold deposit, Quesnel terrane, Takla Group, QR stock, propylitic alteration, carbonatization.

INTRODUCTION

The Quesnel River (QR, MI 93A-151) gold deposit is located in the interior plateau region of central British Columbia, about 58 kilometres southeast of Quesnel (52°40'N; 121°47'W) (Figure 2-7-1). The deposit was discovered during a regional reconnaissance program in 1977 by Fox Geological Consultants Limited for Dome Exploration (Canada) Limited. Exploration work since then has been successful in outlining reserves of 990 000 tonnes grading 7.29 grams per tonne gold in two separate zones (P.E. Fox, personal communication, 1987).

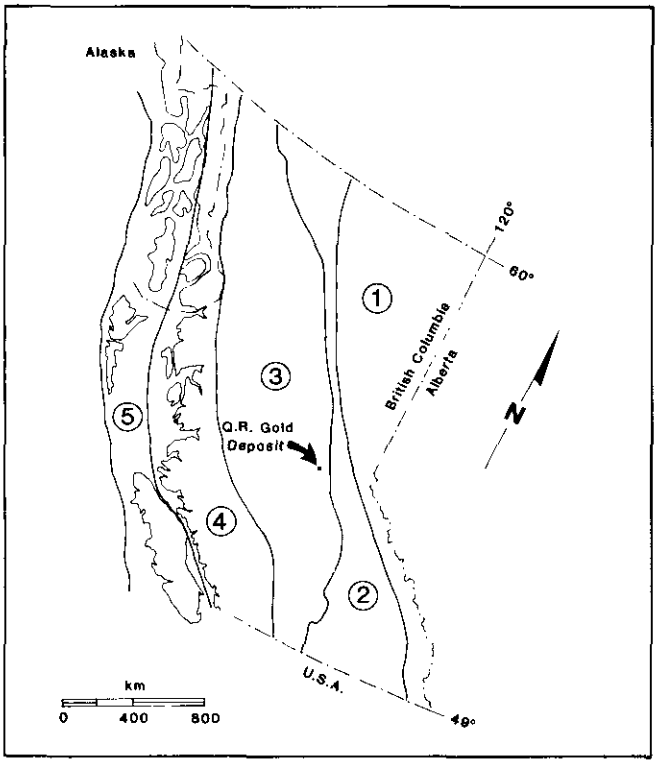


Figure 2-7-1. Location of the Quesnel River (QR) gold deposit with respect to the major tectonic subdivisions of the Canadian Cordillera: (1) Eastern Marginal Belt, (2) Omenica Belt, (3) Intermontane Belt, (4) Coast Belt, (5) Insular Belt (modified after McMillan and Panteleyev, 1980).

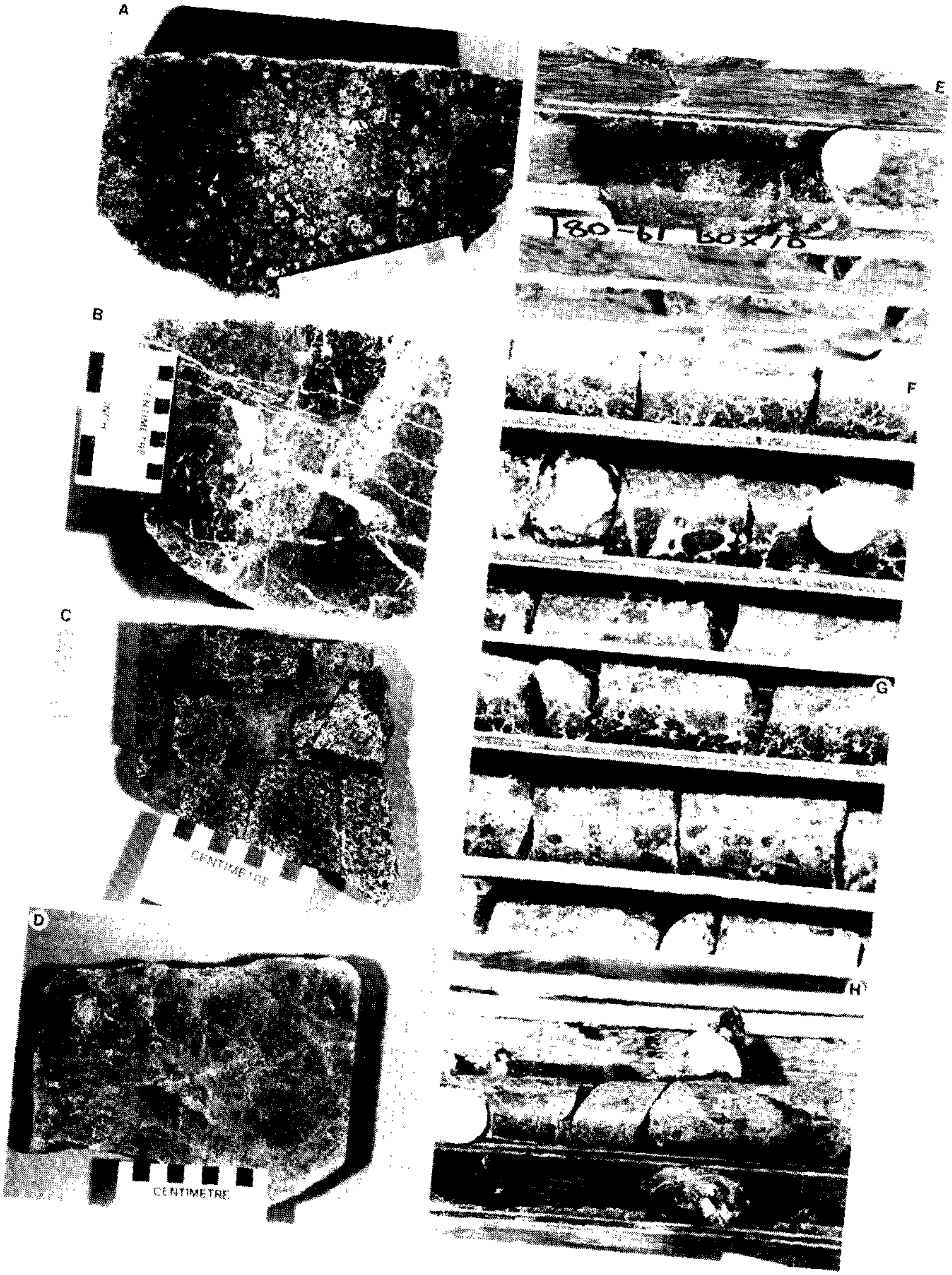
Recent geological work in the area to the east of the QR deposit includes tectonostratigraphic studies by Rees (1981, 1987), Rees and Ferri (1983), Struik (1986) and Bloodgood (1987). Bailey (1978) studied the stratigraphy and petrology of volcanic rocks to the south and Morton (1976) worked on both the volcanic and intrusive rocks and associated copper mineralization to the southeast. University theses on the QR deposit include completed studies by Melling (1982) and Zwicker (1987). Current work by the British Columbia Ministry of Energy, Mines and Petroleum Resources is focusing on the geological setting and economic potential of gold and copper-gold mineralization in the Quesnel belt (Panteleyev, 1987).

The purpose of this report is to: briefly describe the geological setting of the QR gold deposit, document the distribution and types of alteration associated with gold in the deposit, and describe the mineralogy and textures of the principal alteration types with emphasis on those features which may be used to constrain an applicable genetic model.

REGIONAL GEOLOGICAL SETTING

The QR deposit is situated within the allochthonous Quesnel terrane of the Intermontane Belt near its boundary with the Omineca Belt in the Canadian Cordillera. East of the boundary, the Omineca Belt consists of Upper Proterozoic and Paleozoic psammitic and pelitic sedimentary rocks of the Snowshoe Group and deformed Paleozoic granitic intrusive rocks (Quesnel Lake gneiss) (Rees, 1981). West of the boundary the Intermontane Belt consists of Upper Paleozoic basaltic and ultramafic rocks of the Antler Formation, overlain by Lower Mesozoic phyllitic pelites (Black Phyllite) followed by basaltic volcanic, volcaniclastic and sedimentary rocks and cogenetic intrusions collectively called the Takla Group (Rees, 1987).

In the Quesnel Lake area the boundary between the two belts is marked by the west-dipping Quesnel Lake shear zone (Brown and Rees, 1981; Brown *et al.*, 1985), a thrust fault across which marked contrasts in strain and metamorphic gradients occur (Rees, 1987). This structural boundary has also been called the Eureka thrust to the north (Struik, 1986) and to the south (Bloodgood, 1987). The rocks of the Omineca Belt are highly strained by several phases of deformation and metamorphic grade increases from greenschist facies near the boundary, through garnet, staurolite-kyanite and sillimanite facies to the east (Rees, 1987). The rocks of the Intermontane Belt are at low to very low meta-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morphic grades which decrease from greenschist near the boundary (Rees, 1987) to prehnite-pumpellyite facies in the vicinity of the QR deposit to the west (Bailey, 1978). Rocks of the Antler Formation and Black Phyllite unit are strongly foliated, particularly near the Quesnel Lake shear zone. The Takla Group rocks lack evidence of penetrative deformation (Rees, 1981).

Of particular relevance to this study are a group of alkalic intrusions which form northwesterly trending linear belts, several hundred kilometres or more in length, that are largely restricted to the Intermontane Belt. The intrusions (175 to 201 Ma), typically small plugs and stocks up to a few kilometres in diameter, range in composition from syeno-gabbro to alkali syenite (Barr *et al.*, 1976). Based on geochemistry and age determinations, the intrusive rocks are interpreted to be essentially cogenetic with the volcanic rocks which they intrude (Barr *et al.*, 1976; Hodgson *et al.*, 1976; Panteleyev, 1987). The economic potential for porphyry copper and copper-gold deposits associated with this group of alkalic intrusions has been recognized for many years (Campbell and Tipper, 1970; Barr *et al.*, 1976); only recently are they being re-evaluated solely for gold potential with comparisons being drawn with the QR deposit. Chloritized biotite from diorite of the QR stock has been dated recently by potassium-argon at 201 ± 7 million years (Panteleyev, 1987).

LOCAL GEOLOGY

The QR gold deposit is located about 1 kilometre north of the Quesnel River on the crest of the north wall of a deeply incised river valley. The property (Figure 2-7-2) was originally mapped by P.E. Fox in 1976. Outcrop is sparse and consequently much of the geological information presented in Figure 2-7-2 is based on diamond-drilling data. The property is underlain by fragmental basaltic rocks and fine-grained sedimentary rocks, both of the Takla Group. The rock units strike east and dip moderately to the south. These rocks are cut by intrusive rocks of the alkalic QR stock.

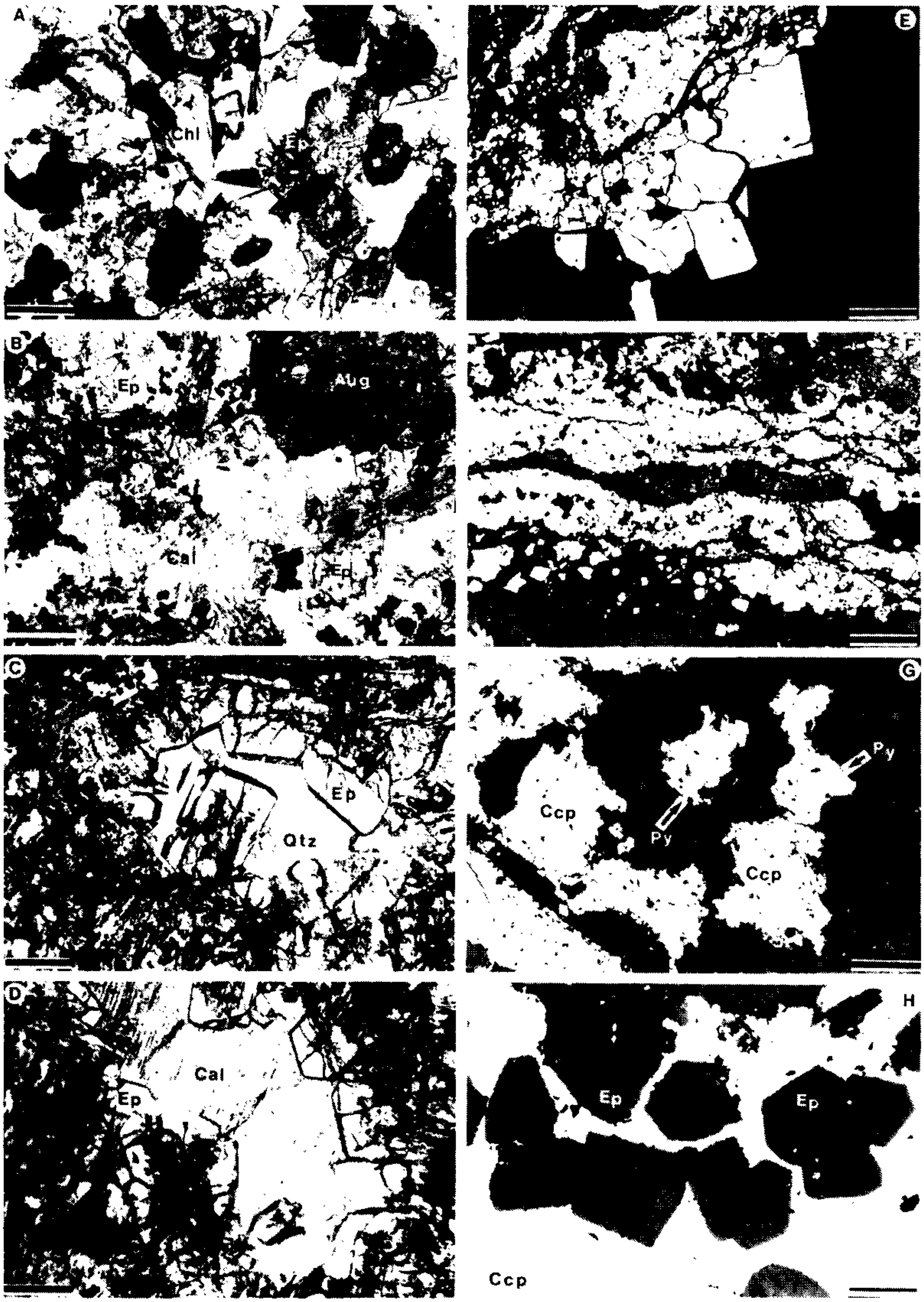
The basaltic rocks occur as layers up to 30 metres thick which are composed of subangular to rounded, lapilli and ash-sized fragments in a fine-grained matrix (Plates 2-7-1A and 2-7-1E). Locally, block-sized fragments are also present. In general, these fragmental rocks are poorly sorted and both matrix and framework-supported types exist. Rarely, both normal and reverse size-grading of the fragments occurs. Individual beds are most commonly monolithologic and the fragments are porphyritic, consisting of phenocrysts of augite, hornblende and plagioclase in an aphanitic, hyalopilitic groundmass. Augite (10 to 20 per cent) is subhedral to euhedral, optically zoned and up to 4 millimetres in size. Hornblende (2 to 20 per cent) is euhedral, prismatic, up to 4 millimetres in length and locally glomeroporphyritic. Plagioclase (1 to 25 per cent) is euhedral, lath shaped up to 2 millimetres in length, and locally aligned within individual fragments (Plate 2-7-1C). Amygdules, where present, comprise less than 3 per cent of the mode. The matrix consists of broken phenocrysts and very fine-grained, ash-sized particles and feldspar microlites.

Overlying the fragmental basalts, and partially interbedded with them, is a succession of sedimentary rocks. These rocks consist of thinly bedded black argillite and siltstone. The rocks are fine grained, locally calcareous and contain up to 7 per cent fine-grained disseminated pyrite.

The QR stock intrudes both the fragmental basaltic rocks and sedimentary rocks. It is medium grained, equigranular and consists of plagioclase (50 per cent), biotite (20 per cent), augite (15 per cent), up to 10 per cent pink feldspar and variable amounts of magnetite. The stock is about 1.5 by 1 kilometre and displays a crude concentric zonation. The diorite margin of the stock is about 100 metres thick and envelops a core of monzodiorite and rare syenite (Fox *et al.*, 1987). All rocks are cut by mafic porphyritic dykes (locally termed hornblende porphyry) which are probably related to the stock. The dykes are fine grained and contain phenocrysts of hornblende (15 per cent) and plagioclase An_31 (15 per cent) which define a trachytic texture. Country rocks near the intrusive contact are hornfelsed. The sediments are recrystallized and andradite garnet is common in the basaltic rocks.

The volcanic rocks and sediments on the property lack evidence of any penetrative tectonic fabric and structural elements are restricted to two types of faults which crosscut stratigraphy at high angles (Figures 2-7-2 and 2-7-3). The first type is characterized by several subparallel, north to northwest-striking, west-dipping normal faults which progressively lower the hangingwall to the west. The second type comprises the youngest structural features on the property. Wally's fault strikes north-northwest and dips 20 degrees to the southeast. It is a reverse fault which truncates the Main zone and displaces the hangingwall about 240 metres to the southwest. The West zone fault is a thrust which strikes northwest and dips 35 degrees to the southwest. Displacement of the hangingwall is estimated to be at least 500 metres to the northeast (Fox *et al.*, 1987). Both faults are characterized by anastomosing, foliated, chlorite-rich gouge and fracture zones.

Plate 2-7-1. Photographs of polished slabs and diamond-drill core from the Main zone: (A) Typical, least-altered, matrix-supported, fragmental basalt. Note the porphyritic texture. (B) Strongly carbonatized, fragmental porphyritic basalt. Note the carbonate matrix which surrounds the fragments and carbonate-infilled drusy cavity. (C) Weaky propylitized fragmental basalt in which the fine-grained matrix has been completely altered to the propylitic mineral assemblage. Note the large relict fragments of porphyritic basalt which contain aligned hornblende phenocrysts. (D) Strongly propylitized fragmental basalt. Note the complete absence of relict unaltered clasts and the presence of disseminated pyrite. (E) Typical, least-altered, matrix-supported, fragmental basalt. (F) Strongly carbonatized, fragmental basalt. Note the carbonate matrix which surrounds the fragments. (G) Strongly carbonatized fragmental rocks. Note the presence of both carbonate cement and carbonatization of the fine-grained basaltic matrix which surrounds the fragments. (H) Strongly carbonatized fragmental basalt containing broken fragments of colloform-textured pyrite. Carbonatization is manifested by the partial replacement of both fragments and matrix.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ALTERATION TYPES AND GOLD DISTRIBUTION WITHIN THE FRAGMENTAL BASALTIC ROCKS

Gold concentrations occur in an alteration halo of variable intensity which extends up to 300 metres into the fragmental basaltic rocks north of the QR stock. The deposit consists of two discrete zones about 800 metres apart (Figure 2-7-2). The West zone is a tabular conformable sulphide body which occurs in propylitically altered fragmental basaltic rocks. It is underlain by variably altered propylitic rocks and overlain by bedded siltstone, argillite and, locally, weakly carbonatized fragmental basaltic rocks. In the Main zone (Figure 2-7-3), highest gold grades occur adjacent to an abrupt, discordant alteration front between the auriferous, propylitically altered fragmental basaltic rocks and barren, strongly carbonatized fragmental basaltic rocks. The deposit is overlain by bedded siltstone and argillite and bounded to the east and at depth by the west-dipping, reverse Wally's fault (Figure 2-7-4).

Four distinct types of alteration are recognized in the rocks adjacent to, and comprising, the QR deposit. These are: weakly carbonatized, strongly carbonatized, weakly propylitized and strongly propylitized. The following discussion of the distribution of alteration types and the mineralogy and

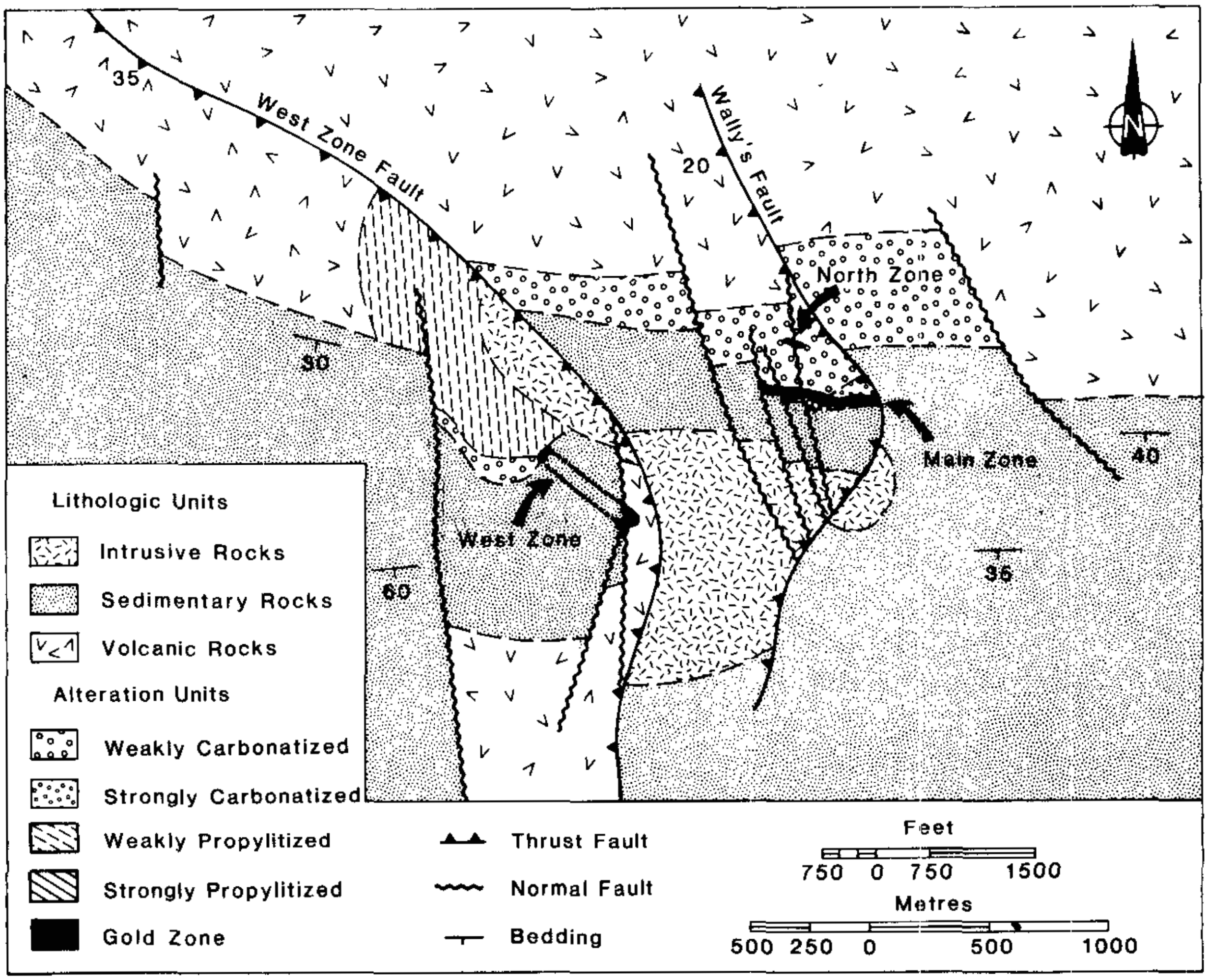


Figure 2-7-2. Geology of the Quesnel River property showing the distribution of lithologic and alteration units, structural features and the location of gold zones (modified after Fox *et al.*, 1987).

Plate 2-7-2. Photomicrographs of the mineralogy and textures in altered fragmental rocks from the Main zone. Mineral abbreviations after Kretz (1983). (A) Bowtie-textured chlorite with epidote, quartz and calcite. Sample 180-21-38.4, strongly propylitized. Transmitted light, crossed nicols. Scale bar = 0.4 mm. (B) Sparry interstitial calcite, euhedral epidote and relict augite phenocryst. Sample QR-8-108.2, strongly propylitized. Transmitted light, crossed nicols. Scale bar = 0.4 mm. (C) Euhedral epidote surrounding and projecting into interstitial quartz. Sample QR-8-37.3 strongly propylitized. Transmitted light, crossed nicols. Scale bar = 0.4 mm. (D) Euhedral epidote surrounding and projecting into sparry interstitial calcite. Sample QR-8-37.3, strongly propylitized. Transmitted light, crossed nicols. Scale bar = 0.4 mm. (E) Adjacent euhedral and anhedral-textured pyrite. Sample QR-8-24.3, strongly propylitized. Reflected light. Scale bar = 0.4 mm. (F) Banded anhedral pyrite. Sample QR-8-24.3, strongly propylitized. Reflected light. Scale bar = 0.4 mm. (G) Anhedral chalcopyrite aggregates rimmed by small euhedral pyrite grains. Sample 180-21-38.4, strongly propylitized. Reflected light. Scale bar = 0.2 mm. (H) Epidote euhedra engulfed by irregular anhedral chalcopyrite aggregate. Sample 180-21-36.1, strongly propylitized. Reflected light. Scale bar = 0.4 mm.

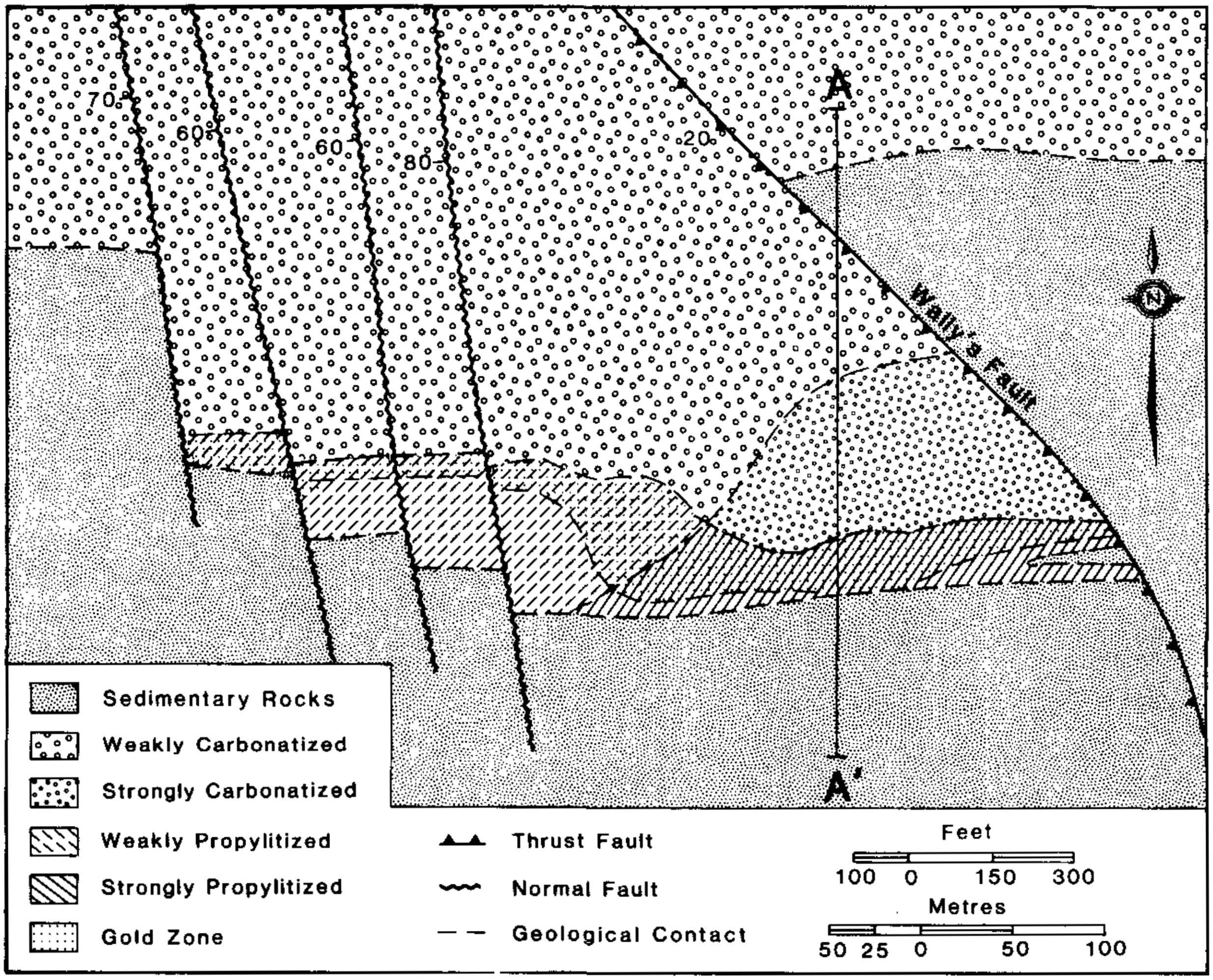


Figure 2-7-3. Geology of the Main zone of the Quesnel River (QR) gold deposit; cross-section A-A′ is shown in Figure 2-7-4 (modified after Fox *et al.*, 1987).

textures which characterize them is restricted to the Main zone of the QR deposit. The mineralogy was determined optically and checked using a combination of staining techniques, X-ray diffraction and microprobe analysis.

PROPYLITICALLY ALTERED FRAGMENTAL ROCKS

The weakly and strongly propylitized alteration types are gradational and reflect the intensity of textural and mineralogic changes of the host rocks. Their hydrothermal mineral assemblages are similar, but their modal proportions vary. Gold is associated with both types of alteration. Figure 2-7-4 illustrates the distribution of primary lithologies, alteration types, structural features and gold.

The weakly and strongly propylitized rocks form thick, interlayered, laterally extensive units which have the same attitude as the overlying and interbedded sedimentary rocks. Due to the intensity of propylitic alteration, subdivision into primary lithologic units was not possible; however, since the degree of hydrothermal alteration is always in part a function of permeability, the distribution of the propylitic alteration types is interpreted to reflect the original stratigraphy. The strongly propylitized fragmental rocks had a greater permeability due to variations in matrix to fragment ratio, fragment size, phenocryst abundance and degree of induration.

Plate 2-7-1C is a typical specimen of of weakly propylitized fragmental basalt. The matrix has been completely altered to the propylitic assemblage and reaction rims are developed around the fragments. Relatively unaltered phenocrysts of augite and hornblende persist within the fragment interiors. Plate 2-7-1D illustrates strongly propylitized fragmental basalt in which vestiges of primary fragments are obscure. The rock has a granular texture and disseminated sulphides are more abundant in this specimen.

The alteration minerals which characterize the propylitic assemblage include: epidote (50 per cent), chlorite (20 per cent), calcite (15 per cent), quartz (10 per cent), tremolite (5 per cent) and traces of clinozoisite. Epidote euhedra (about 1 millimetre in size) are optically zoned and microprobe data indicate that iron content increases systematically within individual grains from core to rim. The abundance of epidote and its uniform grain size give these rocks their green colour and granular texure at the hand-specimen scale. Epidote is an alteration product of augite, hornblende and plagioclase.

Chlorite occurs as irregular fan-shaped aggregates which display sweeping extinction (Plate 2-7-2A) and two different anomalous inteference colours. Berlin blue colours are characteristic of chlorite disseminated in the silicate-rich groundmass. Iron content in this type of chlorite is high and FeO/FeO + MgO ratios average 0.65. Locally chlorite aggregates which display greenish grey birefringence are completely engulfed by sulphides. These are interpreted to have much lower FeO/FeO + MgO ratios. Chlorite replaces both augite and hornblende.

Both quartz (Plate 2-7-2C) and calcite (Plates 2-7-2B and D) form large (>2-millimetres) interstitial patches within the altered groundmass. These segregations consist of medium to coarse-grained interlocking crystals. Commonly, epidote euhedra project into or occur isolated within the interstices. Little or no iron is present in calcite. Calcite replaces augite, hornblende and plagioclase phenocrysts and microlites. *Quartz is an alteration product of augite and hornblende.* Tremolite occurs as curved, parallel fibrous aggregates and is probably an alteration product of hornblende.

CARBONATIZED FRAGMENTAL BASALTIC ROCKS

The weak and strong carbonatization is also gradational and reflects variations in the modal abundance of calcite. Megascopically, the rocks locally consist of lapilli and ash-sized fragments in a coarse-grained calcite cement (Plates 2-7-1F and G). Irregular seams of calcite-cemented fragments and calcite-filled drusy cavities rimmed by fine-grained sulphides also occur (Plate 2-7-1B). In many cases calcite occurs as a pervasive replacement of phenocrysts, groundmass and matrix where veinlets of calcite are common. In Melling's (1982) detailed petrographic study of the strongly carbonatized rocks intersected by diamond-drill hole QR-7, he subdivided them into individual stratigraphic units characterized by their phenocryst assemblages, fragment sizes and shapes, grading and fragment/matrix ratios.

In thin section the carbonatized rocks are seen to consist of vitrophyric fragments cemented by coarse interlocking calcite. Grain boundaries are distinct and crystal dimensions are a function of the sizes of the interstices. The calcite cement may comprise up to 15 per cent of the volume of the rocks. In diamond-drill hole QR-7, the carbonate-cemented fragmental rocks are restricted to the upper half of the strongly carbonatized unit (Figure 2-7-4).

Calcite also occurs in variable quantities as a replacement product of phenocrysts, groundmass and matrix to the fragments. Phenocrysts of augite, hornblende and plagioclase are altered along cleavage traces and grain boundaries. In the groundmass and the matrix, calcite occurs in fine-grained patches which display diffuse grain boundaries. Bifurcating calcite veinlets are particularly abundant in rocks lacking calcite cement. These are locally cut by veinlets containing prehnite, stilbite and calcite.

SULPHIDE MINERALOGY

Sulphide minerals occur in all four types of alteration recognized in the Main zone, but are most common and

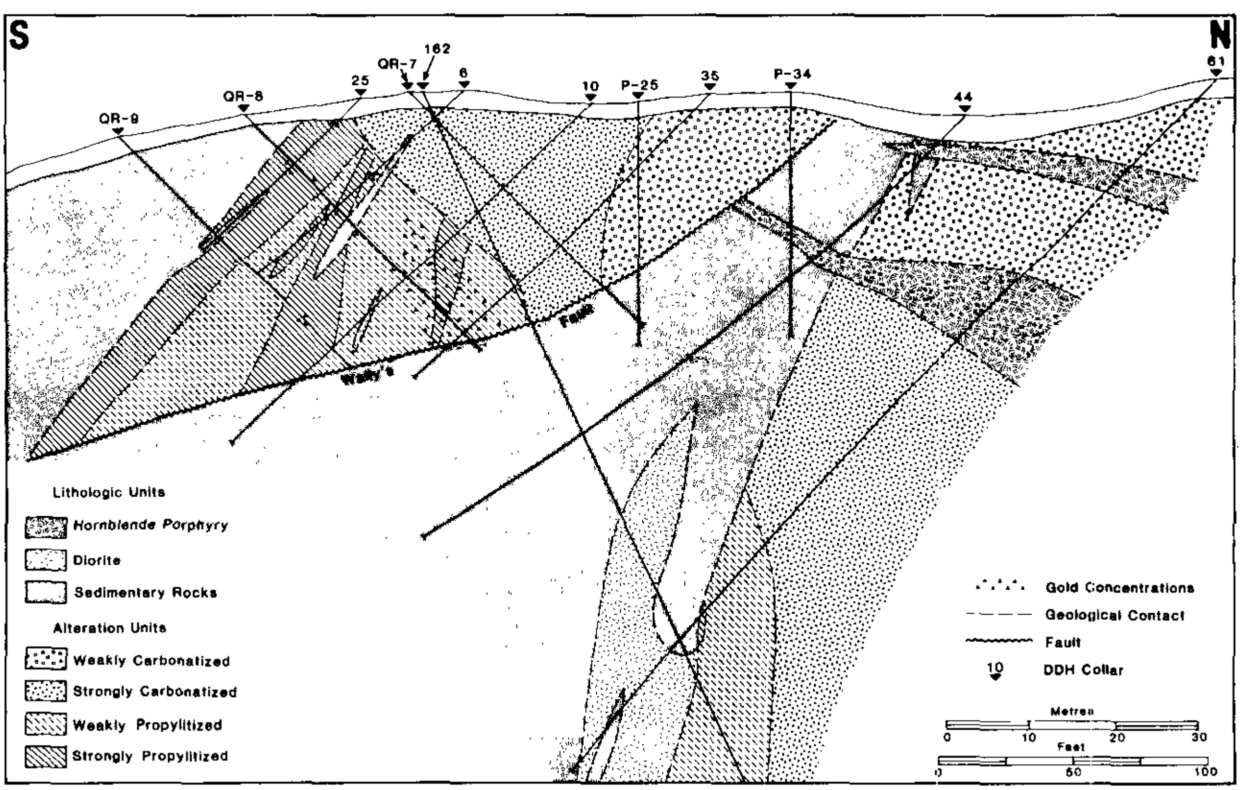
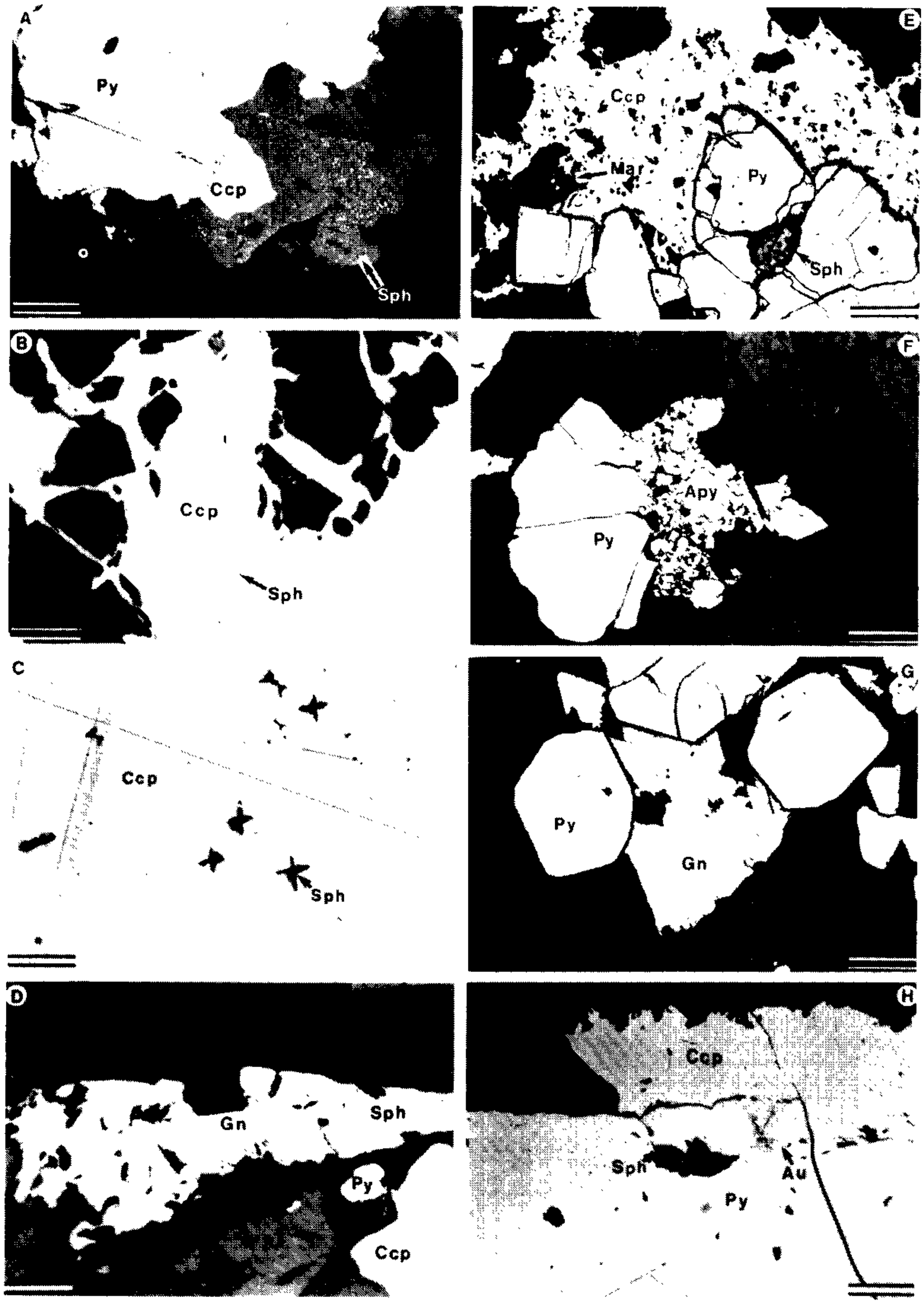


Figure 2-7-4. Cross-section A-A′ looking west through the Main zone of the Quesnel River (QR) gold deposit. Location of cross-section is shown in Figure 2-7-3 (modified after Fox *et al.*, 1987).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Py

abundant in the strongly propylitized fragmental rocks. The more significant sulphide textural relationships, which may be used to constrain the genesis of the deposit, are summarized here for both the carbonatized and propylitized fragmental rocks.

The only sulphide present in the barren carbonatized rocks is pyrite which averages 1 or 2 per cent and rarely comprises up to 7 per cent of the mode. It is common as small subhedra and euhedra homogeneously disseminated within the ash and lapilli-sized fragments. It also occurs at the grain boundaries of altered phenocrysts and rims fragments. Small bifurcating veinlets are also present.

Of particular significance are the framboidal and colloform-textured pyrite in the carbonatized rocks. The framboidal pyrite occurs as equant isolated grains, in clusters (Plate 2-7-4E) and elongate aggregates (Plate 2-7-4F). The colloform-textured pyrite grains are broken and occur at both the microscopic (Plates 2-7-4G and H) and megascopic scales (Plate 2-7-1H). These textural relationships indicate that in the carbonatized rocks, pyrite nucleation and growth occurred in extremely porous host rocks which were susceptible to additional reworking.

The propylitically altered fragmental rocks from the Main zone contain variable amounts of sulphide minerals and gold. Sulphides may comprise up to 40 per cent of the mode and include abundant pyrite and chalcopyrite, lesser sphalerite, rare arsenopyrite, marcasite, galena, pyrrhotite and gold. In the specimens studied, the sulphides typically occur in fine to coarse, irregularly shaped, ragged disseminations and clots up to 1 centimetre in size.

Pyrite comprises about 60 per cent of the total sulphides present, but locally up to 97 per cent of the mode. The smallest grains are euhedral and disseminated, while the larger grains are subhedral to euhedral, moderately fractured and tend to occur in aggregates (Plate 2-7-2E). Rarely, small veinlets of fine-grained pyrite are also present (Plate 2-7-2F). The pyrite locally contains small inclusions of gangue, chalcopyrite, sphalerite and pyrrhotite. These inclusions are generally elliptical to circular. Rare composite inclusions of chalcopyrite/sphalerite and chalcopyrite/pyrrhotite are also present. As there is no evidence to support replacement of other sulphides by pyrite, these textures are interpreted to indicate contemporaneous growth of pyrite and the included sulphides.

Smooth grain boundaries are common where epidote euhedra project into pyrite. Additional smooth and irregular mutual grain boundary relationships occur with chalcopyrite, sphalerite, galena and arsenopyrite (Plates 2-7-3A, E, F and G). In no instance was framboidal or colloform-textured pyrite observed in the propylitically altered rocks.

Chalcopyrite locally comprises up to 40 per cent of the sulphide mode. It generally occurs in ragged, irregular grains of variable size (Plate 2-7-3E) and rarely infills fractures in pyrite. Inclusions of sphalerite are common and locally display delicate stellar and dendritic shapes (Plate 2-7-3C). Small pyrite euhedra occur disseminated within the chalcopyrite and along the perimeter of some of the larger grains (Plate 2-7-2G). Epidote euhedra commonly project into and are locally completely engulfed by chalcopyrite (Plate 2-7-2H). Sphalerite occurs as elongate inclusions within chalcopyrite adjacent and parallel to epidote grain boundaries.

Sphalerite may comprise up to 5 per cent of the sulphide mode. Small blebs and rods of chalcopyrite are very common within most sphalerite grains and rarely display crude crystallographic alignment (Plates 2-7-3A, D and H). Sphalerite is most closely spatially related to chalcopyrite, but isolated grains also occur within the silicate/carbonate gangue. Sphalerite grains which are free of chalcopyrite blebs are rare. In one case intergrowths of chalcopyrite-free sphalerite and sphalerite containing chalcopyrite blebs are present (Plate 2-7-3A). In addition, chalcopyrite-free sphalerite appears to be replacing chalcopyrite along fractures and grain boundaries (Plate 2-7-3B). These textural relationships suggest two stages of sphalerite precipitation.

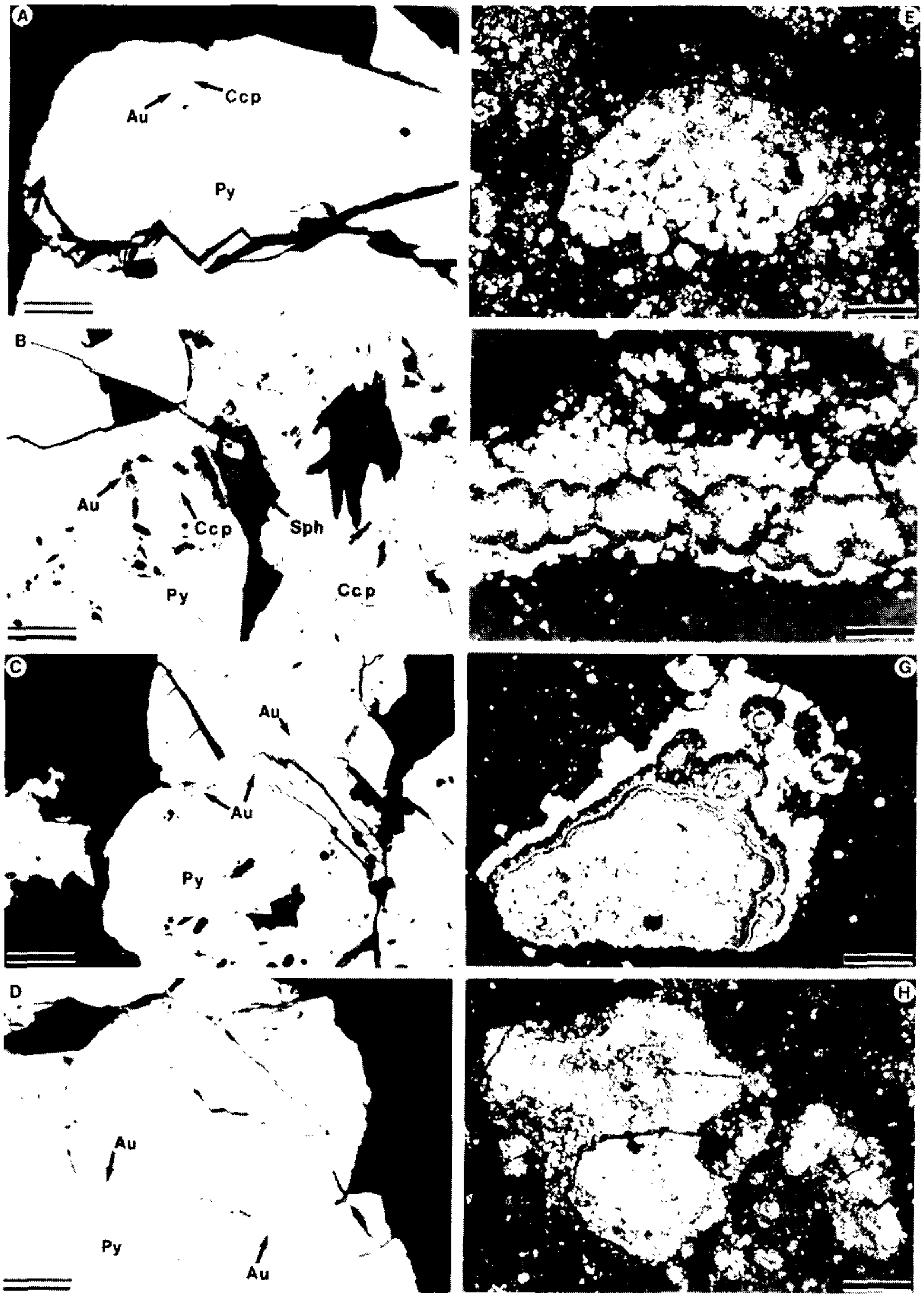
Arsenopyrite is locally present in trace quantities (<1 per cent). It occurs as inclusion-free, fractured euhedra (Plate 2-7-3F). It is most commonly associated with pyrite and either attached to it or forming adjacent isolated grains. No petrographic relationships were noted between arsenopyrite and gold although the specimens containing arsenopyrite were obtained from drill-core assay intervals grading in excess of 20 grams per tonne gold.

Marcasite occurs in trace amounts as ragged clusters adjacent to pyrite and chalcopyrite (Plate 2-7-3E). Rare, inclusion-free galena is anhedral to euhedral and most commonly associated with pyrite and sphalerite (Plates 2-7-3D and G).

Gold in sulphide-rich specimens from the Main zone has several modes of occurrence including:

- Infilling fractures in pyrite (Plates 2-7-4C and D).
- Equant inclusions in pyrite.
- Attached to pyrite grain boundaries.
- At pyrite/chalcopyrite grain boundaries (Plates 2-7-3H, 2-7-4A and B).
- Attached to chalcopyrite grains.

Plate 2-7-3. Photomicrographs of sulphides and gold in samples from the Main zone in reflected light. Mineral abbreviations after Kretz (1983). (A) Sphalerite and chalcopyrite attached to anhedral pyrite. Note the two types of sphalerite, one containing unoriented blebs of chalcopyrite and one containing no chalcopyrite inclusions. Sample 180-21-38.4, strongly propylitized. Scale bar = 0.05 mm. (B) Sphalerite replacing chalcopyrite along grain boundaries and fractures. Sample 180-21-47.4, strongly propylitized. Scale bar = 0.1 mm. (C) Stellate sphalerite inclusions in chalcopyrite. Sample 180-21-23.2, strongly propylitized. Scale bar = 0.05 mm. (D) Sphalerite, chalcopyrite, pyrite and galena. Note the unoriented chalcopyrite blebs in sphalerite. Sample 180-21-36.1, strongly propylitized. Scale bar = 0.01 mm. (E) Subhedral pyrite, chalcopyrite, sphalerite and marcasite. Marcasite is dark mottled grain on left. Sample 180-21-23.2, strongly propylitized. Scale bar = 0.04 mm. (F) Fractured arsenopyrite and pyrite. Sample 180-21-34.1, strongly propylitized. Scale bar = 0.04 mm. (G) Euhedral pyrite and galena. Sample 180-21-36.1, strongly propylitized. (H) Pyrite, chalcopyrite, sphalerite and gold. Note the unoriented chalcopyrite blebs in sphalerite and the occurrence of gold at the grain boundary between pyrite and chalcopyrite, but within the latter. Sample 180-21-38.4, strongly propylitized. Scale bar = 0.05 mm.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- Inclusions in chalcopyrite.
- Isolated grains in the silicate/carbonate gangue.

Gold grains associated with pyrite always tend to occur close to grain boundaries. These textures suggest that gold deposition occurred late in the paragenetic sequence. The gold is an unusually bright whitish yellow under reflected light. Microprobe data indicate that these grains contain about 60 weight per cent silver and are thus electrum.

RELATIONSHIPS BETWEEN THE ALTERED FRAGMENTAL ROCKS AND THE OCCURRENCE OF GOLD

The contact between the propylitically altered and carbonatized rocks is very sharp and may be seen to occur over intervals less than 1 metre and even at the thin-section scale. This alteration front is perpendicular to bedding in the sedimentary and fragmental basaltic rocks (Figure 2-7-4). The propylitic alteration decreases in intensity to the south, away from the front; to the north carbonatization decreases toward the least altered fragmental basaltic rocks. The altered rocks are locally overlain conformably by epidote and calcite-bearing sedimentary rocks and truncated at depth by the west-dipping Wally's fault. Sulphides are more abundant in the propylitically altered rocks and pyrite is the only sulphide present in the carbonatized rocks. Gold is restricted to the propylitically altered rocks. The highest gold concentrations tend to occur adjacent to the alteration front.

DISCUSSION

The preceding discussion of the Main zone of the QR deposit has focused on descriptive documentation of the geological setting, local stratigraphy, alteration types and their distribution, mineralogy and textural relationships. Based on the work completed and in light of published data and models for Canadian mineral deposits, particularly in the Cordillera, constraints may be placed on the origin of the QR deposit.

Carbonatization of the fragmental basaltic rocks appears to have occurred very early, prior to complete induration. The calcite cement and broken colloform-textured pyrite indicate that fluids rich in CO_2, and perhaps sulphur, percolated through the volcanic pile, at depth through fracture networks and at surface through unconsolidated lapilli and ash-sized basaltic fragments. Pyrite and calcite were deposited as colloform-textured aggregates and cement in open spaces in the basaltic gravel. Carbonatization is common in many Archean gold deposits, however, it commonly displays a zonation of carbonate minerals and ankerite predominates (Fyon *et al.*, 1983; Melling *et al.*, 1986). In addition, carbonatization in these deposits appears to have occurred at moderate crustal levels, in or near major zones of deformation (Colvine *et al.*, 1984; Roberts, 1987). Carbonatization associated with Cordilleran mesothermal lode gold deposits is also common, but is generally dominated by ankeritic or dolomitic carbonate assemblages which display a closer spatial relationship to gold (Nesbitt *et al.*, 1986). Cordilleran epithermal gold deposits do occur in the near-surface environment, however, carbonatization is not widespread and is restricted to being only one component of the outer propylitic alteration envelope.

The QR deposit is enriched not only in gold, silver and copper, but also contains significant concentrations of arsenic, zinc, molybdenum, antimony, vanadium, iron and magnesium, as shown by geochemical analyses of till samples (Fox *et al.*, 1987). These elemental associations are common in Archean and epithermal gold deposits and porphyry copper-gold deposts. In the QR deposit, copper content averages about 0.03 per cent (Fox, personal communication, 1987) and arsenic and zinc have been shown to occur in arsenopyrite and sphalerite respectively. Copper contents in porphyry deposits are commonly higher (0.4 to 1.0 per cent) and occur in much greater tonnages (20 million tonnes) (McMillan and Panteleyev, 1980). The volcanic class of porphyry copper-gold deposits has associated gold and silver (Sinclair *et al.*, 1982); however, grades of both are less than a tenth that of the QR deposit.

Gold:silver ratios in the Main zone of the QR deposit are about 1. This is lower than many Archean gold deposits (Kerrich, 1983) and much higher than in many epithermal gold and porphyry copper-gold deposits (Nesbitt *et al.*, 1986; Panteleyev, 1986).

In the QR deposit gold is most closely associated with sulphides in the propylitically altered rocks. Propylitic alteration assemblages are common in both epithermal gold and porphyry copper-gold deposits of the Cordillera; however, they generally form distal envelopes and are not spatially associated with the highest metallic mineral concentrations. Epidote-rich rocks are not commonly associated with Archean or Cordilleran mesothermal gold deposits.

Veining is extremely common within the zones of alteration in Archean mesothermal and epithermal gold deposits. Porphyry copper-gold deposits commonly have extensive fracture and crackle zones in which mineralization is surrounded by narrow alteration envelopes. In the Main zone of the QR deposit alteration is extremely pervasive and veining is minimal to absent.

The propylitic assemblage is at least spatially associated with the QR stock; however, the source of the gold-bearing

Plate 2-7-4. *Photomicrographs of sulphides and gold in samples from the Main zone in reflected light. Mineral abbreviations after Kretz* (1983). (A) Gold at grain boundary between pyrite and chalcopyrite but within the latter. Sample 180-21-38.4, strongly propylitized. Scale bar = 0.05 mm. (B) Composite inclusion of gold and chalcopyrite in pyrite. Sphalerite is also present. Sample 180-21-38.4, strongly propylitized. Scale bar = 0.05 mm. (C) Gold infilling fractures in pyrite. Sample 180-21-38.4, strongly propylitized. Scale bar = 0.05 mm. (D) Gold infilling a fracture in chalcopyrite. Sample 180-21-38.4. Scale bar = 0.05 mm. (E) Equant cluster of framboidal pyrite. Sample 180-30-24.7, strongly carbonatized. Scale bar = 0.2 mm. (F) Elongate aggregate of framboidal pyrite. Sample 180-30-24.7, strongly carbonatized. Scale bar = 0.4 mm. (G) Fragment of colloform-textured pyrite. Sample 180-30-24.7, strongly carbonatized. Scale bar = 0.4 mm. (H) Colloform-textured pyrite. Sample 180-30-24.7, strongly carbonatized. Scale bar = 0.4 mm.

fluids and the timing relationships with respect to carbonatization remain equivocal. Bailey and Hodgson (1979) have demonstrated that the propylitic alteration at the Cariboo-Bell porphyry copper-gold deposit occurred in part prior to cessation of phreatic volcanism. The fragmental host rocks of the QR deposit are hydroclastic breccias formed by thermal quenching or steam explosions (Melling, 1982) and carbonatization has been shown to have occurred before induration and final reworking of the host rocks. Evidence of phreatomagmatic eruptions, which would be expected if the QR stock had intruded into such a fluid-saturated volcanic pile, are lacking.

Fox *et al.* (1987) are correct in suggesting that the alteration front developed between the propylitized and carbonatized rocks would have constituted a pronounced pH-Eh barrier at the time of gold precipitation; however, the timing relationships between these two types of alteration remain unclear. The replacement of the carbonatized rocks by the propylitic assemblage would have required the removal of massive quantities of CO_2, the possibility of which remains to be demonstrated.

Future work will focus on isotopic study of the propylitically altered and carbonatized rocks from the Main zone. Calcite and pyrite samples from both types of alteration have been submitted for sulphur, carbon and oxygen isotopic analyses. These data will be used to constrain the possible sources of various components in the alteration system and the respective roles of meteoric, magmatic and seawater in the genesis of the deposit. These data may also be useful in documenting the timing relationships between the two types of alteration. The temporal relationships of the alteration types and the subjacent alkalic QR stock remain equivocal and will be the subject of further investigation. Study of the West zone deposit will also be initiated.

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British Columbia Geological Survey
Geological Fieldwork 1987

METALLIC MINERALS IN THE SILBAK PREMIER SILVER-GOLD DEPOSIT, STEWART (104B/1)

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Department of Geology,
University of Western Ontario

KEYWORDS: Economic geology, Silbak Premier, Stewart, metallic minerals, paragenesis, veins, breccias.

SUMMARY

This is a preliminary report on metallic minerals in the Silbak Premier silver-gold deposit near Stewart. Distribution and crosscutting relationships of veins on surface, underground and in drill core indicate two main vein types where silica-rich precious metal veins are crosscut by base metal veins. Samples of vein material have been collected from a number of locations spanning over 500 metres of vertical distance along a strike length of 1800 metres. Determination of individual mineral species, their composition, and spatial and temporal relationships augment descriptive work from over the past 50 years.

Veins range from silica-rich low-sulphide assemblages rich in precious metals to semimassive base metal-bearing and sulphide-rich assemblages. The precious metal veins contain polybasite, pyrargyrite, argentiferous tetrahedrite, native silver, electrum and argentite. Combined pyrite, sphalerite, chalcopyrite and galena is normally less than 5 per cent. Base metal veins contain from 20 to 45 per cent combined pyrite, sphalerite, chalcopyrite and galena with minor amounts of pyrrhotite, argentiferous tetrahedrite, native silver, electrum and arsenopyrite.

Precious metal veins are more prominent in the upper levels of the deposit and in the northeast-trending Main zone and base metal veins are dominant in the lower part of the deposit and the northwest-trending West zone. As a consequence, polybasite, pyrargyrite and argentite are concentrated in the upper parts of the deposit and base metal sulphides increase with depth and are more prevalent in the West zone. Tetrahedrite, native silver and electrum maintain relatively constant proportions within each vein type and throughout the Main and West zones.

Anhedral pyrite aggregates are intergrown and contain inclusions of sphalerite, chalcopyrite and galena. Chalcopyrite and galena are present as inclusions in sphalerite and replace sphalerite along grain boundaries. Galena forms mutual boundaries with, and is traversed by, polybasite, pyrargyrite, tetrahedrite and argentite. Minute inclusions of native silver and electrum are present in galena and silver sulphosalts, but wire silver traverses the same mineral assemblage. Idiomorphic pyrite normally contains rounded inclusions or embayments of galena, native silver, tetrahedrite and electrum.

VEIN STOCKWORKS AND BRECCIA ZONES

DISTRIBUTION AND THICKNESS

Sharply defined veins in stockworks and siliceous breccia matrix contain metallic mineral assemblages and follow a number of subparallel trends within and marginal to a potassium-feldspar porphyritic dacite. The porphyritic dacite and metal-bearing veins and breccias exhibit both conformable and crosscutting relationships with andesite and dacite country rocks of the Hazelton Group. Vein stockwork and breccia zones typically range in width from 1 to 20 metres; they have an *en échelon* continuity of over 1800 metres and a down-dip extent of greater than 500 metres.

The Silbak Premier deposit consists of two distinct breccia and vein stockwork zones that dip steeply at surface and gently at depth. The Main zone trends 050 degrees and is cut by the West zone which strikes 290 degrees.

EARLY-STAGE BRECCIA

The early-stage breccia is observed within andesite peripheral to potassium-feldspar-porphyritic dacite. This crackle breccia consists of rounded to angular fragments that vary in size from 1 to 15 centimetres. A darker matrix contains primarily pyrite, chlorite and carbonate.

The proportion of fragments may vary from less than 25 per cent up to 90 per cent. Where the proportion of fragments is low, fragments are rounded and poorly defined; with increasing density, fragments are angular and show little or no rotation.

EARLY-STAGE VEINS

The early-stage veins consist of quartz and chorite and locally have pyritic margins. They crosscut the crackle breccia, but are themselves cut by middle-stage stockwork veins. Quartz-chlorite veins are fairly narrow (0.5 to 3 centimetres), tabular and usually banded.

MIDDLE-STAGE VEINS AND BRECCIA

Middle-stage stockwork veins form irregular networks of banded veinlets that vary in thickness from 0.5 to 4 cen-

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

timetres. Matrix to the breccia is normally chalcedonic and contains patches of metallic minerals. These veins and breccias constitute the bulk of the metal-bearing stockwork and contain the highest silver-gold grades.

In general, the earliest veins are confined to the stockwork area and are quartz-rich with minor carbonate ± potassium feldspar along the margins. Locally, quartz carbonate veins and breccia matrix may contain patches of pyrite, sphalerite and galena with minor tetrahedrite, polybasite, pyrargyrite, native silver and electrum. Veins and breccias with as much as 45 per cent pyrite, galena, sphalerite, chalcopyrite, pyrrhotite, tetrahedrite, native silver and electrum cut the more quartz-rich veins.

LATE-STAGE VEINS

Late-stage veins generally occupy vertical and horizontal fractures filled by coarse-grained quartz and chlorite. They are thickest in the centre (up to 200 centimetres) and pinch out at each end. Although some crosscutting relationships are ambiguous, most late-stage veins crosscut stockwork veins in an *en échelon* pattern.

TABLE 2-8-1. VEIN RELATIONSHIPS

LATE-STAGE VEINS
(10) Quartz-chlorite ± carbonate.
(9) Quartz-carbonate ± white mica.
MIDDLE-STAGE VEINS AND BRECCIA MATRIX
(B) Base metal veins (20-45 per cent sulphides).
(8) Quartz-barite-carbonate with base and precious metal minerals.
(7) Pyrite-quartz-galena ± carbonate and K-feldspar.
(6) Quartz-carbonate ± chlorite ± pyrite ± K-feldspar.
(A) Precious metal veins (<5 per cent sulphides).
(5) Ferrocarbonate-quartz.
(4) Quartz and K-feldspar with precious and base metal minerals.
(3) Quartz-carbonate ± K-feldspar.
EARLY-STAGE VEINS
(2) Quartz-chlorite ± pyrite.
EARLY-STAGE BRECCIAS (CRACKLE AND MOSAIC BRECCIAS)
(1) Pyrite-chlorite matrix.

ORE MINERALS

The ore minerals were identified by ore microscopy and confirmed by electron microprobe and energy-dispersion spectrographic analysis. The metallic minerals are described in order of abundance.

PYRITE

Pyrite is the dominant sulphide mineral. Grain size and habit vary widely from microcrystalline aggregates to discrete euhedral grains 0.1 millimetre to 1 centimetre in size. In some base metal veins, pyrite forms distinct bands separated by discontinuous patches of gangue or base metal sulphide. Euhedral pyrite is commonly embayed and has partly or completely enclosed grains of sphalerite, galena, chalcopyrite, tetrahedrite, native silver and electrum. Fractured pyrite is infilled by ductile minerals such a sphalerite, galena, chalcopyrite and tetrahedrite.

SPHALERITE

Sphalerite is next to pyrite in abundance, occurring in both vein types. In hand specimen it has a light to medium brown colour with minor deep red and black varieties. It occurs as irregular grains 0.1 to 8 millimetres across or as narrow infillings between pyrite grains and filling fractures within grains. Sphalerite commonly occurs with galena, forming smooth mutual boundaries, however, some galena is included within sphalerite grains or forms ragged rims around them.

Many of the sphalerite grains contain inclusions of chalcopyrite 0.5 to 5 microns across (Plate 2-8-1). These inclusions vary from rounded to rectangular in shape and are fairly uniformly distributed. Most inclusions are randomly oriented, but some exhibit straight ordered patterns parallel to crystallographic axes.

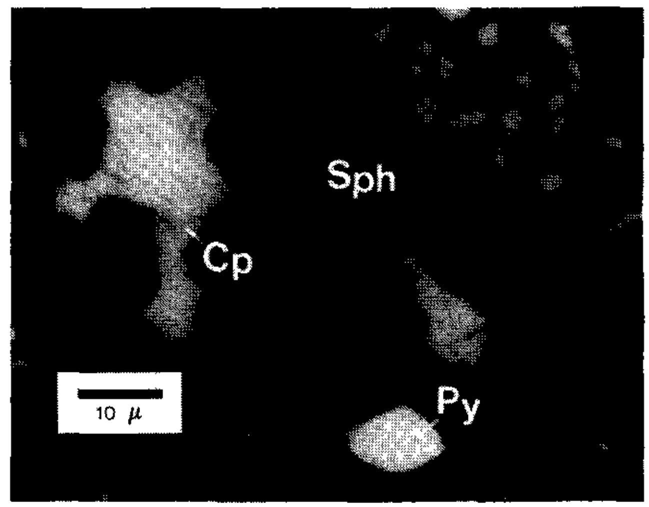

Plate 2-8-1. SP-219-A, ragged chalcopyrite (Cp) and rounded pyrite (Py) inclusions in sphalerite (Sph). Reflected light, oil immersion.

CHALCOPYRITE

Chalcopyrite is a relatively minor component in base metal veins, but can reach concentrations of up to 4 per cent. Large

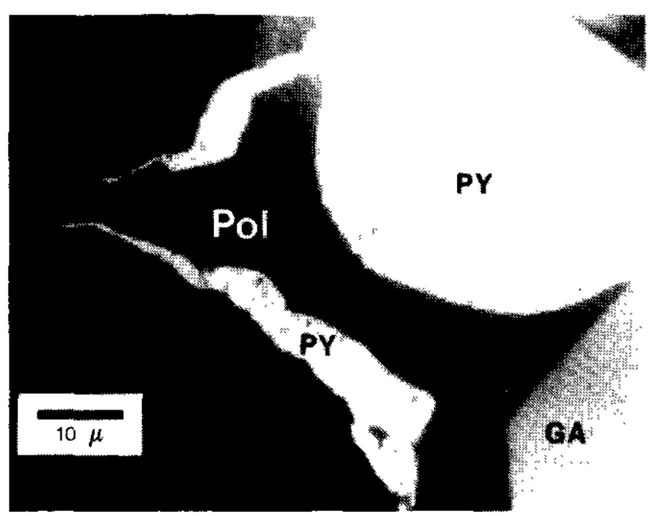

Plate 2-8-2. SP-182-A, polybasite (Pol) has smooth mutual boundaries with pyrite (Py) and galena (Ga). Pyrite partly encloses polybasite. Reflected light, oil immersion.

(0.5 to 10 millimetres) irregular grains of chalcopyrite have mutual boundaries with sphalerite, galena and pyrrhotite. Chalcopyrite aggregates fill voids within pyrite and form veinlets within quartz. In precious metal veins, chalcopyrite is almost exclusively present as inclusions in sphalerite.

POLYBASITE

Polybasite is the most abundant silver mineral and is largely confined to precious metal veins. It normally forms irregular aggregates and is intergrown with galena, pyrargyrite, tetrahedrite and pyrite (Plate 2-8-2). Locally polybasite is present as minute inclusions (5 to 25 microns) in tetrahedrite. Native silver rims and veins polybasite and may form random inclusion patterns.

TETRAHEDRITE

Argentiferous tetrahedrite has been identified in both base and precious metal veins. It forms irregular grains (0.05 to 2.0 millimetres) that have mutual boundaries with galena, polybasite and pyrargyrite. Inclusions and replacement textures of tetrahedrite are observed in galena and sphalerite. Native silver rims and veins tetrahedrite or forms minute inclusions within it.

GALENA

Galena normally makes up less than 1 per cent of the vein material, but may constitute up to 10 per cent. It occurs as irregular euhedral grains from 20 microns to 1 centimetre in width, or as narrow streaks in fractured pyrite.

Galena is closely associated and has mutual boundaries with polybasite, pyrargyrite, argentite and tetrahedrite. Crystals of galena are partly replaced by polybasite and tetrahedrite, and are cut by veinlets of native silver and argentite (Plate 2-8-3). In some instances, galena contains small inclusions of silver.

NATIVE SILVER

Native silver is present as minute inclusions in pyrite and galena, or as free grains in quartz. It also forms replacement rims and traverses grains of polybasite, pyrargyrite and tetrahedrite (Plate 2-8-4).

ELECTRUM

Electrum is the principal gold-bearing mineral. Irregular blebs, 10 to 30 microns in size, are normally inclusions in pyrite and, to a lesser extent, galena. Larger gashes, up to 5 millimetres long, cut quartz-rich patches or vuggy sulphide-rich concentrations. Electrum is present in both precious and base metal-rich ores.

PYRARGYRITE

Pyrargyrite forms irregular grains that are intimately intergrown with polybasite. It is normally a minor constituent and is confined to precious metal veins.

ARGENTITE

Argentite is a minor constituent and occurs exclusively with galena. Normally galena and argentite have sharp mutual boundaries.

ARSENOPYRITE

Arsenopyrite is a very minor component of base metal veins occurring as small (0.1 to 0.3 millimetre) rectangular to subhedral crystals. They are normally free grains, but in places can be composite grains with pyrite and less commonly chalcopyrite and galena.

PYRRHOTITE

Pyrrhotite is a minor component of base metal veins. It is closely associated with pyrite, rimming and infilling fractures within it.

INTERPRETATION

The interpreted age relationships of the metallic minerals are based on spatial associations and replacement textures as they appear in polished sections. The paragenesis diagram

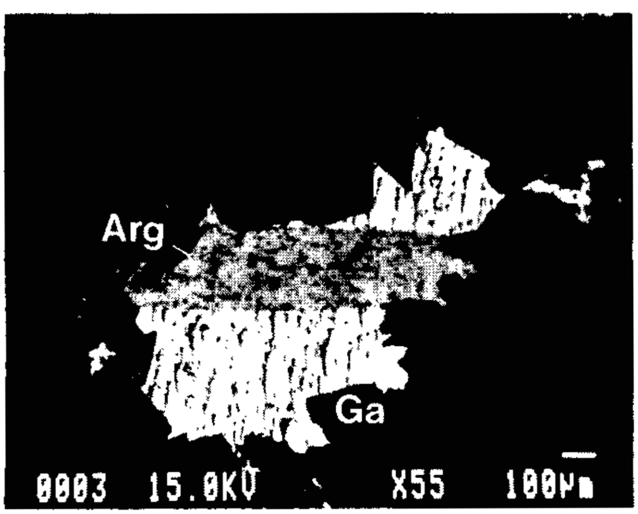

Plate 2-8-3. SP-182-B, narrow veinlet of argentite (Arg) traverses a grain of galena (Ga). SEM backscatter electron photograph.

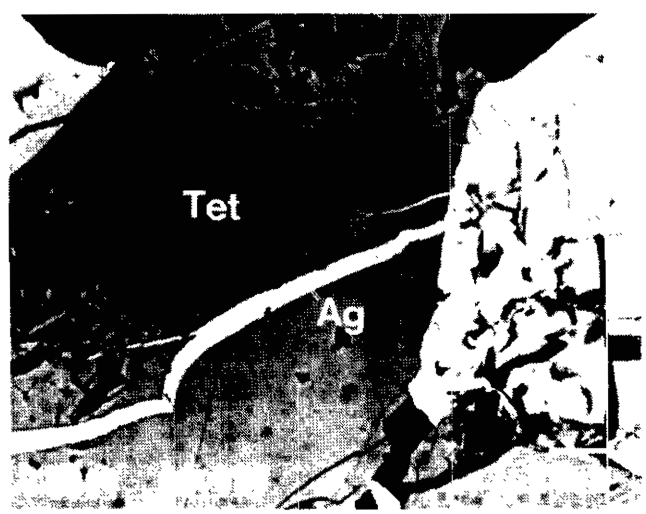

Plate 2-8-4. SP-1088-C, native silver (Ag) veinlets traverse polybasite (Pol) and tetrahedrite (Tet). Tetrahedrite and polybasite have smooth mutual boundaries. SEM backscatter electron photograph.

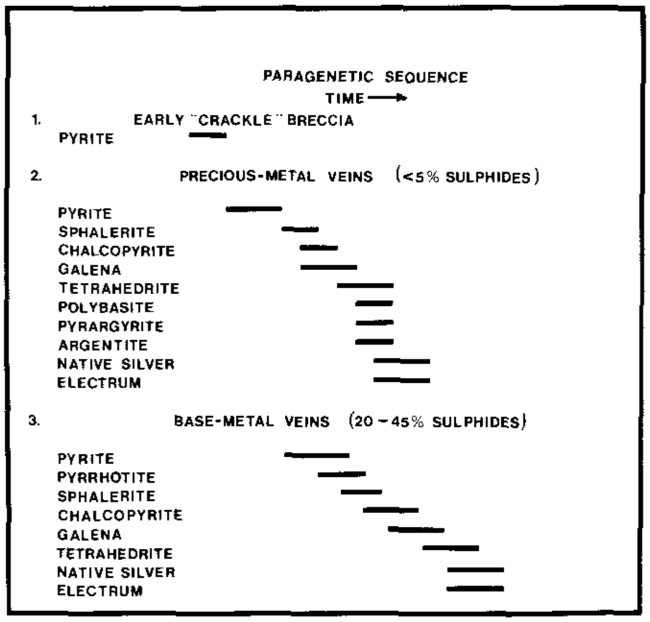

Figure 2-8-1. Paragenetic sequence, Silbak-Premier silver-gold deposit.

(Figure 2-8-1) is vein specific. Sulphide minerals precede sulphosalts and native elements in both vein types.

Some textural relationships described may have resulted from deformation in which more brittle minerals, such as pyrite, were brecciated or formed porphyroblastically. More ductile minerals, such as sphalerite, galena and chalcopyrite, may have been redistributed, obscuring original textures.

CONCLUSIONS

This study has identified a series of temporal veining relationships and the presence of specific silver and gold-bearing minerals. Base metal veins, containing 20 to 45 per cent sulphide minerals, are later than precious metal veins which have less than 5 per cent sulphides. In general, base metal-rich veining is more prominent in the lower parts of the deposit and in the West zone. Precious metal veins tend to be more prevalent closer to surface and in the northeast-trending Main zone.

Base metal sulphides, tetrahedrite, electrum and native silver are observed in both vein types, however, polybasite, pyrargyrite and argentite are confined to precious metal veins. The paragenetic sequence indicates a trend of sulphide-rich minerals to sulphosalts and native elements in both vein types.

ACKNOWLEDGMENTS

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MIDWAY SILVER-LEAD-ZINC MANTO DEPOSIT, NORTHERN BRITISH COLUMBIA* (104O/16)

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KEYWORDS: Economic geology, Midway silver-lead-zinc deposit, McDame Group, skarn, manto, sulphide paragenesis, zoning, Cassiar platform.

INTRODUCTION

The Midway silver-lead-zinc deposit, in map area 104O/16, is 10 kilometres south of the British Columbia – Yukon border and about 80 kilometres west-southwest of Watson Lake, Yukon Territory. The deposit is centred at latitude 59°55′ north, longitude 130°20′ west. Mineralization consists of irregular, pipe-like, open-space filling and replacement massive sulphide bodies in mid-Devonian McDame Group carbonates beneath a major unconformity. Reserves are currently estimated at 1.185 million tonnes grading 410 grams per tonne silver, 9.6 per cent zinc and 7.0 per cent lead (Exploration in British Columbia, 1986; page A41). Regional mapping conducted during the 1986 field season showed that the deposit lies near the southern termination of a broad, north-trending extensional fault system (Tootsee River fault zone, Nelson and Bradford, 1987). This zone intersects a northwesterly trending belt of hydrothermal alteration 5 kilometres long just south of the deposit. Intense sericitic alteration and quartz veining in Devono-Mississipian Earn Group sediments, and geophysical anomalies, strongly indicate that a buried intrusive body cores the Midway hydrothermal system and underlies Brinco Hill, about 2 kilometres southeast of the Midway deposit (Figure 2-9-1). Deposit chemistry, sulphide mineralogy, isotopic signatures and preliminary temperature data indicate that Midway is an epigenetic manto deposit; potassium-argon dates and lead isotope model ages support a Late Cretaceous age of mineralization. The following highlights some of the results of ongoing studies of the Midway deposit and environs.

STRATIGRAPHY

Strata exposed east of Silvertip Creek, in the vicinity of Midway, range from Devonian to Mississippian in age (Figure 2-9-2). Miogeoclinal carbonates of Early to Middle Devonian age are unconformably overlain by Upper Devonian to Lower Mississippian (mid-Famennian to mid-Tournaisian, M. Orchard and Irwin, this volume) basinal shales and turbidites of the Earn Group. The Earn Group is structurally overlain by oceanic sediments and volcanic and intrusive rocks of the Sylvester allochthon.

McDAME GROUP

McDame Group carbonates of Middle Devonian age (Figure 2-9-2, Unit 2) paraconformably overlie Lower Devonian Tapioca sandstone (Unit 1), and outcrop on Silvertip Hill, on the south side of Silvertip Creek in the Midway portal area and on the north end of Tour Peak, south of Silvertip Hill (Figure 2-9-2). The base of the McDame grades upward from nonfetid dolostones and interbedded dolomitic quartz arenite of the upper Tapioca sandstone to alternating light and dark grey, well-laminated, locally fetid dolostones.

Total thickness of the McDame Group in the Midway area is about 350 metres. Dolomitic facies dominate the lower third of the section and consist of dark grey, fetid cryptalgal laminites and interbedded massive dolostone. The upper two thirds of the section consists of fossiliferous fetid rudstones, floatstones, wackestones and packstones, with interbedded micritic limestones. Faunal assemblages of low diversity consist primarily of stromatoporoids, with local concentrations of brachiopods, corals, crinoids, and bivalves (Mundy, 1984).

The upper McDame contact is a regional unconformity marked by topographic relief of over 100 metres. Erosional relief and widespread karsting, as manifested by spar-healed breccias, vugs and coarse spar-filled paleocaverns up to several metres across, testify to uplift and subaerial exposure of parts of the carbonate platform prior to subsidence and deposition of Earn Group basinal shales. Detailed biostratigraphic correlations suggest that uplift may have been accompanied by local block faulting (Mundy, 1984). Following regional extension and submergence of the carbonate platform in the Upper Devonian (middle Famennian), solution collapse within the karsted upper McDame accompanied deposition and diagenesis of the lower Earn. Mixed limestone and uncrenulated shale fragments in spar-healed and lime mud-filled cavities in the upper McDame are widespread. Absence of crenulation lineations developed during Jura-Cretaceous compressional deformation implies that these are premineral breccias (Nelson and Bradford, 1987). They are commonly well compacted and contain abundant stylolites both crosscutting and forming sutured clast boundaries. These stylolites probably developed by pressure solution during Earn diagenesis. Locally, well-bedded mudstones and siltstones occur within compacted shale and limestone breccias in cavities 30 metres or more below the top of the McDame, indicating that some cavities were open to the ocean floor during deposition of the Earn.

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

EARN GROUP

Lowermost Earn Group sediments consist of carbonaceous, locally calcareous or siliceous, black shales (Figure 2-9-2, Unit 3A) up to 40 metres thick. This euxinic basin facies contains a rich conodont fauna of mid-Famennian age (Orchard and Irwin, this volume). Thickness is variable over short distances, and in places the unit is missing entirely, perhaps due to depositional control by McDame paleotopography. Graphitic slickensides are common, indicating that the unit served as a detachment surface between the McDame and overlying thick, coarse siliciclastic sediments of the Earn Group (Unit 3B, below). Some thickening and thinning might therefore be structural in nature.

The black shale unit is overlain by a thick (up to 290 metres) succession of coarse sandstone, mudstone and pebble conglomerate characterized by ubiquitous normal and reverse graded bedding, load and flame structures, rip-ups, mud drapes and sole marks (Unit 3B). The sandstones are litharenites, consisting mainly of quartz, chert and shale grains. According to Gordey *et al.* (1986), the development of this turbidite succession above the euxinic basin facies occurred as a result of local uplift and erosion of miogeoclinal blocks during early Mississippian extension.

A thick succession (up to 640 metres) of argillite, siltstone, calcarenite and sandstone containing several exhalative horizons (Unit 3C) overlies the coarse turbidites of Unit 3B. Conodonts from Unit 3C give early to mid-Tournaisian ages (Orchard and Irwin, this volume). Exhalite horizons consist of orange-weathering laminated silica, barite, pyrite and, locally, sphalerite. They rarely attain thicknesses of over 1 metre in surface exposures. Discontinuous exhalites are exposed along a strike length of almost 10 kilometres southward from Midway. This probably represents a linear string of exhalative centres aligned along a basin-margin fault zone which also controlled later deposition of coarse turbidites.

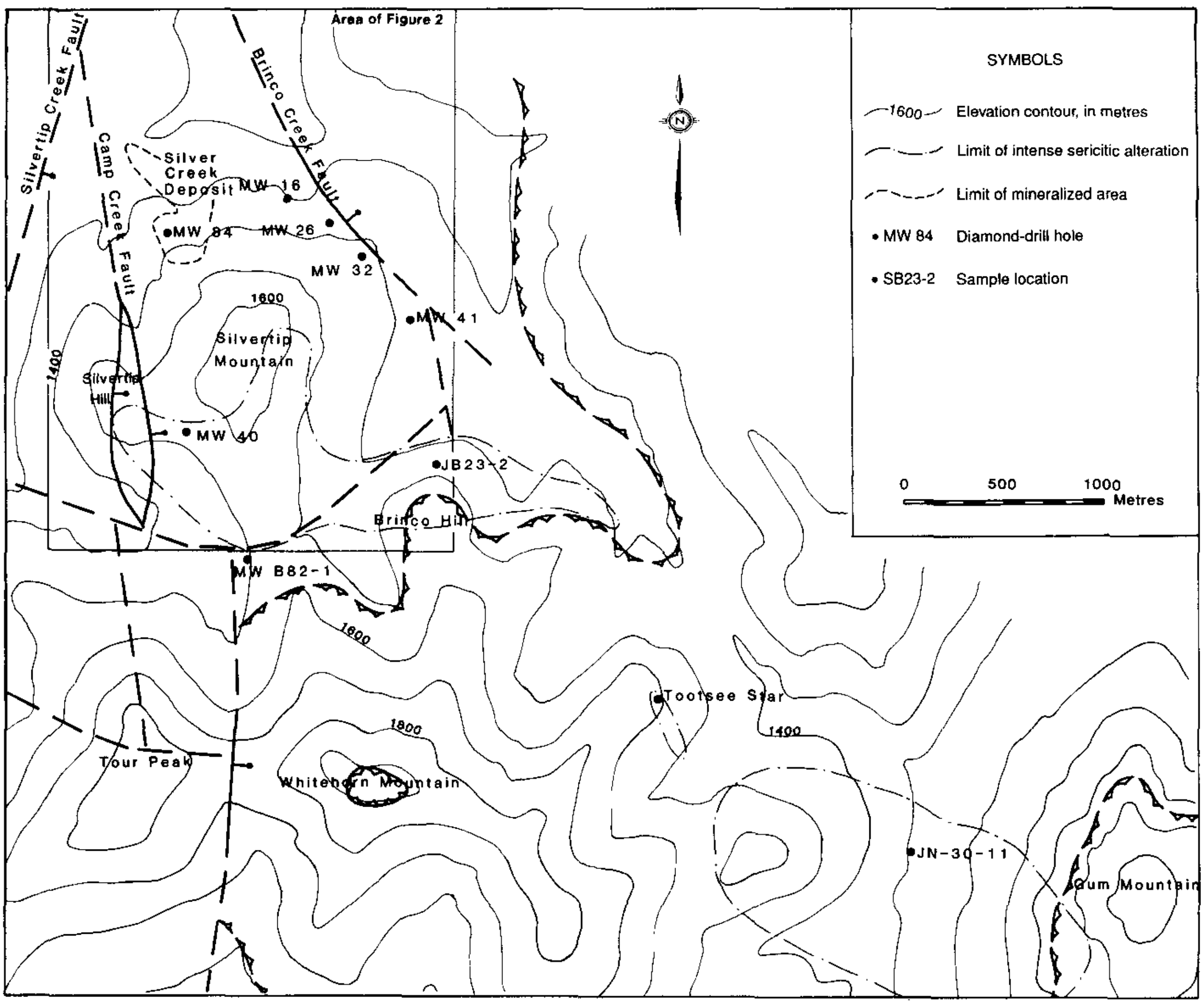

Figure 2-9-1. Midway area alteration and faulting.

A sequence of pebble to boulder conglomerate and lesser sandstone with a thickness of 150 to 200 metres (Unit 3D) overlies exhalite-bearing fine clastics on Silvertip Mountain and Tour Peak. On Tour Peak, a section of well-rounded boulder conglomerate contains clasts of McDame limestone, Tapioca sandstone, quartzite and dolostone, possibly Lower Cambrian Boya Formation quartzite, and black massive chert of undetermined origin.

The transition from fine clastics of Unit 3C to conglomerates of Unit 3D might represent a turbidite feeder channel prograding over its distal lower fan. The channel deposits are confined to the Silvertip Mountain – Tour Peak areas, with no thick conglomerate beds occurring to the south or west. Instead, thinner lensoid conglomerates are interbedded with, and overlain by, fine clastics in the Caribou Ridge area south of Tour Peak, suggesting a lateral facies change.

SYLVESTER ALLOCHTHON

A thick sequence of black argillite, limestone with black chert and green thin-bedded chert and cherty phyllite (Unit 4), assigned to Division I of the Sylvester allochthon (Nelson *et al.*, 1988), abruptly overlies Unit 3D.

STRUCTURE

The cluster of sulphide bodies at Midway which comprises the Silver Creek deposit lies mainly on the west limb of an open anticline plunging gently to the southeast (Figure 2-9-3). The east limb dips to the east at about 25 degrees, while the west limb is folded and cut by a strand of the Tootsee River fault zone. The anticlinal fold axis parallels southeasterly regional structural trends generated during Jurassic compression and emplacement of the Sylvester allochthon. Locally, a later easterly trending phase of folding deforms southeasterly trending structures. This phase is characterized by chevron and kink folds that are often accompanied by *en échelon* quartz-filled extension gashes.

Thrust faulting can be inferred from diamond drilling in the Silver Creek and Silvertip areas. In the southern part of the Silver Creek deposit (Figure 2-9-1, DDH MW 84, 86), a

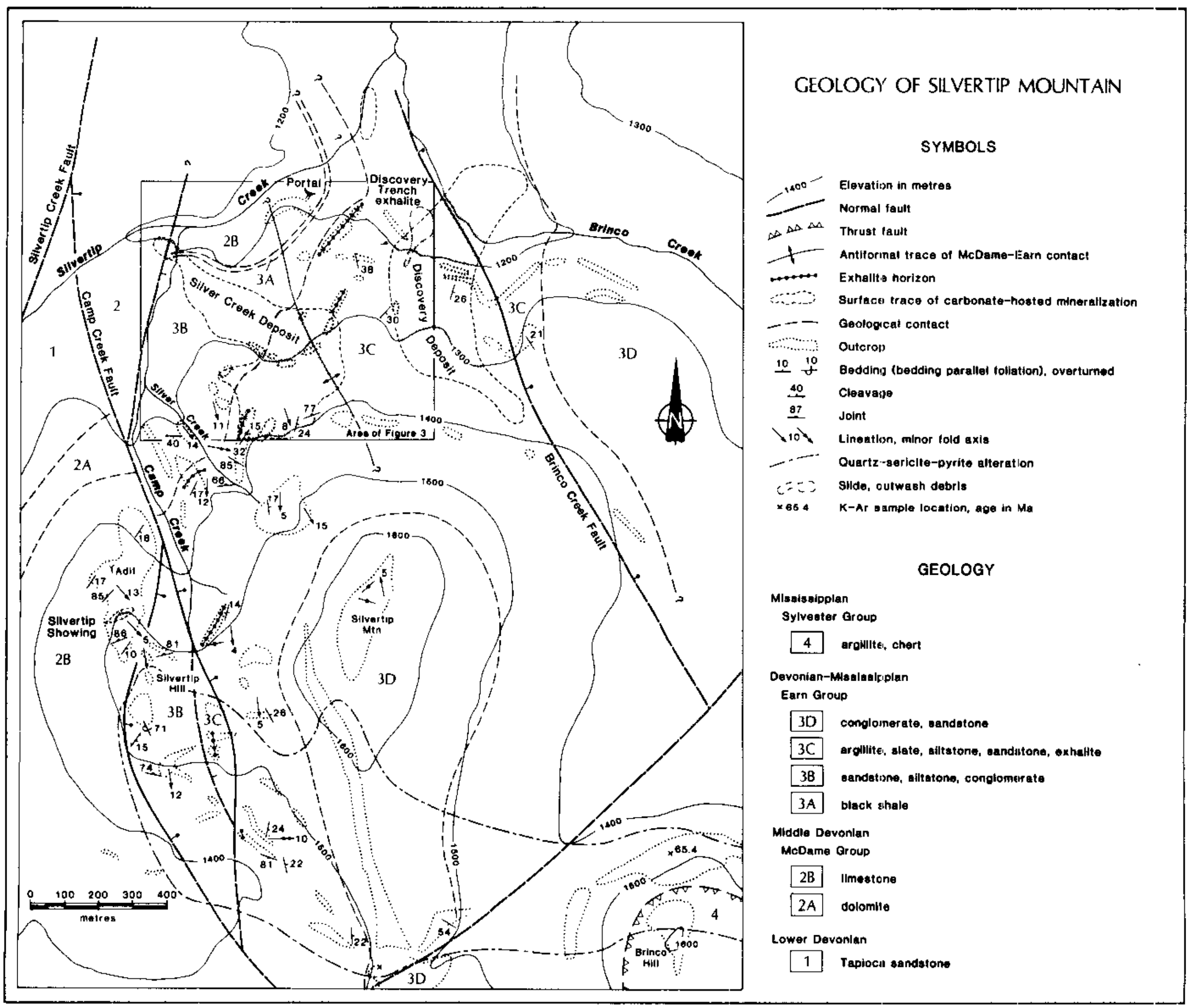

Figure 2-9-2. Silvertip Mountain area, geology.

wedge of Unit 3B is imbricated with Unit 3C above the lowermost exhalite horizon. On Silvertip Hill (DDH MW 40) McDame limestone is imbricated with Unit 3A, which has also undergone structural thickening.

The Silvertip area is cut by several strands of the Tootsee River fault zone, a northerly trending system of anastomosing high-angle faults extending from about 7 kilometres south of Midway to about 17 kilometres north of the British Columbia – Yukon Territory border (Lowey and Lowey, 1987). These include the Silvertip Creek, Camp Creek and Brinco Creek faults (Figure 2-9-1).

The Silvertip Creek fault separates Silvertip Hill and Tricorn Mountain to the west. Rotation of large blocks juxtaposed a southerly dipping panel on Tricorn Mountain with easterly dipping strata on Silvertip Hill. Because of the discordant dips and convergence of several fault strands north of Midway, stratigraphic throw increases from 50 metres west of Silvertip Hill to over 1 kilometre (Lower Cambrian Rosella Formation against Sylvester) in a narrow zone in the Silvertip Creek valley, 3 kilometres to the north.

The Camp Creek fault juxtaposes the McDame Group against Earn Group on Silvertip Hill, where it diverges into two main strands with offsets of about 50 metres, east side down. Between fault strands, Earn Group strata are disrupted and locally overturned. The Silver Creek deposit and the Silvertip showing are both adjacent to this fault zone, which may have been a channelway for hydrothermal fluids.

The Brinco Creek fault offsets strata east of the Discovery deposit, with a displacement of about 100 metres, east side down. Other faults with smaller offsets may occur west of the Brinco Creek fault. The latter appears to die out to the southeast, as the base of the Sylvester allochthon east of Brinco Hill is not offset.

Late Cretaceous (Midway) and Eocene (Butler Mountain) intrusions, as well as numerous silver-lead-zinc showings in the Rancheria district (Abbott, 1984), lie close to the Tootsee River fault zone. Overprinting of Early Mississippian exhalative and Cretaceous to Eocene intrusion-related mineralization within the zone suggests that it might represent a long-lived, periodically remobilized zone of structural weak-

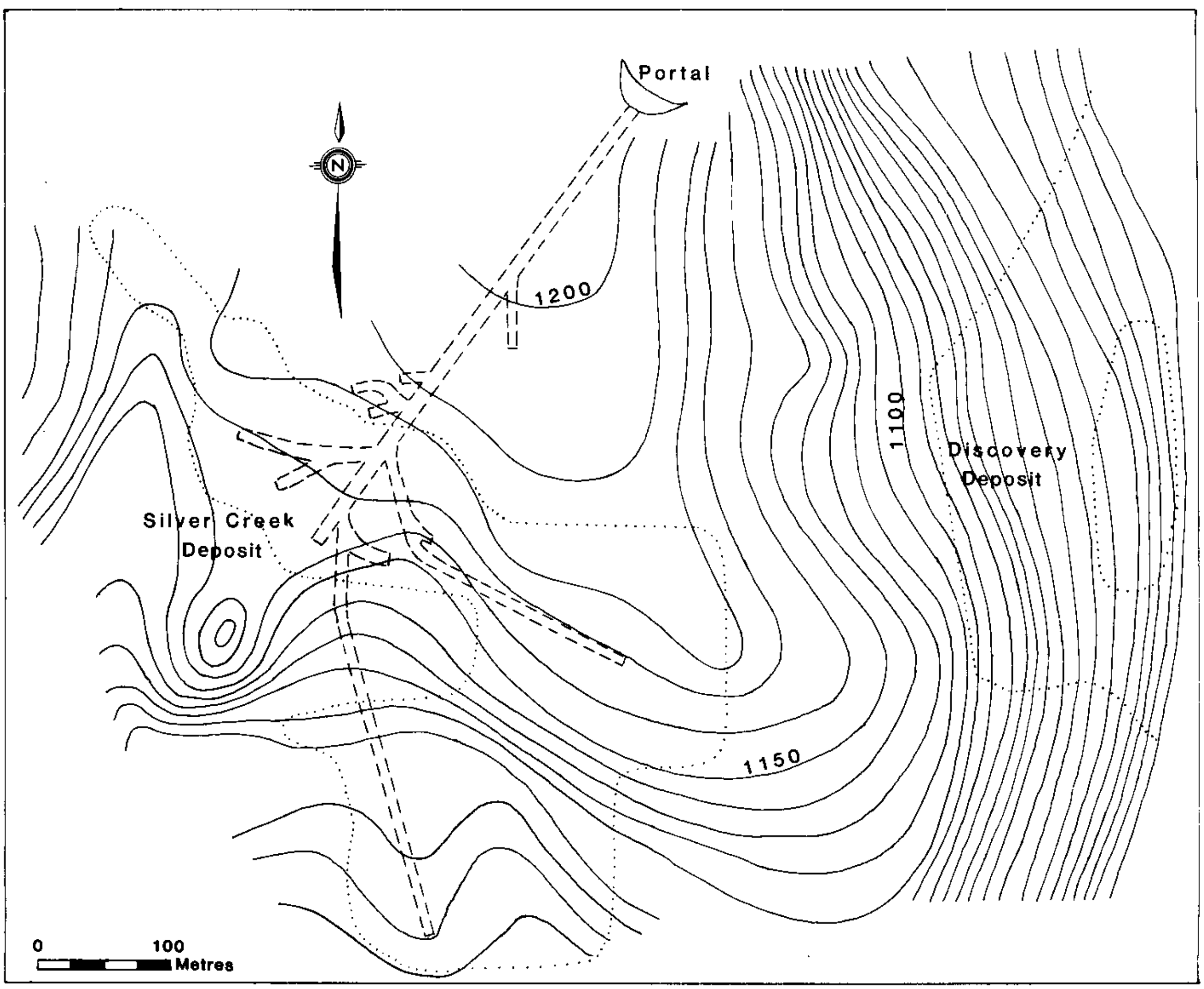

Figure 2-9-3. Elevation contours of McDame Group - Earn Group contact in Midway area.

ness and anomalous heat flow that was initiated in the Late Devonian during extension along the continental margin. Remobilization of old structures during Late Cretaceous to Eocene dextral wrench faulting could have contributed to localization of intrusions postdating the Cassiar batholith.

ALTERATION AND EVIDENCE FOR INTRUSIONS

Intense sericitization of Earn Group and Sylvester sediments occurs in a northwesterly trending zone extending from Silvertip Hill southeast for about 5 kilometres to Gum Mountain (Figure 2-9-1). Strong alteration is also evident at deeper levels in diamond-drill holes in the southeasterly part of the Midway drill grid (near DDH MW 16, 32 and 41), and south of Silvertip Mountain (near DDH B82-1). Its strongest expression is on the north side of Brinco Hill, which coincides with geophysical anomalies interpreted as consistent with a buried intrusion (J. Hylands, personal communication, 1986). At Brinco Hill, Earn Group sandstones and conglomerates are altered to sericite, quartz, pyrite, rutile and rare carbonate, with both matrix and nonsilica clasts being completely replaced. The altered sediments are cut by numerous vuggy, locally comb-textured quartz veins 1 to 10 centimetres thick containing pyrite, chalcopyrite and rare galena blebs. Isotopic analyses of galena from the alteration zone support a genetic relationship between the alteration zone and carbonate-hosted deposits at Midway.

Quartz-feldspar-biotite porphyry dykes crop out west of Gum Mountain, where they intrude intensely sericitized and pyritized argillites and cherts of the Sylvester allochthon. The dykes are commonly altered to sericite, carbonate, quartz and pyrite. Similar dykes observed during the 1987 field season in the Blue Dome map area (104P/12; Nelson *et al.*, this volume), occur as subparallel swarms associated with quartz veins in Sylvester basalts and argillites.

Alteration is associated with anomalous fluorine values Grab samples indicate that the porphyry dykes near Gum Mountain contain up to 1200 ppm fluorine, while sericitized conglomerates at Brinco Hill ran 790 ppm fluorine. Microprobe analyses of sericites from surface and drill core show averaged values for several probe sites per sample ranging from 2900 to 21 900 ppm fluorine (W.D. Sinclair, written communication, 1986). Substitution of fluorine for hydroxyl groups in micas from the alteration zone probably reflects the contribution of magmatic volatiles to the hydrothermal system centred on Brinco Hill.

Subvolcanic felsic intrusives, elevated fluorine in alteration minerals, and a geological setting within an extensional fault system adjacent to an older, voluminous intrusion (Cassiar batholith) are all features typical of A-type (anorogenic) granites (W.D. Sinclair, 1986; Collins *et al.*, 1982). The presence of tin mineralization (for example, stannite and franckeite) at Midway is also consistent with this interpretation, although tin is also associated with S-type granites Intrusions within the Cassiar platform and coeval with the Midway system include the Troutline, Kuhn and Windy stocks in the Cassiar area. Numerous silver-zinc-lead and tungsten skarns and veins, fluorine anomalies, fluorite veins and molybdenum showings are associated with the young Cassiar granites (Panteleyev, 1980). Chemistry of this intrusive suite is more typical of S-type granites, or I-type granites strongly contaminated with upper crustal material (Cooke and Godwin, 1984). In any case, volatile-rich felsic intrusives, whether of the A or S-type, are apparently fundamental to generating hydrothermal systems associated with silver-zinc-lead $\pm$ tin mineralization.

POTASSIUM-ARGON DATING

Potassium-argon dating of samples collected during mapping of map sheet 104O/16 (Nelson and Bradford, 1987)

TABLE 2-9-1
NEW POTASSIUM-ARGON DATES FROM THE MIDWAY AREA, NORTH-CENTRAL BRITISH COLUMBIA
(104D/16)

Sample No	Latitude (N) Longitude (W)	Location (Minfile Number)	Mineral	%K	^{40}Ar rad. 10^{-6} cc/g	%^{40}Ar rad / ^{40}Ar tot	Age (Ma)
JN30-11	59°53′N 130°16′W	Gum Mtn.	Sericite	5.40 ± 0.09 n = 2	14.353	92.1	67.1 ± 2.3
JB23-2	59°54′N 130°16′W	Brinco Hill	Sericite	5.57 ± 0.01 n = 2	14.420	92.0	65.4 ± 2.3
KG28-7	59°59′N 130°28′W	Lucky showing (MI 104-033)	Muscovite	8.67 ± 0.04 n = 2	36.411	92.6	105 ± 4
JB26-12	59°56′N 130°29′W	Amy showing (MI 104-004)	Muscovite	7.38	28.662	93.3	97.3 ± 3.4

K analyses by D. Runkle, The University of British Columbia.
Ar analyses by J. E. Harakal, The University of British Columbia.
Decay constants (Steiger and Jager, 1977):
$= 4.96 \times 10^{-10} yr^{-1}$
$= 0.581 \times 10^{-10} yr^{-1}$.
$^{40}K/K = 0.01167$ atomic per cent.
Errors are one standard deviation.

focused on intrusions and alteration associated with silver-lead-zinc mineralization (Table 2-9-1). Two samples from the alteration zone southeast of Midway were dated (Figure 2-9-1, JN30-11 and JB23-2), as well as one from a late intrusion less than 100 metres from surface exposures of sulphide bodies at the Amy property (JB26-12), and one from sericite envelopes around galena-rich quartz veins at the Lucky showing, hosted in the Cassiar batholith (KG28-7).

The Midway samples include sericitized Earn Group sediments from Brinco Hill (Table 2-9-1, Sample JB23-2), and a sericitized quartz feldspar porphyry dyke near Gum Mountain (Sample JN30-11). These both give a Late Cretaceous age, interpreted as the age of alteration. The alteration is apparently due to emplacement of a buried comagmatic stock.

The intrusion sampled at the Amy property, a silver-lead-zinc replacement deposit in Cambro-Ordovician Kechika Group marbles and calc-silicates, is a tourmaline-bearing equigranular muscovite granite with coarse quartz-muscovite-tourmaline greisen zones. The Middle Cretaceous date of 97.3 Ma (Table 2-9-1) suggests that this may represent a late-stage apophysis of the Cassiar batholith.

Quartz-galena veins in the Cassiar batholith at the Lucky showing are also Middle Cretaceous in age (Table 2-9-1, 105 Ma). This contradicts the suggestion of Abbott (1984), that galena-rich veins in the Midway-Rancheria district are Tertiary in age.

Cretaceous to Tertiary mineralization in the Rancheria district occurred in three separate episodes. Middle Cretaceous showings include silver-lead-zinc replacement deposits (Amy), intrusion-hosted veins (Lucky) and molybdenum-tungsten showings at the margins of the Cassiar batholith (Nancy and Root, Nelson and Bradford, 1987). Carbonate-hosted silver-lead-zinc-tin mineralization at Midway as well as nearby quartz veins (Brinco Hill, Tootsee Star) are related to Lake Cretaceous intrusions. Eocene mineralization includes silver-lead-zinc showings (Butler Mountain) and tin-tungsten veins and greisens (Fiddler). The three intrusive and associated mineralizing episodes correspond to a similar set of intrusive ages in the Cassiar area (Panteleyev, 1985; Christopher *et al.*, 1972; Sinclair, 1986).

SULPHIDE PARAGENESIS AND MORPHOLOGY

Sulphide bodies at Midway are characterized by a complex mineralogy with at least 16 ore and gangue minerals identified (Archambault, 1984). Microscopic and mesoscopic paragenetic relationships indicate four main mineralizing episodes: (1) early silica rich, (2) main stage sulphide-silica, (3) late sulphide-sulphosalt and (4) late carbonate. In addition, postmineral supergene effects have caused some alteration of the sulphide and gangue assemblages. Mesoscopic textures suggest that conditions of sulphide deposition fluctuated cyclically, resulting, for example, in repeated layers of the sequence pyrite-galena-sphalerite. During evolution of the hydrothermal system, local variability of depositional conditions resulted in a great variety of paragenetic relationships.

Sulphide bodies are massive and irregular in form, with abrupt wallrock contacts which are locally bleached or silicified. Both subhorizontal, pipe-like bodies and vertical, keel-shaped chimneys occur, but these do not have predictable compositional differences, as in some manto deposits (J. Hylands, 1986, personal communication; Lovering *et al.*, 1978). Although wallrock contacts are abrupt, gradational transitions occur outward from massive sulphides, to sulphide-matrix breccias with angular "stoped" wallrock clasts, to carbonate-matrix solution breccias, to unbrecciated limestone. This suggests that sulphide deposition was partly controlled by pre-existing porosity as defined by carbonate-healed breccia haloes around premineralization open channels and vuggy breccias, now filled and partly replaced by sulphide.

Stylolite-sutured limestone and shale clasts in breccias with fine-grained nonsparry carbonate matrix occur within and at the base of some sulphide bodies. These could represent relict premineral solution-collapse breccias in a lithified lime silt (calcarenite) karst filling. Internally, massive sulphide bodies contain angular wallrock clasts from pebble to boulder size, occurring as single fragments, mosaics of clasts of diverse sizes, or jumbles of rotated clasts of mixed lithologies. Shale-clast breccia zones within massive sulphide bodies occur well below (100 metres) the Late Devonian unconformity. Mixing of shale and limestone clasts at such depths indicates that solution collapse occurred over great vertical distances within the McDame. In some cases shale fragments exhibit a strong crenulation lineation, showing that collapse occurred after Jurassic compressional deformation, probably during mineralization.

Massive sulphide bodies most commonly occur near the McDame-Earn contact, but also exist up to 100 metres below it. The relatively impermeable black shales of the lowermost Earn constituted a barrier to mineralizing solutions and thus behaved as a fluid flow guide. The shales are commonly brecciated and veined by sulphides (especially pyrite) above major sulphide bodies. Concentration of sulphide bodies near the unconformity indicates that pre-existing carbonate porosity was probably greatest in the upper part of the McDame, producing favorable conditions for sulphide deposition along this horizon. Mixing of shale clasts into sulphide bodies adjacent to the unconformity is suggestive of hydrothermal stoping along the contact.

A further set of breccias, internal to massive sulphide bodies, contains sulphide and quartz fragments from earlier phases of mineralization. Hydrothermal brecciation caused mixing of earlier sulphide fragments (most commonly pyrite, but in some cases including pyrrhotite, arsenopyrite, sphalerite and galena) and shale clasts, sulphides and limestone clasts, or mixed sulphide, shale and limestone clasts in a later sulphide matrix. Mixed clast breccias in a carbonate matrix are also common; these postdate sulphide deposition and involve the latest phase of the hydrothermal system.

Breccias at Midway are multi-episodic and contain diverse combinations of clast lithologies, including sulphide and gangue minerals. Brecciation preceding, postdating and contemporaneous with mineralization can be documented. Premineral brecciation and clast mixing occurred during Earn diagenesis and support a model in which early karsting of the upper McDame provided enhanced permeability for fluid flow and sulphide deposition.

ZONING

Skarn-manto systems often show a district scale compositional or mineralogical zonation, reflecting temperature and chemical gradients surrounding the source of heat and volatiles, and pressure gradients related to depth of burial, for example, Darwin, California (Hall and MacKevett, 1962) and Zimapan, Mexico (Simons and Mapes, 1956). Exploration at Midway has been sufficient to indicate analogous zoning patterns. Within the Silver Creek deposit, a north-south transect shows an apparent mineralogical shift which may be a function of distance from heat source and depth. In the northern part of the deposit, sulphide bodies have high lead-antimony sulphosalt contents, commonly up to 15 per cent and locally as high as 40 per cent, while 300 metres to the south, and at deeper levels, mineralization contains relatively minor sulphosalts. In addition to indicating a possible zonation with respect to heat source and depth, such transitions may also be a function of pre-existing permeability, with high lead:zinc and high silver:lead ratios representing zones of high permeability (Birnie and Petersen, 1977).

The southern part of the Silver Creek deposit contains sulphide bodies with abundant pyrrhotite. Pyrrhotitic assemblages with chalcopyrite and negligible galena also predominate in sulphide intersections in the southern part of the Discovery deposit (Figure 2-9-1, DDH MW 16 and MW 26), and west of Brinco Hill (DDH B82-1). The change from galena-sulphosalt to pyrrhotite-chalcopyrite apparently defines a deposit-scale zonation pattern (Cordilleran Engineering Ltd., 1982). This provides evidence for relating the alteration zone centred on Brinco Hill to the sulphide pipes at Midway. Similar mineralogical transitions in better explored skarn-manto systems correlate with distance from the source intrusion, having an inner zone of iron and copper-rich sulphides and an outer zone of lead-arsenic-antimony-rich mineralization. In addition, deep drill-hole intersections closest to Brinco Hill contain calc-silicates (tremolite and epidote) intimately intermixed with pyrrhotite; skarn mineralogy has not been found elsewhere in the Midway area.

Zonation is also reflected in tin mineralogy. Tin is high (>1000 ppm) in two areas, one in the northern part of the Silver Creek deposit, and the other 300 metres to the south. The two areas differ in that tin-lead-antimony sulphosalts (franckeite) are the primary tin-bearing minerals in the former case, whereas stannite is the only tin mineral in the latter, where it accompanies pyrrhotitic mineralization (Archambault, 1984).

In manto-skarn systems elsewhere, distal, shallower sulphosalt-rich zones are commonly silver rich, while proximal, deeper, iron-rich sulphide zones are commonly gold rich and silver poor. In view of the limited exploration done in areas closer to Brinco Hill (due to the depth of cover rocks), gold-bearing mantos and veins represent an interesting exploration possibility south of currently explored mineralization, although depth of cover rocks is an inhibiting factor.

SUMMARY

Studies of the Midway deposit to date have suggested several exploration guides and controls on mineralization. Regionally, localization of intrusive and associated hydrothermal systems along large-scale, high-angle fault systems is important. The bulk of skarn-manto-vein systems in carbonates in the Cassiar platform are associated with young felsic intrusives (post-Cassiar batholith), which are commonly reclusive in outcrop, but generate large alteration haloes in noncarbonate cover rocks and are associated with fluorine, base metal and lithophile element anomalies. Strongly fractionated late phases of older intrusions may also be mineralizers.

At the deposit scale, fault control of fluid pathways may be significant in areas with coeval or overlapping intrusion and faulting. At Midway, known sulphides are largely distributed between the Camp Creek and Brinco Creek faults, while no mineralization has been found west of the Silvertip Creek fault. These faults converge north of Midway, and the convergent zone may have focused fluid migration. The coincidence of this fault convergence with an antiformal structure below a shale cap of low permeability probably contributed to concentrating hydrothermal fluid flow in the vicinity of the Silver Creek deposit. The southeasterly plunge of this antiform might have controlled upward and outward migration of fluids from the intrusive centre to the trapping structure.

Stratigraphically, both a strongly brecciated, karsted carbonate sequence with enhanced permeability and less permeable capping sequences are significant controls on sulphide deposition.

Deposit-scale mineral zoning may be useful in defining intrusive centres and their spatial relationship to orebodies. At Midway, sporadic sulphides are found throughout the area bounded by the Camp Creek and Brinco Creek faults, in veins in cover rocks as well as in limestone. By comparison with skarn-manto systems elsewhere, major sulphide bodies are probably not limited to the relatively distal unskarned environment of the Silver Creek deposit, and mineralization of different tenor may be expected closer to the intrusive core of the system.

ACKNOWLEDGMENTS

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Industrial Mineral Studies

STRATIGRAPHIC AND STRUCTURAL SETTING OF INTRUSIVE BRECCIA DIATREMES IN THE WHITE RIVER–BULL RIVER AREA, SOUTHEASTERN BRITISH COLUMBIA

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KEYWORDS: Breccia diatremes, kimberlite, Paleozoic stratigraphy, White River, Bull River, Rocky Mountains.

INTRODUCTION

Intrusive breccia diatremes in the White River–Bull River area (Figure 3-1-1), occurring in Paleozoic rocks of the boundary region between the Front Ranges and Main Ranges of southeastern British Columbia, were discovered during reconnaissance mapping (1:126 720 scale) in the late 1950s and early 1960s (Leech, 1958, 1964, 1979, personal communication, 1986), but did not receive closer attention until becoming targets for diamond exploration during the mid-1970s (Grieve, 1981). A small exploration rush started after a diatreme in the Crossing Creek area, originally mapped by Hovdebo (1957), was rediscovered by Cominco geologists and identified as a kimberlite. Although numerous other diatremes were found as a result of this activity, as yet diamond discoveries have not been reported in the literature. The focus of exploration has since moved to a diatreme cluster in the area north of Golden, British Columbia, where microdiamonds are reported to have been discovered from two pipes (Dummett *et al.*, 1985; *see also* Pell, 1986, 1987a, b).

In spite of the apparently low diamond potential, the approximately 40 diatremes of the White River–Bull River area pose a number of interesting petrologic, stratigraphic, structural and geotectonic problems. The Crossing Creek diatreme, also known as the Cross kimberlite (Roberts *et al.*, 1980; Grieve, 1981, 1982; Hall *et al.*, 1986, in press; Pell, 1986, 1987b; Ijewliw, 1987) thus far remains the only kimberlite recognized in the region (Pell, 1987b). It is also unique in that it occurs more than 10 kilometres east of the northerly trending zone of the other diatremes (Figure 3-1-1) in nearly horizontal strata of the Permian Ishbel Group (Grieve, 1982). As a result of the relatively open structural style in the Front Ranges, the remnants of the diatreme are little deformed and the multiphase nature of the intrusion can be recognized clearly (Grieve, 1981; Hall *et al.*, in press). Phlogopite separates from the kimberlite have yielded rubidium-strontium dates of approximately 245 Ma (Grieve, 1982; Smith, 1983; Smith *et al.*, 1987) that closely correspond to the Late Permian age of the country rock. It is thus clear that the diatreme predates the northeastward transport of the Bourgeau thrust sheet in which it is located.

The other diatremes in the area are aligned in a northerly trending zone and have intruded pre-Middle Devonian rocks affected by more complex, Main Range-style structures

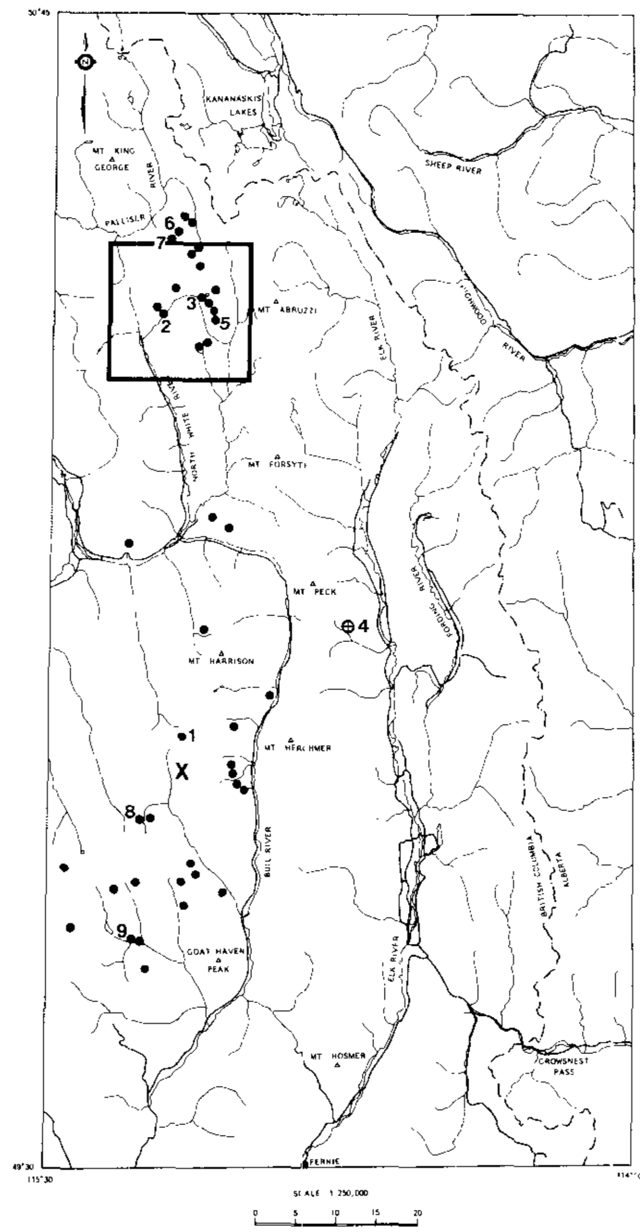

Figure 3-1-1. Location of diatremes in the White River–Bull River area. From Leech, 1979, personal communications, 1986; Pell, 1987b; J.A. Mott, unpublished field data. 1–Blackfoot; 2–White River 2; 3–Rus West; 4–Cross Kimberlite; 5–Rus 1; 6–Joff; 7–Joff West; 8–Quinn 1; 9–Summer 1 and 2; cross south of Blackfoot (1) is location of Swan claims (*see* Pell, 1987b). Black square west of Mount Abruzzi represents area of Figure 3-1-3.

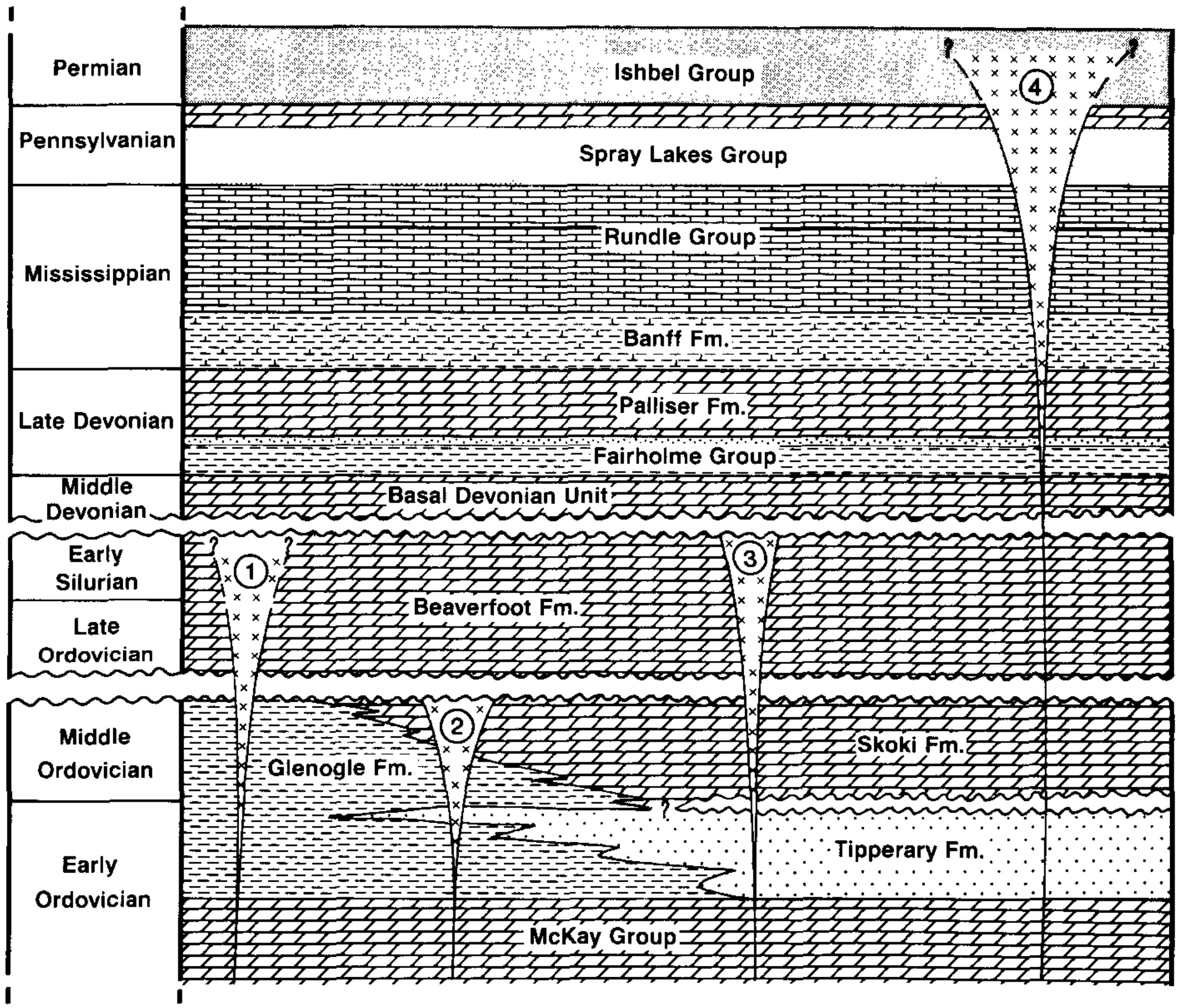

Figure 3-1-2. Diagram illustrating stratigraphic relationships in the White River–Bull River area and position of selected diatremes. Note that thicknesses of formations are not to scale, as vertical axis represents time. Diatremes illustrated area: 1–Blackfoot; 2–White River 2; 3–Rus West; 4–Cross Kimberlite.

(Figures 3-1-3, 3-1-4). Most diatremes were highly deformed during northeastward transport, and the rocks are generally too altered to be amenable to petrographic classification. An affinity to limburgites was proposed by Grieve (1981), and Pell (1987b) reported the presence of olivine melilitites in the some of the diatremes. As radiometric dates are not yet available, all age determinations must rely on relative methods – a task made difficult by the rugged terrain, the degree of deformation and apparently ambigious contact relationships, and a complex stratigraphic sequence ranging from the Late Cambrian – Early Ordovician McKay Group to a basal Devonian unit underlying the Late Devonian Fairholme Group (Figure 3-1-2). Early to Middle Ordovician rocks represent the transition between an eastern carbonate and quartzite facies (Skoki and Tipperary formations) and a western shale facies (Glenogle Formation) and are separated from the Late Ordovician – Early Silurian carbonates of the Beaverfoot Formation by a regional unconformity (Norford, 1969; Leech, 1979; Mott *et al.*, 1986). A second unconformity, also of regional extent, separates the Beaverfoot Formation from a basal Devonian unit consisting of sandy dolostone and red clastics (Leech, 1958, 1979). Pell (1987b) concluded from an interpretation of the stratigraphic position of olivine melilitite flows (Swan claims, Figure 3-1-1), and from the apparent intercalation of crater sediments of the Joff and Rus 1 pipes (Figure 3-1-1) with the carbonates of the Beaverfoot Formation, that all the diatremes were emplaced during the Late Ordovician to Early Silurian. Observations during the 1987 field season, reported in this paper, confirm that some of the magmatism indeed predated the deposition of the Beaverfoot Formation. A number of diatremes, however, postdate deposition of the Beaverfoot Formation and appear to have been emplaced during the interval represented by the post-Beaverfoot – pre-basal Devonian unconformity.

FIELD OBSERVATIONS

Two diatremes discovered by J.A. Mott during the 1986 field season in the upper reaches of North White River show stratigraphic relationships suggesting at least two ages of intrusion (Figure 3-1-2); one prior to deposition of the Beaverfoot Formation, and the other prior to deposition of the basal Devonian strata of the region.

WHITE RIVER 2 DIATREME

This diatreme is located on the steep northern slope of the valley of North White River, approximately 6 kilometres west of Russell Peak (Figures 3-1-1, 3-1-3). It outcrops in a nearly vertical panel of dolostones of the Skoki Formation that forms the east limb of an easterly verging syncline cored by Beaverfoot Formation (Figure 3-1-4). The Skoki Formation

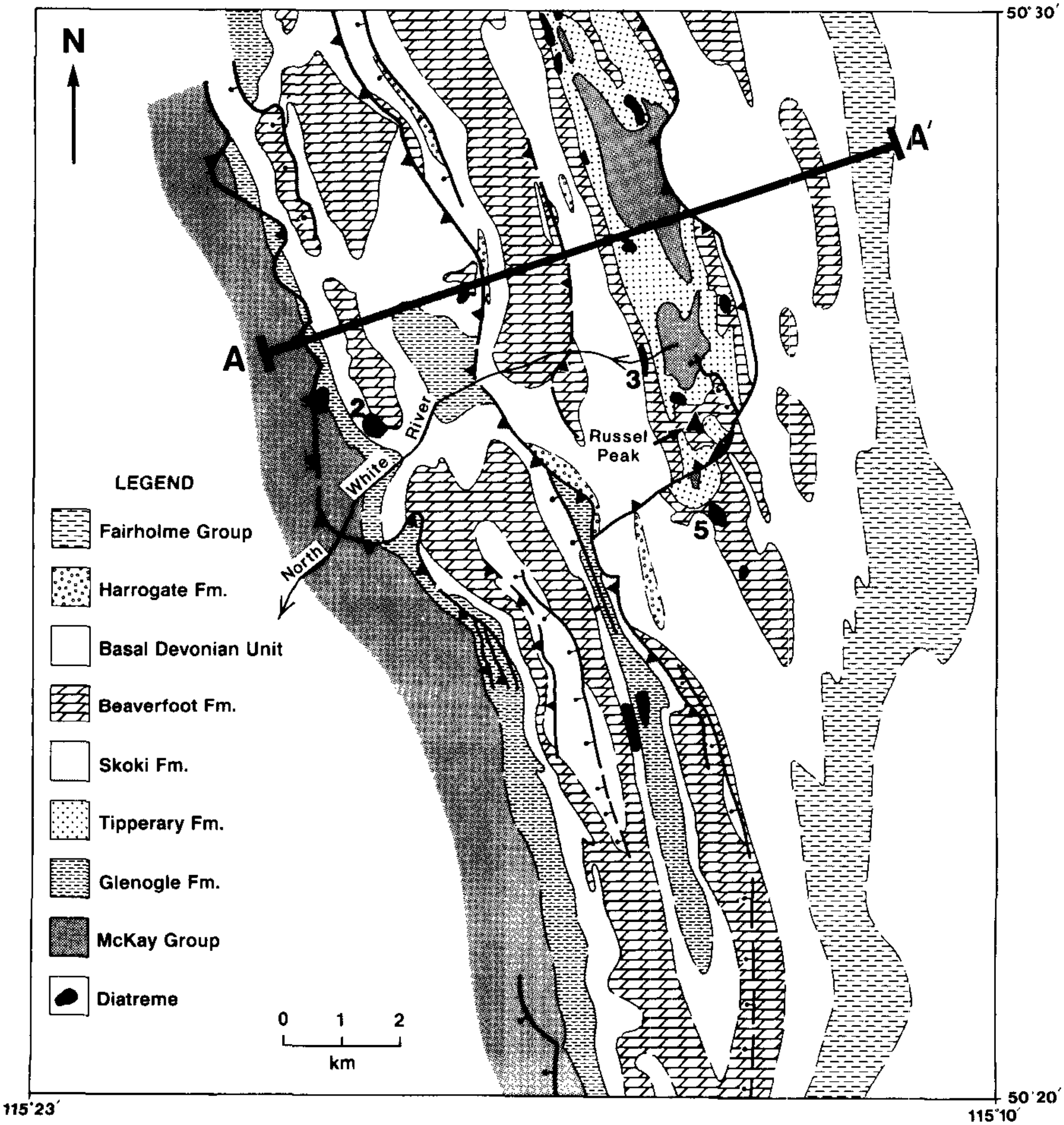

Figure 3-1-3. Location of diatremes in the Russell Peak area (*see* Figure 3-1-1). Geology after unpublished data by J.A. Mott. 2–White River 2; 3–Rus West; 5–Rus 1. Line A – A′ is line of cross-section on Figure 3-1-4.

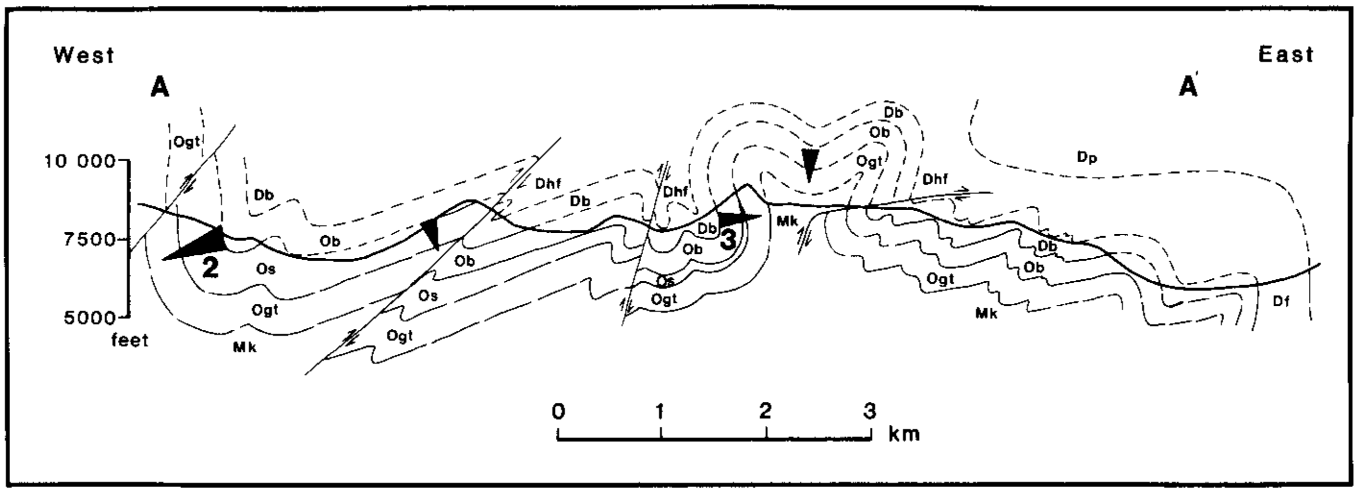

Figure 3-1-4. Cross-section A – A′ (Figure 3-1-3) illustrating stratigraphic and structural position of White River 2 (2), Rus West (3), and two other diatremes of the Russell Peak area. Mk–McKay Group; Ogt–Glenogle and Tipperary formations; Os–Skoki Formation; Ob–Beaverfoot Formation; Db–basal Devonian unit; Dhf–Harrogate and Fairholme Formations; Df–Fairholme Formation; Dp–Palliser Formation. After unpublished data by J.A. Mott.

is underlain at this locality by shales and siltstones of the Glenogle Formation containing two thin ribs of quartzite previously correlated with the Tipperary Formation (Norford, 1969; Norford and Ross, 1978). The lower part of the exposed diatreme is a brown breccia consisting of rafts and fragments of black shale and dolostone within a highly altered matrix. Two fine-grained, highly altered dykes, less than 0.5 metre thick, were observed near the western contact of the diatreme. The breccia is overlain by more than 100 metres of sediments which grade from coarse, crudely layered breccia into black, finely laminated siltstones and shales. The sediments abut abruptly against adjacent Skoki Formation which appears to represent the crater wall. This feature, combined with the unique distribution of the sediments immediately and exclusively overlying the pipe, suggests that they represent a crater-fill facies. The black crater sediments are overlain, with apparent conformity, by a thin unit of quartzites which is continuous with quartzites at the base of the Beaverfoot Formation adjacent to the diatreme.

RUS WEST DIATREME

This diatreme is located slightly more than 1 kilometre northwest of Russell Peak and outcrops across North White River at its headwaters (Figure 3-1-3). The overall shape of the exposed part of the diatreme is that of an elongate body (approximately 500 by 50 metres) which, along its eastern boundary, is in contact with westward overturned dolostones of the Beaverfoot Formation (Figure 3-1-4). Outcrops north of the river consist of a reddish weathering massive breccia surrounded by a greenish grey, highly cleaved breccia which is criss-crossed by numerous fractures with red alteration rims. The massive phase contains numerous carbonate fragments, chloritic fragments and quartz grains that locally define a crude layering. The matrix of this breccia is very fine grained and highly altered. The cleaved greenish phase consists of fragments of carbonates and reddish cherts in a fine-grained, carbonaceous matrix. Bedding in a large raft of dolostone of the Beaverfoot Formation in the cleaved breccia is parallel to the steeply east-dipping Beaverfoot Formation outside the diatreme. The cleavage dips approximately 60 degrees to the east. Discontinuous outcrops along the eastern margin of the diatreme, south of the river, consist of massive and cleaved red breccia containing large fragments and disoriented rafts of dolostone. At the western margin, a thin unit of reddish sandstone and siltstone is interpreted to represent crater-fill sediments. In an outcrop along the river, these sediments are conformbly overlain by a steeply overturned unit of sandy dolostone and red shale corresponding to the basal Devonian unit of Leech (1958, 1979; Figure 3-4-1).

OBSERVATIONS AT THE RUS 1 AND JOFF WEST DIATREMES

The Rus 1 diatreme, described by Pell (1987a, b), is a funnel-shaped pipe located in the crest of an anticline of Beaverfoot Formation overlying Tipperary Formation (Figure 3-1-3). Well-layered crater-facies sediments exposed in a saddle in the crest of the anticline are juxtaposed laterally against Beaverfoot Formation which dips toward the east and west, away from the crest. Beaverfoot Formation on both limbs of the anticline is capped by Devonian strata, and the sub-Devonian unconformity projects approximately 75 metres above the upper part of the diatreme. According to Pell (1987a), thin layers of igneous material are interbedded with carbonates of the Beaverfoot Formation near the top and margins of pipe, implying an Ordovician-Silurian emplacement age. Our observations suggest that the carbonates of the Beaverfoot Formation are not interbedded with pipe material but form the margin of the original crater. Dolostone at the western crater rim, near the top of the pipe, is plastered with a red breccia consisting of small angular fragments of sedimentary and igneous (?) origin in a matrix rich in fine to medium-grained detrital quartz. Although locally parallel to the bedding of the dolostone, this material also crosscuts bedding and fills radial fractures along the pipe margin. Sedimentary breccia near the pipe margin also contains angular clasts of dolostone which appear to be fragments from the crater wall. The breccias are interpreted as slump breccia derived from the original crater rim.

An interesting problem is posed by an occurrence of olivine basalt above crater sediments of the Rus 1 diatreme (*see* Pell, 1987a, b). Unlike any rock type related to the diatremes, this olivine basalt contains exceptionally fresh phenocrysts of olivine, suggesting that it may be much younger than the highly altered and deformed rocks of the diatreme.

The Joff West diatreme (Figure 3-1-1) contains crater fill more than 50 metres thick comprising laminated red shale and siltstone, locally with large angular clasts and rafts of dolostone of the Beaverfoot Formation derived from the crater wall or rim. These sediments are downfaulted against the crater wall and against diatreme breccia containing fragments of dolostone, limestone, quartzite, and reddish chert similar to that occurring in the Rus West diatreme. The crater sediments of the Joff West diatreme resemble the reddish clastics of the basal Devonian strata, suggesting that the diatreme may have breached the pre-Devonian erosion surface.

DISCUSSION AND CONCLUSIONS

The fact that crater sediments of the White River 2 diatreme are overlain by basal Beaverfoot Formation indicates that the diatreme was emplaced about 455 million years ago, during the approximately 10-Ma interval represented by the sub-Beaverfoot unconformity. This corroborates the presence of Late Ordovician magmatism, though it is not known whether the White River 2 diatreme and pre-Beaverfoot Formation olivine-melilitite flows on the Swan claims (Pell, 1987b) are genetically related. It is also not yet clear whether a relationship exists between the flows at the Swan claims and the mafic White River sills in McKay Formation, north of Mount Harrison (Figure 3-1-1). On the other hand, one such sill, outcropping along Thunder Creek on the east limb of the Thunder Creek anticline (Leech, 1979), is cut by a diatreme breccia, approximately 5 kilometres northwest of Mount Harrison.

As shown by the conformable contact between crater sediments and basal Devonian strata at the Rus West pipe, diatremes were also emplaced at about 400 Ma, during the approximately 30-Ma interval represented by the pre-Devonian unconformity. It is likely that several other diatremes (for example, Rus 1, Joff, Joff West) breached the pre-Devonian erosion surface, and their craters were filled with clastics similar to those within the basal Devonian unit. As clasts of Devonian strata have not been recognized in any of the breccias, the diatremes appear to have predated the deposition of the basal Devonian unit. As crystalline xenoliths have been identified in breccias of several pipes, we conclude that the diatremes were emplaced along a north-trending normal fault system located in the pre-Paleozoic sialic basement west of the Alberta arch (Ziegler, 1969). This system was active from Late Ordovician through Mid-Devonian times and may have been reactivated in Permian times to provide a channelway for the Cross kimberlite.

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THE HP PIPE, A PRELIMINARY REPORT* (82N/10)

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KEYWORDS: Alkalic igneous rocks, diatremes, HP pipe, alnöite, aillikite, melilitites, Rocky Mountains.

INTRODUCTION

The HP pipe, located at latitude 51°41'30", longitude 116°57'00" at an elevation of 2400 metres, is the southernmost diatreme in the Golden cluster (Ijewliw, 1986, 1987; Pell, 1986, 1987a, b). It is an ultrabasic, alkaline lamprophyre with alnöitic affinities. The pipe has been chosen for detailed study because it is relatively unaltered and almost completely exposed.

The 347-Ma HP intrusion (Pell, 1987a) is dominated by light green breccia cut by two sets of dykes. North-trending, dark green dykes are cut by a later east-trending set, also dark green. Both sets extend into the surrounding Lower to Middle Cambrian carbonates. Short, narrower, brown dykes that occur entirely outside the diatreme intersect the later dyke set.

PETROGRAPHY

The breccia contains abundant angular, deformed and recrystallized (*marmorized*) *limestone clasts attesting to the* relatively high temperature of emplacement. Nodules resembling dyke material (Ijewliw, 1987, 1986), and rare fragments of altered plutonic rock are also found in the breccia. Megacrysts of black and green clinopyroxenes, biotite books and red-brown spinels form the cores of dark green globular segregations (Pell, 1987a; Plate 4-3-2), in a calcite matrix (Plate 3-2-1). Some clinopyroxenes and biotites (which range from several millimetres to several centimetres in length) are

Plate 3-2-1. Photomicrograph of globular segregations with opaque rims and cores of either zoned clinopyroxene or lithic fragments. Calcite is interstitial. Plane polarized light; field of view = 4 millimetres.

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

Plate 3-2-2. Photomicrograph of mica with resorbed biotite core and two generations of phlogopite overgrowths. Groundmass phlogopites on left and near top have iron-rich rims. Plane polarized light; field of view = 4 millimetres.

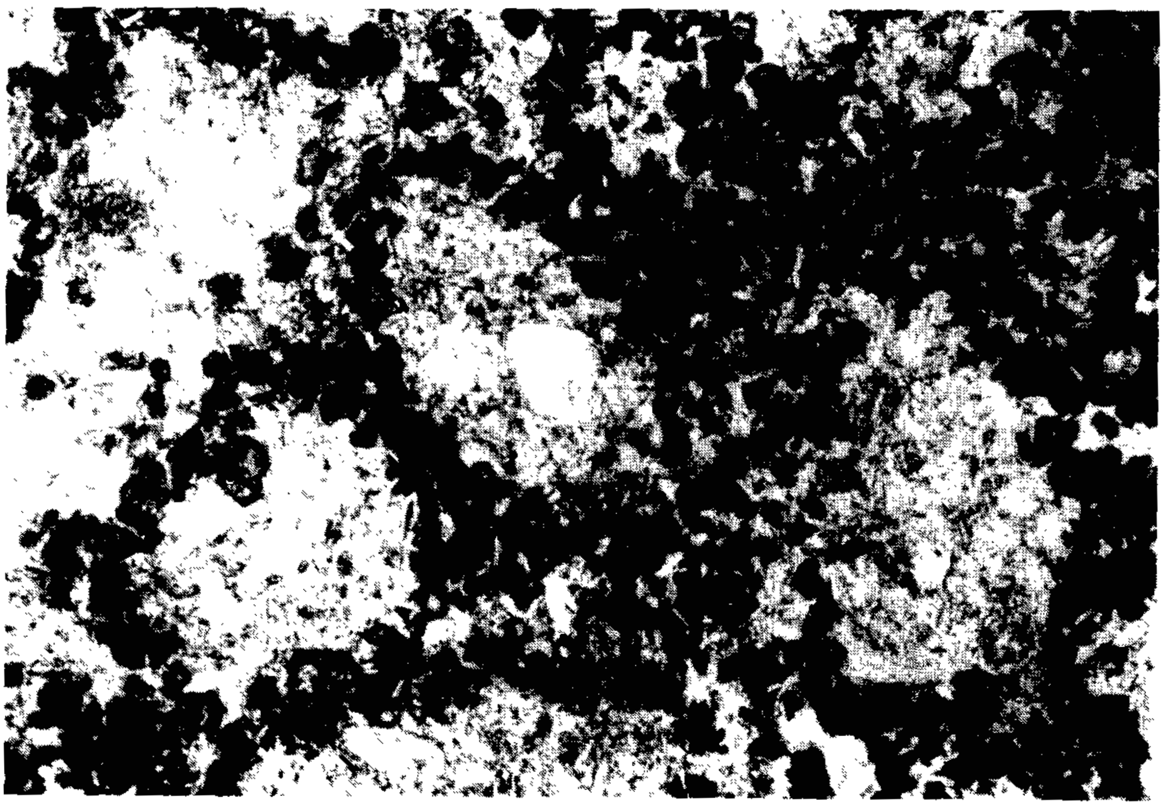

Plate 3-2-3. Photomicrograph of melanite garnet rimming globular segregations. Plane polarized light; field of view = 4 millimetres.

zoned (Plates 3-2-1 and 3-2-2). Melanite garnet, sphene and melanite or opaques rim the globular segregations (Plates 3-2-1 and 3-2-3), which are surrounded by a groundmass consisting of carbonate, serpentine, mica, talc and matted clumps of very fine-grained sphene and melanite. Where the breccia does not contain globular segregations, it consists of rare megacrysts and macrocrysts in a matrix of melanite, mica, serpentine, carbonate, talc, chlorite and pyrite.

Garnets occur as euhedral, complexly zoned grains up to a millimetre in diameter (Plate 3-2-4) and as unzoned, clear, anhedral groundmass crystals (Plate 3-2-5). Dyke melanites are larger, generally zoned and have dark brown cores unlike the yellow cores of the breccia melanites.

Globular segregations and crustal xenoliths do not occur in the dykes. Most megacrysts and macrocrysts of clinopyroxene and biotite are zoned, as are the melanites. The matrix of the green dykes is similar to that of the breccia, though biotite is more abundant. The brown dykes are entirely carbonatized and devoid of megacrysts, macrocrysts or any fresh silicate minerals.

MINERAL CHEMISTRY

Mineral compositions were determined by energy dispersive analysis with an ARL-SEMQ electron microprobe at Queen's University. In Figures 3-2-1 and 3-2-2, the data for the HP pipe are compared with those from olivine-melilitites in South Africa (Boctor and Yoder, 1986), alnöites in Malaita (Nixon and Boyd, 1979; Nixon *et al.*, 1980), the Ile Bizard alnöite (Raeside and Helmstaedt, 1982), and the Colorado-Wyoming kimberlites (Eggler *et al.*, 1979).

The magnesian group of black clinopyroxene megacrysts and macrocrysts are similar in terms of Ca/Mg/Fe values (Figure 3-2-1) to those from the groundmass of the olivine melilitites and Malaita alnöite. The wide range of Mg/(Mg + Fe) values of the entire HP suite is similar to the Ile Bizard clinopyroxene megacrysts, though more calcic [higher content of Ca-Tschermak's molecule

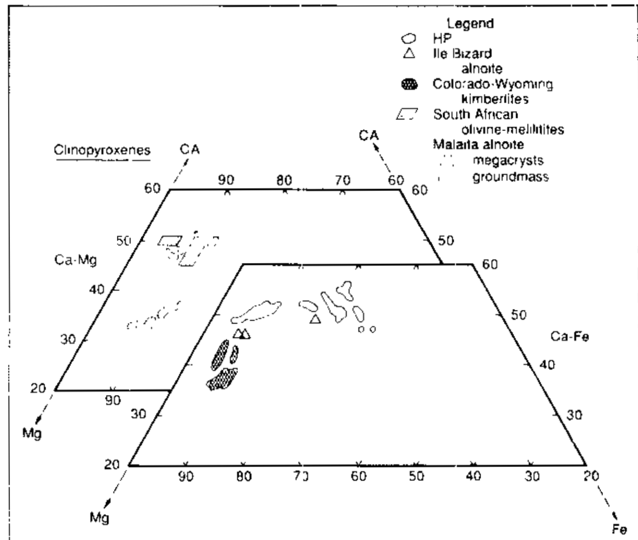

Figure 3-2-1. A Ca-Mg-Fe mole per cent plot showing a comparison of HP clinopyroxenes with those from the Ile Bizard alnöitic rock (Raeside and Helmstaedt, 1982), South African olivine-melilitites (Boctor and Yoder, 1986), Colorado-Wyoming kimberlites (Eggler *et al.*, 1979), Malaita alnöite megacrysts and groundmass pyroxenes (Nixon *et al.*, 1980).

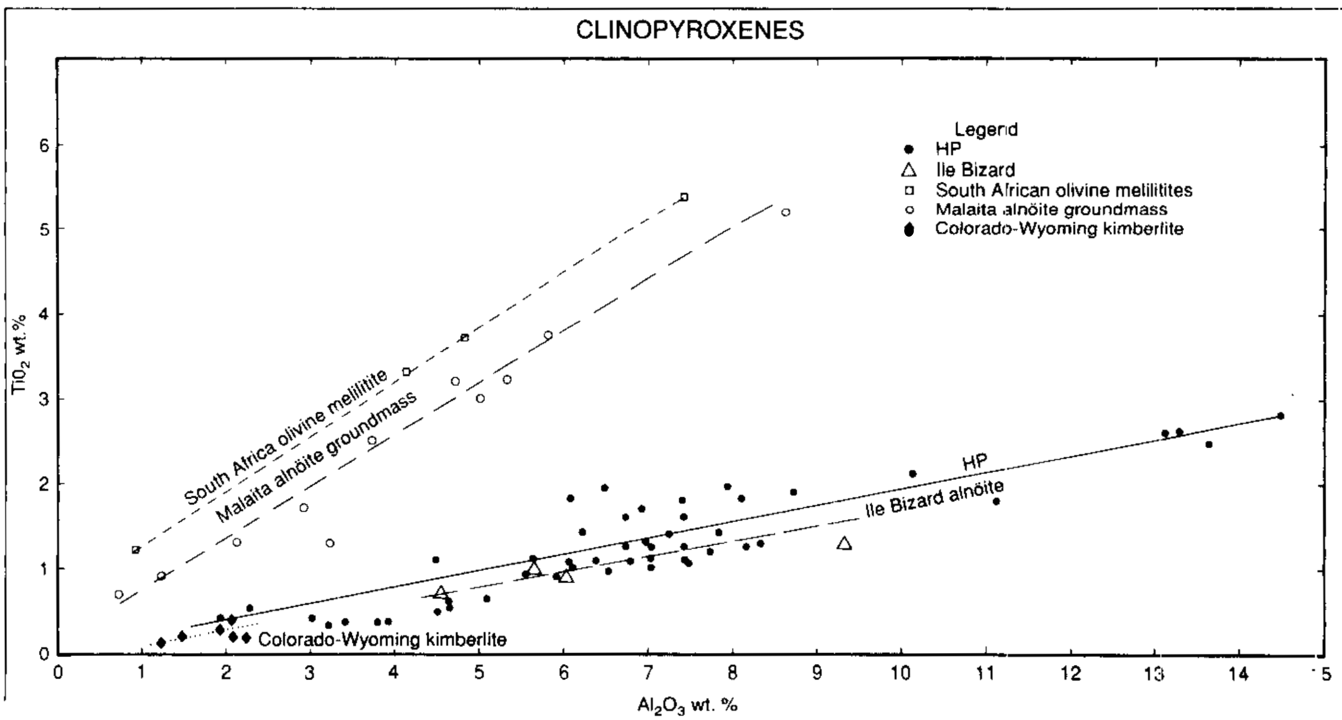

Figure 3-2-2. Al_2O_3 and TiO_2 weight per cent value of HP clinopyroxenes and those from the Ile Bizard alnöitic rock (Raeside and Helmstaedt, 1982), South African olivine-melilitites (Boctor and Yoder, 1986), Colorado-Wyoming kimberlites (Eggler *et al.*, 1979), Malaita alnöite megacrysts and groundmass pyroxenes (Nixon *et al.*, 1980).

Plate 3-2-4. Photomicrograph of oscillatory zoned melanites from the dyke phase. Plane polarized light; field of view = 4 millimetres.

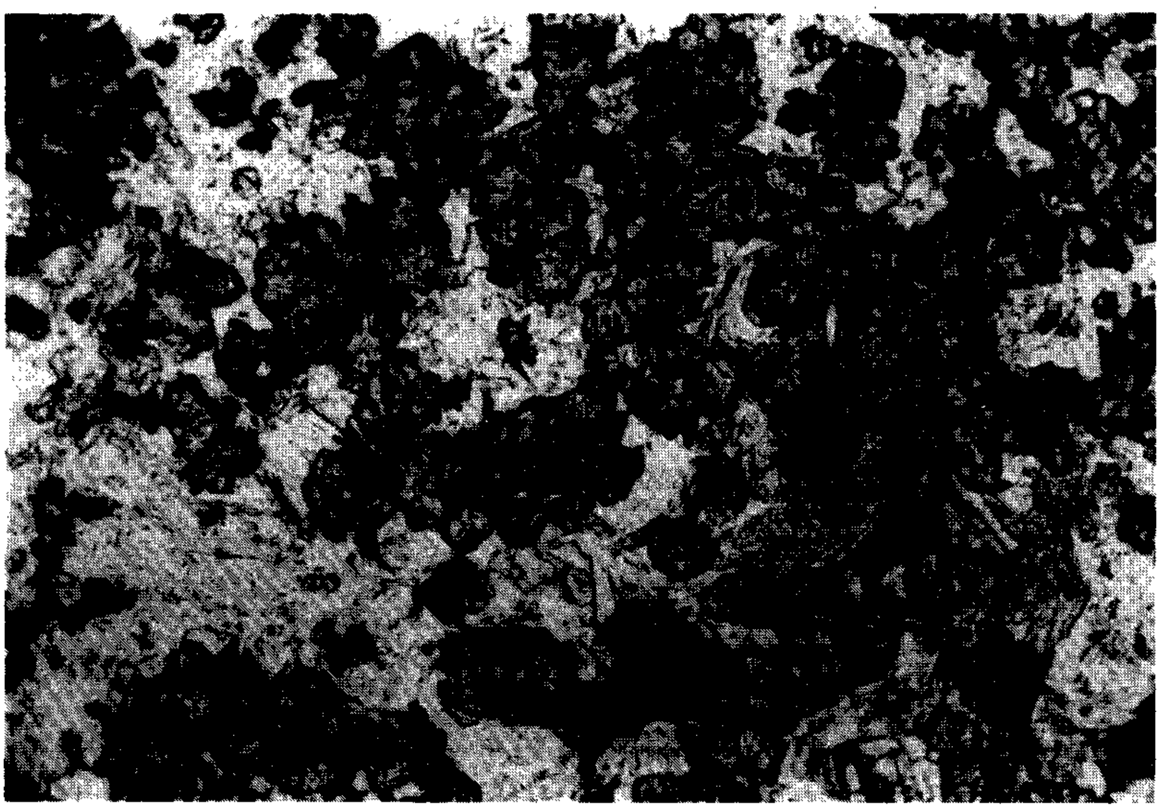

Plate 3-2-5. Photomicrograph of breccia phase groundmass composed primarily of clear, titanium-poor melanite garnet. Plane polarized light; field of view = 1.5 millimetres.

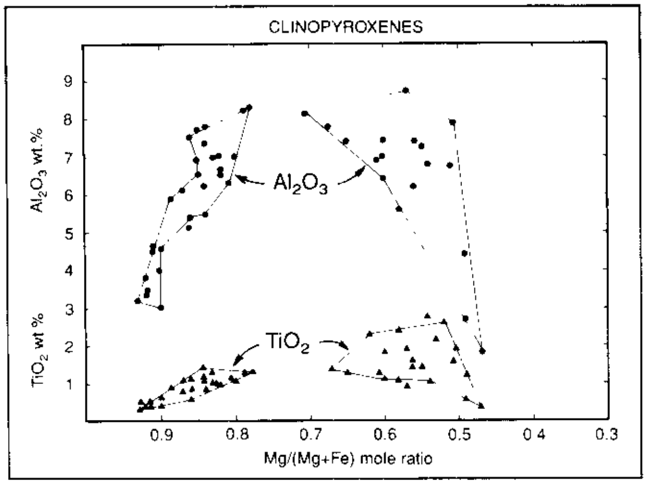

Figure 3-2-3. HP clinopyroxene mineral chemistry showing a bimodal distribtion of Mg/(Mg + Fe) values, enrichment and subsequent depletion of TiO_2 and Al_2O_3.

(Ca,Mg)Al(AlSi)O_6]. HP clinopyroxenes do not overlap with megacrysts from Malaita or the Colorado-Wyoming kimberlites. The black pyroxenes are rich in titanium (up to 2.6 weight per cent TiO_2) and aluminum (up to 14.5 weight per cent Al_2O_3) (Figures 3-2-2 and 3-2-3) and there is a positive correlation between titanium and aluminum (Figure 3-2-2). These values are similar to the clinopyroxene megacrysts from Ile Bizard, but dissimilar to the other clinopyroxenes in Figure 3-2-2.

There is a bimodal distribution of Mg/(Mg + Fe) values for the HP clinopyroxene megacrysts (Figure 3-2-3). Although all data are from mineral cores, preliminary investigations of zoning trends indicate that rims are relatively enriched in iron.

The clinopyroxenes show a good linear fractionating trend in the higher Mg# group with titanium and aluminum increasing as magnesium values decrease. In the lower Mg# group there is more variation, especially in aluminum as magnesium values decrease.

The black clinopyroxenes have low chrome contents (<0.10 weight per cent Cr_2O_3). A single green clinopyroxene megacryst has been analysed and contains approximately 1.0 weight per cent Cr_2O_3, considerably less titanium (0.3 weight per cent TiO_2) and has a higher Mg/(Mg + Fe) value of 0.96 than the black ones.

Mica megacrysts have biotite cores with Mg/(Mg + Fe) values of approximately 0.45. Overgrowths are more magnesian, with ratios ranging up to 0.85. Titanium is approximately constant at 3 to 4 weight per cent TiO_2. These values do not correspond to those of mica megacrysts from either kimberlites or alkalic basalts (Schulze, 1987).

Matrix garnets are the titanium-rich variety of andradite known as melanite. Cores of the yellow melanites in the breccia have 3.0 to 5.5 weight per cent TiO_2 compared to 6 to 10 per cent for melanites from the dyke phase. There is an inverse relationship between aluminum and titanium suggesting that titanium occupies the aluminum site in the andradite-grossular-almandine solid solution series. The Mg/(Mg + Fe) and Ca/(Ca + Fe) ratio ranges are restricted, 0.025 to 0.125 and 0.65 to 0.75 respectively, and do not correlate with titanium or aluminum contents. Compositionally similar melanite garnets also occur in the South African olivine melilitites and the Ile Bizard alnoitic rocks.

HP macrocrystic and groundmass spinels have a restricted compositional range. The $Fe^{2+}/(Fe^{2+} + Mg)$ values are between 0.34 and 0.38, Cr/(Cr + Al) ranges from 0.54 to 0.68 and TiO_2 is less than 1 per cent by weight. These spinels are close in composition to the Ile Bizard spinels (Mitchell, 1982). They are unlike those from the olivine melilitites, which have lower chromium values and a greater range in Fe^{2+} values, and unlike the Malaita spinels which contain 11 to 16 per cent TiO_2.

SUMMARY AND CONCLUSIONS

The compositions of HP clinopyroxene, spinel, melanite and biotite/phlogopite are similar to those of the Ile Bizard alnöitic rock and the South African olivine melilitites, but are distinct from kimberlites and alkalic basalts. The HP intrusion, like the Ile Bizard diatreme (Gold *et al.*, 1986) is tentatively classified as an aillikite, a variety of alnöite (Rock, 1986).

Evidence from textures and mineral chemistry suggests that enrichment of titanium, aluminum and iron occurred as crystallization progressed. The megacrysts are always found singly and are relatively unaltered. No polymineralllic clusters were found and this, combined with the orderly trends in the pyroxene and mica chemistry, suggests that they are cognate to the system.

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CARBONATITES AND RELATED ROCKS OF THE PRINCE AND GEORGE CLAIMS, NORTHERN ROCKY MOUNTAINS*
(93J, 93I)

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KEYWORDS: Economic geology, alkalic igneous rocks, carbonatites, niobium, rare earth elements, Rocky Mountain Trench, ultrabasic rocks.

LOCATION

Teck Explorations Limited holds the Prince and George groups of claims (162 units, Cariboo Mining Division) near Wicheeda Lake, 80 kilometres northeast of Prince George at latitude 54°31′ north, longitude 122°04′ west (93I/5, 93J/8, 93J/9, Figure 3-3-1). Access is by helicopter, although some areas may be reached from nearby logging roads.

HISTORY

Prospecting in the area in 1976 and 1977 yielded minor base metal showings. Later assaying of these samples indicated anomalous niobium values. The claims were staked between April and August 1986 by Teck Explorations Limited. Work completed in 1986 and 1987 included geological mapping, geochemical (soil, stream) as well as total field magnetic surveys, trenching and bedrock geochemical analyses (Betmanis, 1987).

REGIONAL GEOLOGY

The regional geology has been mapped by Armstrong *et al.*, 1969, McLeod Lake) and Taylor and Stott (1979, Monkman Pass). Both map sheets cover parts of the property. The area forms part of a steeply dipping, complexly faulted package of sediments between the McLeod Lake fault to the southwest and the Parsnip River to the northeast. The Rocky Mountain Trench follows the Parsnip Valley farther to the north but loses its identity in the study area. The trench resumes its course further to the southeast, with a 20-degree change in direction at the upper Fraser Valley.

Neither the age of the sediments nor the structure is established. Armstrong *et al.* (1969) indicate that the property is underlain by upper Cambrian Kechika Group sedimentary rocks overthrust by lower Cambrian Misinchinka Group clastic rocks. Lower Cambrian dolomites and limestones overlie the Misinchinka Group southwest of Wichcika Creek. Taylor and Stott (1979) indicate that the property is underlain by lower Ordovician Chushina Formation limestones and argillaceous rocks, and middle Ordovician Skoki Formation dolomites overthrust by metamorphosed Precambrian Misinchinka Group limy sediments. The subvertical thrust fault is mapped on both map sheets on the western slope of the main ridge west of the Parsnip Valley, a short distance to the west of the instrusive bodies examined (Figure 3-3-1).

LOCAL GEOLOGY

A series of carbonatite plugs, sill-like bodies and dykes (Figure 3-3-1) with associated alkaline silicate rocks intrude argillaceous rocks and limestones probably within the same tectonic slab. The intrusions follow the trend of the Rocky Mountain structures, parallel to the steeply dipping schistosity and bedding. Sparse outcrop and the fine-grained lithologies prevent the determination of stratigraphic tops and local structures. The main tectonic feature appears to be thrust faults parallel to bedding. Tight isoclinal structures, however, may be present. Steep faults at high angles to the Rocky Mountain trend are commonly outlined by topographic features.

AGE

No radiometric date has been obtained. Material suitable for radiometric dating includes biotite in carbonatite and zircon in some syenitic rocks.

Unambiguous field relationships are not exposed, so that it is possible to imagine a pre-Rocky Mountain or a post-Rocky Mountain age. Well-developed parallel fabrics are visible in thin section in most intrusive rocks. These fabrics are concordant with fabrics in the adjacent sedimentary rocks. The authors believe that the intrusions were emplaced prior to the formation of the Rocky Mountains and were subsequently deformed during the Columbian orogeny. It should be emphasized that carbonatites are very resistant to deformation and weathering, if contained in incompetent host rocks (Aley carbonatite complex, Mäder, 1987).

It is therefore likely that the intrusions are related to the Devono-Mississippian group of alkaline/carbonatite intrusive bodies emplaced into the old North American continental margin, which roughly follows the trend of the present-day Rocky Mountain Trench (Pell, 1986, 1987).

INTRUSIVE ROCKS

All intrusions show mineralogies typical of true igneous carbonatites and alkaline rocks (Table 3-3-1), but each stock has its distinctive petrographic features.

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

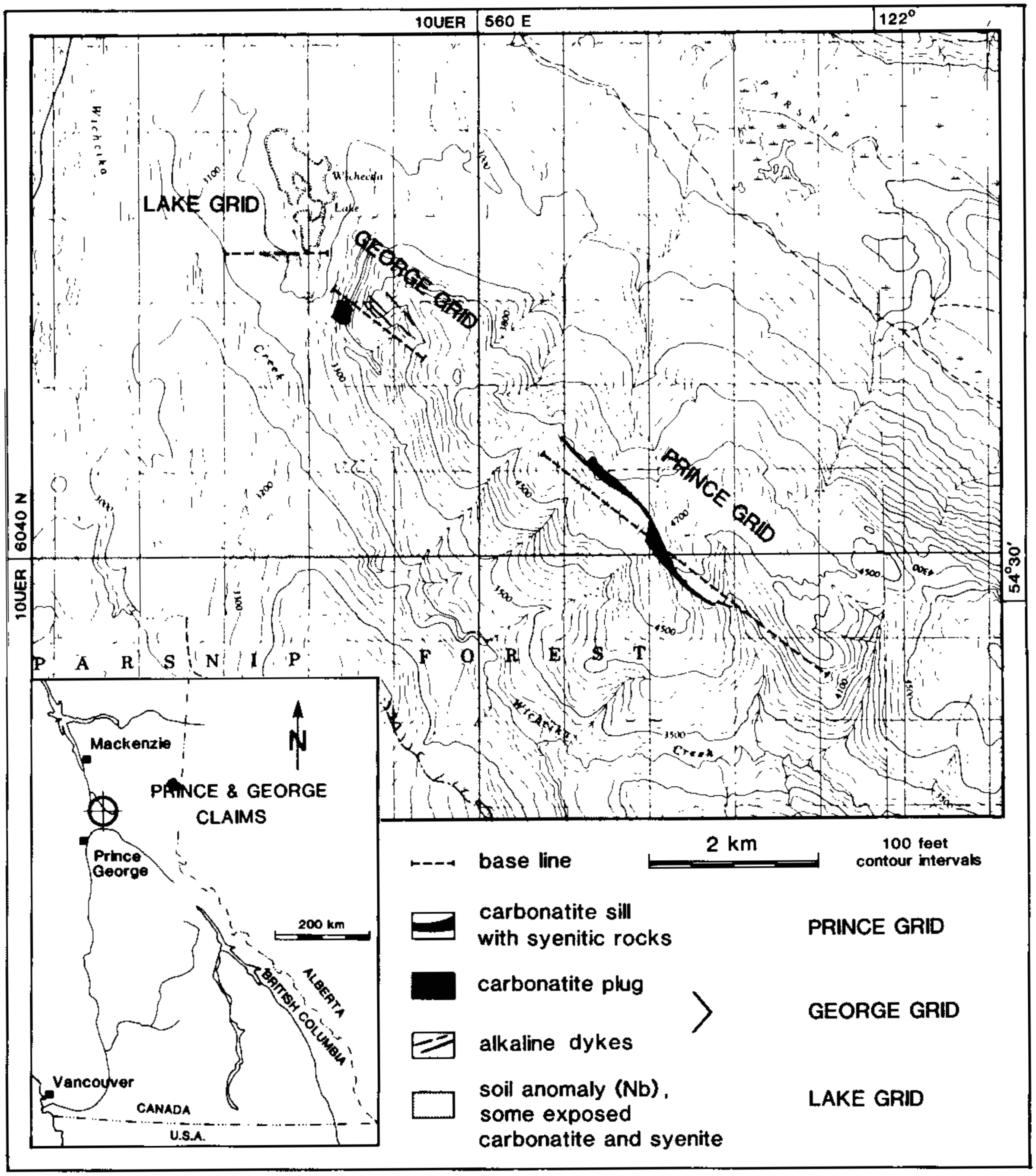

Figure 3-3-1. Location map of the intrusive bodies of the Prince and George groups of claims.

Carbonatites range from almost pure calcite carbonatite to pyroxene-biotite-rich varieties and rare-earth-rich ferrocarbonatite. Feldspathic rocks range from albite-rich and potassium-feldspar-rich leuco to mesotype syenites to leucitites. The suite is therefore a highly differentiated series of alkaline rocks. Unfortunately, sparse outcrop does not permit the establishment of field relationships between most units.

The group of igneous rocks as a whole is characterized by the ubiquitous presence of ilmenite and sodic pyroxene. A summary of the mineralogy is presented in Table 3-3-1. Methods of mineral identification include transmitted and reflected light microscopy, X-ray diffraction and the scanning electron microscope with an energy-dispersive analytical system.

CARBONATITE SILL (PRINCE GRID)

The carbonatite/alkaline sill can be traced for nearly 3 kilometres along strike (Figure 3-3-2) and may extend further to the northwest. The northwestern half of the intrusion, west of a northerly trending, steeply dipping fault, is petrographically distinct from the thickened southeastern half.

The northwestern part consists of medium to coarse-grained calcite carbonatites with variable amounts of aegirine

TABLE 3-3-1. LIST OF MINERALS

Mineral		Carbona-tite	Silcate Rocks
Aegirine	AEG	x	x
Albite	ALB	x	x
Alstonite[1]	ALS	x	x
Ancylite ?	ANC	x	
Ankerite	ANK	x	
Apatite	APA	x	x
Arag-stront[2]	ASS	x	x
Arfvedsonite	ARF		x
Augite	AUG		x
Barite	BAR	x	
Biotite	BIO	x	x
Burbankite	BUR	x	
Calcite	CAL	x	x
Cancrinite	CAN	x	x
Dolomite	DOL	x	x
Garnet (Ca-Fe)	GAR		x
Hyalophane	HYA		x
Ilmenite	ILM	x	x
K-feldspar	KSP	x	x
Leucite	LEU		x
Magnetite	MAG	x	x
Melanite	MEL		x
Monazite	MON	x	
Muscovite[1]	MUS		x
Parisite[3]	PAR	x	
Phlogopite	PHL		x
Pyrite	PYR	x	x
Pyrochlore	PCH	x	x
Rutile	RUT	x	
Sodalite	SOD		x
Sphalerite	ZNS	x	x
Sphene	SPH	x	x
Zircon	ZIR		x

[1] Alteration product.
[2] Aragonite-strontianite solid solution.
[3] Or röntgenite, synchysite.

and biotite and a pronounced subvertical mineral layering (Figure 3-3-3, Table 3-3-2). Felsic rocks, interbedded with carbonatites, include albite-rich and minor potassium-feldspar-rich leucocratic to mesocratic varieties with aegirine and biotite. The contacts between silicate and carbonatite rocks are distinct or gradational, but without clearly defined relationships, possibly indicating closely timed pulses of magma or *in situ* differentiation of the sill. Contacts with the argillaceous wallrock sediments appear to be conformable, but with surprisingly little visible alteration or contact metamorphism.

The southeastern, thickened part of the intrusion is comprised of white, layered calcite carbonatite, coarse-grained leucosyenite, augite leucite syenite and thinly layered, fine-grained, mesocratic augite syenite (Figure 3-3-4, Table 3-3-2). All rock types contain abundant sphene. The carbonatite clearly intrudes the leucosyenite (irregular on a small scale) and the layered mesocratic syenite (formation of intrusive breccia). The relation of the undersaturated syenite to the other rocks is unknown. The relationship between the two distinctly different parts of the sill across the fault is unclear.

CARBONATITE PLUG (GEORGE GRID)

The oval carbonatite intrusion is about 250 metres in diameter with an undefined northwestern boundary. A series of trenches from southwest to northeast exposes a nearly complete cross-section. The intrusion consists largely of uniform ankerite carbonatite, in parts with 5-centimetre rhombic ankerite phenocrysts and 2-centimetre pyrite cubes. Minor constituents include potassium feldspar, ilmenite, and a parisite-like rare-earth carbonate (20 to 200 microns). Toward the southwestern margin, a variety of albite-rich

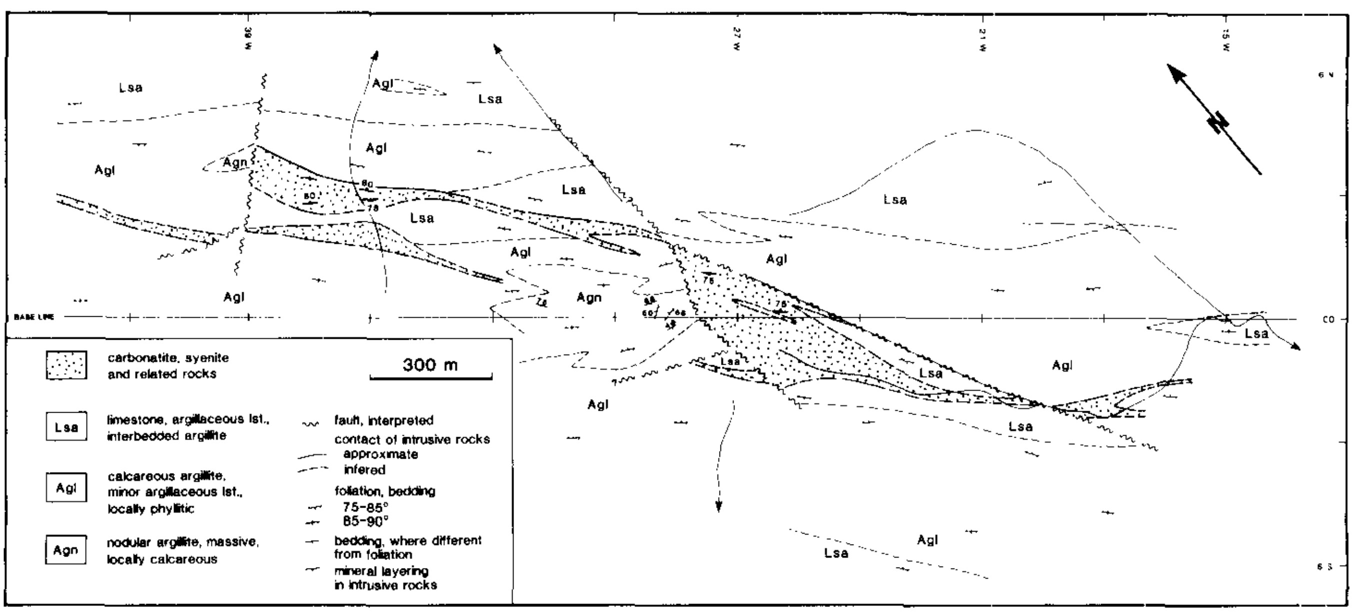

Figure 3-3-2. Geological map of the Prince grid, simplified after Betmanis, 1987, Teck Explorations Limited.

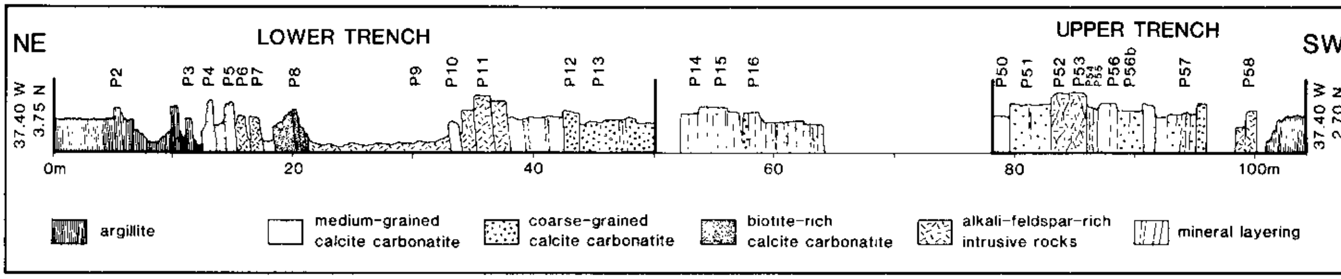

Figure 3-3-3. Geological cross-section of the northeastern part of the Prince grid.

TABLE 3-3-2.

MODAL COMPOSITION OF ROCKS FROM THE PRINCE GRID

Sample	CAL	ALB	KSP	LEU	BIO	AEG	AUG	CAN	BUR	APA	Accessory
Rocks of Figure 3-3-3											
P8	30	11			27	21				6	MAG(4),PYR
P9	5	44	30			15		3		2	PYR,ILM,PCH
P10	88				2	6			3		PYR,PCH
P11		42				11		45			DOL(1).ILM
P12	79	5				15					PYR,PCH
P13	78	19				2					PYR
P15	75	12			5	5			2		PCH,PYR,ILM
P16	78				8	6		4	3		PCH,ZNS,PYR
P50	69	25				4				2	ILM
P53	3	76				18				3	ILM
P54	73				4	5		17			PYR,ZNS
P56	80	2			8	5			5		PCH,ZNS,PYR
P57	88	1				4			6		PYR,PCH,ILM
P58	10		76		2					2	alteration(10)
Rocks of Figure 3-3-4											
Carb[1]	93		6	<1						<1	SPH
Syen[2]	10		5	76		2	2	2			ALS,ZIR,PCH
Leuc[3]	2		19[5]	58			18			<1	SPH(2),MEL
b-syen[4]	10		43				45			1	SPH(1)

[1] Carbonatite.
[2] Leucosyenite.
[3] Augite-leucite syenite.
[4] Banded mesotype augite syenite.
[5] Barian feldspar (hyalophane).

rocks are mixed with ilmenite-rich carbonatite. The argillaceous and calcareous sediments close to the intrusion appear somewhat baked, but with no macroscopically visible contact metamorphic mineral assemblages.

ALKALINE DYKES (GEORGE GRID)

Three types of dykes (50 to 150 centimetres in thickness) are slightly discordant to the trend defined by bedding and schistosity. The dykes appear to be undeformed.

The first type is a potassium-feldspar-phyric rock with a fine-grained albite-rich matrix with abundant iron-rich biotite. Accessory minerals include poikilitic calcite, ilmenite and zircon.

The second type has abundant blue sodalite phenocrysts, rare xenoliths of microsyenite and a fine-grained matrix of albite and sodalite. Accessory minerals include calcite, ilmenite, sphalerite and zircon.

The third type is a feldspar-augite-phyric intermediate dyke with an aphanitic groundmass. This type is observed to cut the sodalite dykes and appears to be of much younger age.

The alkaline dykes (Types 1 and 2) may well be related to the carbonatite intrusions of the area, although at present neither the extent of the dyke swarm nor its relationship to the carbonatite stock are known.

CARBONATITE INTRUSION (LAKE GRID)

Outcrop is scarce, with good exposure limited to three trenches, but soil anomalies appear to be well defined and to be capable of defining the underlaying intrusive bodies rather well.

The main rock type appears to be a deeply weathered, medium to coarse-grained calcite carbonatite with accessory feldspar, pyrite and apatite. A band of fresh, distinctly pink fine-grained calcite carbonatite with aegirine mineral layering contains relatively large (0.1 to 0.8 millimetre) euhedral pyrochlore grains accumulated within pyroxene-rich layers. At least one syenite body of unknown size and shape appears to be associated with the carbonatites. Besides laths of potassium feldspar, variable amounts of aegirine, albite, biotite, cancrinite and calcite are present with accessory pyrite, apatite, ilmenite and sphene.

GEOCHEMISTRY

Limited data on bedrock samples are available at present (Betmanis, 1987). All the intrusive rocks are enriched in the elements typical of alkaline/carbonatite rocks, enabling the use of niobium, barium, strontium or cerium to define geochemical anomalies in soil surveys.

Chondrite-normalized rare-earth patterns fall into the range of values defined by other intrusions in British Columbia enriched in light rare-earth elements (Betmanis, 1987; Pell, 1987).

ECONOMIC ASPECTS

Niobium: The only niobium-bearing mineral observed is pyrochlore, $(Na,Ca)_2(Nb,Ti,Fe)_2O_6(OH,F)$, mostly of grain sizes less than 0.3 millimetre. Pyrochlore occurs in both carbonatite and syenitic rocks. All specimens examined with the energy-dispersive system of the scanning electron microscope show thorium and uranium contents below or near detection limits. All pyrochlores are titaniferous, with low or undetectable contents of iron and other elements (Sr, Ba, Ta), which explains the occurrence of some colourless, glass-clear grains visible in thin section.

The absence of other thorium/uranium-bearing minerals explains the observed strong correlation between pyrochlore

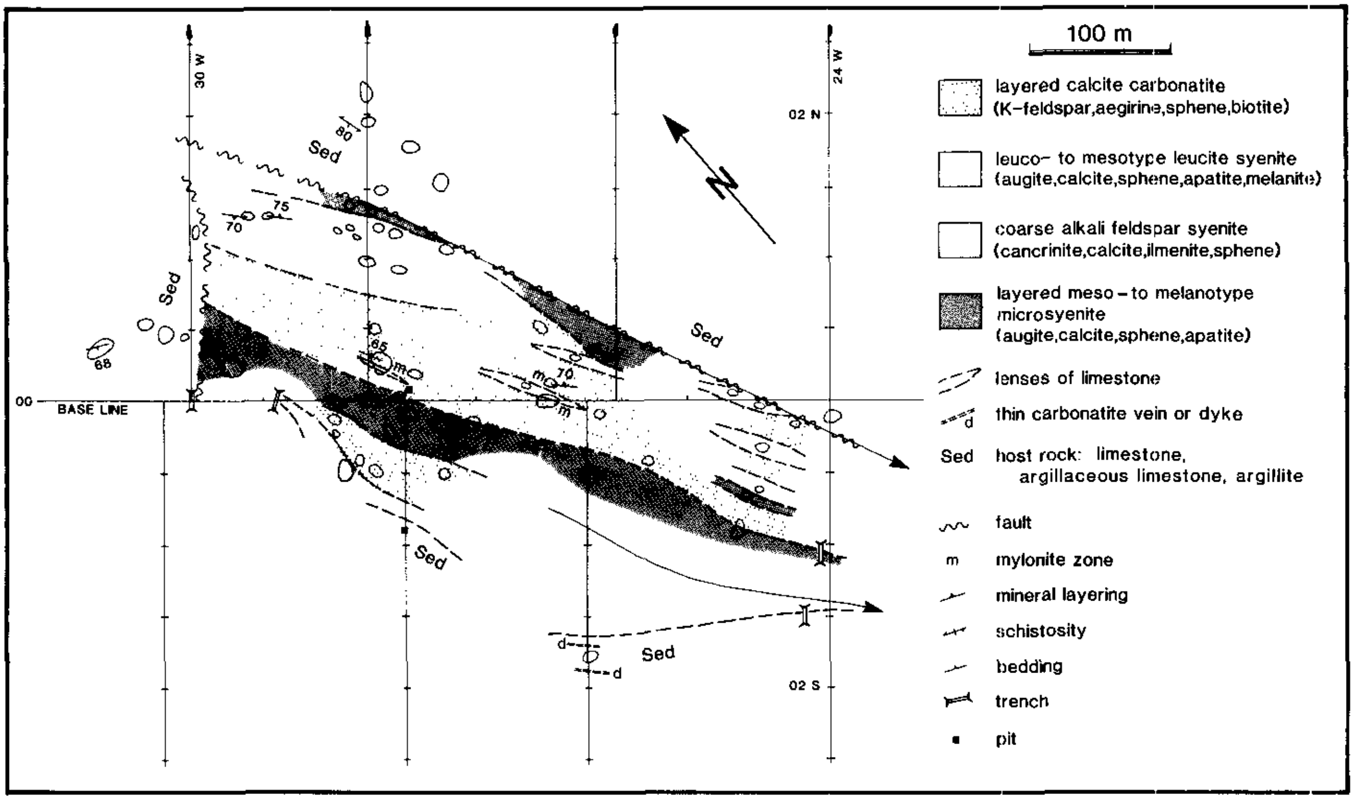

Figure 3-3-4. Geological map of the southwestern part of the Prince grid based on mapping by Greenwood, Hora and Mäder (July 1987).

content (niobium grade) and gamma activity (scintillometer readings) (Betmanis, personal communication, 1987).

Rare-earth Elements: Many carbonatite samples from the Prince grid show visible, pinkish, fine-grained rare-earth carbonates (mostly burbankite) in hand specimen.

The ferrocarbonatite plug on the George grid shows no mesoscopic rare-earth mineralization, but abundant fine-grained monazite (Ce-La phosphate) and parisite (Ca-Ce-La fluor-carbonate) are visible in thin section and under the scanning electron microscope.

All rare-earth minerals analysed are strongly enriched in light rare-earth elements, dominated by cerium, followed by lanthanum, neodymium and praseodymium. Yttrium and heavy rare-earth elements were not observed at the detection limits of the energy-dispersive system.

DISCUSSION

Although the age of the intrusions is not established, we think that they must be older than the Columbian orogeny, possibly of mid-Paleozoic age. The nature of the petrogenetic link amongst carbonatites and syenites, if it exists, is not known. The close spatial relationship was most probably present prior to the formation of the Rocky Mountains. The shapes of the igneous bodies prior to deformation may be envisaged as sills and tube or laccolith-like plugs with dykes subparallel to bedding. The depth of the intrusions and the ages of the host rocks are not known. There is no evidence of volcanic activity associated with the intrusions.

ACKNOWLEDGMENTS

We thank William Meyer of Teck Explorations Limited for making possible our visit to the property through financial and logistical support. Liberal access to geological data was very helpful.

A.E. Betmanis and Bing Lovang (Teck Explorations Limited) provided expert guidance and discussions in the field. Z.D. Hora (B.C. Ministry of Energy, Mines and Petroleum Resources) joined us in the field and lent his experience with alkaline rocks. Support by the Canada/British Columbia Mineral Development Agreement for current research is fully acknowledged.

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THE EVALUATION OF OLIVINE SAND PREPARED FROM TULAMEEN DUNITE* (92H/10)

By Z. D. Hora and G. V. White

KEYWORDS: Industrial minerals, olivine, dunite, Tulameen, foundry sand, laboratory testing.

INTRODUCTION

A geological mapping and sampling program carried out during 1986 identified three zones of fresh dunite (loss on ignition less than 2 per cent) in the core of the Tulameen ultramafic complex (White, 1986). Following this survey, a 20-kilogram sample of dunite was collected from one of the zones (Figure 3-4-1) and sent to the CANMET/Energy, Mines and Resources laboratories in Ottawa for physical tests to determine if the dunite would meet commercial specifications for foundry sand applications. Encouraging preliminary results (Szabo *et al.*, 1987) prompted the collection, during the 1987 field season, of a 300-kilogram bulk sample of dunite to verify its suitability as a foundry-grade olivine sand which would be competitive with imported sands. The sample was forwarded to the CANMET laboratories in Ottawa to undergo the full-scale testing required to evaluate a potential foundry sand.

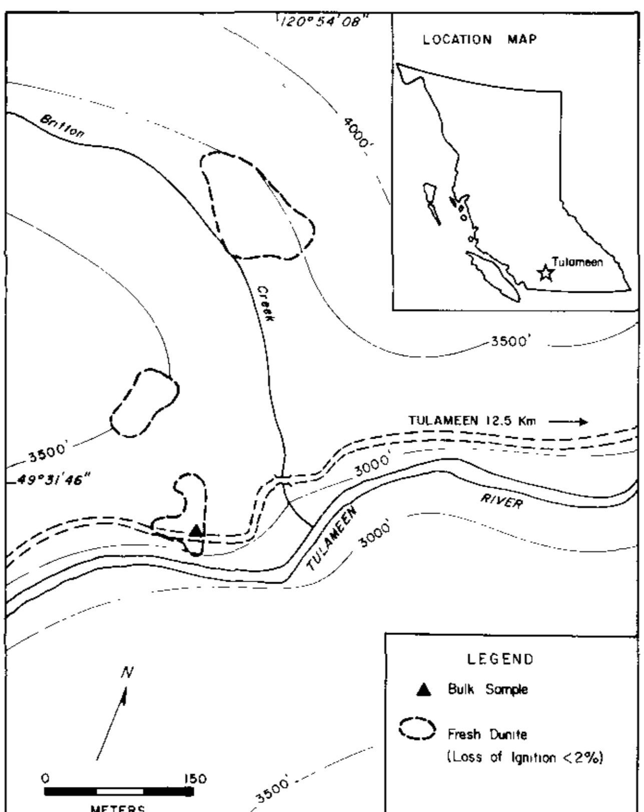

Figure 3-4-1. Location of "fresh" zones of dunite, Tulameen ultramafic complex.

SAMPLE PREPARATION

The 300-kilogram bulk sample consisted of rock fragments 10 to 15 centimetres in diameter. In order to determine optimal breakdown of the dunite and to produce sand-sized particles, three crushing modes, jaw plus rolls, hammer mill and pin mill, were employed. As a first step, the dunite was crushed to 2.5 centimetres by a large jaw crusher. Three corresponding 25-kilogram head samples designated A, B and C were then treated as follows:

(1) Sample A: stage-crushed and screened to 8 mesh by jaw crusher (2 passes) and roller (1 pass).

(2) Sample B: crushed to 8 mesh in pin mill (1 pass).

(3) Sample C: crushed to 8 mesh in hammer mill with 4.125-millimetre (1/8-inch) slotted grate.

Sieve analysis (Table 3-4-1) indicates that the hammer mill is the preferred crushing method for optimum production and recovery of −20+100-mesh product. On this basis the remainder of the 2.5-centimetre jaw-crusher product was crushed in the hammer mill, screened on a Rotex screen at 20 and 100 mesh, the product blended and sampled, and five 40-kilogram samples selected for foundry evaluation. The results of a sieve analysis on the five blended samples are summarized in Table 3-4-2. The five samples were then forwarded for the foundry-sand evaluation tests.

TABLE 3-4-1
SIEVE ANALYSES FROM THE THREE CRUSHING PROCESSES
(from Whiting *et al.*, 1987)

Mesh Size	Head Sample	Sample A* (Jaw + Rolls) 15 min.	30 min.	Sample B* (Pin Mill) 15 min.	30 min.	Sample C* (Hammer Mill) 15 min.	30 min.
+4	57.6						
−4, +8	17.0						
−8, +14	6.4						
−14, +20	2.4	30.6	30.8	14.5	14.0	18.7	18.7
−20, +28		12.9	12.6	7.4	7.4	8.6	8.6
−28, +35		10.6	11.5	10.1	10.2	10.9	10.7
−35, +48	11.6	9.4	9.3	13.3	13.3	13.7	13.5
−48, +65		8.3	8.1	14.7	15.1	14.1	14.1
−65, +100		7.6	7.6	14.3	14.1	13.1	12.9
−100	5.0	20.6	20.1	25.7	25.9	20.9	21.5
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* 15 and 30 min. Retap intervals.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

TABLE 3-4-2
SIEVE ANALYSES — BLENDED SAMPLES FOR FOUNDRY EVALUATION (Wt. %)
(from Whiting *et al.*, 1987)

Mesh Size	IMC Olivine	*	Tulameen Olivine **	***
+28	6.9	7.8	7.8	9.4
−28, +35	27.4	18.7	18.7	22.6
−35, +48	28.3	23.5	23.5	28.4
−48, +65	29.0	24.3	24.3	29.3
−65, +100	7.3	19.0	6.3	7.6
−100	1.1	6.7	2.2	2.6
	100.0	100.0	100.0	100.0

* Hammer mill product screened at 20 and 100 mesh on Rotex.
** Product screened at 65 mesh, ⅓ of minus 65 reblended, remaining ⅔ discarded.
*** Calculated sieve analysis of screened and reblended sample.

TABLE 3-4-4
EVALUATION OF SCAB BLOCK CASTINGS*
(from Whiting *et al.*, 1987)

Casting Property	Sand Type	Casting Trial Number 1	2	3	4	5
Surface finish	IMC olivine	3	3	3	3	2
	Tulameen olivine	3	3	3	3	2
Scabbing	IMC olivine	1	1	1	1	1
	Tulameen olivine	1	1	1	1	1
Burn on	IMC olivine	2	2	2	2	2
	Tulameen olivine	2	2	2	2	2
Erosion	IMC olivine	2	2	2−	2	2
	Tulameen olivine	2	2	2	2	2
Penetration	IMC olivine	2	2	2	2	2
	Tulameen olivine	2	2	2	2	2

* Each casting was rated subjectively for each property for every trial, using a scale of 1 to 5, where 1 = good and 5 = bad.

TABLE 3-4-3
GREENSAND PROPERTIES BEFORE AND AFTER EACH TRIAL
(from Whiting *et al.*, 1987)

Casting Property	Sand Type	Casting Trial Number 1	2	3	4	5
Sand Properties Before Each Casting Trial						
Compactability %	IMC olivine	44	45	48	44	49
	Tulameen olivine	49	47	45	45	49
Moisture %	IMC olivine	2.15	2.15	2.24	2.20	2.15
	Tulameen olivine	2.16	2.21	2.14	2.13	2.23
Density, g/cm³	IMC olivine	195	195	193	192	190
	Tulameen olivine	186	185	185	185	183
Permeability, AFS units	IMC olivine	200	195	210	215	228
	Tulameen olivine	249	240	240	243	253
Green compressive strength, psi	IMC olivine	30.0	27.1	29.0	30.2	28.9
	Tulameen olivine	25.7	25.2	28.0	29.6	28.6
Clay additions, %	IMC olivine	6.0	0.1	0.1	0	0
	Tulameen olivine	6.0	0.3	0.15	0.05	0.2
Methylene blue clay, %	IMC olivine	6.1	6.1	6.3	5.8	5.8
	Tulameen olivine	6.1	6.1	6.2	6.0	5.8
Mould hardness, B scale	IMC olivine	88	88	88	90	88
	Tulameen olivine	88	88	90	90	88
AFS grain fineness number, AFS units	IMC olivine	42.7				*50.6
	Tulameen olivine	44.3				*54.5
Acid demand, ml	IMC olivine at pH 5	9.6				
	at pH 7	8.5				
	Tulameen olivine at pH 5	33.6				
	at pH 7	30.5				
Loss on ignition, %	IMC olivine at 500°C	0.55				
	at 700°C	1.25				
	at 975°C	1.51				
	Tulameen olivine at 500°C	0.90				
	at 700°C	1.82				
	at 975°C	1.83				
After Casting Trials						
Moisture, %	IMC olivine	0.85	0.82	0.94	0.81	N/D
	Tulameen olivine	0.93	0.83	0.98	0.85	N/D
Methylene blue clay, %	IMC olivine	5.9	5.9	6.1	6.1	N/D
	Tulameen olivine	5.7	5.9	5.6	5.8	N/D
AFS clay, %	IMC olivine	N/D	N/D	N/D	N/D	8.96
	Tulameen olivine	N/D	N/D	N/D	N/D	8.48

* After fifth trial and after washing for AFS clay test.

FOUNDRY TESTING

Evaluation of the Tulameen olivine sand samples was done by comparing the casting performance using Hadfield manganese steel "scab blocks" as a test casting, with a widely used and available standard foundry sand (IMC Olivine 50). Such testing follows 14 specific steps according to standard foundry-sand tests as recommended and defined by the American Foundrymen's Society. The resulting values for individual casting properties of sand are presented in Table 3-4-3 and the evaluation of scab-block castings in Table 3-4-4. With the exception of using some specialty chemical binder systems, the Tulameen dunite foundry sand compares favourably with the imported product, both in moulding performance and casting quality.

SUMMARY

Although limited in extent, the results of the detailed mapping of the least serpentinized part of the Tulameen ultramafic complex, followed by comprehensive laboratory testing, give a good indication that the Tulameen dunite is suitable for the production of foundry sand which is at present imported to Canada with other olivine rock products from the United States.

ACKNOWLEDGMENTS

The authors would like to express their thanks to the Mineral Processing Laboratories and Foundry Section of CANMET for carrying out the mineral preparation and foundry tests. This project was in part funded by the Canada/British Columbia Mineral Development Agreement.

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SANDSTONE QUARRIES ALONG THE STRAIT OF GEORGIA*
(92F/10; 92G/4W; 92B/13E, 14)

By G. V. White

KEYWORDS: Dimension stone, heritage buildings, sandstone, Nanaimo Group, Denman, Newcastle, Gabriola, Jack Point, Mayne, Saturna, Saltspring.

INTRODUCTION

During the middle to late 1800s sandstone from local quarries was used as chiseled and scobed ashlar (rough-hewn blocks of stone) in construction of prominent buildings in Vancouver, Victoria and other Vancouver Island communities. The use of sandstone was discontinued in the 1920s but many of these historic structures have been designated as heritage buildings. This report documents the current status of abandoned quarries and identifies reserves of stone potentially needed for maintenance of these buildings. Eight sites examined during 1987 (Figure 3-5-1) are described.

All the quarries examined were opened in medium-grained (0.05 to 2 millimetres) Upper Cretaceous Nanaimo Group sandstones (Table 3-5-1). Descriptions are listed by geographical location starting in the north with Denman Island.

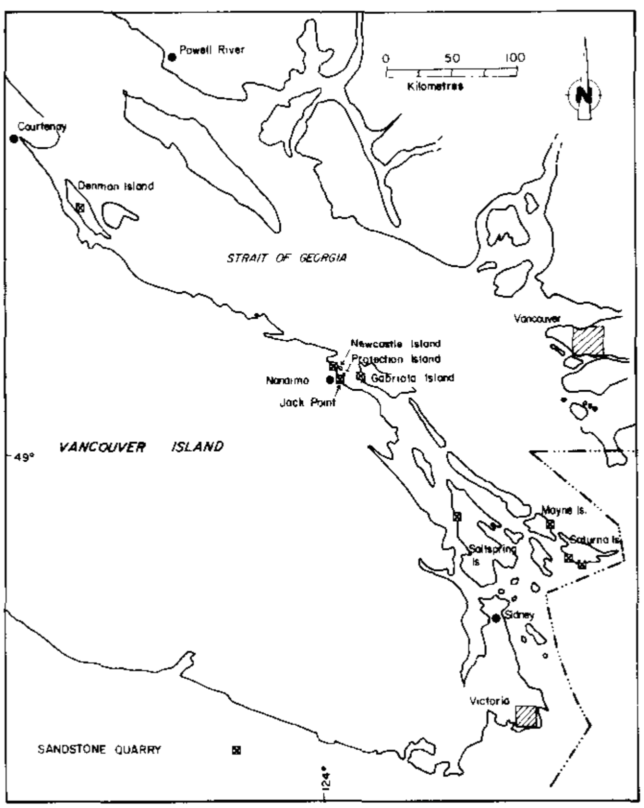

Figure 3-5-1. Location map, sandstone quarries.

Sandstone samples from each quarry were tested by Parks (1917), and the values are within limits set by the American Society For Testing and Materials (ASTM) for sandstone building stone (Table 3-5-2).

TABLE 3-5-1
SANDSTONE QUARRIES ON SOUTHERN VANCOUVER ISLAND AND THE GULF ISLANDS

Quarry	Location	Formation	Description
Denman Island	92F/10	De Courcy Formation	Sandstone, conglomerate, minor siltstone, shale
Jack Point	92G/4W	De Courcy Formation	Sandstone, conglomerate, minor siltstone, shale
Newcastle Island	92G/4W	Extension-Protection Formation	Sandstone, conglomerate, minor siltstone, shale
Gabriola Island	92G/4W	Gabriola Formation	Sandstone, conglomerate, minor siltstone, shale
Saltspring Island	92B/13E	Cedar District Formation	Shale, siltstone, minor sandstone
Mayne Island	92B/14	Gabriola Formation	Sandstone, conglomerate, minor siltstone, shale
Saturna Island	92B/14W	Cedar District Formation	Shale, siltstone, minor sandstone

DENMAN ISLAND QUARRY (92F/10)

An abandoned sandstone quarry (Mineral Inventory 92F-426), located 1.65 kilometres from the British Columbia ferry terminal on Denman Island, produced stone used to construct the Normal School and Drill Hall in Victoria and the Metropolitan Building and Dawson School in Vancouver (Parks, 1917).

SAMPLE DESCRIPTION

Fresh sandstone has a grey tone, is medium grained and generally displays a uniform texture although thin (4 to 5-centimetre) beds of coarse (greater than 2 millimetres) material are present. White to black cherty fragments, up to 3 millimetres across, commonly give the rock a coarse appearance.

Exposed surfaces weather in distinct colours of light to dark yellowish grey. Parks' description of the Normal School in Victoria notes: "Much variation in the colour of individual blocks detracts from the appearance of the building; when a light yellowish block is close to a very dark one the difference is striking".

Thin sections show that fresh angular quartz grains (40 per cent by volume) up to 0.75 millimetre in size are enclosed by a green, cloudy cement, probably chlorite (T. Höy, personal

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

TABLE 3-5-2
SANDSTONE QUARRIES ALONG THE STRAIT OF GEORGIA — PHYSICAL PROPERTIES

Quarry Name	Specific Gravity	Density lb./ft.^{3}	Density kg/m^3	Absorption by Weight % 1 hr.	Absorption by Weight % 2 hrs.	Compressive Strength PSI Dry	Compressive Strength PSI Wet	Compressive Strength PSI Freezing	Compressive Strength MPa Dry	Compressive Strength MPa Wet	Compressive Strength MPa Freezing	Traverse Strength PSI	Traverse Strength MPa	Shearing Strength PSI	Shearing Strength MPa
Denman Island	2.713	145.45	2330	1.73	2.06	8,551	3,963	2,052	58.96	27.32	14.15	1,128	7.77	846	5.83
Jack Point	2.689	153.36	2457	1.92	2.27	11,276	7,116	5,265	77.75	49.06	36.30	841	5.80	1,053	7.26
Newcastle Island	2.656	152.38	2441	1.09	1.34	14,849	11,874	9,670	102.38	81.87	66.67	1,170	8.07	1,406	9.69
Gabriola Island	2.695	152.34	2440	2.38	2.69	10,589	10,068	7,564	73.01	69.42	52.15	849	5.85	1,054	7.27
Saltspring Island	2.67	157.21	2544	1.40	1.67	27,229	17,800	17,797	187.74	122.73	122.71	2,296	15.83	1,926	13.28
Mayne Island	2.661	149.02	2387	2.73	2.98	16,505	10,869	8,893	113.81	74.94	61.32	892	6.15	1,227	8.46
Saturna Island	2.667	148.31	2376	2.42	2.68	14,800	11,837	11,601	102.04	81.61	79.99	1,212	8.36	1,404	9.68
Physical Requirements — American Society for Testing and Materials (A.S.T.M.)															
Sandstone*	N/A	140 (min)	2440	20 (max)		2,000 (min)				13.8		300 (min)	2.1	N/A	N/A

* Sandstone (Commercial Definition) — a consolidated sand in which the grains are composed chiefly of quartz or quartz and feldspar, or fragmental (clastic) texture, and with various interstitial bonding materials, including silica, iron oxides, calcite, or clay.

Source: 1984 Annual Book of ASTM Standards.

Physical Tests: Parks (1917).

Conversion Factors: PSI → MPa = # × 6.894757 × 10^{-3}.
lb./ft.^{3} → kg/m^3 = # × 1.601846 × 10.

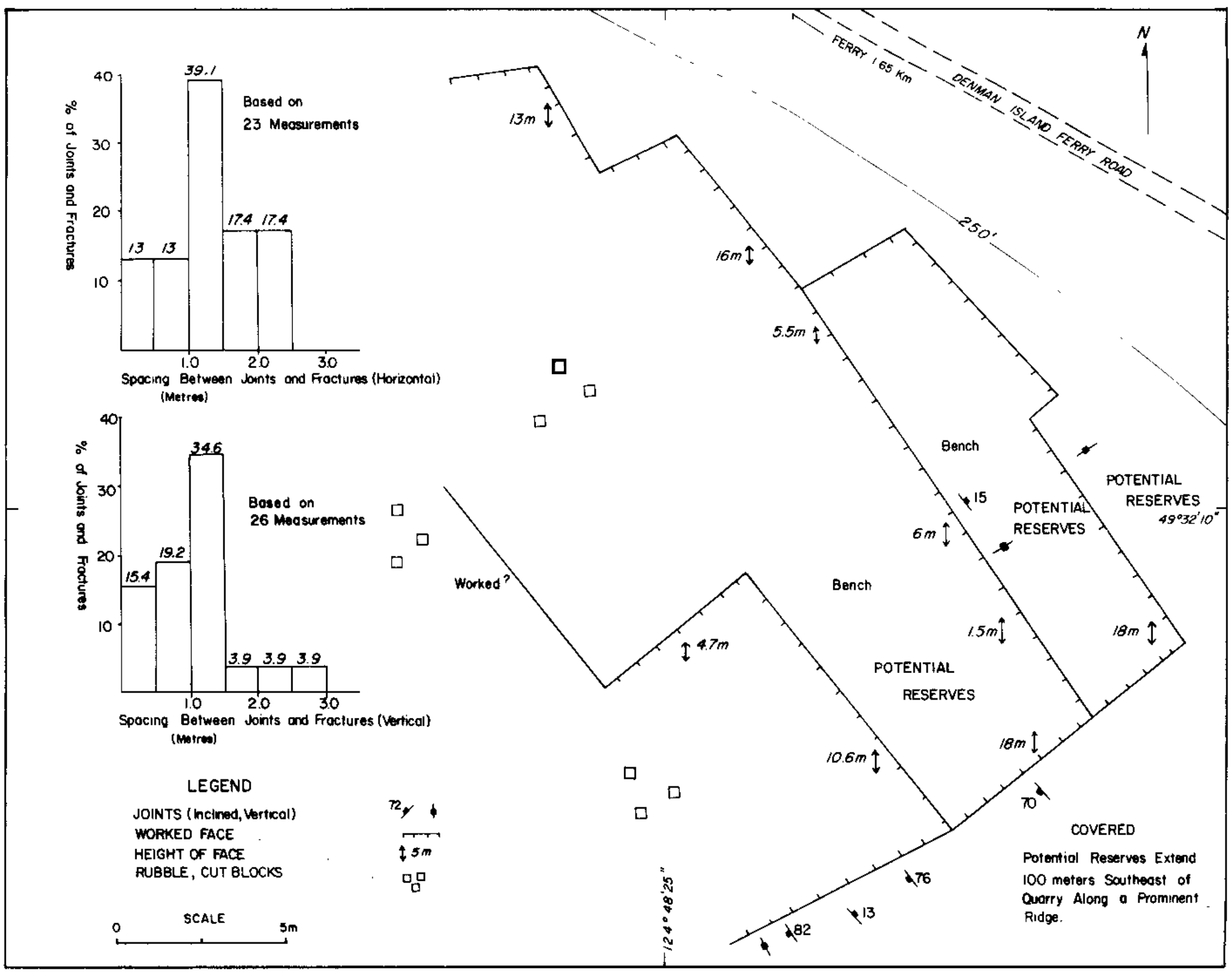

Figure 3-5-2. Denman Island sandstone quarry (92F/10).

communication, 1987). Sericite comprises 50 per cent of the rock and accessory minerals include plagioclase, biotite and an unidentified isotropic mineral.

QUARRY DEVELOPMENT AND STRUCTURE

The quarry, approximately 26 metres long and 17 metres wide, was developed in three benches along prominent joints striking northwest and dipping steeply southwest (Figure 3-5-2). Other irregular northwest-striking joints dip moderately northeast while well-developed northeast joints at the middle and upper benches, dip vertically.

Spacing between vertical joints and fractures varies from 0.4 to 20.3 metres with most spaced approximately 1.5 metres apart. Horizontal joints are regularly spaced, averaging between 1.5 and 2.0 metres apart. Beds strike northwest and dip 10 to 15 degrees east.

On the upper bench the rock contains concretions of medium-grained sandstone, 50-centimetre bands of pebbles, and rounded cherty pebbles up to 7 centimetres long which have a distinct north-south orientation. The stone in the middle bench is similar in appearance and it represents one distinct bed.

The lower bed is 9 metres thick, is dark grey in colour, and has a uniform texture and occasional shaly partings. It is intensely fractured and would not produce large blocks. Bedding is poorly defined.

Blocks left on site measure 1.5 by 1.6 by 2.9 metres but Parks described blocks "25 feet by 12 feet" (7.6 by 3.6 metres) successfully removed from the middle bench. Blocks left on site are in good condition although pitting and occasional peeling were observed.

RESERVES

Potential reserves of sandstone extend 100 metres southeast of the developed site along a well-defined ridge 20 to 25 metres high. Quarry development north of the upper bench is restricted by the road to the Denman Island ferry dock; outcrop is covered to the south and east.

JACK POINT QUARRY (PORTAGE QUARRY) (92G/4W)

This sandstone quarry (Mineral Inventory 92G-049), located east of Nanaimo harbour on Jack Point, produced building stone used to construct the Nanaimo Post Office (Parks, 1917).

SAMPLE DESCRIPTION

Sandstone ranges from medium to dark blue-grey in colour and is the coarsest of eight sandstones examined, with an average grain size between 1 and 2 millimetres. Cherty pebbles (up to 2 centimetres) and large sand concretions (up to 1.4 metres in diameter) disrupt an otherwise uniform texture.

Buildings constructed of Jack Point sandstone were not examined, but exposed stone at the site remains fresh, giving an indication of its durability and weathering characteristics.

In thin section angular to subangular quartz grains between 0.25 and 1.5 millimetres in size are seen to comprise 50 per cent of the rock. A cloudy green chlorite cement is visible between grains of orthoclase which are often partially altered to sericite. Other constituent minerals include plagioclase, biotite and an unidentified isotropic mineral.

QUARRY DEVELOPMENT AND STRUCTURE

The Jack Point quarry described by Parks was 46 metres long and located 6 metres above sea level. He described the jointing as: "not very distinct, but there seems to be an ill-defined set striking with the face and dipping 70 degrees towards the harbour".

Recent excavation on Jack Point has removed a large volume of sandstone (probably for fill, but the final destination and use of the stone is not known) and exposed a face 520 metres long and 5 to 7 metres high (Figure 3-5-3). Distinct sets of joints are exposed, with the main set striking northeast and dipping steeply northwest. Irregular west-northwest-striking joints dip steeply to the northeast. A subhorizontal joint set strikes parallel to the worked face and dips moderately east.

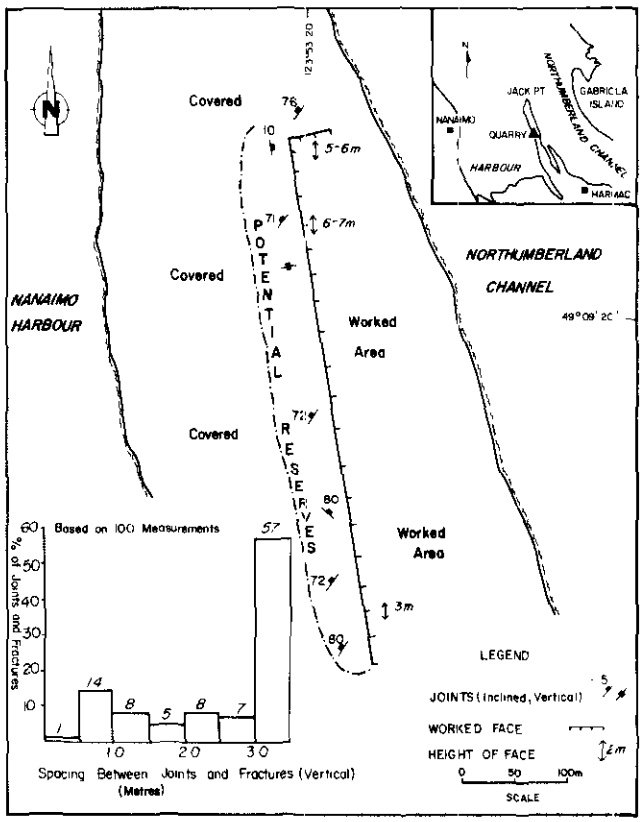

Figure 3-5-3. Jack Point sandstone quarry (92G/4W).

Vertical joints are widely spaced with 85 per cent more than 1 metre apart and nearly 60 per cent spaced over 3 metres apart. The greatest distance measured between two sets of vertical joints was 25 metres. Bedding along the west shore of the point strikes northwest and dips 10 to 15 degrees southeast. Individual beds range from 1.6 to 3 metres thick and are continuous.

RESERVES

Reserves of sandstone similar in appearance to stone described extend 40 to 50 metres west of the worked face.

NEWCASTLE ISLAND (92G/4W)

The Newcastle Island sandstone quarry (Mineral Inventory 92G-022) was the first quarry developed in the region (Parks, 1917). It provided building stone used to construct the San Francisco Mint (1873), the British Columbia Penitentiary (1875), Esquimalt Graving Dock (1880), Lord Nelson School in Vancouver (1911) and Christ Church Cathedral in Victoria (1955). This important quarry is located on the west shore of Newcastle Island, opposite Pimbury Point, and lies within the Newcastle Island Provincial Park.

SAMPLE DESCRIPTION

Medium-grained sandstone displays a uniform texture, has an attractive light grey tone and a speckled salt-and-pepper appearance. Occasional lenses of coal up to 5 by 20 centimetres in size lie parallel to bedding and concretions of coarse sandstone are common.

Christ Church Cathedral, constructed using Newcastle Island sandstone, is darker than fresh outcrop suggesting the stone darkens on exposure. Examination of the quarry face and buildings indicates pitting and peeling take place on exposed surfaces.

Thin sections show 50 to 60 per cent of the rock is comprised of closely packed, fresh, angular to subangular quartz grains, commonly 0.5 millimetre in size, with interstitial orthoclase, plagioclase and biotite. In many instances orthoclase is altered to sericite and occasional microfractures cut grain boundaries.

QUARRY DEVELOPMENT AND STRUCTURE

The worked face is 73 metres in length and has a height of 2 to 6 metres (Figure 3-5-4).

Bedding strikes northwest and dips gently southwest toward Newcastle Island Passage. A prominent set of joints strikes north-northeast and dips steeply east.

Over 85 per cent of joints and fractures measured are spaced more than 100 centimetres apart with 57 per cent greater than 300 centimetres apart.

RESERVES

Reserves of light grey sandstone lie northeast of the quarry. Measurements of joint and fracture density suggest blocks greater than 3 by 3 by 3 metres are available.

GABRIOLA ISLAND (92G/4W)

Building stone from a sandstone quarry (Mineral Inventory 92G-021), located on the west coast of Gabriola Island just south of Descanso Bay, was used to construct the main Post Office in Victoria, the Federal Life Building (Williams Building) and the Dunsmuir Street Roman Catholic Church in Vancouver (Parks, 1917). Blocks 1.4 metres across by 1.5 metres deep were quarried for use as grindstones in pulp mills.

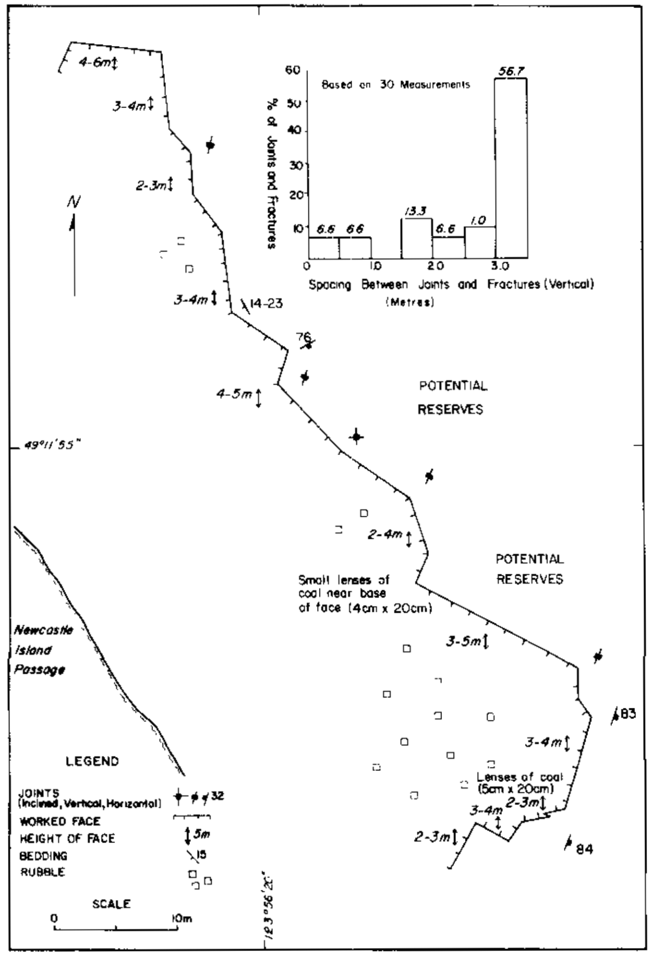

Figure 3-5-4. Newcastle Island sandstone quarry (92G/4W).

SAMPLE DESCRIPTION

The sandstone is medium grained, displays an even texture and a light to medium brown tone similar to Saturna Island sandstone. Small angular quartz crystals and blades of biotite (up to 3 millimetres) speckle the rock. Occasionally coarse concretions (up to 60 by 90 centimetres in size) and pebbles (up to 4 centimetres) disrupt the continuity of the bedding.

The stone darkens on weathered surfaces (Victoria Post Office) but remains solid and "fresh".

As seen in thin section, quartz grains range from 0.25 to 1.5 millimetres in size, are angular and comprise 70 per cent of the rock. Other minerals include orthoclase, plagioclase and biotite. Alteration of feldspar to sericite is pronounced, giving these grains a cloudy appearance.

QUARRY DEVELOPMENT AND STRUCTURE

The quarry has a length of 45 metres with worked faces between 2 and 15 metres high developed parallel to northeast-strikng joints (Figure 3-5-5).

Vertical joints are widely spaced with 90 per cent greater than a metre apart and 50 per cent more than 3 metres apart. Flat-lying bedding planes, which define individual beds, are regularly spaced between 2 and 14 metres apart.

Beds dip 10 to 15 degrees northeast and strike northwest.

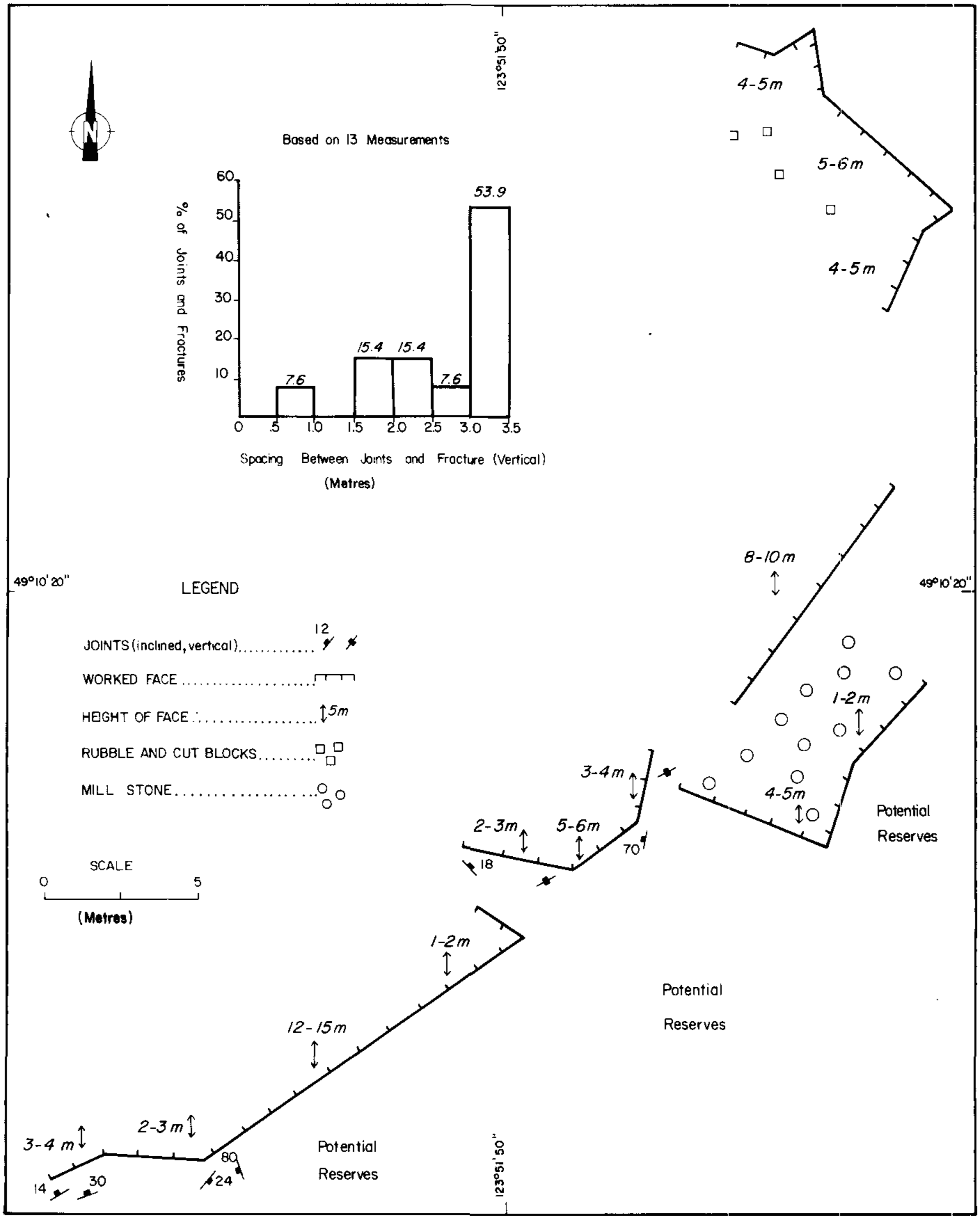

Figure 3-5-5. Gabriola Island sandstone quarry (92G/4W).

RESERVES

Potential reserves of quarriable stone extend 20 metres southeast of the worked face; beyond this distance heavy forest cover prevents detailed examination.

SALTSPRING ISLAND (92B/13E)

Sandstone from a small quarry opened parallel to the north shore of Booth Bay on Saltspring Island (Mineral Inventory 92B-072) was used to construct a part of the main Victoria Post Office (Parks, 1917).

SAMPLE DESCRIPTION

The stone is medium grained, displays a uniform texture and a moderate light to dark brown colour. Exposed faces darken and according to Parks "the weathering properties of the stone as indicated by this building (Victoria Post Office) are not of a high order, as so much disintegration had occurred in a few years that re-facing was resorted to in order to make the structure presentable". An examination of the post office suggests the original stone was replaced by more weather-resistant Gabriola sandstone, but this has not been confirmed.

At the quarry, thin lenses of coal and shale partings are common along joint and bedding planes.

Thin sections show that fresh angular quartz grains, up to 1 millimetre in size, occupy 50 per cent of the volume. Orthoclase is altered to sericite and forms nearly 40 per cent of the interstitial minerals. Other, largely unaltered minerals include plagioclase and biotite.

QUARRY DEVELOPMENT AND STRUCTURE

The worked face extends intermittently for 150 metres along a vertical bedding plane and is cut by steeply dipping north-northwesterly striking joints (Figure 3-5-6). Vertical joints are widely spaced (up to 16 metres) while flat-lying joints (bedding planes) are regularly spaced 2 to 4 metres apart.

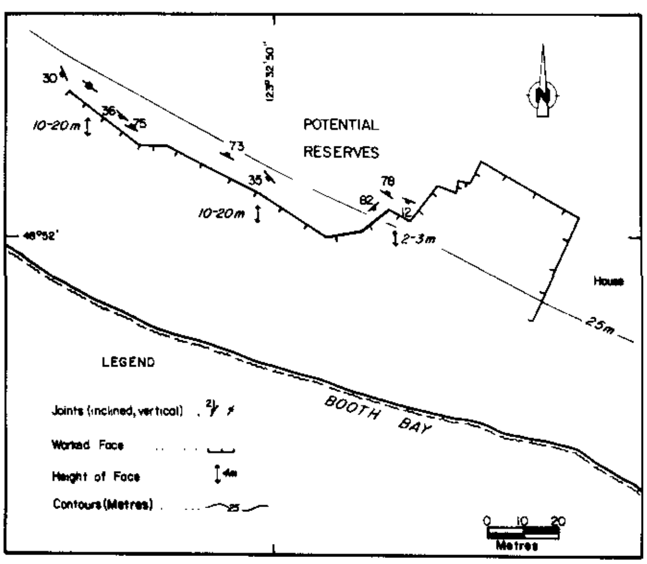

Figure 3-5-6. Saltspring Island sandstone quarry (92B/13E).

RESERVES

Potential reserves of sandstone extend 20 metres north and east of the worked face although a developed residential lot immediately east of the quarry will restrict expansion.

Block size will be restricted by flat-lying joints and by shaly partings along bedding planes.

MAYNE ISLAND (92B/14)

This small sandstone quarry (Mineral Inventory 92B-071) was developed along the north shore of Campbell Bay on Mayne Island, approximately half the distance to Edith Point. The stone was used "in Postal Station C at the corner of Main and 15th streets in Vancouver" (Parks, 1917).

SAMPLE DESCRIPTION

The sandstone has a light to medium brown tone, is medium grained and has a fresh uniform texture. Exposed surfaces weather yellow-brown and variations in colour extend along the quarry face depending on exposure. Parks, in describing the post office, commented "This building presents a very fair appearance, but there is considerable variation in colour of different blocks". This statement supports recent observations of the quarry's exposed face. While there are colour variations along individual beds, the stone maintains a solid, "fresh" appearance and does not display pitting or peeling.

In thin section quartz grains are seen to be angular and up to 1.75 millimetres in diameter, although they are commonly between 0.25 and 0.75 millimetre. Interstitial minerals include orthoclase (often altered to sericite), plagioclase and biotite. Individual grains do not appear to be well cemented and a few of the quartz, orthoclase and feldspar grains are cut by microfractures.

QUARRY DEVELOPMENT AND STRUCTURE

Located on tidewater, the abandoned quarry (Figure 3-5-7) is 34 metres long by 3 to 4 metres high, and was developed

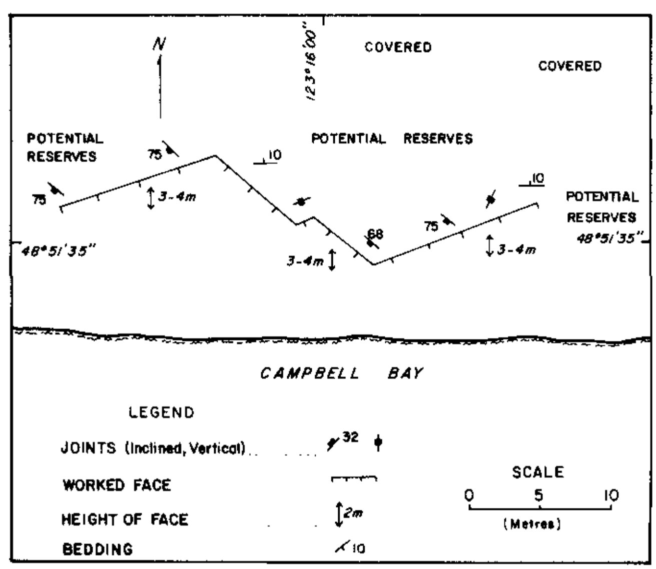

Figure 3-5-7. Mayne Island sandstone quarry (92B/14).

along prominent joints striking northwest and dipping steeply southwest. Vertical cross joints strike northeast and are spaced between 1 and 5 metres apart, while horizontal joints define the worked face. Bedding strikes easterly and dips north 10 degrees.

RESERVES

Potential reserves of sandstone are exposed for at least 100 metres along the coast east and west of the quarry, but north of the face, thick forest cover prevents close examination.

SATURNA ISLAND (92B/14W)

Two sandstone quarries (Mineral Inventory 92B-015 and 068) on the south shore of Saturna Island provided stone for a number of prominent buildings. Rock from the larger quarry (Mineral Inventory 92B-055), located on Taylor Point, was used in construction of the Carnegie Library (Plate 3-5-1), Hatley Park House, the Bank of British North America and the First Presbyterian Church in Victoria; the New Westminster Post Office; and the Normal School and P. Burns Building on Hastings Street in Vancouver (Parks, 1917).

Sandstone from the small quarry was used in the Weiler Block at the corner of Government and Broughton streets in Victoria.

SAMPLE DESCRIPTION

Saturna Island sandstone is buff coloured, medium grained and displays a uniform texture. The stone darkens on oxidized surfaces.

The Carnegie Library and Weiler Block have retained their attractive appearance and solid character, an indication of the stone's durability.

Thin sections show that angular to subangular, often interlocking quartz grains, dominantly 0.5 millimetre in size, comprise 50 to 60 per cent of the rock. Interstitial minerals include orthoclase, plagioclase and biotite. The orthoclase is commonly altered to sericite.

QUARRY DEVELOPMENT AND STRUCTURE

The Taylor Point quarry is 175 metres in length and was developed in a series of benches between 2 and 8 metres high (Figure 3-5-8).

Bedding strikes northwest and dips moderately to the northeast. One prominent set of joints strikes northwest, dipping steeply southwest and a second vertical set strikes north-northeast. Joint and fracture density measurements indicate that 66 per cent of vertical joints are spaced greater than 1 metre apart and 15 per cent greater than 3 metres, while flat-lying joints are up to 2 metres apart.

RESERVES

Potential reserves of sandstone extend north of the worked faces.

CONCLUSIONS

(1) Based on joint and fracture density surveys and examination of exposed outcrop at each of the eight sites, suffi-

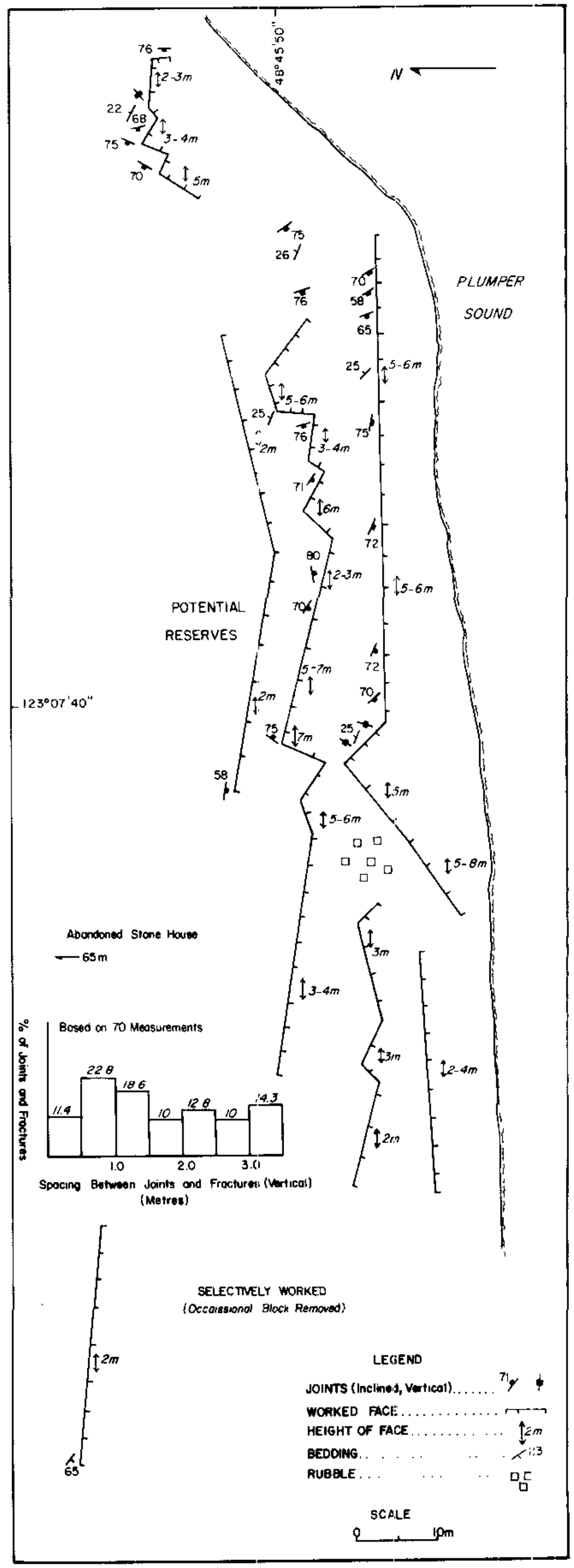

Figure 3-5-8. Saturna Island sandstone quarry (92B/14W).

Plate 3-5-1. The old Victoria Public Library (Carnegie Library), designated a heritage building, was constructed using Saturna Island sandstone.

cient quantities of stone remain to complete any necessary repairs or maintenance on heritage buildings located in the Lower Mainland or on Vancouver Island.

(2) Due to slight differences in colour, grain size, texture and weathering properties, the stone from one quarry cannot be replaced by rock from another source. The quarries which produced material for historically significant buildings should therefore be preserved.

(3) Inclusion of the Newcastle Island quarry in a Provincial Park and the close proximity of the Saltspring Island quarry to a residential subdivision will restrict their future development and access.

(4) The Saltspring Island sandstone breaks down with exposure and in at least one instance has had to be replaced.

ACKNOWLEDGMENTS

The author would like to acknowledge Z.D. Hora for suggesting the study and reviewing the paper. David Hannay provided capable and cheerful field assistance throughout the project. Figures were drafted by Janet Fontaine.

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KNIGHT INLET GRANITE QUARRY (92K/12W)

By G. V. White

KEYWORDS: Dimension stone, Knight Inlet, granite quarry, Catherine Blue Granite, hornblende diorite.

INTRODUCTION

A dimension-stone quarry (MINFILE 92K-140), located approximately 250 kilometres northwest of Vancouver on the north shore of Knight Inlet, was opened in 1985 after several years of sampling and evaluation. The quarry has operated intermittently since, producing monumental and ornamental stone known locally as "Catherine Blue Granite". Examples of the stone can be viewed at the British Columbia Pavillion (dedication panels) in Vancouver and at the cenotaph on Crescent Beach near White Rock.

This article is a continuation of a program to evaluate dimension-stone quarries in British Columbia begun in 1985 (White, 1986).

SAMPLE DESCRIPTION

The quarry was opened in hornblende diorite of the Coast plutonic complex (Roddick *et al.*, 1979). The diorite is medium grained (1 to 5 millimetres) and has an attractive blue-grey tone which is darkened by euhedral phenocrysts of hornblende and blades of biotite. The groundmass consists of light blue-grey plagioclase which constitutes approximately 50 per cent of the rock, and minor epidote (less than 1 per cent) which is present as tiny pale green grains. The contrast between felsic and mafic minerals is sharp and attractive, particularly when surfaces are polished, although occasional pitting and blind spots may develop when slabs are polished (Hora, 1982).

Pyrite (less than 1 per cent) is observed in outcrop and polished slabs; the rock is weakly magnetic, has few knots of mafic minerals greater than 5 millimetres across and is generally free of stains. There is a gradual but significant darkening of the stone over a 40-metre interval south of the worked face.

Samples collected and tested meet American Society for Testing and Material (ASTM) standards for granite building stone (Table 3-6-1).

The working face (Plate 3-6-1), approximately 24 metres long by 2.4 metres high, has been developed along a prominent set of joints which strike north-northeast and dip vertically (Figure 3-6-1). A second set of northeasterly striking joints dips moderately to steeply southwest and occasionally north.

Measurement of joint and fracture density in outcrop indicates 35 per cent of joints are spaced more than 1 metre apart. Quarry manager, Kelly Robertson, indicated blocks up to 1.5 by 2.1 by 2.6 metres have been quarried, although average blocks measure 1.2 by 1.5 by 2.4 metres. Up to 50 per cent of waste is produced during quarrying, due to irregular and closely spaced joints (Kelly Robertson, personal communication, 1987).

RESERVES

Seven diamond-drill holes (145.4 metres) have delineated 62 500 cubic metres of unaltered hornblende diorite (Cavers, 1983). There is good potential for additional reserves of stone east of the worked face, however, much of the area is covered by thin overburden and the area could not be examined in detail.

ACKNOWLEDGMENTS

The author would like to thank Kelly Robertson for his hospitality and helpful discussions in the field. I would like to acknowledge Z.D. Hora for reviewing the paper and the British Columbia Ministry of Transportation and Highways (Geotechnical and Materials Branch) for carrying out phys-

TABLE 3-6-1
KNIGHT INLET DIMENSION STONE; PHYSICAL PROPERTIES

Commodity	Quarry Name	NTS	Specific Gravity	Absorption by weight %	Traverse Strength[1] psi	Traverse Strength[1] MPa	Compressive Strength[1] psi	Compressive Strength[1] MPa
Granite	Knight Inlet	92K/12W	3.05	0.113	3510	24.2	23 946	165.1
Physical requirements — American Society for Testing and Materials (ASTM)								
Granite*			n/a	40 (max.)	1500 (min.)	10.34	19,000 (min.)	131

* Granite (commercial definition) — a visibly granular, igneous rock generally ranging in colour from pink to light or dark grey and consisting mostly of quartz and feldspar, accompanied by one or more dark minerals. The texture is typically homogeneous but may be gneissic or porphyritic.

Source: 1984 Annual Book of American Society of Testing Material (ASTM).

Physical tests: B.C. Ministry of Transportation and Highways (Geotechnical and Materials Branch). Results obtained from samples collected by Hora, 1982 and White, 1987.

[1] Results of 3 samples — tested dry.

Conversion Factor: psi→MPa = # × 6.894757 × 10^3.

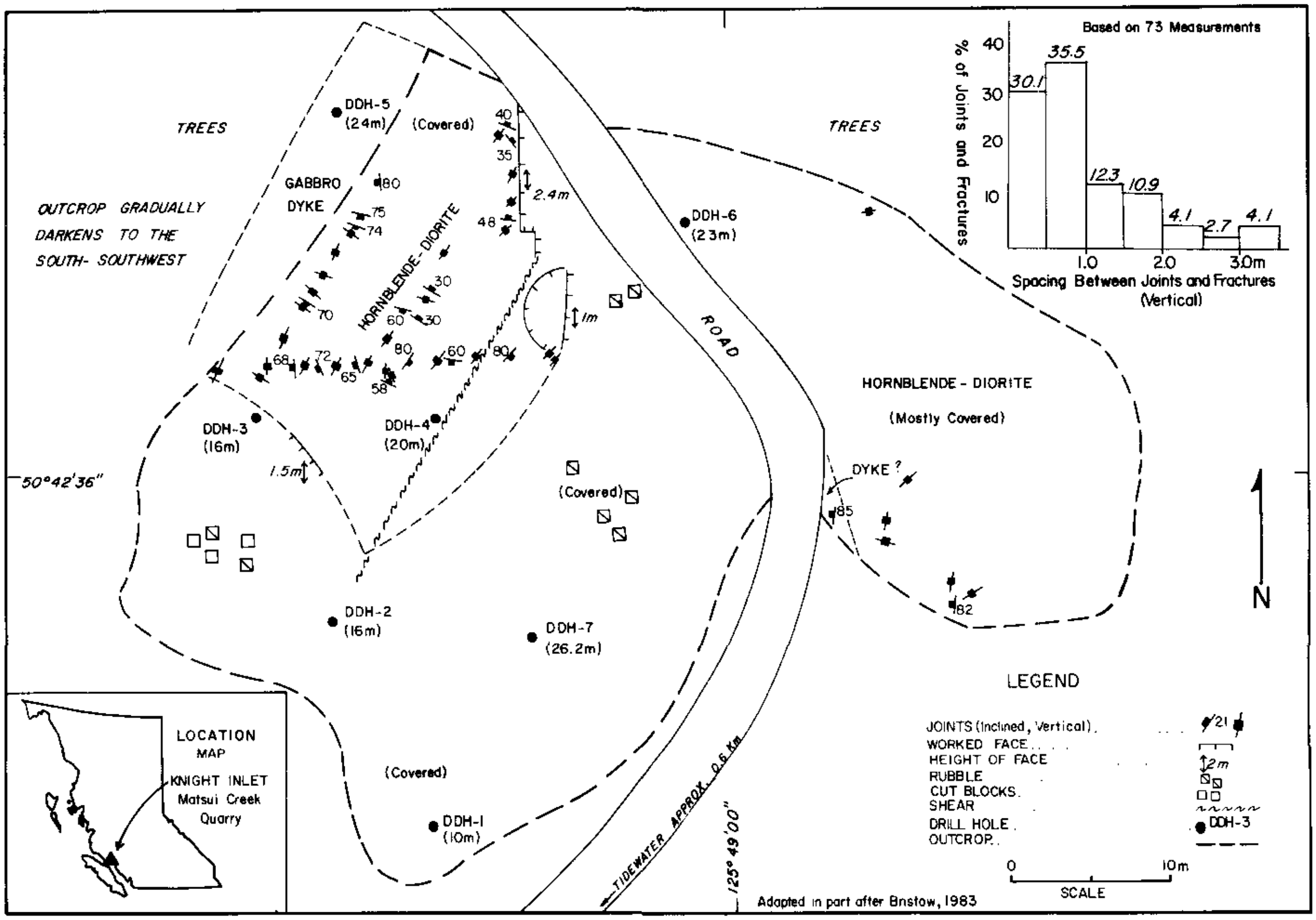

Figure 3-6-1. Knight Inlet Granite Quarry (92K/12W).

Plate 3-6-1. Working face — Knight Inlet Quarry (92K/12W).

ical tests. David Hannay provided capable and cheerful assistance in the field. Figures were drafted by Janet Fontaine.

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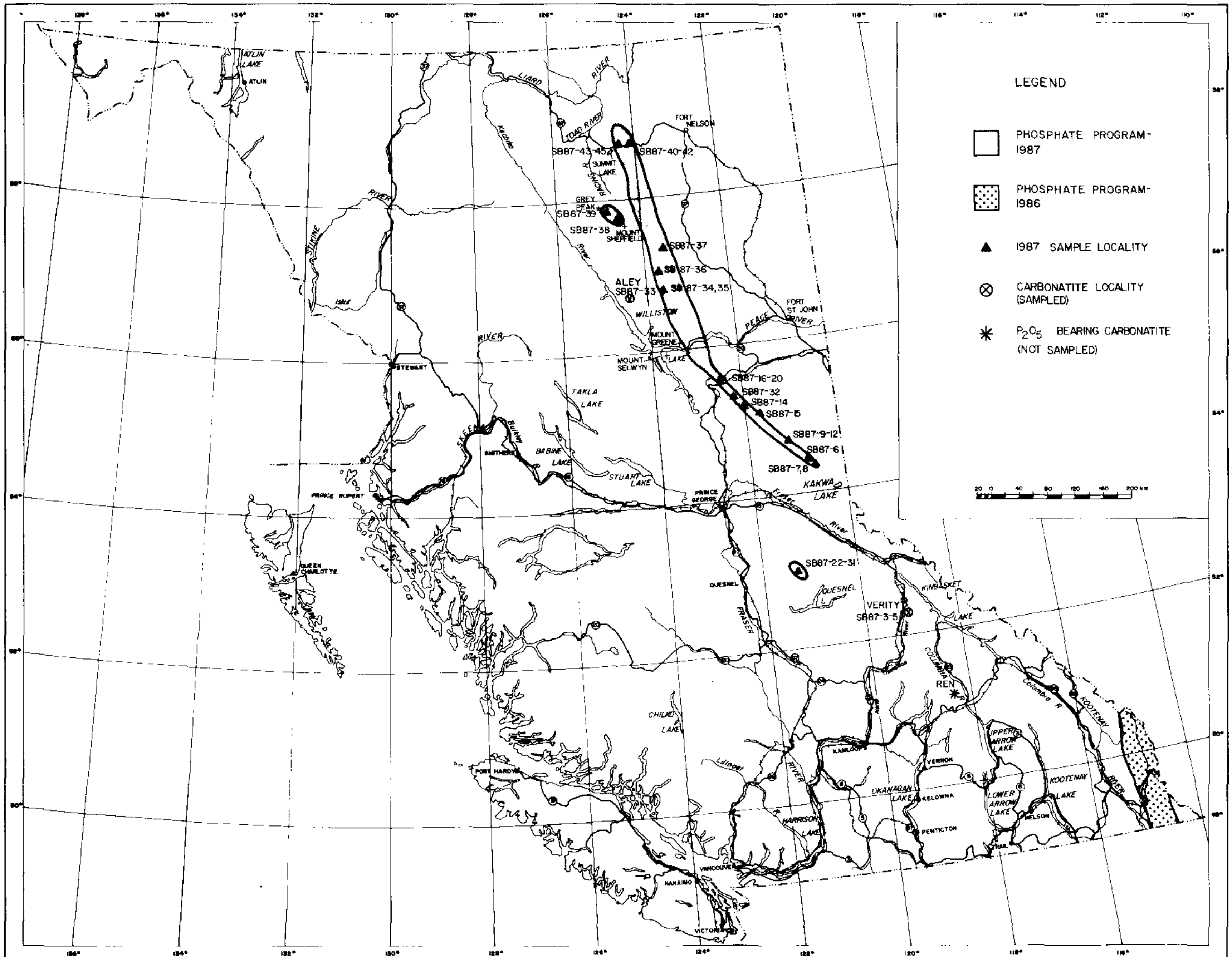

Figure 3-7-1. Sample location map.

PHOSPHATE INVENTORY: NORTHEASTERN BRITISH COLUMBIA*

By S.B. Butrenchuk

KEYWORDS: Economic geology, phosphate, Kechika Formation, Road River Formation, Fantasque Formation, Sulphur Mountain Formation, Toad Formation, Grayling Formation, Fernie Formation, carbonatites.

INTRODUCTION

The study of phosphate deposits in British Columbia continued through 1987 with the fieldwork component concentrating on marine strata in the northeastern corner of the province. Triassic rocks between Kakwa Lake and the Alaska Highway west of Fort Nelson were the main focus of this work. Permian strata along this same trend, and Cambrian to Lower Ordovician rocks in the Mount Sheffield – Grey Peak area to the west, were also the subject of field reconnaissance. Twenty-seven sample sites representing 14 localities along this sedimentary belt were examined (Figure 3-7-1).

In the Wells-Barkerville area east of Quesnel, the Black Stuart Formation of Ordovician-Mississippian age and associated volcaniclastic rocks of the Waverly member of the Devonian Guyet Formation were also investigated for their phosphate potential. Locally these rocks contain anomalous phosphate concentrations. Ten localities were sampled in this area.

Two apatite-bearing carbonatite localities were also visited (Figure 3-7-1), the Aley carbonatite north of Mackenzie and the Verity carbonatite north of Blue River.

Samples collected during the field season are being analysed for phosphate, zinc, uranium, vanadium, yttrium, lanthanum and cerium. In addition, petrographic studies and whole-rock and trace-element analyses are being done on selected specimens. Samples from the Wells-Barkerville area will also be analysed for precious metals, base metals and barite.

This is the third in a series of reports on phosphate deposits in British Columbia. The reader is referred to *Geological Fieldwork, 1986*, Paper 1987-1 and Open File 1987-16 for descriptions of phosphate deposits in southeastern British Columbia.

Phosphate terminology used in this report is defined as follows:

Phosphorite: A sedimentary rock composed principally of phosphate minerals. In this report it is applied to those rocks having a pelletal texture and containing greater than 7 per cent P_2O_5.

Phosphatic: A sedimentary rock containing phosphate minerals and in which the phosphate content ranges from 2 to 5 per cent P_2O_5.

Pellet: Phosphate grain less than or equal to 2.0 millimetres in size.

Nodule: Phosphate grain greater than or equal to 1.0 centimetre in size.

REGIONAL GEOLOGY

Phosphate deposits in the Rocky Mountains of northeastern British Columbia occur in a sequence of marine strata ranging in age from Cambrian to Jurassic (Figure 3-7-2). These beds were deposited in a miogeosynclinal environment along the western edge of the stable craton. Depositional environments varied from platformal to basinal with phosphate occurring most often in a platformal or shelf-edge environment similar to that in southeastern British Columbia (Butrenchuk, 1987).

Cambrian to Mississippian strata consist of shallow-marine carbonate assemblages that pass westward into a more basinal limestone, shale and siltstone facies (Cecile and Norford, 1979; McMechan, 1987). These rocks are host to several stratabound lead-zinc-barite deposits. The upper Paleozoic sequence consists of chert and fine-grained clastic rocks that unconformably overlie the lower Paleozoic sequence.

Mesozoic strata, consisting dominantly of fine-grained clastic sediments, unconformably overlie the Paleozoic sequence. During the Early Triassic, there was a marine transgression over Paleozoic strata between the Liard and Peace rivers. Deposition was continuous through the Toad Formation and continued into the Liard Formation (Douglas *et al.*, 1970). South of Pine Pass, in the vicinity of Wapiti Lake (Figure 3-7-3), there appears to have been a disconformity of short duration between the Vega-Phroso and Whistler members of the Sulphur Mountain Formation, and phosphorite approaching economic grade was deposited above it.

Structurally this region of the province is characterized by broad open folds and westerly dipping thrust faults. There is also a general thinning of stratigraphic units eastward.

STRATIGRAPHY: PHOSPHATIC UNITS IN THE ROCKY MOUNTAINS

CAMBRIAN-ORDOVICIAN

UPPER CAMBRIAN

Investigation of Upper Cambrian strata was restricted to the Mount Sheffield area. Lithologies consist of fine-grained sandstone, shale and siltstone. These strata are thin to medium bedded and weakly calcareous. Present at this locality is a grey calcareous siltstone that contains lenses of phosphatic material. The stratigraphic position of this unit may be in the uppermost section of the Upper Cambrian sequence or in the lower part of the Kechika Formation.

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

Age	Formation (Thickness, Metres)			Lithology	Phosphate
Cretaceous	Monteith (700)			Sandstone, minor shale; marine	
Jurassic	Fernie (350)			Shale, siltstone, minor limestone and sandstone; marine	As phosphatic limestone of the Nordegg member of Sinemurian age – reported as far north as Wapiti River (Irish, 1970)
				Unconformity	
Upper Triassic	Baldonnel (155)			Limestone, dolomite, siltstone, sandstone; marine	
	Charlie Lake (290)			Silty dolomite, dolomitic siltstone, sandstone; marine	
Middle and Upper Triassic	Ludington (400)			Dolomitic to calcareous siltstone, limestone; marine	
	Liard (450)			Dolomitic to calcareous sandstone and siltstone, dolomite, limestone; marine	
Lower and Middle Triassic	Toad (300)	Sulphur Mountain Formation	Llama member (60-350)	Calcareous siltstone, silty limestone, silty shale, siltstone, minor sandstone; carbonaceous siltstone and shale; marine	1-1.5-metre-thick pelletal and nodular phosphorite bed at base of Whistler; also phosphatic limestone and siltstone
			Whistler member (30)	Local disconformity at base of Whistler	Phosphate nodules in beds 1-3 metres thick over stratigraphic intervals of 20-200 metres; also phosphatic siltstone and shale; minor pelletal phosphate north of Richards Creek
	Grayling (75)		Vega-Phroso member (50-250)		Minor phosphate in the upper part of the Vega-Phroso member and lower part of the Llama member; minor phosphate in upper part of Grayling Formation
				Unconformity	
Permian	Fantasque (10-40)			Chert, phosphatic chert, siltstone	Phosphatic nodules in siltstone (1 metre thick) near top of formation Cherts are weakly phosphatic
Pennsylvanian Mississippian Devonian	Kindle Fm. (70)			Argillaceous limestone, shale, calcareous siltstone	Phosphatic lenses in shale along the Alaska Highway
				Unconformity	
	Flume			Limestone	30-centimetre-thick phosphate bed reported near Kakwa Lake
Lower Ordovician	Road River			Black shale, siltstone, limestone, minor dolomite; marine	Phosphatic siltstone in basal part of formation; also thin phosphatic shale beds higher in section
Lower Ordovician – Upper Cambrian	Kechika (1500)			Argillaceous, nodular limestone, minor shale; banded limestone; marine	Thin beds (5 centimetres) containing phosphatic fossil debris, pellets and microcrystalline phosphate (phosphate pavements) Parts of the nodular limestone phosphatic; thin veneer of phosphatic shale or limestone around nodules
Upper Cambrian				Shale, siltstone, argillaceous limestone	Thin beds containing phosphate lenses or nodules

Figure 3-7-2. Stratigraphy of phosphate-bearing formations in the Rocky Mountains of northeastern British Columbia.

KECHIKA FORMATION

Investigation of the Kechika Formation was restricted to the Grey Peak area. Previous work by Cecile and Norford (1979) has documented the presence of phosphate at various intervals in the upper part of the formation. Work was restricted to the uppermost unit (Unit OK4 of Cecile and Norford) of the Kechika Formation and lower units of the Road River Formation (Plate 3-7-1).

Cecile and Norford divided the Kechika Formation into five units. The lower two units consist of platy and arenaceous limestones and a putty grey-weathering, nodular, argillaceous limestone. A banded limestone overlies these units and is in turn overlain by a thick sequence of argillaceous, nodular calcilutite which is in excess of 500 metres thick in the Grey Peak area. This nodular unit can be traced southward into the Mount Selwyn area (MacIntyre, 1981, 1982; McMechan, 1987). The uppermost unit of the Kechika Formation consists of yellowish orange-weathering limestones. It was not observed at Grey Peak.

Cecile and Norford (1979) postulate that the Kechika Formation was deposited in a shelf-margin environment. From east to west, deposition took place at the edge of a subtidal carbonate platform, in a shelf facies, and in a deeper part of a shelf facies at Grey Peak. There is a corresponding increase in thickness of this formation westerly, toward the basin.

ROAD RIVER FORMATION

The Early to Late Ordovician Road River Formation consists primarily of black siltstone and shale, calcareous shale and minor limestone. In the Grey Peak area, fine siltstone and graptolitic shale conformably overlie nodular limestone of the Kechika Formation (Plate 3-7-1). The lowermost unit is approximately 60 metres thick and phosphatic throughout (Unit OR1 of Cecile and Norford). Locally, it contains glauconite. It is overlain by a nonphosphatic carbonate sequence which in turn is overlain by siltstone and shale. Phosphate occurs in thin (1-centimetre) beds throughout the basal portion of this upper clastic unit (Unit OR3 of Cecile and Norford).

The Road River Formation was deposited in a basinal environment. The basal Road River represents a period of slow sedimentation as evidenced by the presence of phosphate and glauconite.

PERMIAN

KINDLE FORMATION

The Kindle Formation outcrops in a belt along the western Rocky Mountains from the Halfway River northwards to the Toad River. Better exposures occur between the Racing and Toad rivers (Taylor and Stott, 1973). The formation also crops out along the Alaska Highway near Summit Lake.

This formation, comprising a sequence of siltstone, shale, siliceous limestone and chert, unconformably overlies older strata and is unconformably overlain by the Fantasque Formation. It is 90 to 205 metres thick, with the variation in thickness being due to erosion prior to deposition of the overlying Fantasque Formation.

FANTASQUE FORMATION

The Fantasque Formation of Permian age outcrops in a discontinuous band from north of Kakwa Lake into the Yukon Territory. It disconformably overlies younger Permian strata and is unconformably overlain by Triassic rocks. It consists primarily of chert with minor interbedded siliceous mudstone and siltstone. The chert is medium to dark grey in colour, locally pyritic, contains sponge spicules and very often is weakly phosphatic. The top of the formation is marked by a siltstone bed, approximately 1 metre thick, containing phosphate nodules. This phosphate-bearing bed was not observed at all Permian localities investigated.

In the Wapiti Lake area, McGugan and Rapson assign the chert to the Ranger Canyon Formation and the overlying sandstone to the Mowitch Formation. It is this sandstone bed that contains the phosphate nodules. The depositional environment is considered to be shallow water near the eastern shoreline of the basin (McGugan and Rapson, 1964).

TRIASSIC

Triassic strata in northeastern British Columbia outcrop in a north-northwest-trending belt from north of Kakwa Lake into the Yukon Territory (Figure 3-7-3). Fieldwork in 1987 focused on Lower and Middle Triassic rocks in which phosphate has been reported by Gibson (1971, 1972, 1975) and Pelletier (1961, 1963, 1964). The Sulphur Mountain Formation south of Pine Pass and the Toad and Grayling formations north of Pine Pass were of particular interest.

Triassic sedimentation took place on a stable shelf characterized by a pattern of embayments and platforms (McCrossan and Glaister, 1964). A minor embayment, flanked to the south by the Wapiti platform and to the north by the Nig Creek platform, developed south of Fort St. John during the Early Triassic (McCrossan and Glaister, 1964) (Figure 3-7-4). These conditions prevailed into the early Middle Triassic and probably exerted some control on phosphate deposition.

SULPHUR MOUNTAIN FORMATION

The Early to Middle Triassic Sulphur Mountain Formation is subdivided into the Vega-Phroso, Whistler and Llama members. The formation consists of shale, siltstone and limestone and exhibits a general thickening westward. The Whistler member is absent in southeastern British Columbia.

Vega-Phroso Member

The Vega-Phroso member of Early Triassic age unconformably overlies Permian strata. It is typically a flaggy, brownish weathering unit consisting of grey siltstone and calcareous siltstone with minor shale and bioclastic limestone. Thin phosphatic beds (10 to 20 centimetres) occur locally in the upper part of the section. The unit varies from 80 to 270 metres in thickness.

Whistler Member

The Whistler member, which overlies the Vega-Phroso member disconformably, is a recessive unit, 20 to 85 metres thick, consisting of grey-weathering, dark grey siltstone,

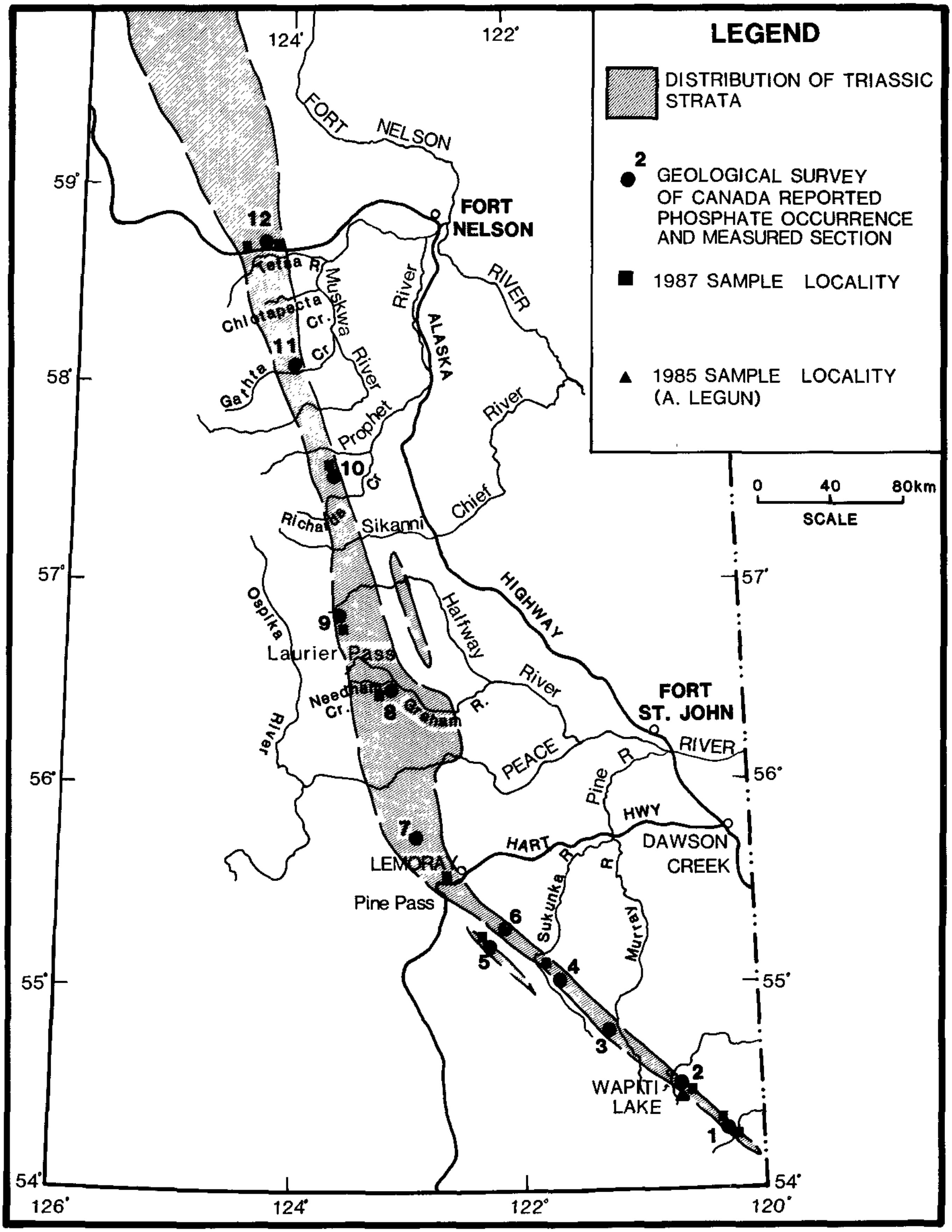

Figure 3-7-3. Distribution of Triassic strata in northeastern British Columbia.

shale and limestone. At most localities its lower contact is marked by the presence of a thin phosphorite bed that may contain a thin basal phosphatic conglomerate. This basal conglomerate was not observed in sections measured at Meosin Mountain but was observed in the Wapiti Lake area. Gibson (1975) suggests that the better phosphate occurrences are associated with "shelf" or thinning trends. These thinning trends may reflect areas of nondeposition or extremely slow sedimentation where phosphate deposition was not diluted by detritus. There may also have been some winnowing of detrital material resulting in higher phosphorite concentrations.

Llama Member

The Llama member is a resistant sequence of dolomitic quartzitic siltstone and limestone with minor sandstone and dolostone conformably overlying the Whistler member. It varies in thickness from 60 to 360 metres. Phosphate is reported in the lower part of this unit from a single section measured at Meosin Mountain (Gibson, 1972).

Grayling Formation

The Grayling Formation comprises strata of Early Triassic age north of Pine Pass and is correlatable with the lower part of the Vega-Phroso member of the Sulphur Mountain Formation. It consists of recessive, flaggy argillaceous siltstone, dolomitic siltstone and silty shale. Locally, strata containing phosphate nodules are present in the upper part of the formation. The Grayling Formation unconformably overlies strata of Permian or Mississippian age and is conformable with the overlying Toad Formation, but is not always present.

Toad Formation

The Toad Formation comprises Early to Middle Triassic strata north of Pine Pass. It is correlatable with the upper Vega-Phroso, Whistler and lower Llama members of the Sulphur Mountain Formation. Typically this formation consists of grey to dark grey-weathering, generally dark grey siltstone, shale, calcareous siltstone and silty limestone, most of which are weakly to moderately carbonaceous. The unit varies in thickness from 155 to 820 metres with an average thickness slightly in excess of 300 metres.

Phosphate occurs in numerous beds throughout the middle part of the Toad Formation. The phosphate-bearing interval varies in thickness from a few tens of metres to approximately 290 metres. The basal part of the phosphatic section generally contains calcareous, ovoid concretions several centimetres in diameter. Phosphate is present as nodules, phosphatic lenses, phosphate cement and occasionally as pellets and phosphatized fossil debris. Phosphorite is rare or absent.

Overlying the Toad Formation are clastic and carbonate strata of the Liard Formation or carbonate and fine-grained clastic strata of the Ludington Formation (Plate 3-7-2).

JURASSIC

Fernie Formation

The outcrop of Jurassic Fernie Formation parallels Triassic strata from the Kakwa Lake area to the Sikanni Chief River where it pinches out. Exposures are restricted to the foothills area. North as far as Wapiti River the basal sequence (Nordegg member) consists mainly of black phosphatic limestone. These strata are of Sinemurian age, similar to those in the Fernie Basin of southeastern British Columbia (Butrenchuk, 1987). In the Halfway River area, equivalent strata consist of recessive, fissile, dark grey to black calcareous shale (Irish, 1970) with no reported phosphate occurrences.

PHOSPHATE DEPOSITS

Unlike the southeastern corner of the province, there has been little exploration for phosphate in the Rocky Mountains of northeastern British Columbia. In 1967, KRC Inc. did some work on a phosphate occurrence at Lemoray in the Pine Pass area. Esso Minerals Canada carried out an extensive reconnaissance of the area between 1978 and 1980. In 1980 Esso completed an exploration program, including diamond drilling, on its Wapiti claim group southeast of Wapiti Lake. A. Legun investigated this property in 1985 on behalf of the Ministry of Energy, Mines and Petroleum Resources.

While phosphate occurs at several stratigraphic horizons, from early Paleozoic to Mesozoic, only Triassic occurrences appear to have possible economic significance.

CAMBRIAN-ORDOVICIAN

At Mount Sheffield, strata of Late Cambrian age contain nodular phosphate beds varying in thickness from 1 to 5 centimetres. The nodules are black, irregular to ovoid, 3 to 5 millimetres in size and constitute 20 to 80 per cent of the rock by volume. Cecile and Norford (1979) report the presence of phosphate nodules as large as 0.5 to 1.0 centimetre. Their work indicated that the phosphate horizons lie 220 to 120 metres below the base of the Kechika Formation.

A siltstone unit containing the phosphatic lenticles occurring higher in the sequence and not previously documented was also observed at this locality. The lenticles are 5 to 20 centimetres thick and black in colour, in contrast to the grey calcareous siltstone host. Bedding planes are often marked by pyrite bands, 1 to 2 millimetres thick. This unit is located either immediately below or in the basal part of the Kechika Formation.

Thin phosphate beds occur at five horizons in the upper 100 metres of the nodular limestone unit of the upper Kechika Formation in the vicinity of Grey Peak. Phosphate is present as microcrystalline coatings, 1 to 10 millimetres thick, around limestone nodules, and as phosphatized fossil debris in beds 5 to 50 centimetres thick. Some pelletal and oolitic phosphate is also present. The phosphatic beds are recognized by their blue-weathering surfaces and black colour contrasting with the pale grey of the host limestone. Also present, but not obvious, are thin phosphatic coatings,

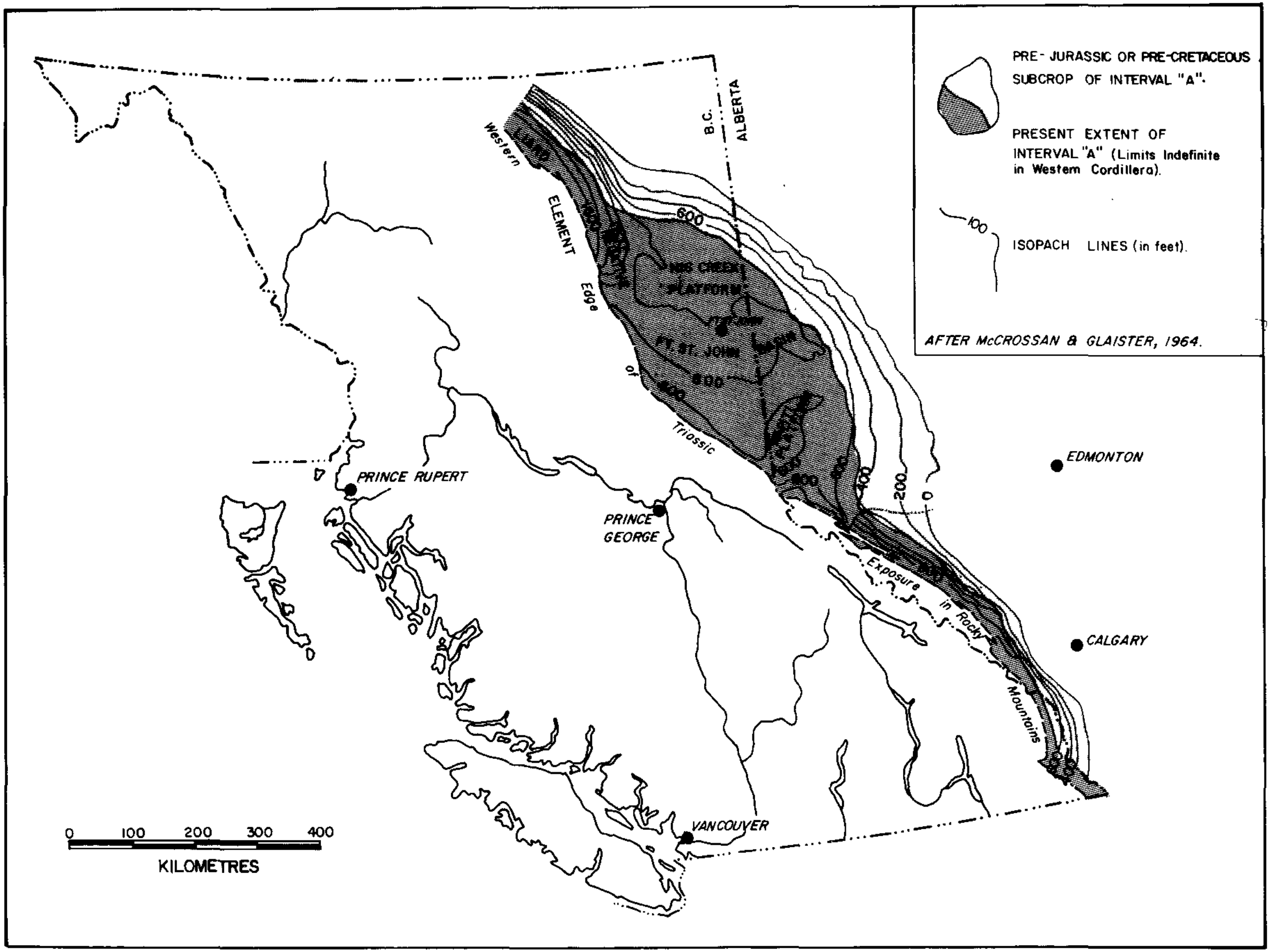

Figure 3-7-4. Interpretative map of the Early Triassic.

Plate 3-7-1. Section through Upper Kechika Formation (K) and Lower Road River Formation (RR) at Grey Peak in Kwadacha Park.

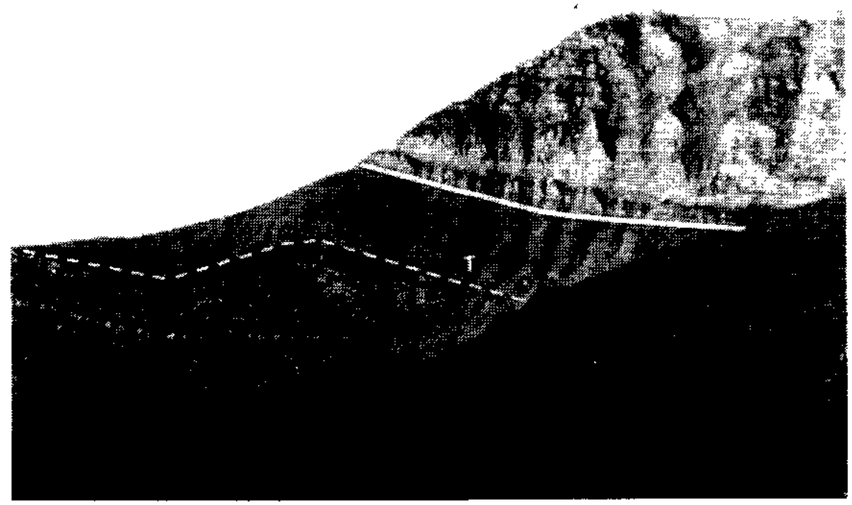

Plate 3-7-2. Section through Upper Toad Formation (T) and Lower Ludington Formation (Lud) at Mount Ludington . Dashed line marks the top of the phosphatic sequence.

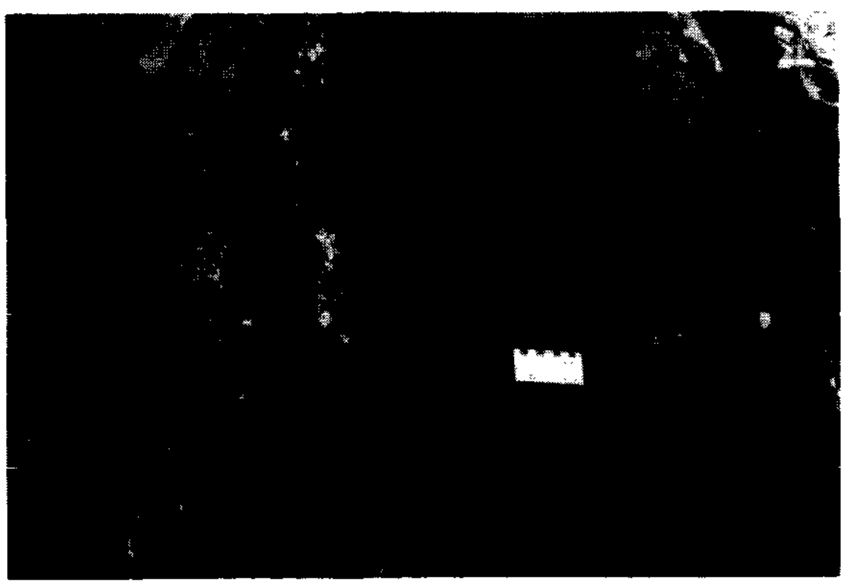

Plate 3-7-3. Phosphate nodules and lenses in phosphatic siltstone of the Toad Formation north of Laurier pass.

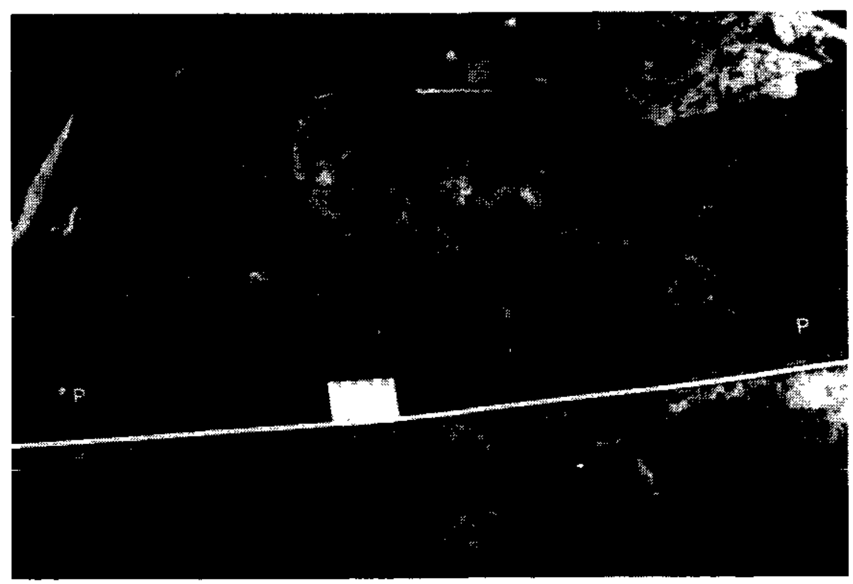

Plate 3-7-4. Phosphorite bed (P) in Toad Formation along the Alaska Highway north of the Tetsa River.

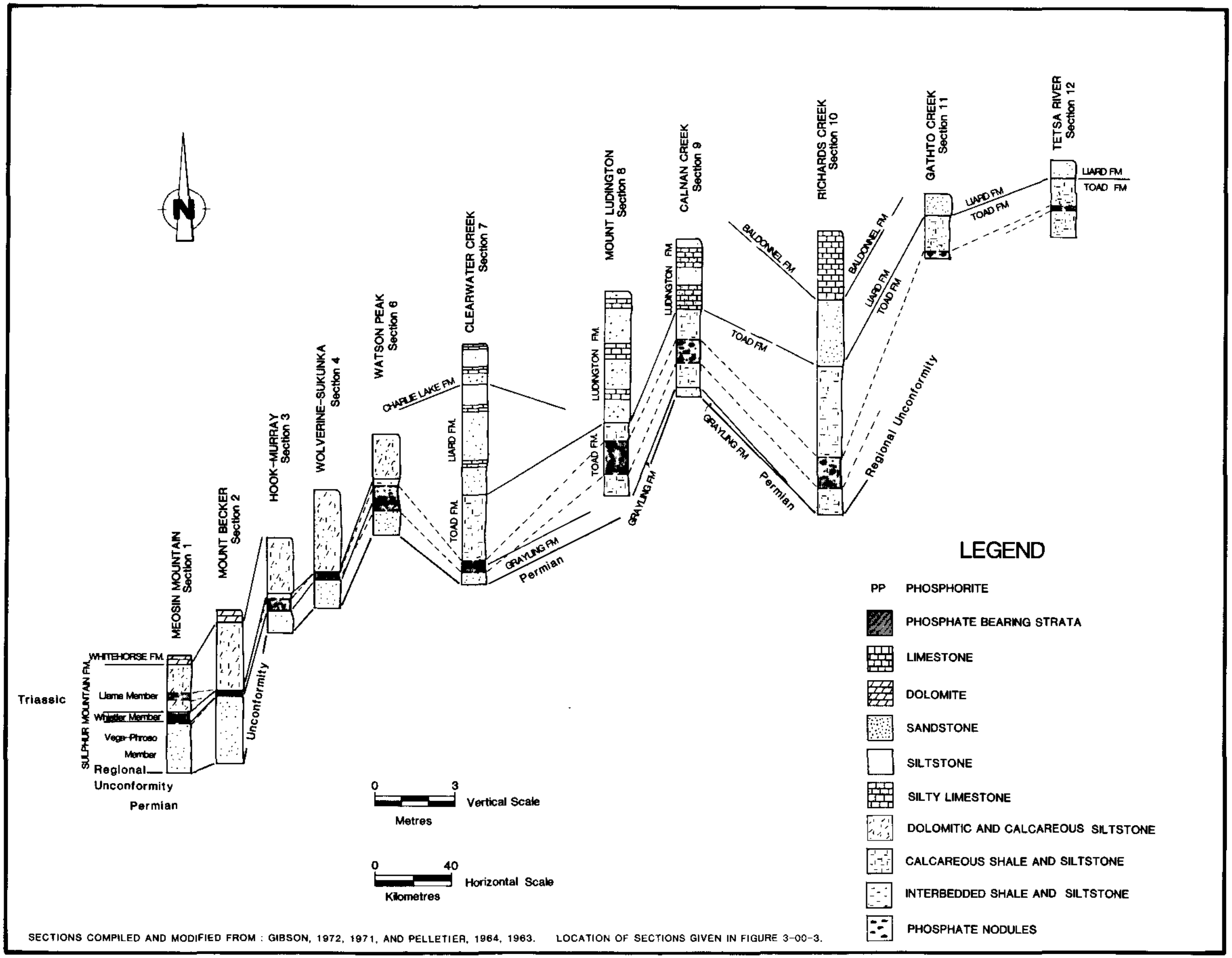

Figure 3-7-5. Stratigraphic correlation of phosphate-bearing strata in the Triassic of northeastern British Columbia.

1 millimetre or less in thickness, surrounding limestone nodules in beds 2 or more metres thick. Phosphate also occurs at several horizons in the lower banded limestone unit. Cecile and Norford (1979) describe these lower phosphate occurrences as "sea floor pavements or lag deposits".

Very fine-grained phosphate clasts, sometimes associated with glauconite, are disseminated throughout the shale and fine siltstones of the Road River Formation.

PERMIAN

Phosphate nodules occuring in a siltstone bed at the top of the Fantasque Formation were observed in the Burnt River area, south of Wapiti Lake and at Meosin Mountain. This siltstone bed is approximately 1 metre thick and contains 10 to 40 per cent nodules by volume. A. Legun (personal communication, 1987) obtained values of 6.8 and 16.2 per cent P_2O_5 across thicknesses of 63 and 34 centimetres respectively from samples collected from this bed in the Wapiti Lake area. This horizon was not observed at Richards Creek nor along the Alaska Highway. The author interprets this horizon to be correlative with a similar bed occurring at the top of the Ranger Canyon Formation in the vicinity of Connor Lakes (Butrenchuk, 1987).

Locally, along the Alaska Highway immediately east of Summit Lake, phosphate is present in the Kindle Formation. The phosphate is present as black, wispy lenses and laminations in a dark grey siliceous shale. Phosphatic chert is also present within the sequence which is restricted to the upper part of the formation.

At Mount Greene, north of the Peace River, phosphatic horizons were noted in strata underlying the Ranger Canyon Formation (McGugan, 1967). These rocks are tentatively correlated with the Kindle Formation (Bamber *et al.*, 1968) and are lithologically similar to the Johnson Canyon Formation that is host to several phosphate occurrences in southeastern British Columbia (Butrenchuk, 1987).

TRIASSIC

The majority of the known phosphate occurrences and phosphatic sediments occur in the Whistler member of the Sulphur Mountain Formation and in correlative rocks of the Toad Formation (Figure 3-7-5), both Anisian age. Phosphate is present in the Vega-Phroso and Llama members in only very minor amounts at a few localities. It is present in a variety of forms that include pelletal phosphorite, nodules, phosphate cement, phosphatic fragments or clasts and phosphatized fossil debris.

A phosphorite bed, occurring at or near the base of the Whistler member, extends from Meosin Mountain (Figure 3-7-5) to Watson Peak. At Meosin Mountain this phosphorite bed is 1.3 metres thick (Figure 3-7-6) and consists of both pelletal and nodular phosphate. South of Meosin Mountain this phosphorite passes into phosphatic, bioclastic and silty limestone and phosphatic calcareous siltstone (Figure 3-7-7). A single thin section of limestone from this location revealed that phosphate pellets 0.1 to 0.35 millimetre in size are dispersed throughout abundant fossil debris. Many of the pellets contain carbonate cores. North of Watson Peak, at Lemoray, a 1 to 2-centimetre phosphorite bed is present, but its exact stratigraphic position is uncertain.

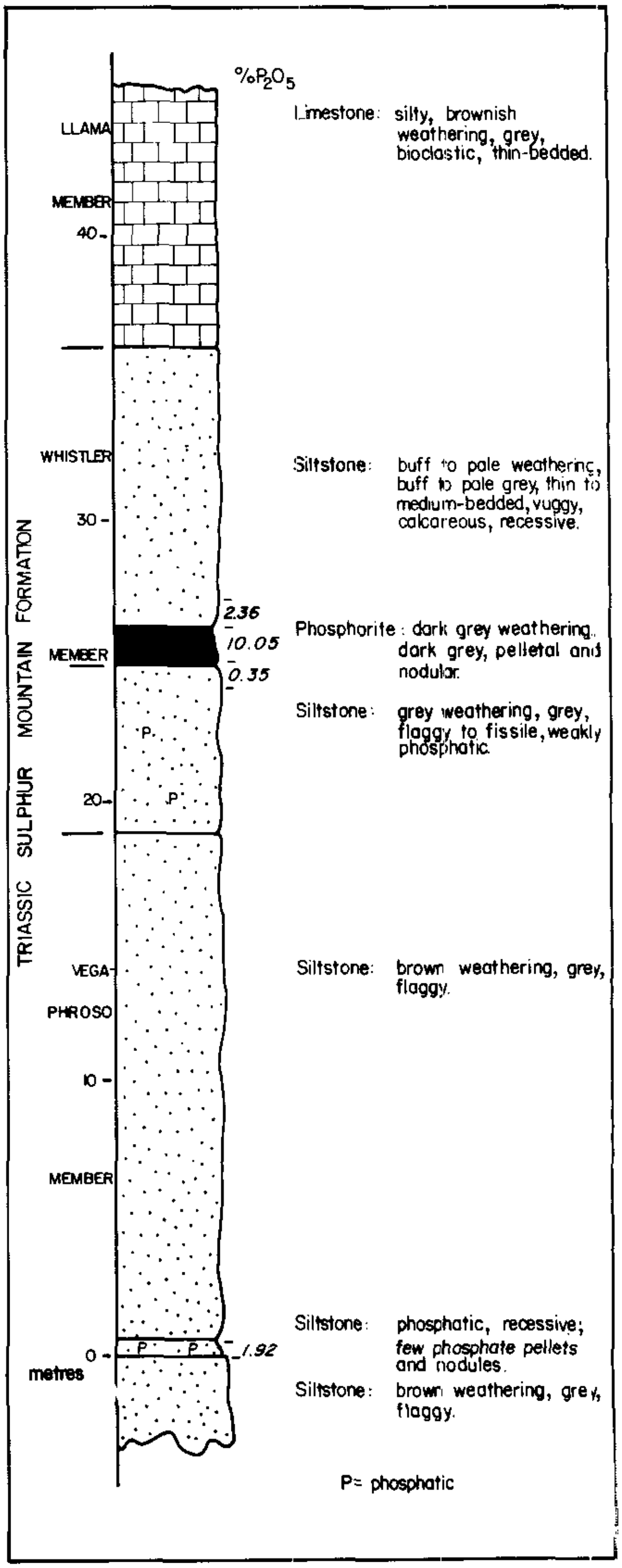

Figure 3-7-6. Section 87-6: Meosin Mountain north.

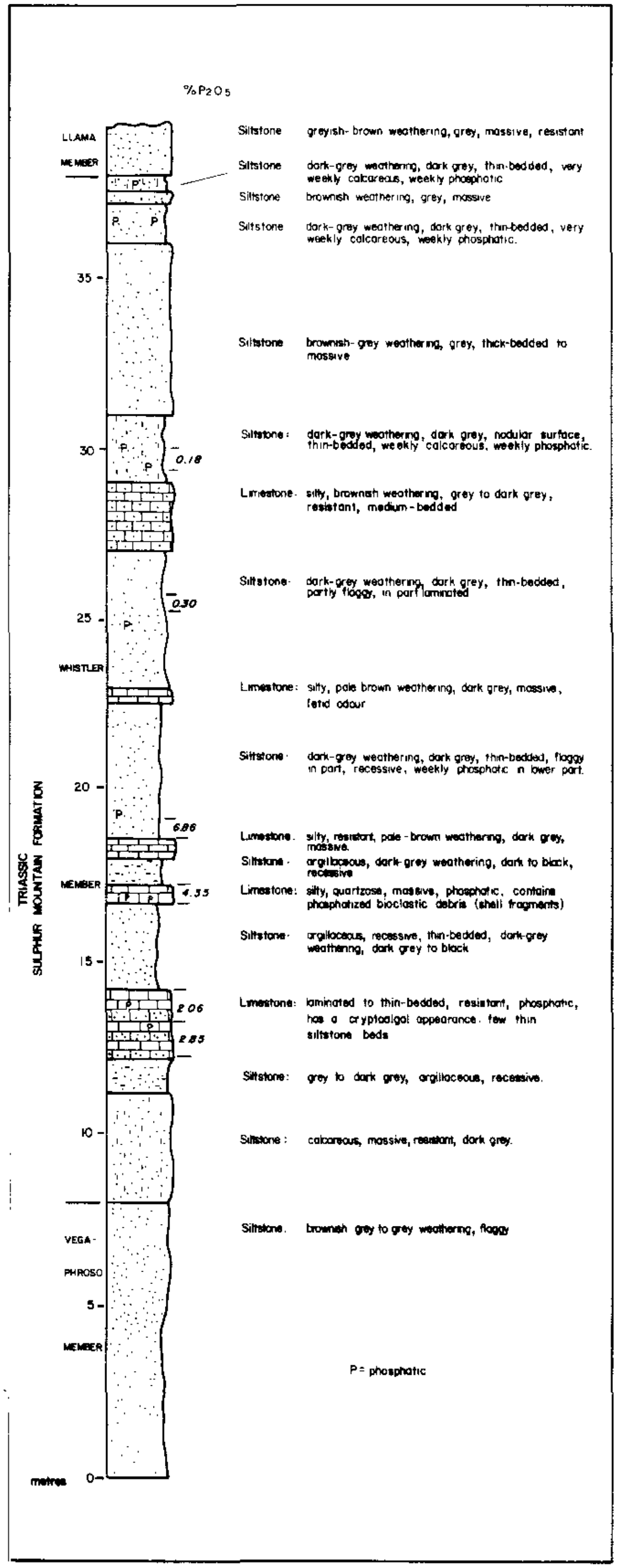

Figure 3-7-7. Section 87-7: Meosin Mountain south.

Near Wapiti Lake the Triassic sequence containing phosphorite has been folded into series of plunging folds. Here the phosphorite ranges in thickness from 0.8 to 3.2 metres with assays varying 11.9 to 23.7 per cent P_2O_5 (Heffernan, 1980; A. Legun, personal communication, 1987). The phosphorite which outcrops on a dip slope on the eastern limb of the Wapiti syncline, represented by an apparent exaggerated thickness of the phosphate horizon in Figure 3-7-8, is of particular significance. Mining of this bed could conceivably be done by open-pit methods with a relatively low stripping ratio. The base of the phosphorite bed is marked by a thin phosphatic conglomerate that varies in thickness from 5 to 20 centimetres. Analytical results are given in Tables 3-7-1 and 3-7-2 and sample locations are shown in Figure 3-7-8.

The phosphorite consists of pellets, together with a few oolites and nodules, in a carbonate-quartz matrix. Many of the pellets have an irregular carbonate core suggesting replacement of carbonate by phosphate. The cores also contain quartz, feldspar, shell fragments and rarely pyrite.

In contrast to the Wapiti Lake area, Triassic strata between Lemoray and the Alaska Highway do not contain any well-defined phosphorite beds. Phosphate is generally of the nodular type with phosphatic lenticles and sediments also present. Some pelletal material was observed immediately north of Richards Creek (*see* Figure 3-7-3).

TABLE 3-7-1
PHOSPHATE VALUES, WAPITI LAKE AREA

Sample No.	Average per cent P_2O_5	Thickness (metres)
TE-06	15.3	1.40
	or 11.9	or 3.19
TE-05	22.0	1.20
	or 18.6	or 1.56
TE-07	22.8	0.66
TE-01	21.4	0.73
85-26/2	14.8	0.94
85-23/3	20.9	0.94
85-23/1	6.8	0.63
TE-02	21.0	1.64
85-26/3	20.3	1.37
85-26/1	16.2	0.34
85-21/3	22.4	1.04
85-21/4	20.3	0.81
TL02	20.3	1.39
TL01	23.7	0.84
TG01	22.2	0.93
	or 14.4	or 1.84
TG02	23.6	0.99
	or 16.6	or 1.72
TR03	21.2	1.08
TR04	20.0	0.90
85-24/2	19.9	1.04
85-25/1	17.8	0.97
85-25/2	15.5	0.76
T6-03	17.9	1.42
85-23/4	14.8	0.46
TL-03	21.3	0.50
DDH 6-11,12	19.1	0.98
DDH 3-5,6	16.6	1.70

Note:

(1) All samples are Triassic Whistler member except 23/1 and 26/1 which are from Permian Mowitch Formation.

(2) Samples prefixed TE, TL, TG and TR are from Heffernan (1980); samples prefixed 85 are from Legun (personal communication, 1987).

(3) Thicknesses are those calculated by A. Legun.

TABLE 3-7-2.
WHOLE ROCK ANALYSES, WAPITI LAKE (A. LEGUN, 1985)
(Values in % unless otherwise indicated)

Sample Number	P_2O_5	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	S	F	Cd (ppm)	Pb (ppm)
85-21-3	22.33	8.17	0.80	0.39	0.56	49.40	0.34	0.35	0.09	0.018	0.34	2.31	14	15
85-21-4	20.29	9.31	1.00	0.52	0.64	48.72	0.40	0.40	0.08	0.021	0.33	2.49	10	15
85-23-1	6.83	76.13	0.88	1.26	0.14	10.87	0.08	0.29	0.06	0.008	0.08	0.56	3	8
85-23-3	20.30	16.32	2.09	1.06	1.07	42.82	0.54	0.80	0.21	0.020	0.36	2.12	3	12
85-23-4	14.81	18.16	2.14	0.82	2.11	40.73	0.48	0.84	0.18	0.024	0.28	1.62	1	0
85-24-2A	19.79	16.50	1.98	1.24	0.57	43.45	0.54	0.78	0.18	0.018	0.34	1.93	1	12
85-24-2B	20.08	11.13	1.11	0.45	1.21	45.96	0.36	0.43	0.11	0.014	0.42	2.19	21	12
85-24-2C	3.28	38.46	6.57	3.00	4.56	18.55	0.62	2.75	0.46	0.027	0.25	0.55	10	14
85-25-1A	17.82	15.28	1.78	0.99	0.93	45.17	0.52	0.66	0.16	0.019	0.37	1.78	12	13
85-25-1B	8.24	12.70	1.71	1.26	2.31	44.60	0.23	0.77	0.10	0.029	0.19	1.04	4	8
85-25-2	15.52	10.69	1.04	0.69	0.60	48.32	0.31	0.44	0.10	0.015	0.23	1.53	13	11
85-26-1	16.22	52.77	0.83	0.79	0.14	25.32	0.13	0.26	0.04	0.016	0.22	1.51	2	13
85-26-2	14.77	16.48	2.04	0.94	2.36	42.51	0.46	0.79	0.13	0.025	0.59	1.67	8	10
85-26-3	20.33	22.15	2.90	1.26	0.57	38.32	0.67	1.15	0.27	0.033	0.46	2.02	6	12
85-21-3D	22.54													

Localities at Mount Ludington, north of Laurier Pass, and Richards Creek were investigated. At Mount Ludington phosphate occurs over a stratigraphic interval of 150 metres in the middle Toad Formation (Plate 3-7-2) as nodules, phosphate-cemented siltstone, phosphatic lenticles and phosphatic fossil debris in a sequence of dark grey, weakly carbonaceous, calcareous siltstone and shale. Phosphate nodules are black, ovoid to spherical, 1 to 3 centimetres in size and comprise 5 to 20 per cent of the rock by volume. On weathered surfaces they stand out in relief. The lower part of the phosphate-bearing sequence is marked by the presence of large calcareous concretions and the upper limit by a change to less carbonaceous and more calcareous strata.

At a locality north of Laurier Pass and southeast of Calnan Creek, phosphate occurs over a stratigraphic interval of at least 100 metres. As at Mount Ludington, the dominant form of phosphate is nodular. Calcareous concretions occur in the lower part of the phosphatic sequence together with an abundance of phosphatic lenticles (Plate 3-7-3).

At Richards Creek the phosphatic section is 290 metres thick with phosphate nodules occurring in several beds over an interval of 220 metres. Unlike the previous two localities, calcareous concretions occur in the middle portion of the phosphatic sequence. Nodules remain the dominant form of phosphate, but thin beds of pelletal phosphate were also observed. These beds lie stratigraphically above strata containing the calcareous concretions. The pellets occur in a carbonate-rich matrix, with 10 to 20 per cent of the pellets containing either a quartz or carbonate core.

The northernmost Triassic exposures investigated are located along the Alaska Highway north of the Tetsa River. The presence of pelletal material and a thin phosphorite bed (Plate 3-7-4) within the Toad Formation is significant in this area. No nodules were observed at the phosphorite locality but were seen in outcrops to the west.

CARBONATITES

Carbonatites and related alkaline intrusives are the second most important source of phosphate worldwide, accounting for approximately 20 per cent of world reserves. In British Columbia phosphate-bearing carbonatites, two of which are the Aley and Verity, occur at a number of localities. In addition to phosphate these carbonatites represent potential sources of niobium, tantalum and rare earth elements.

The Aley carbonatite complex is described as an oval-shaped body, 3 to 3.5 kilometres in diameter, consisting of a dolomite-calcite carbonatite core with an outer ring of metasomatically altered syenite (Mäder, 1987). Apatite is present as fine-grained crystals and aggregates in both phases of the core but is more abundant in the calcite carbonatite. K.R. Pride (personal communication, 1987) suggests that the average grade of the carbonatite is approximately 5 per cent P_2O_5 representing approximately 10 per cent apatite. If the entire carbonatite core contains this amount of apatite then the Aley deposit may have a resource potential exceeding 15 billion tonnes at this grade.

Unlike the Aley complex, the Verity carbonatite is a tabular body that has undergone intense structural deformation (J. Pell, personal communication, 1987). Exploration of this deposit by Anschutz (Canada) Mining Limited (Aaquist, 1981) has indicated grades of 2 to 5 per cent P_2O_5 in the carbonatite. Apatite, occuring as subrounded grains 1 to 4 millimetres in diameter and in amounts up to 10 per cent by volume, is disseminated throughout the rock. The resource potential of this carbonatite is only a few million tonnes.

DISCUSSION

Phosphatic and associated siliceous sediments have generally been deposited at the structural hinge line between cratons and geosynclines (Sheldon, 1987). Deposition is episodic and generally takes place at paleolatitudes lower than 30 degrees (Christie, 1980). Sheldon postulates that there is an association between chert and phosphorite. This association is not necessarily one of coincidence but may be a geographic one.

An association between chert and phosphorite, although not always readily apparent, can be demonstrated for all the major phosphate occurrences in British Columbia. For the Permian this association is well documented both in the Phosphoria Formation of the Western United States and throughout the Ishbel Group in southeastern British

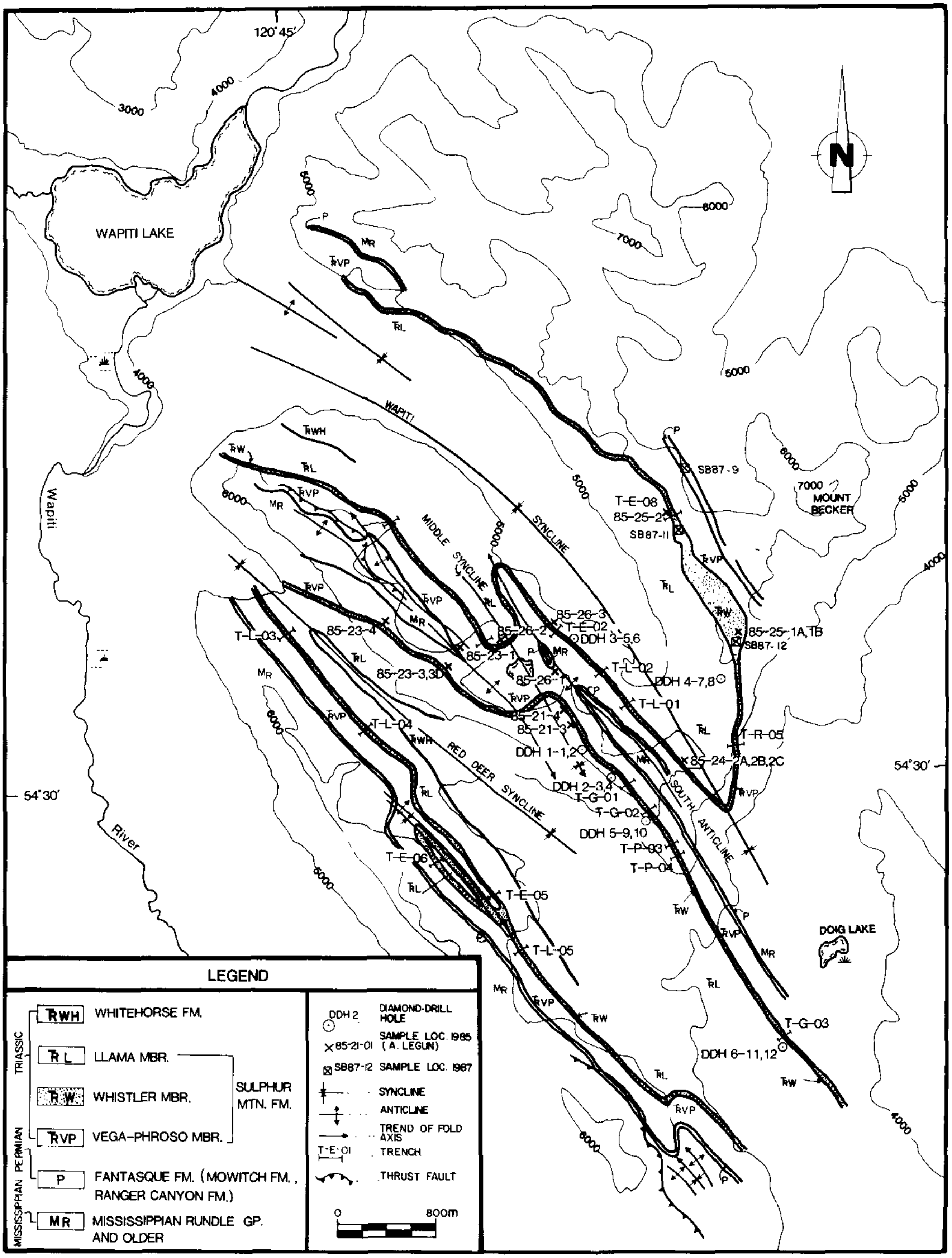

Figure 3-7-8. Geology of the Wapiti Lake area (modified from Hefferman, 1980 and Legun and Elkins, 1986.

Columbia and the Fantasque Formation in northeastern British Columbia. Similarly, both chert and phosphorite are present in the basal section of the Fernie Formation. In southeastern British Columbia the association between chert and phosphate is not readily apparent as chert was not observed during our study of this area. However, chert is present in equivalent strata of the Nordegg member of Sinemurian age in the northeast and in Alberta (MacDonald, 1985). MacDonald reports that phosphate is present below the Nordegg member and sporadically within it. In the Triassic, thin chert-pebble beds are reported along the eastern edge of the Doig Formation (McCrossan and Glaister, 1964). In thin section, minor chert is seen to be present in some of the siltstones of the Toad Formation.

Phosphate deposition is best developed in stable environments where the rate of sedimentation is very low. Thus telescoped stratigraphic sections often typify areas of good phosphorite. In British Columbia the majority of significant phosphorite deposits appear to have developed above unconformities during periods of marine transgressions.

In northeastern British Columbia significant phosphorite is restricted to Triassic strata between Lemoray and Meosin Mountain, north of the Wapiti platform. Here a small disconformity exists between the Vega-Phroso and Whistler members, while to the north deposition was continuous throughout the equivalent stratigraphic interval. A transgression began in early Whistler time and was accompanied by very slow sedimentation, allowing the development of the phosphorite bed. Paleogeographic reconstruction indicates that the Whistler member was deposited within 30 degrees of the paleoequator (Irving, 1979; MacDonald, 1985) while Triassic strata north of Lemoray were deposited further to the north. Theoretically we should not expect these more northerly exposures to contain extensive phosphorite deposits. However, although not abundant, phosphate deposits have also developed in more temperate climates. Phosphorite in the Jurassic Fernie Formation is an example of such a deposit. There are extensive nodular phosphate beds in the Toad Formation and the occasional thin phosphorite bed north of the Tetsa River. These occurrences also are interpreted to have formed in a temperate climate.

This study indicates that the area with the best phosphate potential is between Watson Peak and Meosin Mountain in strata of Middle Triassic (Anisian) age. There may also be some potential north of the Alaska Highway where thin phosphorite beds appear that are not present or only poorly developed to the south. Another potentially economic source of phosphate is the Aley deposit. Although it is presently being evaluated for its niobium potential it does contain a very large phosphate resource. In terms of contained P_2O_5 it may represent the second most important phosphate resource in British Columbia after the Fernie Formation.

ACKNOWLEDGMENTS

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INDUSTRIAL MINERALS IN TERTIARY ROCKS, LYTTON TO GANG RANCH, SOUTHERN BRITISH COLUMBIA* (92I/05, 12, 13; 92O/01, 08; 92P/04)

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KEYWORDS: Industrial minerals, perlite, zeolites, bentonite, Eocene stratigraphy, Fraser fault, Spences Bridge Group, Jackass Mountain Group.

INTRODUCTION

This report summarizes results of 44 days of fieldwork investigating the occurrence of industrial minerals, and those aspects of the structure and Tertiary and Cretaceous stratigraphy which control their development in an area along the Fraser River from the Stein River to China Gulch. In this area, the industrial minerals of major interest are bentonite, perlite and zeolites in Eocene rocks. In addition to the regional geology of Monger (1982) for Ashcroft map area (92I), Tipper (1978) for Taseko Lakes map area (92O), and Campbell and Tipper (1971) for Bonaparte Lake map area (92P), Trettin (1961) and Mathews and Rouse (1984) have done detailed geological studies in the southern and northern parts of the area respectively. In the Ashcroft map area, investigation was restricted to those rocks considered by Monger to be of Eocene age. The only industrial mineral deposit, the perlite mine of Aurun Mines Ltd., lies beyond the northwest corner of the mapped area. In 1988, K. Green intends to carry this investigation northward. Laboratory investigations of samples are in progress, but tests of materials relative to ASTM specifications, and the radiometric and palynological dating of samples have not started.

CRETACEOUS AND TERTIARY STRATIGRAPHY AND STRUCTURE

North of the Stein River, over 1000 metres of mainly pebble to cobble conglomerate, some greywacke and rare siltstone occupy a northerly trending syncline truncated by the Fraser fault on the east (Monger's Fountain fault) and the Lillooet fault on the west. X-ray diffraction shows that the greywacke contains appreciable laumontite, a zeolite that occurs in the Cretaceous rocks of the Ashcroft area (Duffell and McTaggart, 1952, page 43; Read, 1974, page 20) but is absent in Eocene rocks. The succession is devoid of suitable host rocks for Cenozoic industrial minerals and may even be of mid-Cretaceous rather than Eocene age.

From Fountain to Watson Bar creeks, Slok Creek and Fraser faults bound a wedge of volcanic rocks mapped mainly as the Lower Cretaceous Spences Bridge Group by Trettin and mostly as Eocene by Monger. Both Lower Cretaceous and Eocene are present as Trettin proved the former based on palynology, and Mathews (unpublished date) and Monger the latter on radiometric dating; only their distribution is in contention. The distribution shown in Figure 3-8-1, closely adheres to that of Trettin, except that his Fountain Valley assemblage is considered to be Eocene as is an area of radiometrically dated rocks northwest of Glen Fraser. In contrast to Monger's Eocene designation, most of the remainder of the rocks to as far north as Watson Bar Creek are probably Spences Bridge Group, and are devoid of industrial mineral occurrences. Several samples have been collected for radiometric dating to resolve the age of these unfossiliferous rocks.

On the west side of the Fraser River, north of its junction with Pavilion Creek, the trace of Fraser fault separates rocks of the Spences Bridge Group to the southwest from a partly preserved, southwesterly dipping wedge of probable Eocene rocks to the northeast. They lie unconformably on the Pavilion Group. Trettin had placed fault "e" (Fraser fault) along this surface, but good exposure at EM0579000mE, EM5638800mN shows the unfaulted and unconformable nature of this contact. Northward, the Fraser fault outcrops on the right wall of High Bar Canyon where it dips 65 degrees southwest and shows strike-slip slickensides in a 15-metre-wide zone of crushed rocks.

Slok Creek fault forms the southwestern side of the fault wedge and juxtaposes it against the Lower Cretaceous Jackass Mountain Group to as far north as Watson Bar Creek. The fault outcrops at river level on the left bank of the Fraser at EM0581400mE, EM5622600mN where it dips 77 degrees northeast and has strike-slip slickensides.

North of Watson Bar Creek, the fault wedge widens and contains mainly Eocene stratified rocks and minor volcanics of the Spences Bridge Group. Some of the palynologic and radiometric age determinations of Mathews and Rouse come from rocks within this area, and support the stratigraphic distribution shown (Figure 3-8-1). At Watson Bar Creek, dull maroon and grey-brown-weathering volcanic rocks of the Spences Bridge Group give way northward to varicoloured creams, pink, grey, brown and maroon-weathering stratified rocks of Eocene age. The change is abrupt and along a zone of no exposure which is an assumed extension of Hungry Valley fault rather than an unconformity. The fault apparently truncates the Slok Creek fault, but terminates southeastward against the Fraser fault. The Eocene succession of varicoloured volcanics with intercalated volcanogenic sediments underlying sandstone, shale, bentonite and volcanic conglomerate compares closely to that outlined by Mathews and Rouse to the north in Churn Creek (Figure 3-8-2). Flow

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

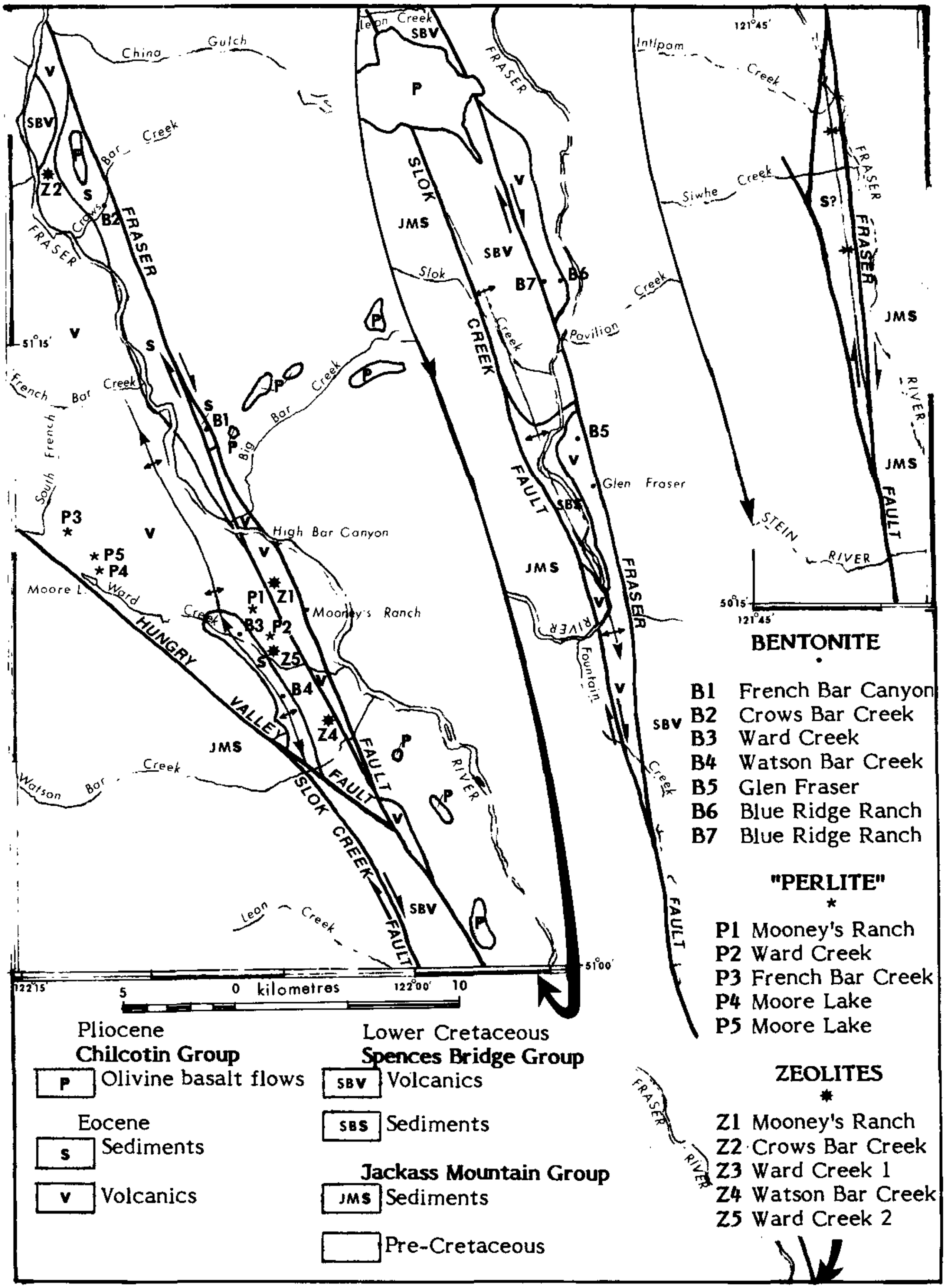
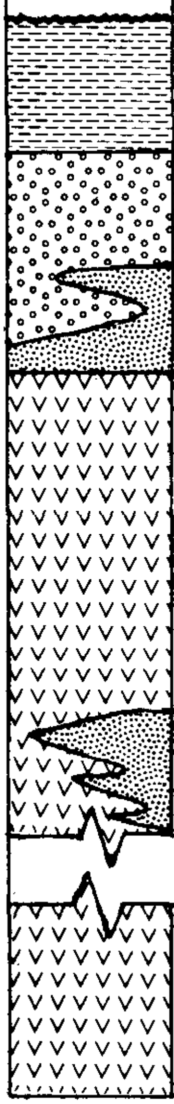


Figure 3-8-1. Simplified geological map along the Fraser River from Stein River to China Gulch showing industrial mineral occurrences.

layering and scattered bedding attitudes outline a north-northwesterly trending, sharp monoclinal flexure with a steep northeastern limb and a subhorizontal to gently dipping southwestern limb. Hungry Valley fault truncates the flexure to the south, and to the north the flexure opens as the fault wedge widens and passes into an easterly dipping homocline near Churn Creek. All the industrial mineral occurrences of the mapped area lie within the Eocene.

Northward from the south side of Leon Creek to at least Dog Creek, Pliocene olivine basalt flows, up to 125 metres in thickness, form erosional remnants of the Chilcotin Group that lie in a 10-kilometre-wide belt centred along the present course of the Fraser River. As noted by Mathews and Rouse, the elevations of the base of the remnants decrease northwards from nearly 1280 metres (4200 feet) south of Leon Creek to 1030 metres (3375 feet) north of Big Bar Creek, but the Pliocene erosion surface has at least 100 metres of relief under some remnants. Although Monger and Mathews and Rouse showed Pliocene sediments beneath the flows, usually a 100-metre-thick zone of no outcrop intervenes between the lowest flow and the highest basement outcrops. Even south of Leon Creek, fluviatile sediments mapped as Pliocene (Monger, 1982) could as easily be Pleistocene or Recent and plastered against the flows, as Pliocene and underlying them. Bevier (1983) noted that although the bulk of the Chilcotin Group lies in a 6-10 Ma range, an earlier pulse lies in a 19-25 Ma range and a later pulse in the 2-3 Ma interval. In contrast to the Miocene portion of the Chilcotin Group (Read, 1988), the Pliocene part is apparently devoid of industrial mineral occurrences.



Lithology and Thickness	Loc #	Industrial Mineral	Age	Map Unit / Previous Unit
Fraser Fault Shale, siltstone, sandstone, bentonite, rare coal (±200 m)			Eocene	S Eocene[1]
Volcanic conglomerate (150-400 m)			Eocene	S Eocene[1]
Tuffaceous sandstone, siltstone, bentonite (0-200 m)	B1 B2	bentonite bentonite	Eocene	S Eocene[1]
Grey, brown, maroon andesite-dacite breccia, local bentonite, minor flows; intercalated rhyolite-rhyodacite flows and tephra, locally waterlain (500-1000 m)	P1 P2 P3 P4 P5 Z1 Z2 Z3 Z4 Z5	"perlite" "perlite" "perlite" "perlite" "perlite" zeolites zeolites zeolites zeolites zeolites	Eocene	V Eocene[1] Ward Creek[2] Fountain Valley[2]
Lenticular sandstone, siltstone, fine bentonitic breccia (0-100 m)	B3 B4	bentonite bentonite	Eocene	S Ward Creek[2] Spences Bridge[3]
unknown thickness of volcanic rocks				
Grey, brown, maroon andesite-dacite breccia, local bentonite, local rhyolite (100-200 m) (may be basal portion of overlying thick volcanic unit)	B5 B6 B7	bentonite bentonite bentonite	Eocene	V Eocene[4] Spences Bridge[2]

[1] Mathews and Rouse (1984)
[2] Trettin (1961)
[3] Tipper (1978)
[4] Monger (1982)

Figure 3-8-2. Generalized stratigraphic column for the Eocene rocks showing the approximate stratigraphic positions of the industrial mineral occurrences.

INDUSTRIAL MINERAL OCCURRENCES IN EOCENE ROCKS

"PERLITE"

Volcanic glass having the hand specimen and thin section characteristics of perlite, and here designated as "perlite", outcrops at five localities on the north side of Ward Creek. On a unused portion of the farm road descending to Mooney's Ranch, a small roadcut exposes medium to dark grey perlite (P1, Figure 3-8-1) at EM0562800mE, EM5665750mN and 1080 metres (3550 feet) elevation. At 1.4 kilometres to the southeast, on the ridge crest on the north side of Ward Creek (EM0563700mE, EM5664700mN), a subvertical perlite (P2) of unknown thickness outcrops for 45 metres along strike before passing northwestward beneath overburden. These two perlite localities may connect in subcrop to yield a steeply dipping body of 1500 metres strike length but unknown thickness.

Northwest of Moore Lake at EM0554550mE, EM5668450mN and 1590 metres (5225 feet) elevation on the ridge, flow-layered perlite (P3) outcrops over a minimum thickness of 10 metres, with top and bottom contacts unexposed. At 2.5 kilometres to the southeast and 1510 metres (4950 feet) elevation on the southwest face of the same ridge (P4) (EM0556000mE, EM5667550mN) and 1.8 kilometres to the southeast (EM0555800mE, EM5668400mN) and 1650 metres (5400 feet) elevation on the same ridge crest (P5), are medium to dark grey flow-layered perlite outcrops. The attitudes of the flow layering suggest that the three localities may expose the same perlite layer which would outline a northwesterly trending and horizontally plunging, upright syncline with a preserved hinge line 2500 metres long. The perlite near Moore Lake probably lies at a stratigraphically deeper level than that near Mooney's Ranch. Samples from all localities await whole-rock analyses and testing relative to ASTM specifications.

BENTONITE

Bentonite-rich rocks subcrop at several localities within the fault wedge, and in the southwest-dipping succession of probable Eocene rocks to the northeast of Fraser fault. Most bentonite probably developed as lenses within fine, locally waterlain, andesite breccia. Within the fault wedge, the most extensive areas of bentonite lie along the northeastern side of the wedge between Big Bar and Crows Bar creeks. Bentonite subcrops in a northwesterly elongate, 300 by 2500 metre area of rounded hills and landslides (B1) best displayed at EM0560700mE, EM5674000mN and 750 metres (2450 feet) elevation. This area of bentonite has generated landslides which flowed through a breach in the volcanic conglomerate cliffs and dropped nearly 500 metres to the Fraser River. Some cream-weathering rhyolite tephra and brown and maroon-weathering, fine andesite breccia layers and lenses lie within the bentonite. Northwestward, an outcrop gap 8 kilometres long, probably underlain by bentonitic rocks, separates this area from a second northwesterly elongate area (B2) [500 by 1500 metres centred at EM0556300mE, EM5683650mN and 640 metres elevation (2100 feet)] which straddles Crows Bar Creek. The rounded hills expose slumped bentonite with bentonitic shale, siltstone, maroon and brown andesite breccia and rhyolite tephra. These two areas of bentonite lie either immediately above or below the volcanic conglomerate. To the southeast, between Big Bar Ferry and Watson Bar Creek, bentonitic rocks lie lower in the stratigraphy, beneath andesite breccia and acid flows and tephra. In a northwesterly elongate area of about 1 by 5 kilometres straddling Ward Creek, bentonite lenses up to a few metres in thickness are scattered through fine, varicoloured andesite breccia, acid tephra and bedded volcanigenic sediments. Exposures centred at EM0562500mE, EM5664900mN and 1010 metres (3300 feet) (B3), and EM0564400mE, EM5662100mN and 1040 metres (3400 feet) (B4) typify the lenticular and impure nature of the bentonite. The southernmost occurrence of bentonite (B5), northwest of Glen Fraser at EM0580100mE, EM5631100mN and 490 metres (1600 feet), has similar host rocks.

Of the two bentonite localities northeast of Fraser fault, the bentonite slope (B6) at EM0579400mE, EM5638100mN and 460 metres (1500 feet) appears free of intercalated volcanic breccia. The other locality (B7), at EM0578100mE, EM5638350mN and 560 metres (1850 feet), is spatially related to cream-weathering acid tephra, and maroon and brown-weathering andesite breccia.

ZEOLITES

Zeolitized waterlain rhyolite ash occurs in intercalated rhyolite and andesite tephra up to 1000 metres beneath the volcanic conglomerate (Figure 3-8-2). At EM0563800mE, EM5667250mN and 900 metres (2950 feet) 1.7 kilometres northwest of Mooney's Ranch, a poorly exposed bedded tephra layer over 5 metres thick, with neither top nor bottom contact exposed, contains a clinoptilolite-rich intermediate member of the heulandite group. At EM0554000mE, EM5685450mN and 580 metres (1900 feet) 3.2 kilometres north-northwest of the mouth of Crows Bar Creek, samples from the north end of a more than 700-metre-long lens of bedded rhyolite tephra contain intermediate compositions in the heulandite group. Although all seven samples from these localities yield heulandite-clinoptilolite, both localities require detailed sampling. At EM0564000mE, EM5664550mN and 1020 metres (3350 feet) 2.2 kilometres southwest of Mooney's Ranch, a 100-metre-thick rhyolite tephra is variably zeolitized with clinoptilolite (Z3). Other clinoptilolite-bearing tephra occurrences are at EM0666350mE, EM5660900mN and 640 metres (2100 feet) (Z4) and EM0563900mE, EM5664000mN and 890 metres (2925 feet) (Z5). Rare, tuffaceous arenite layers are weakly zeolitized with clinoptilolite up to 100 metres beneath the volcanic conglomerate. X-ray diffraction and thermal stability investigations (Boles, 1972) form the basis for the heulandite to clinoptilolite designations within the heulandite group.

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INDUSTRIAL MINERALS IN THE TERTIARY OF THE BONAPARTE TO DEADMAN RIVER AREA, SOUTHERN BRITISH COLUMBIA*
(92I/14, 15; 92P/02, 03)

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KEYWORDS: Industrial minerals, bentonite, zeolites, diatomaceous earth, Eocene stratigraphy, Kamloops Group, Deadman River Formation.

INTRODUCTION

This report summarizes results of 31 days of fieldwork investigating the occurrence of industrial minerals, and those aspects of the Tertiary stratigraphy which control their development in the area between Bonaparte and Deadman rivers. In this area, the industrial minerals of major interest are bentonite and zeolites in the Eocene Kamloops Group, and diatomaceous earth in the Miocene Deadman River Formation. In addition to the regional geology of Monger (1982) for Ashcroft map area (92I), and Campbell and Tipper (1971) for Bonaparte Lake map area (92P), McCammon (1960, pages 181 to 185) described volcanic ash and its pozzolanic properties at Sherwood Creek to the north of the study area; Cockfield (1948, page 149) and Hora (1986, page 239) reported on the Red Lake diatomite, now in production as "fuller's earth" under the ownership of DEM Resource Processors Ltd., to the east of the study area; and Read (1987) discovered zeolitized tuffs (heulandite-clinoptilolite) in the Cache Creek Hills north of McAbee. Laboratory investigations of samples are in progress, but tests of materials relative to ASTM specifications have not yet started.

TERTIARY STRATIGRAPHY AND STRUCTURE

Because the basal parts of the Kamloops and Chilcotin groups locally contain the necessary sedimentary rocks to host industrial mineral occurrences, these portions of the stratigraphy were examined in detail. Between the Bonaparte and Deadman rivers, more than a 1000-metre thickness of mainly volcanic rocks of the Kamloops Group lie on a pre-Tertiary basement with more than 300 metres of relief (Figure 3-9-1). The rocks lie in an open, northwesterly trending syncline strike-slip faulted on the east by the north-northwesterly striking Deadman River fault. The basal 500 metres of the group contains lenses of volcanogenic sediments up to 9 kilometres long and 200 metres thick, which locally host zeolite and bentonite occurrences. More than 300 metres of the undeformed Chilcotin Group overlies the Eocene and older rocks on a basement with more than 400 metres of relief. Rhyolite ash, minor siltstone, sandstone and pebble conglomerate, and rare diatomaceous earth comprise the Miocene Deadman River Formation which is the lower part of the group. The formation includes fluviatile deposits filling deep river channels, such as the one exposed east of Gorge Creek, and probable lacustrine accumulations such as the one poorly displayed northwest of Red Lake. The Chilcotin Group is more extensive than previously mapped in the Ashcroft map area (compare Monger, 1982). In the vicinity of Deadman River. the erosional remnants outline a southward draining Miocene river valley that closely coincides with the present position of the river.

INDUSTRIAL MINERALS IN THE KAMLOOPS GROUP

ZEOLITES

Up to 500 metres above the base of the Eocene succession are conglomerate, lithic sandstone, shale and zeolitized tuffaceous lenses. Of the two lenses described north of McAbee (Read 1987, page 253), a section through the 89-metre-thick western lens has been sampled every metre in its exposed portions. Waterlain, zeolitized acid tephra locally underlies the upper 4 metres of the lens, and forms a 10-metre-thick bed near the middle of the lens. A thermal stability investigation of the zeolitized samples shows that heulandite and heulandite-rich intermediate compositions predominate and that clinoptilolite occurs only near the margins of the 10-metre-thick bed. The low cation exchange capacity (CEC) of sample 424B from the upper part of the lens also indicates heulandite (Table 3-9-1).

The thickest sedimentary lens forms a 9-kilometre-long line of cliffs up to 200 metres high on the west side of Deadman River between Clemes and Gorge creeks. A grey-brown andesite cobble to boulder conglomerate occupies the

TABLE 3-9-1
EXCHANGEABLE Ca, Na, K AND Mg ANALYSES AND CATION EXCHANGE CAPACITY (CEC)

Sample	Exchangeable Cation Analysis (milli-equivalent/100g) Mg	Ca	K	Na	Total	CEC (milli-equivalent /100g)
C86-424B	4.4	9.6	5.6	8.1	27.7	22.3
C86-424B	4.8	12.5	7.5	12.3	37.1	28.1

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

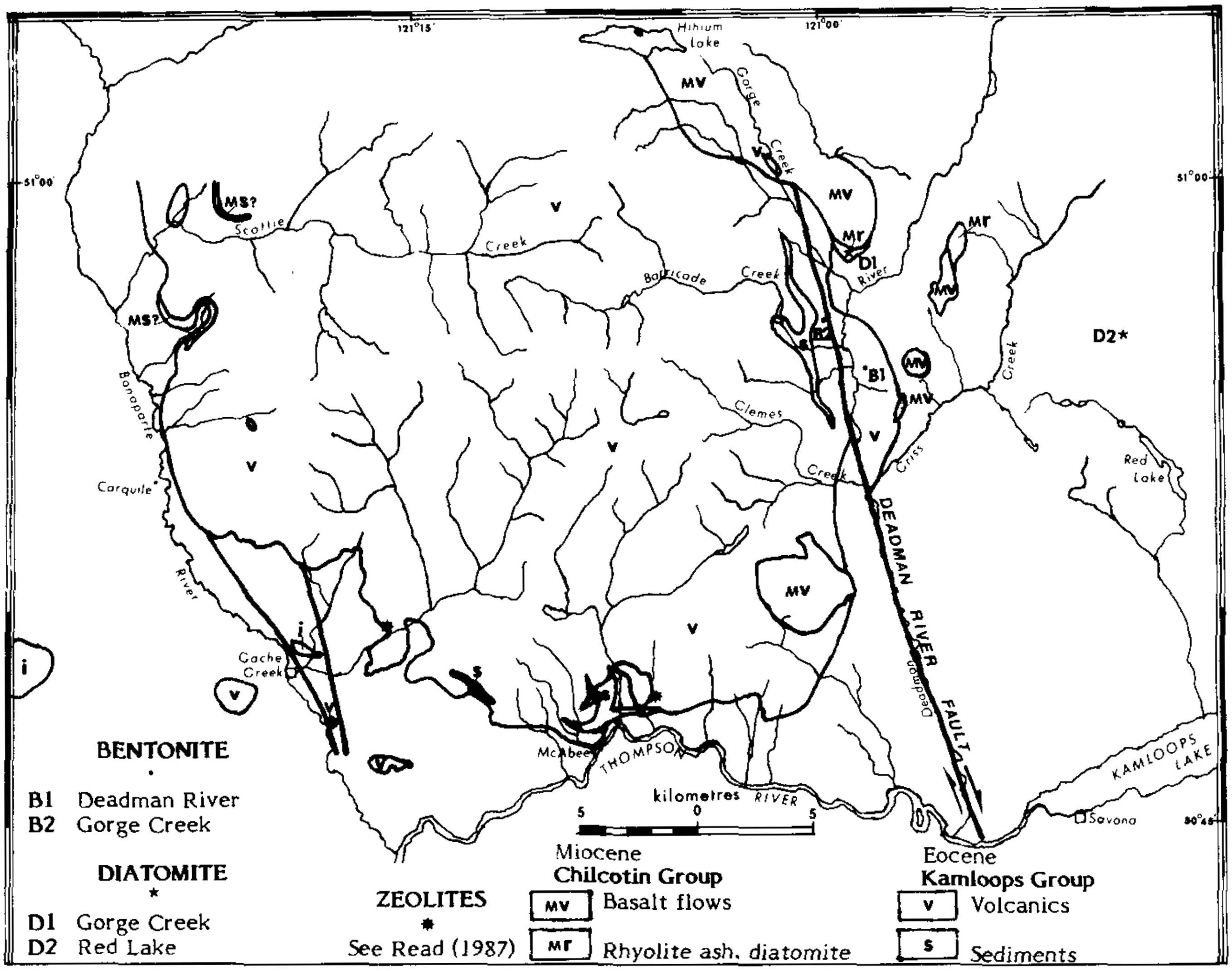

Figure 3-9-1. Simplified geological map of the area between Bonaparte and Deadman rivers showing the industrial mineral occurrences.

lower part of the lens, a white-weathering, glassy rhyodacite(?) pebble to cobble conglomerate or breccia occupies the middle, and andesite or rhyodacite layered tuffs up to a few metres in thickness are scattered throughout. This conglomerate lens may be the proximal portion of a fan delta whose distal segment consists of the two sedimentary lenses of volcanic conglomerate and overlying sandstone, shale and zeolitized tuff exposed north of McAbee. Bedded lithic andesite tuff and tuffaceous wacke form lenses up to a few tens of metres in thickness and hundreds of metres in length which outcrop up to 5 kilometres southeast of Carquile. An X-ray diffraction investigation of 77 samples from these lenses shows that only those lenses previously described are zeolitized (Read, 1987).

BENTONITE

From a kilometre north of Clemes Creek to a kilometre north of Gorge Creek, landslide debris underlies Deadman River and mantles the valley walls up to 1070 metres (3500 feet) in elevation. The most extensive slides are from the east or dip-slope side of the valley where an approximately 60-metre-thick bentonite-rich layer (B1), with intercalated fine volcanic breccia layers, outcrops for a kilometre along strike near the base of slope. It is best exposed at FM0642650mE, FM5643150mN and 690 metres (2250 feet) elevation. On the west side of the valley from Barricade to Gorge creeks, bentonitic volcanic breccia and bentonite-rich lenses up to a few tens of metres in thickness are scattered throughout the andesite breccia that underlies the sedimentary lens. Ferrier's (Keele, 1920, page 161) and Cockfield's (1948, page 150) descriptions of bentonite near the mouth of Gorge Creek (B2) probably apply to bentonite-rich layers in andesite breccia exposed at FM0641000mE, FM5645800mN and 750 metres (2450 feet) elevation.

INDUSTRIAL MINERALS IN THE CHILCOTIN GROUP

DIATOMACEOUS EARTH

North of the junction of Gorge Creek and Deadman River (D1), float of diatomaceous earth occurs in roadcuts at FM0648100mE, FM5648200mN. It must subcrop between the roadcuts at 1010 metres (3300 feet) elevation and the base of the overlying olivine basalt flows at 1110 metres (3650 feet). Between 9 and 14 kilometres north of the mapped area, on the north side of Sherwood Creek, Campbell and Tipper (1971, Section 2-2TD-1964) reported a minimum aggregate thickness of 4.3 metres of diatomaceous earth in two beds lying within 41.5 metres of the base of the section; and 3.8 metres in two beds lying within 50.9 metres of the base of Section 1-2TD-1964 on the east side of Deadman River at the north end of Skookum Lake (Campbell and Tipper, 1971, page 56). Six kilometres east of the mapped area, diatomaceous earth material up to 37 metres in thickness has been outlined over an area of 64.8 hectares at the deposit of DEM Resource Processors Ltd. at Red Lake (D2). Because the Deadman River Formation is incompletely mapped and exposures are restricted to roadcuts, the diatomaceous earth potential of the area has not been adequately assessed.

VOLCANIC ASH

Massive rhyolite ash underlies olivine basalt flows in the Miocene residua north of Gorge and Criss creeks. Farther north, near and in Scottie Creek valley, are two lenses up to 100 metres thick and 3 kilometres long which consist of rhyolite ash containing layers of andesite volcanic conglomerate with clasts lying in the acid tuff matrix. Because similar rocks occur in the Kamloops Group and both of these lenses lack overlying olivine basalt flows, they are correlated only tentatively with the Chilcotin Group. Outside the mapped area, volcanic ash is present at Sherwood Creek and farther north (Keele, 1920, pages 161 and 162; Eardley-Wilmot, 1927, pages 85 to 89). At Sherwood Creek, McCammon (1960, page 180) 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 ceramic ware (McCammon, 1960) or as an abrasive (Eardley-Wilmot, 1927).

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THE INDUSTRIAL MINERAL POTENTIAL OF KYANITE AND GARNET IN BRITISH COLUMBIA*

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KEYWORDS: Industrial minerals, economic geology, garnet, kyanite, sillimanite, andalusite, Omineca crystalline belt, Coast Mountain belt.

INTRODUCTION

Garnet, kyanite, sillimanite and andalusite are minerals found in contact and amphibolite facies regional metamorphic rocks. In British Columbia, such metamorphic rocks are confined mainly to two belts, the eastern Omineca crystalline belt and the western Coast Mountain belt (Figure 3-10-1), where they are accompanied by granitic plutons. Garnet, kyanite and the other aluminosilicate minerals which are present throughout these belts have potential industrial applications, although currently there is no production of these commodities in the province, or elsewhere in Canada.

Garnet is used as an abrasive; high-quality garnet, usually the variety almandine, is used in the form of powders and loose grains for grinding and lapping glass, ceramics and other materials. It is also used in coated and bonded abrasives such as sandpaper, and wheels for grinding and finishing wood, metal, rubber and plastic. Lower quality garnet is used for sandblasting aluminum and other soft metals by, among others, the aircraft industry, and for water filtration (Hight, 1983; Smoak, 1985).

Kyanite and the related minerals, sillimanite and andalusite, are prized mainly for their refractory properties. They are used directly, or calcined to form mullite, in the production of high-temperature mortars or cements and castable refractories, kiln furniture, insulating brick, firebrick and similar products. Finely ground kyanite is used in sanitary porcelains, wall tile and miscellaneous special purpose ceramics (Bennett and Castle, 1983; Potter, 1983; 1985). These refractory products are chiefly used by the metallurgical (steel) and glass industries, and secondarily, by the ceramics industry (Varley, 1968).

GARNET – CURRENT WORLD PRODUCTION AND ECONOMIC CONSIDERATIONS

The United States is the world's leading producer and consumer of garnet, accounting for approximately 75 per cent of the world output and 70 per cent of the world consumption (Smoak, 1983, 1985). The remaining production is from Australia, India and the U.S.S.R.; Canada is currently not a garnet producer. There are four producers of garnet in the U.S., located in New York, Maine and Idaho. In the later two areas, only low-quality garnet used for sandblasting and water filtration is produced. The geographic areas in which garnet occurs are widespread; however, commercially attractive industrial garnet occurrences are relatively few.

Deposits mined in the U.S. grade from 30 to 80 per cent garnet, with crystal sizes reaching in excess of 90 centimetres; however, on average grains are less than 10 centimetres in diameter. The best abrasive garnets are almandines (hardness 7.5), but pyrope, andradite and grossular, which are all softer, are also used (Smoak, 1985). The presence of incipient fractures or mineral inclusions reduces the usefulness of the garnet (Hight, 1983). As with most industrial minerals, location of deposits and transportation costs are factors of paramount importance in determining viability. Studies by the U.S. Bureau of Mines (Smoak, 1985) indicate world reserves should be adequate to supply world demand for garnet at least until the year 2000; therefore, any new deposits would have to be extremely high grade, high quality and well located in order to break into the market.

KYANITE – CURRENT WORLD PRODUCTION AND ECONOMIC CONSIDERATIONS

The United States, the Republic of South Africa and India are the leading world producers of aluminosilicate minerals (Potter, 1983). There is currently no production of sillimanite, andalusite or kyanite in Canada, although, in the past, attempts were made to recover kyanite from schists in the Timiskaming area (Bennett and Castle, 1983). The consumption of kyanite is concentrated in a relatively few highly industrialized areas, which are typically close to the major iron and steel producing regions in northern Europe, eastern U.S., England and Japan (Bennett and Castle, 1983).

The majority of U.S. production comes from quartzites in Virginia and Georgia which contain 15 to 40 per cent kyanite. No schists are currently being mined for kyanite (Bennett and Castle, 1983); beneficiation of kyanite from schists has traditionally proved problematic, due largely to the presence of iron-rich mineral inclusions. Massive sillimanite is produced in India and coarse sillimanite from schists could potentially be produced; however, the beneficiation of fibrolitic sillimanite is usually impossible. An-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

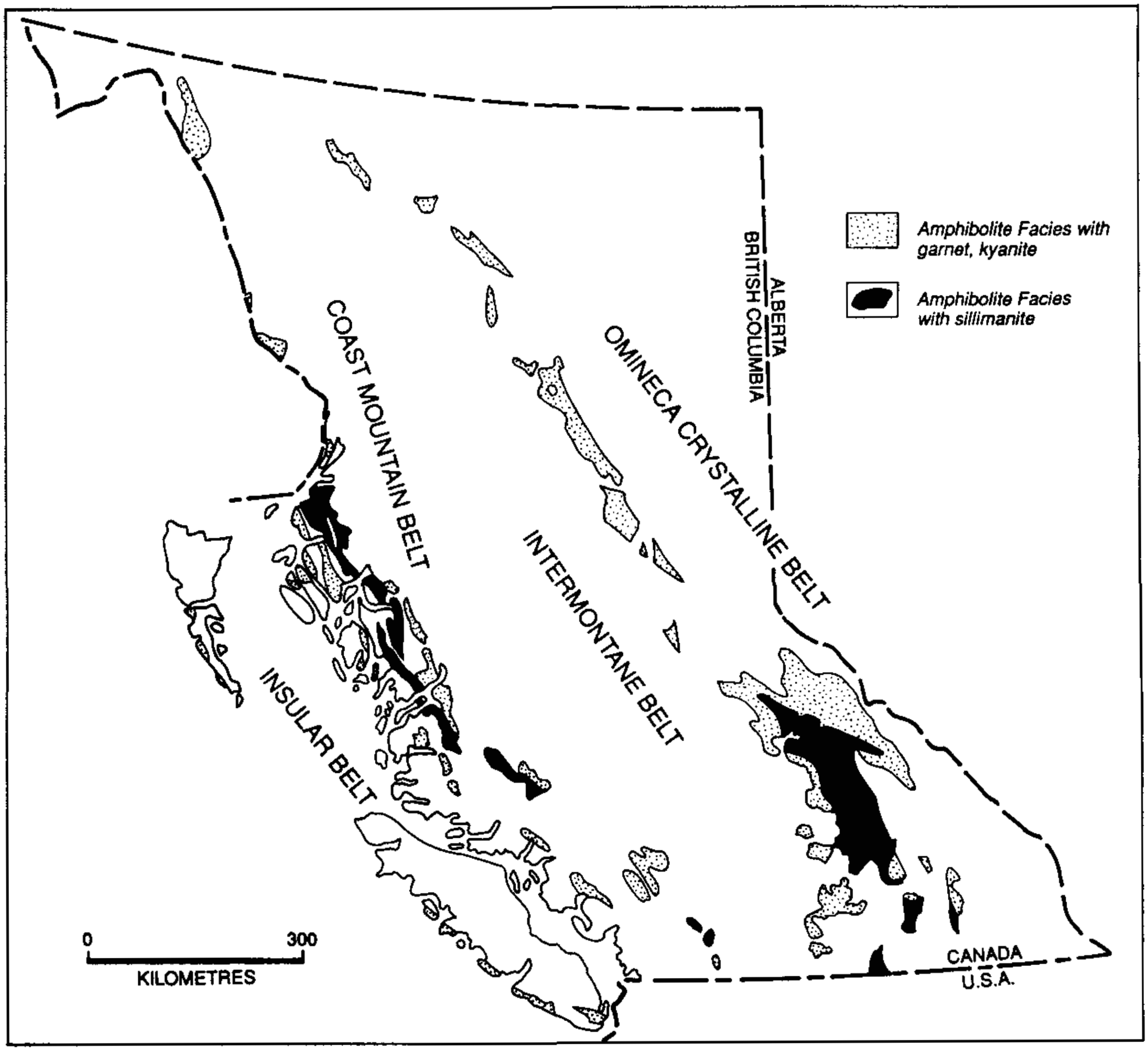

Figure 3-10-1. Distribution of amphibolite facies of classical regional metamorphism in British Columbia (from Monger and Hutchison, 1970).

dalusite is being mined from weathered schists in France and from alluvial deposits in South Africa (Bennett and Castle, 1983).

The potential supply of kyanite group minerals from regional metamorphic terranes vastly exceeds the potential market; therefore, an important preliminary consideration in any exploration project is the cost of delivering kyanite to the geographically limited markets. Also, grade and size of crystals must be considered; an economic kyanite deposit is one from which a −35 to −28 mesh concentrate can be produced which contains less than 2 per cent combined impurities (Fe_2O_3, TiO_2, CaO, MgO, etc.) (Bennett and Castle, 1983). As with garnet, studies indicate that an ample supply of kyanite group minerals is likely to exist at least until the year 2000 (Potter, 1985).

GARNET AND KYANITE LOCALITIES IN BRITISH COLUMBIA

Garnet and kyanite group minerals occur mainly in two belts in the Cordillera, the Omineca crystalline belt and the Coast Mountain belt, with minor occurrences elsewhere (Figure 3-10-1). Within these belts, pelitic metasedimentary rocks containing small amounts (that is, less than 5 per cent) of these minerals are extremely abundant. Rocks containing significant concentrations of these minerals, however, are found considerably less frequently. The scope of this study is to identify areas of potential economic grade, for example, greater than 10 to 15 per cent kyanite group minerals and greater than 25 per cent garnet; economic viability as a function of transportation costs, market access, beneficiation possibilities and other factors will not be addressed.

SOUTHERN SHUSWAP – OKANAGAN AREA (82F), OMINECA BELT

Coarse metapelitic schists containing abundant sillimanite and garnet are reported from the Valhalla and Passmore dome area, west of Slocan Lake (Reesor, 1965). Valhalla and Passmore are two of a series of domal structures containing gneisses which form the core of the Shuswap metamorphic complex. Sillimanite locally comprises 20 to 25 per cent of the sillimanite-garnet-biotite schists, and may be very coarse. In the vicinity of the Passmore dome, sillimanite occurs in knots or groups of crystals over 2.5 centimetres long and 1 centimetre wide. These schists also locally contain up to 30 per cent garnet, with an average crystal size of 0.5 centimetre or less. Garnet is also present in interbedded amphibolitic rocks in amounts up to 40 per cent (Reesor, 1965).

Coarse-grained kyanite has been reported from the Creston area (McCammon, 1965). It forms clean, bladed crystals in clumps 10 to 15 centimetres in diameter associated with the pegmatites, and is disseminated throughout schists and micaceous quartzites, where crystals vary from small needles to 1 to 5 centimetres in size (McCammon, 1964).

REVELSTOKE – FRENCHMAN CAP – BIG BEND AREA (82M, N), OMINECA BELT

Coarse, kyanite-rich schists have long been known to exist in rocks of the Shuswap complex in the Revelstoke – Frenchman Cap – Big Bend area (O'Grady and Richmond, 1932; Carnochan and Rogers, 1934; Cummings, 1948; Eichelberger, 1953). Locally, kyanite may constitute 20 to 30 per cent of the micaceous schists, and individual crystals may be over 3 centimetres in length (T. Höy, personal communication, 1987). Areas particularly noted for kyanite are: the Death Rapids – Priest Rapids area, along the west side of the Columbia River, approximately 60 kilometres north of Revelstoke (O'Grady and Richmond, 1932; Carnochan and Rogers, 1934; Cummings, 1948); the Big Bend (Mica Creek) – Kinbasket Lake area underlain by Horsethief Creek Group strata, 100 kilometres to the north and northeast of Revelstoke (Eichelberger, 1953; T. Höy, personal communication, 1987); the Trident Mountain area, 15 kilometres east-southeast of Mica Creek (Perkins, 1983); and the mantling gneisses on the north and northwestern margin of Frenchman Cap dome in the vicinity of Ratchford Creek, the headwaters of Perry River and Kirbyville Creek (Wheeler, 1965; T. Höy, personal communication, 1987). Sillimanite is also locally abundant in the latter localities.

CANOE RIVER – VALEMONT AREA (83D), OMINECA BELT

Horsethief Creek Group strata in the Canoe River area were locally sufficiently pelitic to produce abundant garnet and aluminosilicate minerals when subjected to high-grade regional metamorphism. In the southeastern Cariboo Mountains, approximately 30 kilometres southwest of Valemont, pelitic schists locally contain 20 to 25 per cent kyanite, with or without fibrolitic sillimanite, and 15 to 25 per cent garnet (Pell, 1984). Kyanite grains are commonly more than 2 centimetres in length. Pelitic schists in this region also frequently contain quartz-kyanite-rich segregation lenses In the northern Monashee Mountains approximately 30 kilometres southeast of Valemont, near the headwaters of Howard Creek, Horsethief Creek Group schists contain 20 to 25 per cent coarse garnets which range from 2 to 6 centimetres in diameter. Kyanite is also present, but not abundant at this locality. Abundant coarse kyanite has been noted in the vicinity of Albreda, on the main line of the Canadian National Railway, approximately 25 kilometres south of Valemont (Cummings, 1948).

HOPE – YALE – HARRISON LAKE AREA (92G, H), COAST MOUNTAIN BELT

Pelitic schists crop out in a number of localities in the Hope – Yale – Harrison Lake area of southwestern British Columbia and locally contain abundant kyanite, sillimanite and garnet. The Settler schist, of uncertain age, is found between Harrison Lake and Yale. Locally, it contains up to 30 per cent garnet and 23 per cent kyanite, 24 per cent fibrolitic sillimanite or 15 per cent coarse sillimanite in prisms more than 4 centimetres long (Lowes, 1972; Pigage, 1973). Sillimanite is generally present adjacent to granitic plutons, notably along the ridge north of Cogburn Creek and Zofka Ridge (Lowes, 1972).

Pelitic schists and gneisses of the Breakenridge and Cairn Needle formations of Late Paleozoic and Mesozoic age also crop out in the Harrison Lake area. Schists of the Breakenridge Formation are extremely pelitic and may contain up to 50 per cent garnet (average approximately 20 per cent) and up to 40 per cent coarse-grained kyanite (average approximately 15 per cent) (Reamsbottom, 1971). Schists of the Cairn Needle Formation are slightly less pelitic, containing from 4 to 50 per cent garnet, with averages of approximately 10 to 15 per cent, minor kyanite or andalusite and from 0 to 20 per cent sillimanite (Reamsbottom, 1971).

PRINCE RUPERT – SKEENA RIVER – DOUGLAS CHANNEL AREA (103H, I, J), COAST MOUNTAIN BELT

Pelitic schists and gneisses of uncertain age and affiliation occur in abundance as inliers and adjacent to granitic plutons in the Prince Rupert – Skeena River – Douglas Channel area, northwestern British Columbia (*see* Hutchison, 1982). The Central Gneiss Complex of the Prince Rupert – Skeena map area contains zones of biotite-garnet-sillimanite-muscovite gneisses 30 to 300 metres thick in the Mount Ponder, Redcap Mountain, Kwinamass Peak and Kateen River areas. Within these zones sillimanite comprises up to 50 per cent of the rock and garnets up to 0.75 centimetre in diameter form an additional 15 to 20 per cent. On Highway 16, 1 kilometre east of Kwinitsa, excellent exposures of garnet-sillimanite-biotite-quartz-feldspar gneiss contain 5 to 30 per cent garnet and 5 to 30 per cent sillimanite; the sillimanite is generally present in densely felted layers from 0.2 to 2.5 centimetres thick (Hutchison, 1982). Numerous other garnet and sillimanite localities are present in the Prince Rupert – Skeena area.

Kyanite-staurolite-almandine schists are exposed on Hawksbury Island, south of Prince Rupert and contain up to 20 per cent almandine garnet and up to 20 per cent kyanite (Money, 1959). The garnet is present as subhedral to euhedral grains up to 5 centimetres in diameter or as anhedral rounded aggregates, 7.5 centimetres across. Kyanite may be extremely coarse; blades reach 20 centimetres by 1 centimetre in size. Sillimanite is reported from only one locality on Hawksbury Island (Fishtrap Bay), where it is present as rounded knots in gneiss and comprises up to 15 per cent of the rock (Money, 1959). In the Douglas Channel – Ecstall River area, south of Prince Rupert, extremely garnetiferous schists and gneisses have been reported. Euhedral garnets 1 to 2 centimetres in diameter locally comprise up to 20 per cent of the rocks; some schists from the shores of Douglas Channel contain 50 per cent garnet with an average grain size of 0.25 centimetre (Padgham, 1959).

ACKNOWLEDGMENTS

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Coal Studies

ELK VALLEY COALFIELD, NORTH HALF (82J/02, 07, 10, 11)

By R. J. Morris and D. A. Grieve

KEYWORDS: Coal geology, Elk Valley coalfield, Mount Veits, Mount Tuxford, Henretta Ridge, Bourgeau thrust, coal rank, Elk River syncline, Alexander Creek syncline.

INTRODUCTION

Detailed geological mapping and sampling of the north half of the Elk Valley coalfield began in 1986 and were completed in 1987. The end poduct, a preliminary map at a scale of 1:10 000, will extend available map coverage in the coalfield north from the areas covered by Preliminary Maps 51 and 60 (Figure 4-1-1), which in turn expanded previous coverage in the adjacent Crowsnest coalfield (Preliminary Maps 24, 27, 31 and 42).

Work in 1986 (Grieve, 1987) was mainly concentrated in the Weary Ridge – Bleasdell Creek area. The more extensive 1987 field program was completed by R.J. Morris.

The study area, which includes some of the least well-explored parts of the southeast coalfields, extends 40 kilometres in a north-south direction. The southern boundary of the area is formed by Henretta and Britt creeks, and is immediately north of the Fording River operations of Fording Coal Ltd. (Figure 4-1-1). The northern boundary is the British Columbia – Alberta border. The map area includes the upper Elk Valley and a portion of the upper Fording Valley.

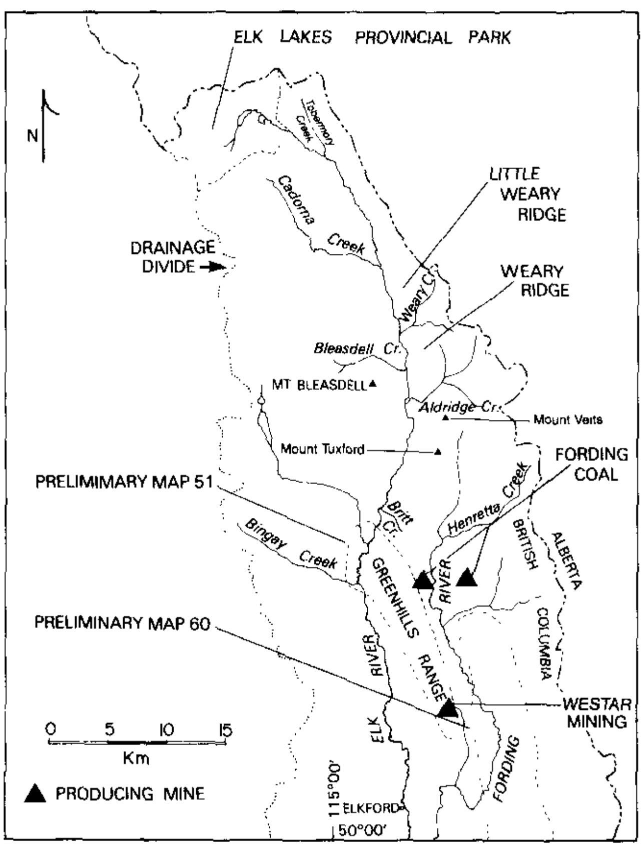

Figure 4-1-1. The Elk River valley north of Elkford.

Most of the area is Crown land and includes three coal properties. The most southerly comprises the north end of the Fording Coal Ltd. Fording River property. Adjacent to the north is the Elk River property, in which Fording Coal currently holds a 50-per-cent interest. Coal rights to the most northerly property, formerly known as the Vincent option, are reserved to the Crown.

Exploration history of the Weary Ridge – Bleasdell Creek area was summarized by Grieve (1987). Of the remaining parts of the study area, only Little Weary Ridge and vicinity has received a significant exploration effort. Little Weary Ridge was the focus of considerable attention in the 1970s as the proposed site of the planned Elco mine development. Other parts of the area have received some exploration, including drilling programs in the north end of the reserve area by Rio Tinto Canadian Exploration Ltd., and at Henretta Ridge and in the Aldridge Creek area by Fording. Mount Tuxford on the Fording River property has received essentially no exploration and as such is the largest unassessed block of coal-bearing land in the southeast coalfields.

The part of the map area north of Cadorna Creek has been the subject of two previous geological studies. Pearson and Duff (1977) carried out a mapping and core logging program. Graham *et al.* (1977) carried out a study which included mapping and drilling of four diamond-drill holes, for a total of 1641 metres, at the extreme north end of the Elk Valley.

Access to most parts of the area is good, ultilizing the Elk Valley road, Fording mine access roads (permission required), the powerline access road and subsidiary exploration roads. The upper Fording Valley, however, has no vehicle access, and consequently most of Mount Tuxford can only be reached by helicopter. The west side of the Elk River north of Cadorna Creek, and Henretta Ridge, also have no road access.

Relief varies throughout the area from very low in the north, where the coalfield essentially occupies the bottom of the Elk Valley, to relatively extreme on Mount Tuxford and Mount Veits. Elevations range from 1500 to over 2400 metres.

FIELDWORK AND METHODS OF STUDY

Field data were plotted directly on British Columbia government air photographs, enlarged to a scale of approx-

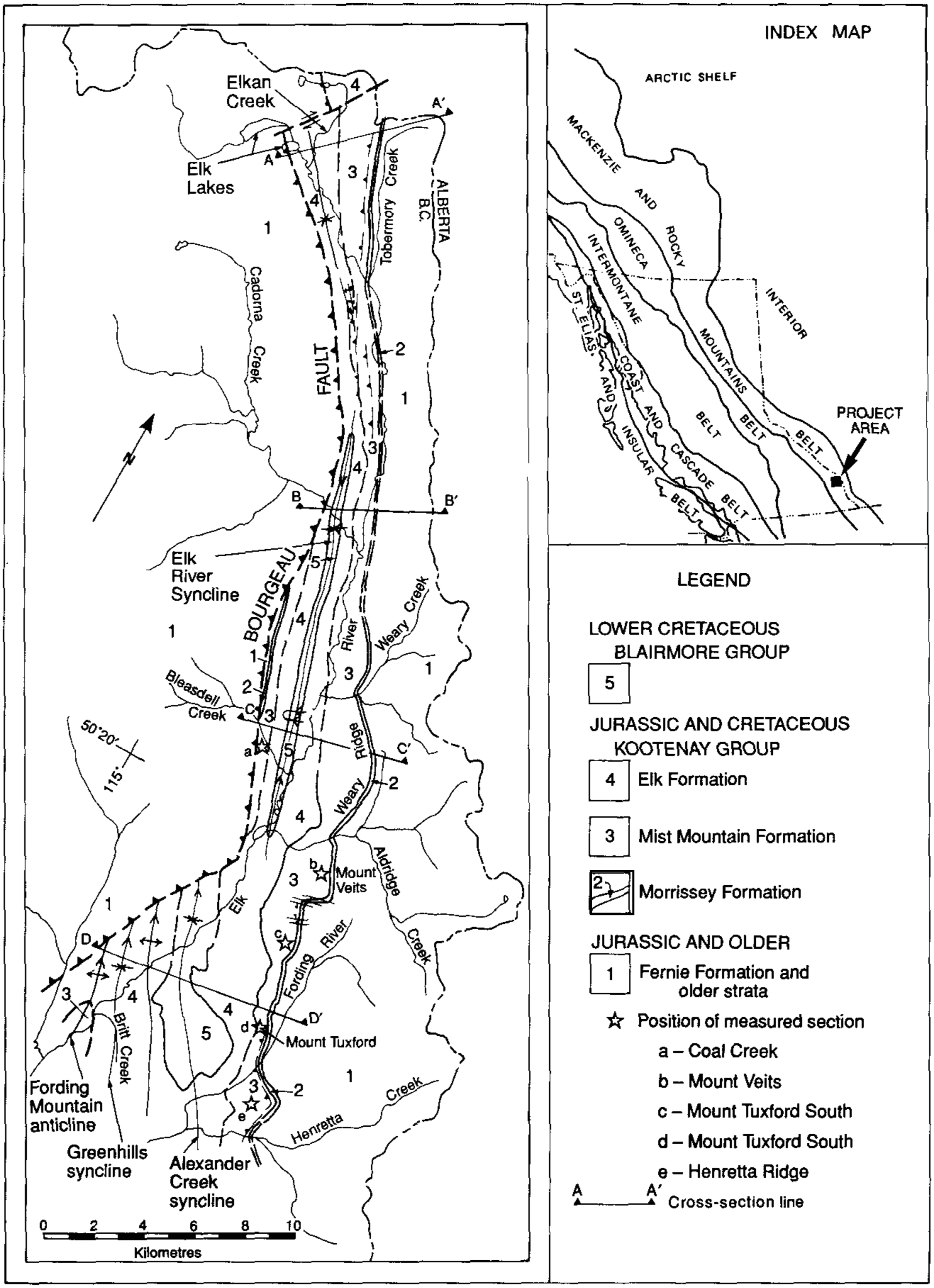

Figure 4-1-2. General geology of the north half of the Elk Valley coalfield.

imately 1:7500. Data and interpretations will be transferred to specially prepared 1:10 000-scale orthophoto base maps.

Stratigraphic sections were measured on Mount Veits, Mount Tuxford and Henretta Ridge and at Coal Creek, using pogo stick, compass and chain. They have been generalized for inclusion here. Coal units thinner than 1.0 metre are not included in the generalized sections.

Grab samples of coal were taken frequently to provide material for petrographic rank determinations. In all cases, bloom and other highly degraded coal was avoided, usually by sampling from fresh-looking cuts or by digging through softer material. Average sample size was 250 grams and no attempt was made to make the samples representative.

Petrographic rank of coal was determined by the $\bar{R}_o$max method (mean maximum vitrinite reflectance in oil) on pelletized particulate samples. Samples were lightly crushed using mortar and pestle; only the -20-mesh fraction was utilized. Maximum readings on 50 grains per sample were measured and averaged. Coals are classified into ASTM categories as follows: high volatile bituminous, $\bar{R}_o$max $<$1.12 per cent; medium volatile bituminous, 1.12 per cent $<\bar{R}_o$max $<$1.51 per cent; and low volatile bituminous, $\bar{R}_o$max $>$1.51 per cent.

STRATIGRAPHY

The stratigraphic column in the study area is shown as the legend in Figure 4-1-2. Economic coals in southeastern British Columbia are contained within the Jurassic-Cretaceous Kootenay Group. The Kootenay Group conformably overlies the Jurassic Fernie Formation, a marine unit predominantly composed of shale. The Kootenay is conformably (?) overlain by the Lower Cretaceous Blairmore Group. The basal unit of the Blairmore Group is the Cadomin Formation, a distinctive marker conglomerate, which is preserved in two areas and represents the only exposed Blairmore strata in the study area.

MORRISSEY FORMATION

The basal unit of the Kootenay Group is the Morrissey Formation, a resistant sandstone unit ranging in thickness from 20 to 80 metres (Gibson, 1979). It consists of two members, the lower Weary Ridge member and the upper Moose Mountain member. The Moose Mountain is a distinctive marker which is utilized in all surface and subsurface studies of the Kootenay Group to define the base of coal occurrences. It is a well-indurated, medium to coarse-grained, medium grey-weathering, quartz-chert sandstone (Gibson, 1979). Within the study area it was observed to be more variable than normal. For example, it includes one or more carbonaceous partings in the area between Weary Ridge and Mount Tuxford, and at two localities it was observed to include an unusual light grey-weathering, quartzose facies.

MIST MOUNTAIN FORMATION

The overlying Mist Mountain Formation contains essentially all the coals of economic interest in southeastern British Columbia. Its average thickness south of the study area is between 500 and 600 metres, of which coal forms roughly 10 per cent of the total thickness. An almost complete section of Mist Mountain Formation measured on Weary Ridge in 1986 (Grieve, 1987, Figure 5-1-4) is 507 metres thick, and contains 63.8 metres of coal. Good exposures of the formation occur throughout much of the southern part of the area; some of these were measured and are generalized here in Figure 4-1-3 and are discussed below. North of Little Weary Ridge, however, exposures of Mist Mountain Formation are extremely poor and little can be said about its general features. Logs of drill cores from the extreme north end of the area are shown in Graham *et al.* (1977).

COAL CREEK

At Coal Creek, a tributary of Bleasdell Creek, a partial section of Mist Mountain Formation in the immediate footwall of the Bourgeau thrust fault was measured (Figure 4-1-3). At this location the Morrissey Formation and the base of the Mist Mountain are not present due to movement on the Bourgeau thrust (*see* Figure 4-1-2). The base of the section chosen was an arbitrary point beneath a prominent coal seam in the lower Mist Mountain Formation. A structurally complex area within the lowest part of the exposed section was not included. The starting point was on the north side of the creek. On the opposite side, the lowest seam in the measured section has been locally tectonically thickened to considerably more than its true thickness (*see* Structure).

The top of the section corresponds with the last of the exposures in the creek. It is estimated to be within 100 metres of the top of the Mist Mountain Formation.

Of the 304.2 metres of section represented in Figure 4-1-3, 29.4 metres consists of coal seams greater than 1 metre in thickness. These range from 1.0 to 5.9 metres; only three are greater than 3 metres. Prominent channel sandstones occur near the base of the section, notably in the roof of the lowest major seam, and at the top of the section.

MOUNT VEITS

Mist Mountain Formation on Mount Veits dips westerly and underlies the west slope (dip slope) and upper east slope. A partial section was measured on the east slope. The base of the section is the contact between the Morrissey and Mist Mountain formations; the top corresponds with the peak of the mountain.

The Mount Veits section (Figure 4-1-3) includes 127.7 metres of strata, of which only 7.6 metres represents coal seams thicker than 1 metre. These range from 1.5 to 2.5 metres in thickness. A prominent channel sandstone unit marks the top of the section.

MOUNT TUXFORD NORTH

A complete section of Mist Mountain Formation was measured along the north-trending spur of Mount Tuxford, roughly 3 kilometres south of Mount Veits. At this point, the Mist Mountain Formation is 550.5 metres thick (Figure 4-1-3). It contains at least 39.5 metres of coal in seams greater than 1 metre in thickness. It is possible that more coal seams underlie the covered intervals within the section, particularly those in the lowest 50 metres. The observed

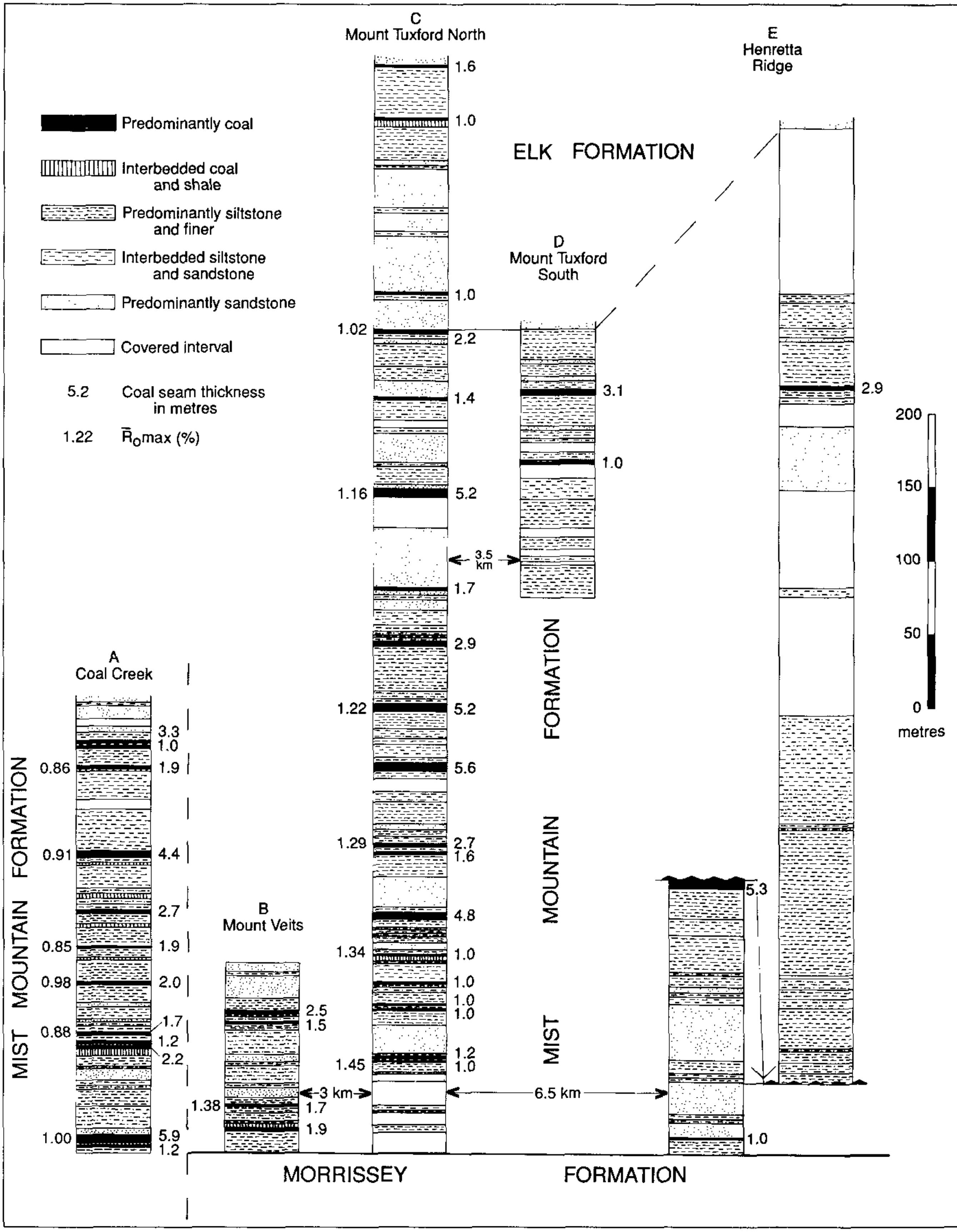

Figure 4-1-3. Generalized measured sections of parts of the Mist Mountain and Elk formations in the north half of the Elk Valley coalfield. *See* Figure 4-1-2 for locations; sections are described in the text.

seams range from 1.0 to 5.6 metres thick, and four seams are in the range of 4.8 to 5.6 metres. Channel sandstone units are mainly confined to the lowermost and uppermost 200 metres of the section. The intervening 150 metres of predominantly recessive strata contains two closely spaced coal seams each greater than 5 metres in thickness.

Mount Tuxford South

A partial section of upper Mist Mountain Formation was measured on the east-facing slope of Mount Tuxford, roughly 3.5 kilometres south of the previous section. The base of the section was chosen arbitrarily and represents the lowest point of consistently good exposure. The top of the section corresponds with the base of a prominent channel sandstone believed to mark the base of the Elk Formation.

The Mount Tuxford south section is 181.6 metres thick and contains only two coal seams (1.0 and 3.1 metres thick) which exceed 1 metre in thickness. Covered zones within the section may hide more coal seams. In contrast with the upper 200 metres of the Mount Tuxford north section, this section is relatively recessive and devoid of major channel sandstone units.

Henretta Ridge

A section, representing all Mist Mountain strata underlying Henretta Ridge, was measured 3 kilometres south of the Mount Tuxford south section. The base of the section corresponds with the Morrissey – Mist Mountain contact and the top corresponds with the Mist Mountain – Elk contact. Unfortunately, the section location is characterized by structural complications and poor exposure. A thrust repeat of roughly 135 metres of strata in the lower Mist Mountain Formation was noted and split out (Figure 4-1-3). At just under 700 metres, however, the total Mist Mountain section is still anomalously thick, which suggests that other structural repetitions probably occur within thick recessive or covered intervals.

The part of the section occupying the footwall of the thrust (plotted on the left in Figure 4-1-3) is well enough exposed to permit the observation that it is remarkably lacking in coal (it contains only two coal seams, one 1.0 metre thick and the other 5.3 metres thick), and contains a relatively large thickness of channel sandstone units. The presence of channel sands may have a bearing on the lack of coal; channel sandstones often fill washouts of coal seams.

The hangingwall portion of the section (plotted on the right in Figure 4-1-3) defies generalization. It contains almost no coal, although the thick covered intervals are almost certainly hiding some coal seams. However, the lowest 250 metres is well exposed, and contains no coal. The continuous thick intervals of fine-grained rocks are extremely anomalous.

It is noteworthy that the overlapping portion of the Mist Mountain Formation on Henretta Ridge is very different in each of the two thrust sheets (Figure 4-1-3). The hangingwall portion contains a predominantly recessive sequence, lacking the major sandstone unit present in the footwall. Further-

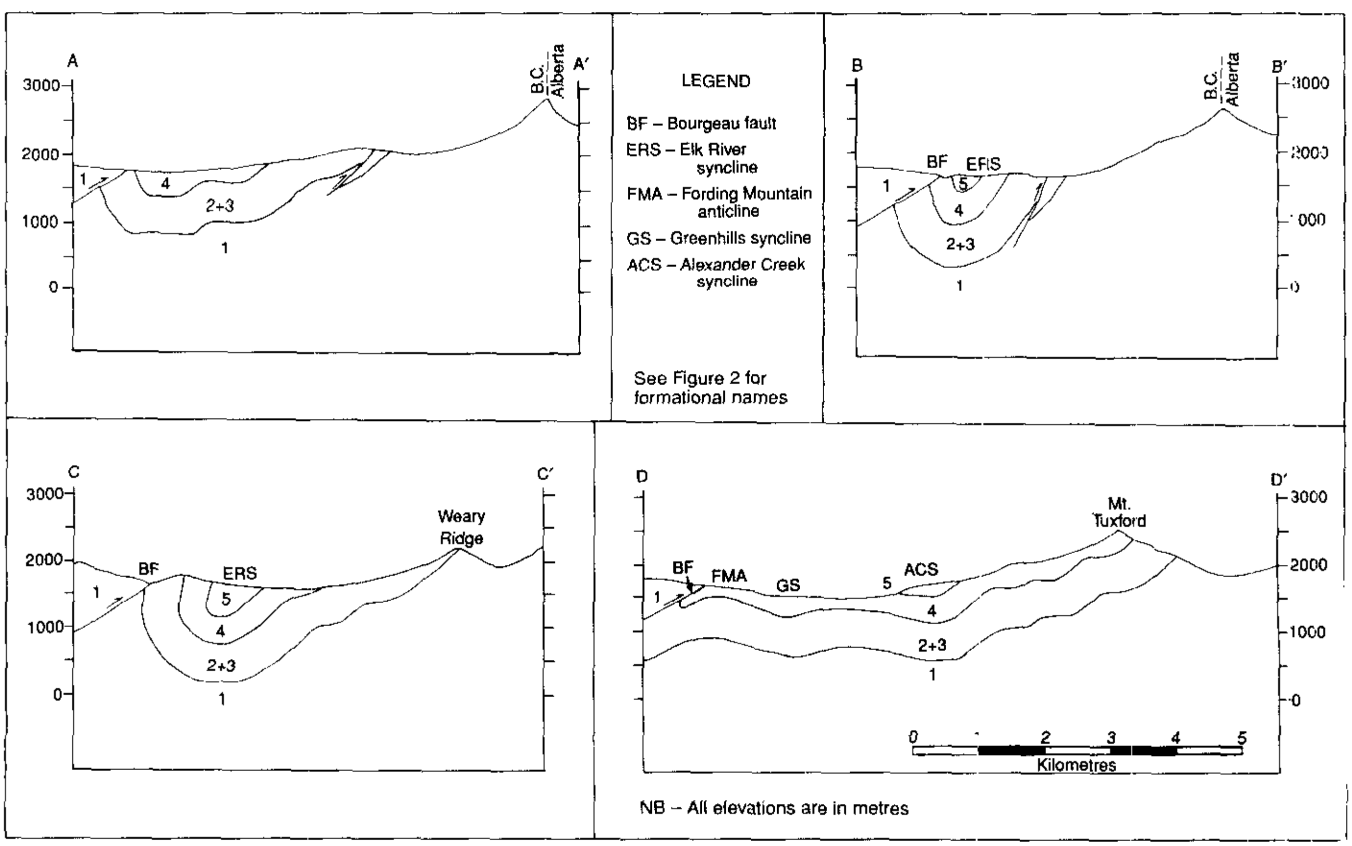

Figure 4-1-4. Generalized cross-sections through the north half of the Elk Valley coalfield. *See* Figure 4-1-2 for locations.

more, the 5.3-metre seam just beneath the thrust is apparently absent in the hangingwall.

ELK FORMATION

The overlying Elk Formation is a coarser grained facies than the Mist Mountain and distinguished from it in several ways. In particular it generally lacks thick coal seams and contains unusual sapropelic coals known as "needle coals" (*see* Kalkreuth, 1982). In the Mount Tuxford and Henretta Ridge areas the Elk Formation is distinguished by a yellow or orange-brown weathering colour to the resistant sandstone units.

Based on cross-sections, the thickness of the Elk is approximately 350 to 400 metres throughout the study area (Figure 4-1-4).

A partial section containing 177.9 metres of the lower Elk Formation was measured on the north end of Mount Tuxford, and is included in Figure 4-1-3 (Section c). The base of the section is the Mist Mountain – Elk contact and the top is at an arbitrary point. The relatively coarse-grained nature of the Elk, in comparison with the Mist Mountain Formation at this point, is noticeable in Figure 4-1-3. The lower two-thirds of the section consists of several stacked channel-sandstone units separated by thin, recessive, finer grained intervals, including a 1.0-metre coal seam. The upper third is a recessive interval including coal seams 1.0 and 1.6 metres thick. The section is overlain by a prominent cliff-forming sandstone which marks the base of another sequence of stacked sandstone units.

At Elkan Creek, at the extreme north end of the study area, a series of several thick, cliff-forming conglomerates and conglomeratic sandstones occurs within the Elk Formation. The coarseness of this occurrence is unusual for the Elk Formation in the Elk Valley coalfield, but we see no reason to place these strata in the Blairmore Group as was done by Graham *et al.* (1977). We feel this occurrence is analagous to the Elk Formation occurrences on the west side of the Crowsnest coalfield, including the type area near Fernie. The type area is believed to represent an alluvial fan facies of Elk Formation (Gibson, 1985; Grieve and Ollerenshaw, in preparation) and perhaps the north end of the Elk Valley coalfield is on the fringes of another fan system.

Precise identification of the Elk – Mist Mountain contact in southeastern British Columbia is generally difficult (Grieve and Ollerenshaw, in preparation). The study area is no exception. In the case of the good exposures near the summit of Mount Tuxford, it was possible to detect a significant colour change in the sandstone units at a stratigraphic horizon which also seemed to mark the base of a more resistant, coarser grained facies devoid of thick coal seams. The so-called needle coals were only observed near the top of the Kootenay at this location. This horizon was mappable for a short distance to the north and south, although confidence in its position decreases with distance. Using airphoto interpretation it was possible to extend it from Mount Tuxford to Weary Ridge, where the contact was mapped previously (Grieve, 1987). Definition of the contact lacks precision on the west side of the Elk River and throughout the area north of Weary Creek.

STRUCTURE

The study area lies in the Front Ranges of the Rocky Mountains and is part of the Lewis thrust sheet. The dominant structures are therefore thrust faulting and folding.

The area can be divided at Aldridge Creek into two distinct zones with contrasting structural elements. The zone south of Aldridge Creek contains north-plunging folds, northward extensions of those affecting the adjoining part of the coalfield. The major folds are, from east to west, the Alexander Creek syncline, the Greenhills syncline and the Fording Mountain anticline (Figure 4-1-2); minor folds are also observed. These folds are open and roughly symmetrical (Figure 4-1-4, Section D-D').

Until now it was believed that the Alexander Creek syncline was continuous throughout the Elk Valley coalfield (for example, Pearson and Grieve, 1980; Grieve, 1987). It is evident now, however, that north of Aldridge Creek the coalfield is underlain by another newly defined major fold, the Elk River syncline (proposed name). The Elk River syncline is east and north of the Alexander Creek syncline, although its east limb becomes the east limb of the Alexander Creek syncline and is possibly related to it in an *en echelon* fashion (Figure 4-1-2).

The Elk River syncline is asymmetrical, with a steep to overturned west limb and a shallow to moderately west-dipping east limb (Figure 4-1-4). It is doubly plunging with a depression in the vicinity of Cadorna Creek (Cadorna Creek depression of Pearson and Grieve, 1980). It is cylindrical throughout except for the area of its origin where it is conical. In many areas its east limb is modified by zones of shallow dip which have been interpreted as minor step folds. Thrusting in the east limb is also common.

Concomitant with the change in structural style which takes place at Aldridge Creek is a pronounced change in the width of the coalfield (Figure 4-1-2). This is primarily due to the behaviour of the Bourgeau thrust fault. The Bourgeau fault is a regional feature which marks the western boundary of the surface exposures of the Lewis thrust sheet and, from Bingay Creek northward, the western boundary of the Elk Valley coalfield. Starting at a point roughly corresponding with the southern boundary of the study area, the trace of the Bourgeau fault begins to step to the northeast, possibly reflecting lateral ramping. In the process the fault cuts upsection relative to its footwall and cuts off the traces of all fold axes in the footwall, including the Greenhills and Alexander Creek synclines. At the point where the Elk River syncline begins to develop, the trace of the Bourgeau fault returns to a more normal northerly orientation.

From Aldridge Creek northwards, the Bourgeau thrust remains parallel to, and in contact with, the west limb of the Elk River syncline. The stratigraphic position of its footwall varies along its trace from the uppermost Fernie Formation to uppermost Kootenay (Figure 4-1-2). At the north end of the study area the Bourgeau fault is offset 2 kilometres to the northeast by a transverse fault (Leech, 1979).

Minor structures associated with the Bourgeau thrust are not generally observable because of poor exposure. At Coal Creek, the location of measured section A in Figure 4-1-3, a highly disturbed zone of Mist Mountain Formation occurs in the footwall of the thrust. This zone contains structures similar in style and orientation to the Bourgeau fault itself, as well as a transverse fault, parallel to the creek (roughly east-west). The former structures have caused local thickening of the strata, including one coal seam, while the latter has resulted in a dramatic contrast in the degree of structural deformation of the strata on opposite sides of the creek. In particular, the thickened coal seam referred to above, which outcrops on the south side of the creek, is undisturbed on the north side of the creek, where exposed at the base of our measured section. For this reason, the probability that the economic potential of this seam may be enhanced by structural thickening is believed to be low.

Late-stage, crosscutting normal faults occur in the Mount Tuxford and Mount Veits area parallel to prominent joint orientations. They have resulted in mass wasting of the Morrissey Formation, forming both topographic steps and landslide blocks. A large slide-block of Morrissey Formation on the north end of Weary Ridge is probably a related feature.

RANK DISTRIBUTION

Preliminary data on the coal rank distribution in the Weary Ridge – Bleasdell Creek area were given by Grieve (1987). They indicated an extreme rank contrast between opposite limbs of the syncline in this area. Coals from Weary Ridge, on the east limb, have reflectance values anomalously high for southeastern British Columbia, while reflectance values in the Bleasdell Creek area are anomalously low. For example, the Mist Mountain Formation on Weary Ridge contains coals which range in reflectance from 1.59 per cent down to 0.99 per cent, with a general decrease up-section. In contrast, Mist Mountain Formation coals from the Bleasdell Creek area range in rank from 1.00 per cent down to 0.65 per cent, with a less well-defined stratigraphic variation. Values plotted alongside the Coal Creek Section A in Figure 4-1-3 range from 1.00 per cent to 0.85 per cent, providing a further example of the low relative ranks in this area. A possible explanation for this contrast was briefly reviewed by Grieve (1987) based on work by Hughes and Cameron (1986).

To date only 25 of the 1987 samples have been analysed. These are from three general areas, which are discussed separately below.

LITTLE WEARY RIDGE TO MOUNT TUXFORD (EAST LIMB)

Samples from Little Weary Ridge, Mount Veits and Mount Tuxford have been analysed. One value from Mount Veits and six values from Mount Tuxford are plotted in Figure 4-1-3 by their appropriate stratigraphic positions.

The four samples from Little Weary Ridge have reflectances of 1.51, 1.48, 1.40 and 1.31 per cent. The two highest values represent seams very near the base of the Mist Mountain Formation, while the other two are both within the lower one-third of the formation.

Three samples from the lower half of the Mist Mountain Formation on Mount Veits have also been analysed. One corresponds with the Mount Veits measured section, and is plotted in Figure 4-1-3. The other two are from positions higher than the top of the measured section. The plotted value of 1.38 per cent represents a coal seam within 20 metres of the base of the formation. The other two values, in ascending stratigraphic order, are 1.36 and 1.31 per cent.

Six samples from Mount Tuxford have been analysed, representing stratigraphic positions ranging from 56 metres above the base of the Mist Mountain Formation to immediately beneath the Elk contact. All correspond with the measured section of Mount Tuxford north, and are plotted alongside it in Figure 4-1-3. The reflectance values range from 1.45 to 1.02 per cent, decreasing with ascending stratigraphic position.

The number of analyses is not sufficient to define rank trends. However, it appears that ranks along the east limb of the Elk River syncline are at a maximum in the vicinity of Weary Ridge and Little Weary Ridge, and decrease to the south.

BLEASDELL CREEK TO CADORNA CREEK (WEST LIMB)

Reflectances of six samples of Mist Mountain Formation from north of Bleasdell Creek, on the west limb, range from 0.63 to 0.84 per cent. Although stratigraphic control is poor in this area, this range appears to represent the entire Mist Mountain Formation. These results are compatible with those obtained last year from the Bleasdell Creek area.

ELK LAKES AREA

Five samples from the Mist Mountain Formation and one from the Elk Formation collected at the north end of the study area have been analysed. Reflectances of the Mist Mountain samples decrease from 1.06 to 0.70 per cent with ascendng stratigraphic position. The highest value corresponds with a seam in the lower part of the formation, but its exact stratigraphic position is unknown. The sample from the Elk Formation has a reflectance of 0.57 per cent.

These values are anomalously low, and are in general agreement with results of Pearson and Grieve (1980) who found the entire section in this area to be high volatile ($\bar{R}_o$max <1.12 per cent), and Graham *et al.* (1977) who determined that the highest reflectance value reached in subsurface (core) samples from this area is 1.16 per cent. Pearson and Grieve invoked the presence of a normal fault separating the north part of the study area from the area to the south, to account for the anomalously low ranks. However, we see no geological evidence for the existence of the fault, and, moreover, a major fault is not a necessary factor in producing large rank variations, given the extreme rank variation across the Elk River syncline within the south part of the study area.

Further analyses of samples collected in 1987 should allow refinement of rank trend definition. However, the lack of good exposure in key areas may limit our ability to interpret rank variations.

ACKNOWLEDGMENTS

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INORGANIC MATTER CONTENT AND SPECIALIZED ELEMENT POTENTIAL OF THE NANAIMO AND COMOX COALFIELDS, VANCOUVER ISLAND* (92G, F, K)

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KEYWORDS: Coal geology, Vancouver Island, geochemistry, mineralogy, specialized element potential.

INTRODUCTION

The Nanaimo and Comox basins are the two major coal-bearing regions on Vancouver Island. Mining was begun in 1849 and 59 million tonnes were recovered from the Nanaimo, Comox and Suquash coalfields between then and 1914. While the Nanaimo basin is mostly mined out (Muller and Atchison, 1971), considerable resources remain in the Comox basin (154 million tonnes, inferred and indicated). Renewed interest in coal in the 1980s, and the subsequent opening of the Wolf Mountain mine in Nanaimo and the Quinsam mining operation in Comox, have led to a revival in geological investigation of these resources. The purpose of the present study is to examine the inorganic geochemistry of the Nanaimo and Comox coalfields and to assess the potential of these coal deposits for secondary uses such as the extraction of specialized elements. Preliminary results are given below.

GEOLOGY

The Nanaimo and Comox coalfields are located on the east coast of Vancouver Island in the Insular Belt of the Canadian Cordillera. The coal-bearing units are the Comox Formation (Comox) and the Extension and Protection formations (Nanaimo) of the Upper Cretaceous Nanaimo Group (Muller and Jeletzky, 1970; Muller and Atchison, 1971). The coal is high-volatile bituminous A and B in the Comox and Nanaimo basins respectively and is generally considered a thermal coal. Seams are overlain and underlain by shales and carbonaceous shales, and to a lesser extent sandstones. Varying numbers of shaly partings and lenses and light-weathering volcanic horizons are intercalated with the coal. Thicknesses of these units range from several millimetres to tens of centimetres. The Nanaimo Group unconformably overlies the Vancouver Group and Island Intrusions in the Comox basin and the Sicker Group, Karmutsen Formation and Island Intrusions in the Nanaimo basin. These units are exposed at the basin margins to the north, south and west (Figure 4-2-1), and represent probable sources for the conglomerate, sandstone and shale cycles, deposited in both marine and non-marine environments in the successor basin adjacent to the Coast plutonic complex (Yorath *et al.*, 1985). The Nanaimo basin and the several subfields and outliers which make up the Comox basin may represent erosional remnants of a once more extensive basin fill.

The structure in the coal-bearing basins is quite complex. The sedimentary section is shallow dipping and appears to be cut by numerous high and low-angle faults. A basin model and subsidence history are currently being constructed by T. England (personal communication, 1987).

METHODS

A field program carried out in July 1987 was designed to sample the major coal seams in a number of localities in the Nanaimo and Comox basins (Figure 4-2-1). Seventy-one samples were taken, 60 from the Comox basin and 11 from the Nanaimo basin. Recent excavations in the Comox area facilitated more extensive sampling, while the generally poor exposures in the Nanaimo region made sampling difficult. Channel samples across entire seams were taken at Quinsam, Hamilton Lake and Chute Creek, while grab samples were collected at Woodus Creek, Anderson Lake and all locations in the Nanaimo basin. Where possible samples were taken from fresh coal exposures, for example, recent open-pit faces at Quinsam and Chute Creek; however the majority of the seams sampled were weathered. All coal exposures were cleaned to a depth of at least 5 centimetres prior to sampling.

The samples were analysed as shown in Figure 4-2-2. X-ray defraction was carried out on unwashed samples at the British Columbia Ministry of Energy, Mines and Petroleum Resources by Y.T.J. Kwong and M. Chaudry. The abundance of amorphous material in the samples and the presence of poorly crystalline mineral phases make determination of relative proportions of minerals present difficult, however on the basis of peak intensity, a relative measure of mineral content was obtained. Samples for chemical analysis were crushed to −200 mesh and analysed by a variety of techniques including X-ray fluorescence (XRF), direct current plasma emission spectroscopy (DCP) and instrumental nuclear activation analysis (INAA). Portions of each sample were set aside for scanning electron microscope (SEM) and petrographic work to be carried out at a later date.

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

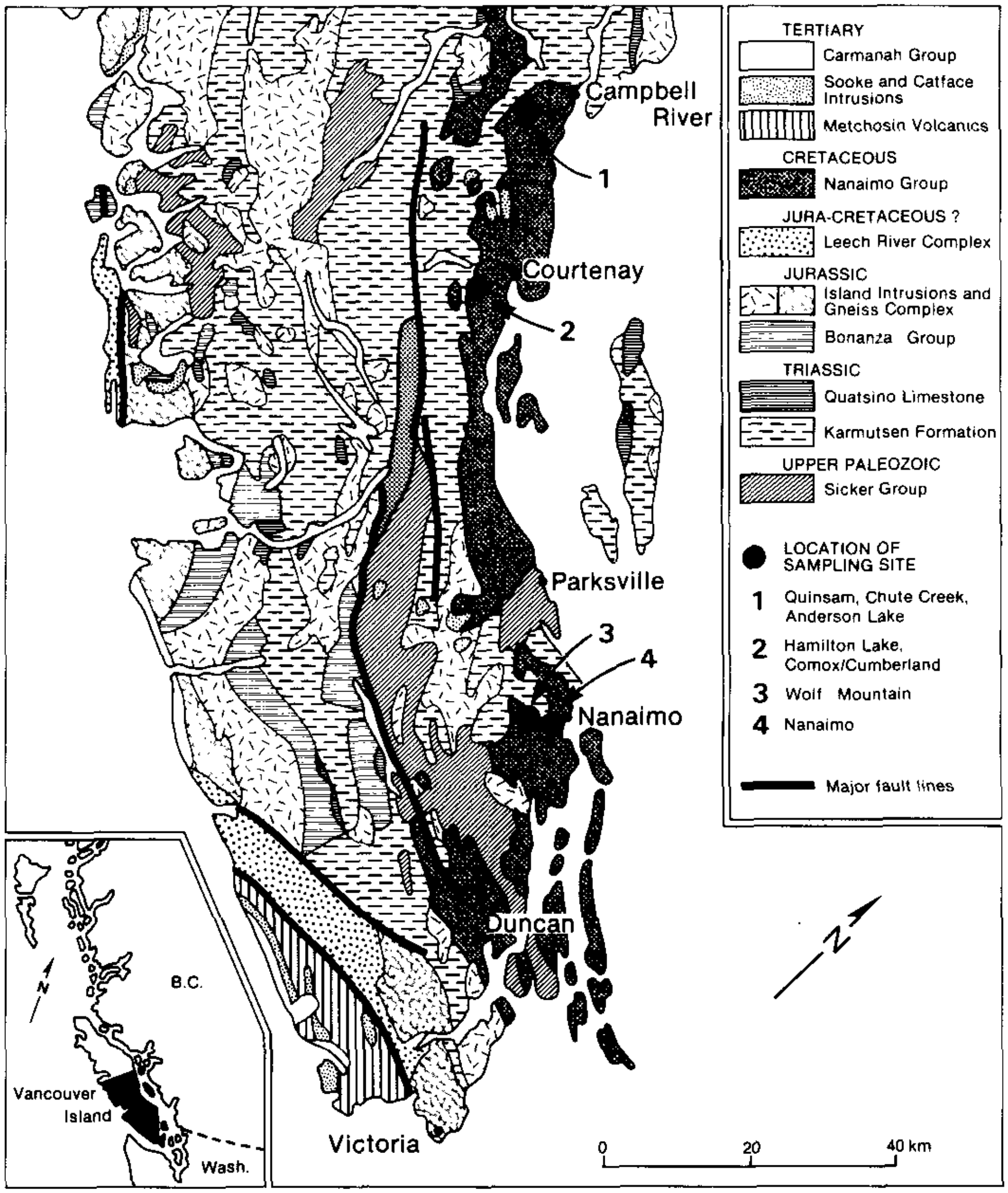

Figure 4-2-1. Geology and location of sampling sites in the Comox and Nanaimo coalfields.

RESULTS

MINERALOGY

Coals and sedimentary rocks in the Nanaimo and Comox basins contain a varied suite of minerals. Major mineral phases in the coal include calcite, kaolinite and quartz. Pyrite is commonly present and lesser amounts of dolomite, siderite, chlorite, ankerite, potassium feldspar, plagioclase, illite and montmorillonite were also noted in a few samples. Minerals in shales associated with the coals typically include pyrite, quartz, kaolinite and subsidiary marcasite, illite, plagioclase, potassium feldspar and chlorite.

The mineral content of unweathered coals from the Comox and Nanaimo basins is summarized in Table 4-2-1. While the basic mineralogy is the same in all areas, a number of variations are observed. The Quinsam coals contain the most restricted mineral assemblage – calcite, kaolinite, trace quartz and pyrite. Of these, pyrite is only present in the upper part of the seam. Associated with the pyrite nodules which occur in the upper seam are marcasite, rozenite, gypsum and

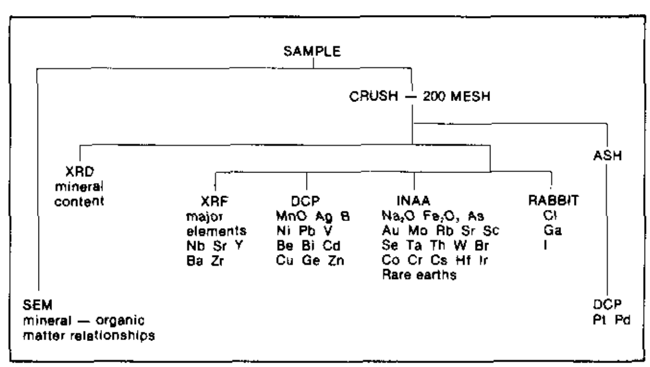

Figure 4-2-2. Flow diagram showing sample preparation and analytical methods.

TABLE 4-2-1
MINERAL MATTER IN UNWEATHERED COALS FROM THE NANAIMO AND COMOX COAL BASINS

		Calcite	Kaolinite	Quartz	Pyrite	Dolomite	Siderite	Ankerite	Montmorillonite	Other
Quinsam........ No. 1 Seam.	Upper	xxx	xx	tr	xx					
	Lower	xxx	xx	tr						
Chute Creek No. 1 Seam.. Quinsam? ..	Upper		xxx	tr	x	xx				
	Lower	xxx	x	xx	x	xx		x	x	
Nanaimo....... Wellington.. Seam..........		xxx	xx	xxx	tr	x		x	x	Plagioclase K-feldspar

TABLE 4-2-2
SUMMARY OF COAL GEOCHEMISTRY BY BASIN
(ppm except as indicated)

	Comox Basin (22 samples)			Nanaimo Basin (10 samples)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Si (%)	5.93	1.030	19.78	8.422	0.670	19.70
Al (%)..	3.50	0.740	10.80	2.847	0.760	9.04
Ca (%).	1.65	0.100	6.07	1.734	0.640	3.38
Mg (%)	0.12	0.010	0.65	0.363	0.140	0.61
Na (%).	0.02	0.010	0.07	0.118	0.010	0.40
K (%)..	0.06	0.010	0.34	0.174	0.010	0.70
Fe (%)	1.51	0.050	8.55	0.676	0.400	1.53
Mn	45.38	4.800	166.00	61.950	4.200	129.00
Ti	0.25	0.030	0.80	0.152	0.030	0.43
P	0.16	0.010	0.74	0.062	0.010	0.23
As	55.88*	0.400	580.00	3.810	2.000	6.90
Au (ppb)	10.14	1.000	88.00	4.700	1.000	14.00
B	70.00	10.000	130.00	106.000	10.000	270.00
Ba ..	108.64	10.000	480.00	499.000	120.000	820.00
Be	1.18	1.000	3.00	1.400	1.000	3.00
Br.......	2.00	0.800	4.30	1.910	0.500	6.10
Cl.	261.82	50.000	600.00	128.000	30.000	300.00
Co	4.17	1.100	15.00	4.050	1.800	10.00
Cr	19.09	10.000	59.00	28.900	10.000	64.00
Cs	0.44	0.100	2.20	0.690	0.100	3.50
Cu	18.23	3.000	49.00	12.200	2.000	33.00
Ga	6.50	5.000	14.00	5.900	5.000	13.00
Hf	0.95	0.200	3.20	0.900	0.200	1.80
I	7.64	0.500	14.00	3.520	0.600	13.00
Mo	2.28	0.400	11.00	2.220	1.100	3.90
Nb ..	10.00	10.000	10.00	10.000	10.000	10.00
Ni.....	9.64	2.000	27.00	13.300	5.000	24.00
Rb	10.45	10.000	20.00	12.800	10.000	32.00
S	20 713.64	3 300.000	64 600.00	6 970.000	3 000.000	15 000.00
Sb	0.59*	0.100	3.73	0.600	0.100	1.90
Sc ..	6.08	1.400	14.80	3.936	1.130	11.30
Se ..	0.91	0.500	2.80	0.600	0.500	0.90
Sr.....	336.82	10.000	1 900.00	368.000	130.000	760.00
Ta	0.27	0.100	0.70	0.360	0.100	0.60
Th ...	1.02	0.300	4.20	0.990	0.300	2.00
U ...	0.60	0.090	2.17	0.737	0.230	1.37
V........ ..	43.18	4.000	130.00	31.800	6.000	100.00
W. ...	1.00	1.000	1.00	1.700	1.000	7.00
Y...	16.36	10.000	90.00	11.000	10.000	20.00
Zn . ..	11.27	2.000	40.00	9.600	1.000	38.00
Zr........	27.27	10.000	110.00	21.000	10.000	50.00
La	5.23	1.400	12.10	4.250	1.400	7.40
Ce ..	10.34	2.900	24.50	8.650	2.800	18.00
Nd......	4.29	1.400	12.50	4.410	1.300	10.50
Sm .	1.10	0.370	3.17	0.910	0.320	2.32
Eu ...	0.35	0.100	1.15	0.244	0.070	0.65
Tb	0.18	0.050	0.52	0.137	0.050	0.44
Yb........	0.82	0.160	2.77	0.628	0.160	1.65
Lu	0.14	0.030	0.43	0.117	0.030	0.32
LOI (%)	86.14	64.900	94.20	84.410	66.900	96.00

* Abnormally high values As and Sb have not been included.

szomolnokite. The Chute Creek and Nanaimo coals have a more diverse mineral assemblage including dolomite, ankerite, plagioclase, potassium feldspar and montmorillonite in addition to calcite, kaolinite, quartz and pyrite. Considerable variations in the proportions of minerals present have been noted within these seams. For example, in the upper part of the main seam at Chute Creek, kaolinite is the most common mineral, with lesser dolomite, pyrite and trace quartz. In the remainder of the seam, calcite, quartz and dolomite are the major minerals and kaolinite, pyrite and ankerite occur to a lesser extent.

The most common mode of occurrence of the calcite is in the form of cleat and fracture fills. Pyrite occurs in nodules and also coating bedding-plane surfaces. Clay minerals and quartz occur disseminated throughout the coal, as a result of incorporation during deposition and in the early stages of coalification.

GEOCHEMISTRY

Thirty-two coal and 12 shale samples were analysed for 58 major and trace elements. Ag, Cd, Ge and Ir are below detection limits in all the samples analysed. For a number of other elements, notably Be, Ga, Nb, Se, W and Zr, "less than" values are frequently quoted. Where these occur the actual value is taken to be equivalent to the "less than" value. Pb, Pt and Pd values are not quoted as the samples are being rerun with lower detection limits. Results of the analyses are summarized, by basin, in Table 4-2-2. Compared with average values in the earth's crust (Krauskopf, 1967; Fairbridge, 1972) only As, Cl, Au, Mo, Se and I are enriched in the coals.

One of the more noticeable trends in the results is that element concentrations are variable. Geochemistry varies between basins, for example, the mean values for Fe_2O_3, Al_2O_3, P_2O_5, TiO_2, S, As, Au, Cl, I, V, Y, Cu, Sc and rare earth elements (REE) are significantly higher in Comox coals than in Nanaimo coals, and the Nanaimo samples on average exhibit higher concentrations of SiO_2, MgO, Na_2O, K_2O, MnO, B, Ba, Cr, Ni, W and Cs.

In addition considerable variations are observed between seams within a basin. For example, six different seams were sampled in the Nanaimo basin. Variations in major and trace element contents in these samples are shown in Table 4-2-3. Some seams are considerably more enriched in certain elements than others, for example, Zn, V, Cs, Cu, Ga, Cr, Al, Fe, Cl, Rb, Mn, Th, Sb and Zr contents are highest in sample N87-9, the No. 3 seam of the Northfield Coal Measures (C.

TABLE 4-2-3
GEOCHEMISTRY OF NANAIMO COALS
(ppm except as indicated)

Samples	Si %	Al %	Ca %	Mg %	Na %	K %	Fe %	Mn	Ti	P	As	Au ppb	B	Ba	Be	Br	Cl
N87-1	2.17	1.72	0.98	0.14	0.02	0.02	0.51	47.6	0.05	0.05	2.9	1	10	320	3	1.6	30
N87-2	0.67	1.17	1.70	0.18	0.01	0.02	0.61	4.2	0.03	0.01	5.2	1	10	120	2	6.1	40
N87-3	2.91	1.58	1.29	0.59	0.14	0.03	0.47	63.8	0.07	0.02	2.0	2	270	330	1	1.5	220
N87-4	0.93	0.76	0.77	0.25	0.01	0.01	0.40	45.6	0.03	0.02	2.6	1	50	280	1	2.2	270
N87-5	6.83	2.39	2.69	0.36	0.07	0.14	0.72	69.7	0.13	0.03	3.9	7	130	460	1	1.1	90
N87-6	18.40	3.07	3.38	0.40	0.23	0.30	0.57	106.0	0.25	0.08	3.9	14	90	820	1	0.9	60
N87-7	5.47	1.96	3.11	0.34	0.05	0.09	0.52	49.1	0.09	0.15	2.8	6	140	540	1	1.5	60
N87-8	18.50	2.75	2.14	0.39	0.19	0.23	0.57	69.4	0.24	0.01	6.9	2	100	810	1	0.5	60
N87-9	19.70	9.04	0.64	0.61	0.06	0.70	1.53	129.00	0.43	0.02	3.3	6	60	700	2	0.8	150
NI MIX	8.64	4.03	0.64	0.37	0.40	0.20	0.86	35.1	0.20	0.23	4.6	7	200	610	1	2.9	300

Samples	Co	Cr	Cs	Cu	Ga	Hf	LOI %	I	Mo	Nb	Ni	Rb	S	Sb	Sc	Se	Sr
N87-1	4.4	10	0.2	6	5	0.6	93.2	0.6	3.0	10	6	10	3,600	0.9	4.41	0.5	570
N87-2	10.0	10	0.3	10	5	0.3	94.0	2.4	2.3	10	23	10	3,000	0.5	3.27	0.6	130
N87-3	2.4	10	0.3	8	5	0.5	91.6	1.1	1.1	10	10	10	5,400	0.2	1.98	0.6	240
N87-4	2.4	10	0.1	2	5	0.2	96.0	2.2	1.5	10	5	10	12,000	0.1	1.13	0.5	170
N87-5	5.6	20	0.5	10	5	0.9	85.7	12.0	2.4	10	13	10	15,000	0.9	3.27	0.8	320
N87-6	2.8	56	0.7	8	5	1.2	71.8	0.8	1.8	10	10	13	3,700	0.4	3.30	0.5	380
N87-7	1.8	10	0.2	7	5	0.9	87.0	13.0	1.6	10	8	10	11,000	0.3	2.12	0.6	620
N87-8	3.0	64	0.3	11	5	1.6	73.5	0.9	2.2	10	13	13	4,200	0.4	2.97	0.9	260
N87-9	4.8	56	3.5	33	13	1.8	66.9	1.4	3.9	10	21	32	4,300	1.9	11.30	0.5	230
NI MIX	3.3	43	0.8	27	6	1.0	84.4	0.8	2.4	10	24	10	6,700	0.4	5.61	0.5	760

Samples	Ta	Th	U	V	W	Y	Zn	Zr	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
N87-1	0.5	0.8	1.37	12	7	10	4	10	7.3	11.5	5.0	1.13	0.31	0.23	1.07	0.19
N87-2	0.3	0.8	0.68	12	2	10	4	10	3.1	7.9	5.8	1.32	0.41	0.11	0.92	0.16
N87-3	0.4	0.8	0.29	14	1	10	2	10	2.9	5.3	3.0	0.47	0.09	0.05	0.26	0.04
N87-4	0.4	0.3	0.79	6	1	10	1	10	1.4	2.8	1.3	0.32	0.07	0.05	0.16	0.03
N87-5	0.1	0.9	0.61	30	1	10	9	20	4.3	8.9	4.4	0.74	0.28	0.11	0.41	0.10
N87-6	0.6	1.1	0.63	34	1	10	12	30	3.4	6.5	2.0	0.51	0.16	0.05	0.44	0.07
N87-7	0.1	0.6	0.23	20	1	10	11	10	3.7	6.5	3.7	0.59	0.11	0.05	0.33	0.07
N87-8	0.5	1.1	0.71	30	1	10	8	40	1.9	5.4	1.9	0.46	0.17	0.05	0.42	0.08
N87-9	0.3	2.0	1.37	100	1	20	38	50	7.4	18.0	10.5	2.32	0.65	0.44	1.65	0.32
NI MIX	0.4	1.5	0.69	60	1	10	7	20	7.1	13.7	6.5	1.24	0.19	0.23	0.62	0.11

Key to Samples:
N87-1 Reserve seam—Cedar Bridge.
N87-2 Reserve seam.
N87-3 Douglas seam.
N87-4 Newcastle seam—Fiddick's mine.
N87-5 Wellington seam—Wolf Mountain.
N87-6 Wellington seam.
N87-7 Wellington seam.
N87-8 Wellington seam.
N87-9 No. 3 seam—Northfield coal measures.
NI MIX Newcastle seam.

Bickford, personal communication, 1987). High values also occur in the Wellington seam, samples N87-6 and N87-8. These samples contain tonstein bands and elevated element contents may be due to the presence of inorganics introduced from a volcanic source. The tonstein bands are generally obvious and may be readily removed during cleaning. Clean samples from the same seam have low values of the elements listed above but show elevated iodine concentrations. The Douglas seam is enriched in boron and chlorine. Variations between seams are also present in the Quinsam area. For example, the main seam, No. 1, has the highest CaO, I, S and Sr values. Seam No. 2 is most enriched in gold, and seam No. 3 contains maximum values of SiO_2, As, B, Ba, Cr, Cu, Hf, Mo, Sc, Zn, Zr, Ta and V.

In addition to variations in chemistry between basins and between seams within basins, considerable variations are observed within a single seam both laterally and vertically. This is illustrated by examining the changes in chemistry through a channel section of the Quinsam No. 1 seam. The majority of trace elements including As, Zn, Mo, Cu, Ni, V, Au, Rb, Sc and major element oxides such as SiO_2, Al_2O_3, TiO_2, MgO, K_2O, Na_2O and Fe_2O_3 show an overall trend of decreasing concentration from top to bottom of the seam. Values are highest in the roof and floor and in the carbonaceous shale partings within the seam. Bromine and chlorine values remain constant with depth and iodine values increase.

DISCUSSION AND CONCLUSIONS

Although the results presented here are preliminary, a number of conclusions concerning the inorganic matter content and specialized element potential can be made. The coals are generally comparable to other western Canadian coals in terms of inorganic matter contents, however variations in major and trace element contents between and within basins are considerable. Within the Nanaimo and Comox coals, two groups of elements can be identified: (1) those which are enriched in shales, carbonaceous shales and coals with high ash contents, for example, arsenic, vanadium and molybdenum and (2) elements such as iodine, bromine and chlorine with distributions that bear no obvious relationship to the ash content of the coal.

On the basis of Pearson correlation coefficients, the associations or modes of occurrence of elements can be examined (Van der Flier-Keller and Fyfe, 1985, 1987). Statistical analysis of the results shows that for coals from the Nanaimo and Comox basins SiO_2, Al_2O_3, TiO_2, K_2O, Cr, Cs, Cu, Ga, Hf, Mo, Ni, Rb, Sc, Ta, Th, U, V, Zn, Zr and the rare earth elements are strongly correlated, indicating that these elements are associated with coal ash and particularly with silicate mineral phases. Molybdenum, sulphur and zinc are associated with iron. Iodine shows a weak correlation with calcium, and a large number of elements are negatively correlated with loss on ignition (LOI). LOI can be used as an approximate measure of organic content. Although many elements are associated with a single phase in the coal, others may occur in a variety of ways, for example, associated with the organic matter and the clay minerals. This will result in lower correlation coefficients than when elements are associated with a single phase.

COAL QUALITY

The samples analysed in this study have not been cleaned or upgraded in any way prior to analysis. In terms of coal quality, two points are important: the concentrations of elements and minerals in the coal (discussed above) and the ease with which these phases may be extracted. This depends largely on the mode of occurrence of the inorganic phase, for example, associated with the organic matter or with the sulphides in the coal. A large number of elements present in the Nanaimo and Comox coals appear to be associated with the silicate mineral phases. Ease of extraction of these elements cannot be evaluated until further research is carried out to determine grain size and degree of dissemination of these minerals and their relationship to the organic portion of the coal.

SPECIALIZED ELEMENT POTENTIAL

Of the elements analysed (results for several elements are not yet available), none are significantly enriched throughout the entire area examined. Elevated values for certain elements are, however, found in isolated samples. For example, arsenic values are extremely high (up to 1400 ppm) in Anderson Lake coal. Gold is enriched in the Quinsam No. 2 seam (88 ppb), and antimony concentrations of 110 ppm were determined in a sample from Chute Creek. More detailed sampling and analysis will be required to establish whether these anomalies are widespread or restricted to isolated samples.

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COALFIELD GEOLOGY OF EASTERN VANCOUVER ISLAND (92F)

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KEYWORDS: Coal geology, Vancouver Island, Nanaimo coal basin, Comox coal basin, stratigraphy, coal quality, thermal coal.

INTRODUCTION

Revived interest in the coal deposits of Vancouver Island has stimulated a project to compile and analyze existing data and to provide a field update to determine critical geological relationships. The aim of the study is to provide sufficient data and analysis to assist government and industry in assessing the potential of the deposits with respect to new uses such as coal seam gas and coal water fuel, as well as traditional thermal applications.

Coals of Late Cretaceous age along the southeastern coast of Vancouver Island have been intensively prospected and mined from 1849 to the present day. Initial discoveries were made by Indians, who reported coal showings at Nanaimo to the Hudson's Bay Company. Development was rapid and coal mining in the Cumberland and Nanaimo areas was a mainstay of the Vancouver Island economy until the early 1950s, when production began to decline rapidly. Small mines have recently opened at Wolf Mountain and Extension (Nanaimo coalfield) and Quinsam (Quinsam coalfield). Much air-rotary drilling has been done since 1974, to locate and prove mineable coal deposits.

This report summarizes the findings of 13 years' mapping (surface and underground) and office study of the coalfields of eastern Vancouver Island together with reconnaissance mapping and sampling of the major coal deposits during the 1987 field season.

LOCATION

The study area occupies part of the eastern coastal plain of Vancouver Island, from Campbell River in the north to Mount Maxwell in the south (Figure 4-3-1). The Comox sub-basin is approximately 1230 square kilometres in area and the Nanaimo sub-basin encompasses about 780 square kilometres. The basins are accessible by coastal waterways, paved highways and secondary roads. The distribution of secondary access roads is dependent on logging development in the area and local population density.

Topography is fairly gentle though elevations range from sea level to 457 metres. Many rivers and creeks drain into the Strait of Georgia. Abundant thick underbrush covers most of the area and generally limits coal exposures to creeks and roadcuts. The climate is mild and humid, and snow is usually found only at higher elevations.

Campbell River, Courtenay, Port Alberni and Nanaimo are the major population centres. Small towns and resort areas are scattered along the coast. The logging and fishing industries form the economic base of the area.

PREVIOUS WORK

The earliest report to specifically address coalfield geology is that of Hector (1861), who described the early workings of the Hudson's Bay Company at Nanaimo. Mapping of the coal measures at Nanaimo and Comox was subsequently done by Richardson (1872, 1873, 1878) and Clapp (1912a, 1912b, 1914). Published reports by McKenzie (1922) and Buckham (1947a, 1947b) present only a small fraction of their findings; maps, notebooks and working papers are in the Provincial Archives of British Columbia (as Additional Manuscript 436). Muller and Atchison (1971) produced the most recent summary report on the Vancouver Island coals and there are many unpublished reports by company geologists. Reports by Morrison and Forster Brown (1910), Curcio (1975), Bickford and Lee (1980) and Perry (1981) are regional in scope. Many other reports dealing with individual properties are on file with the ministry.

CATALOGUING OF OLD BOREHOLE RECORDS

Log information for 600 coal exploration boreholes (1889 to 1975) was collected and entered in the following Coal Assessment Report files in Victoria:

(1) Report No. 720 — Nanaimo sub-basin (303 boreholes).
(2) Report No. 694 — Comox sub-basin (297 boreholes, 118 maps).

Information contained in the above reports originated from the Provincial Archives, the Nanaimo and Cumberland civic museums, the Engineering and Inspection Branch and the Geological Survey Branch of the Ministry of Energy, Mines and Petroleum Resources. Source data included old survey notebooks, mine plans, geological maps, borehole log notes and site surveys at recognizable borehole locations.

Efforts were made to ensure the collection of the most reliable of several versions of a given log, by checking

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

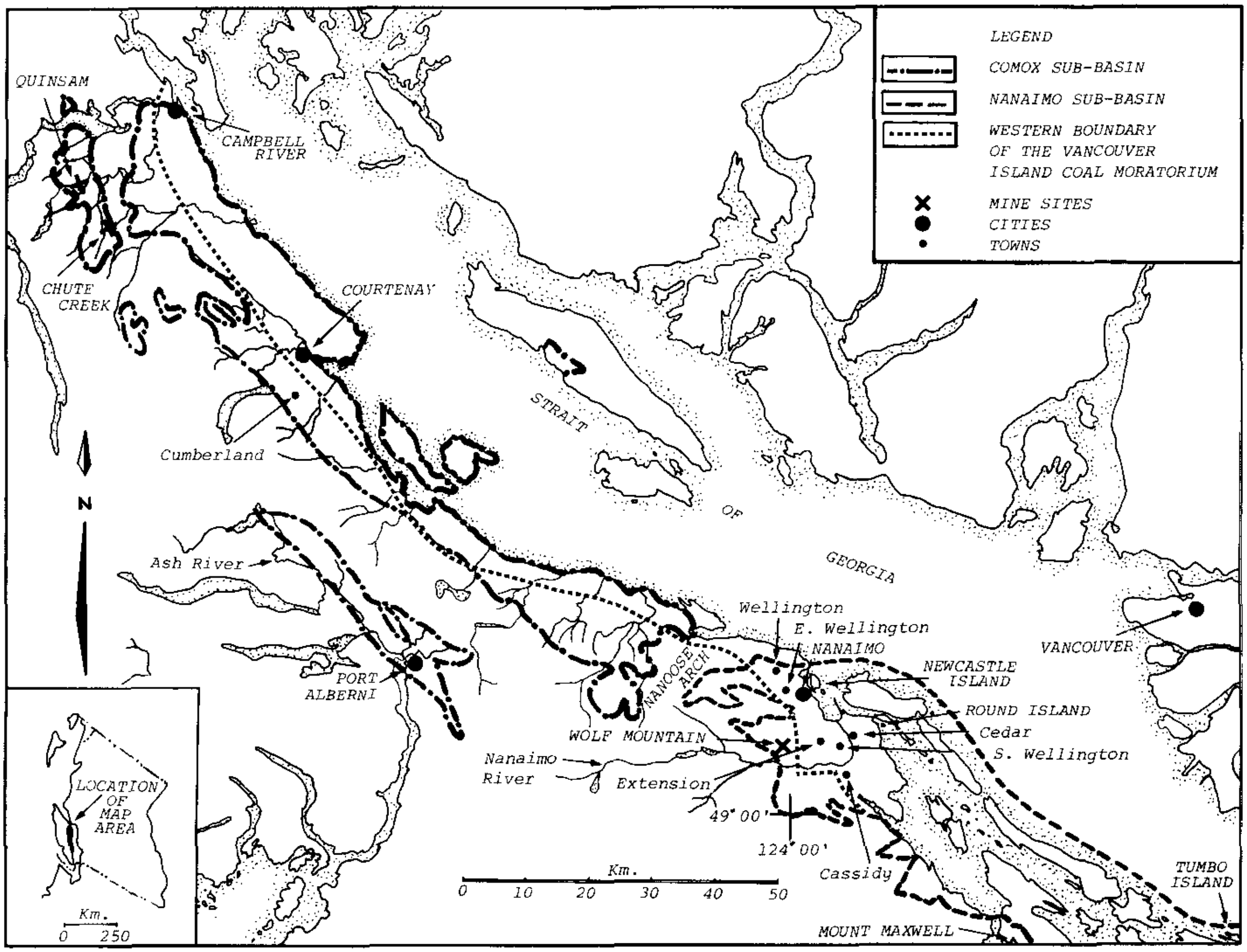

Figure 4-3-1. Location map, Vancouver Island coal basin.

against drillers' time sheets, site geologists' notes and mine managers' records. Most of the borehole locations are accurate within 50 metres and are available in computerized format.

COAL-MEASURE STRATIGRAPHY

The coal measures of eastern Vancouver Island are part of the Nanaimo Group of Santonian to Maastrichtian age (Jeletzky, in Muller and Jeletzky, 1970). These rocks occupy the western erosional margin of the Late Cretaceous Georgia basin, which is largely concealed beneath the waters of Georgia Strait. Two sub-basins (Comox to the north, Nanaimo to the south) are separated by a northeast-trending basement uplift, the Nanoose arch. Table 4-3-1 and Figure 4-3-2 show the component stratigraphic units of the Nanaimo Group, and Figure 4-3-3 depicts their changes along strike.

The two sub-basins will be discussed as separate entities. The Nanaimo sub-basin contains the Nanaimo coalfield, and minor coal showings at Tumbo Island and Mount Maxwell. The Comox sub-basin contains the Quinsam, Cumberland and Tsable River coalfields, together with minor showings at Ash River and Port Alberni.

NANAIMO SUB-BASIN

In the Nanaimo sub-basin, coal occurs in the Spray, Protection, Pender, Extension and Comox formations. Mines have been developed only in the Pender and Extension coals.

Spray Formation

The Spray Formation (Muller and Jeletzky, 1970) consists mainly of thin-bedded silty shales with thick lenses of sandstone and conglomerate. Boreholes on Tumbo Island encountered about 50 metres of dark shale containing a 1.5 to 2.4-metre coal bed; this coal-bearing unit forms the top of the Spray Formation.

Protection Formation

The Protection Formation (Clapp, 1912a) in the Nanaimo area, contains three mappable members. From top down, these are the McMillan sandstone, Reserve coal measures and Cassidy sandstone.

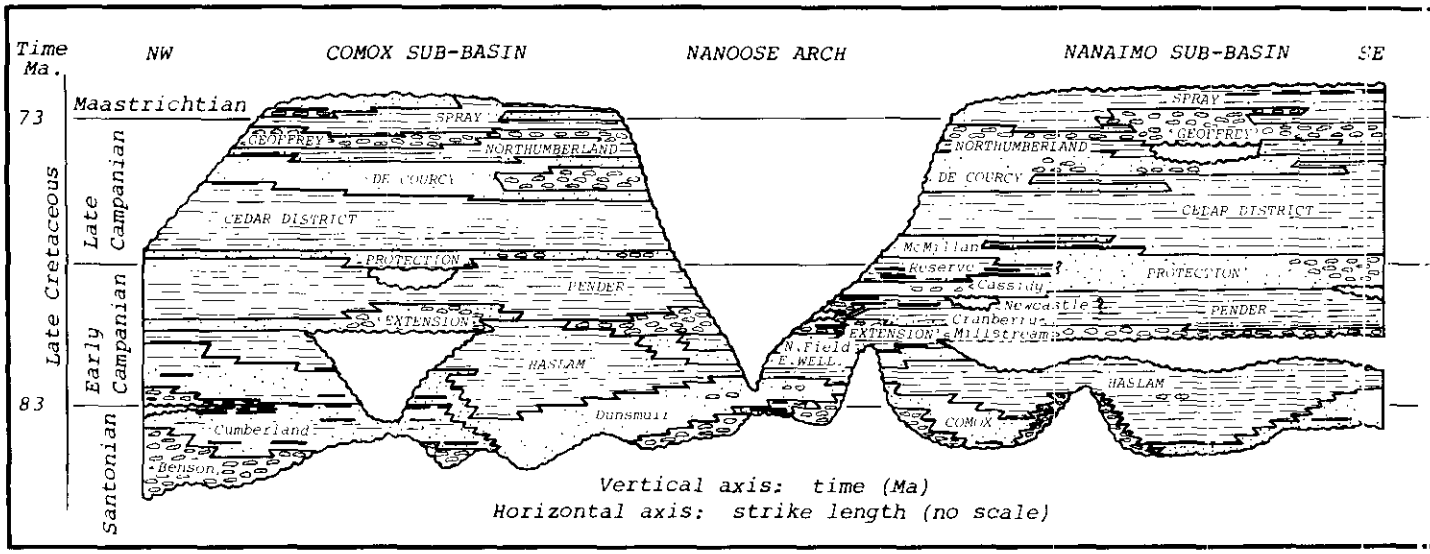

Figure 4-3-2. Stratigraphic relationships of the Nanaimo Group. Refer to Table 4-3-1 for legend.

The McMillan member is well exposed along the lower Nanaimo River, consisting of 60 to 90 metres of coarse-grained, thick-bedded, white arkosic wacke with thin interbeds of dark grey to greenish grey sandy siltstone.

The Reserve member crops out over the old workings of the Reserve mine near Cedar village, and also forms Round Island. It consists of 40 to 60 metres of green to brownish grey sandy siltstone and fine to medium-grained, medium-bedded, greenish grey lithic wacke with abundant lenses and pods of silty to carbonaceous mudstone and thin dirty coals. In the middle of the coal measures is the Cedar Bridge coal zone, comprising several closely spaced thin coals.

The basal Cassidy member outcrops in the Nanaimo River gorge at Cassidy. It consists of 80 to 105 metres of coarse-grained to gritty, thick-bedded to massive, white arkosic wacke and arenite, locally grading to quartzose pebble conglomerate.

Southwards from the Nanaimo coalfield, the Reserve coal measures appear to pinch out, and the McMillan and Cassidy sandstones are no longer separately mappable.

Pender Formation

The Pender Formation (Ward, 1978) consists of two mappable members in the Nanaimo coalfield, both initially given formational rank by Clapp (1912a) and subsequently reduced to members by Muller and Jeletzky (1970): the upper Newcastle coal measures, and the basal barren Cranberry shales.

TABLE 4-3-1
STRATIGRAPHIC UNITS OF THE NANAIMO GROUP

	Tertiary rocks of Whatcom Basin	
	DISCONFORMITY	
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	

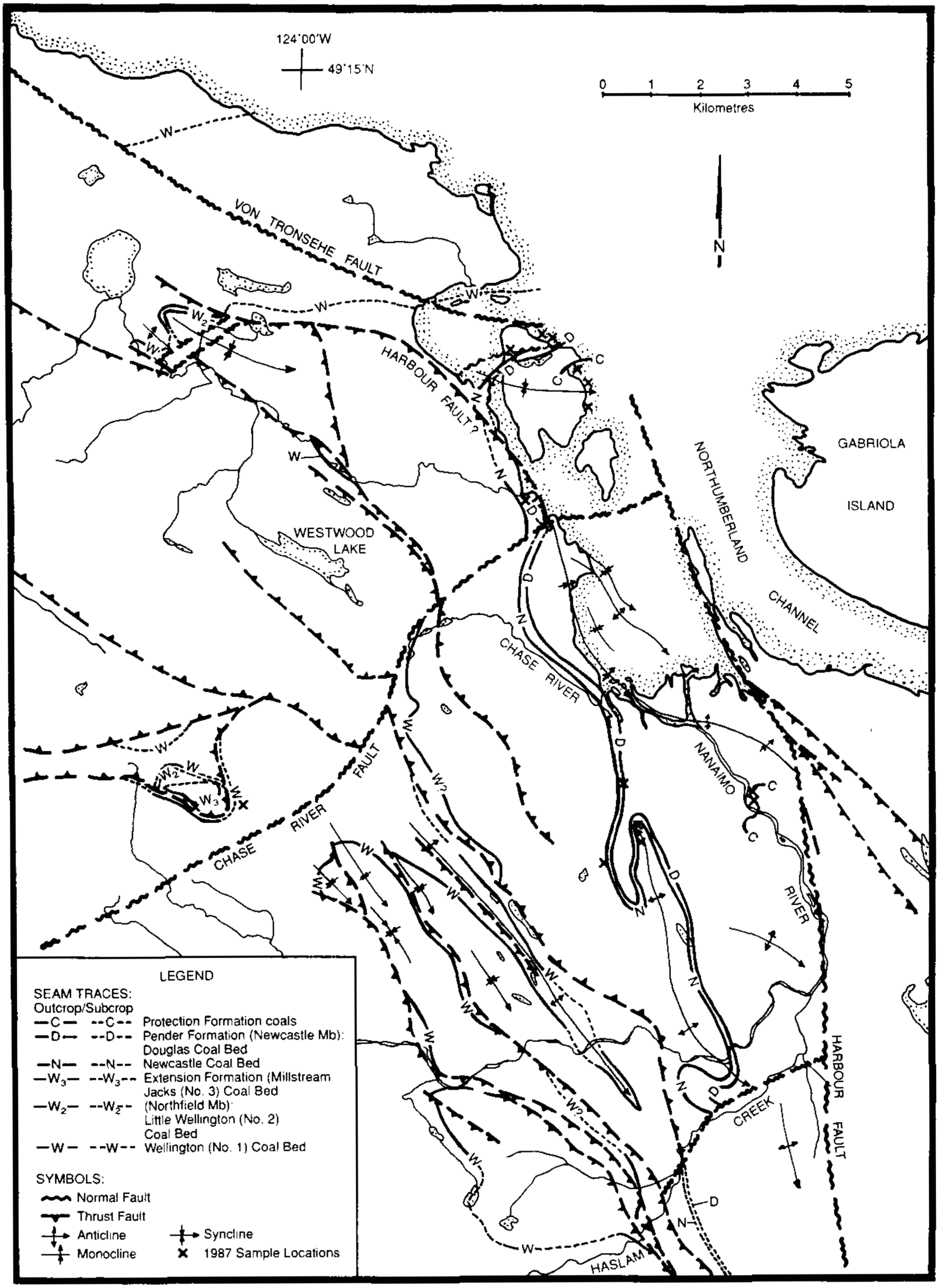

Figure 4-3-3. Coal seam traces, Nanaimo coalfield.

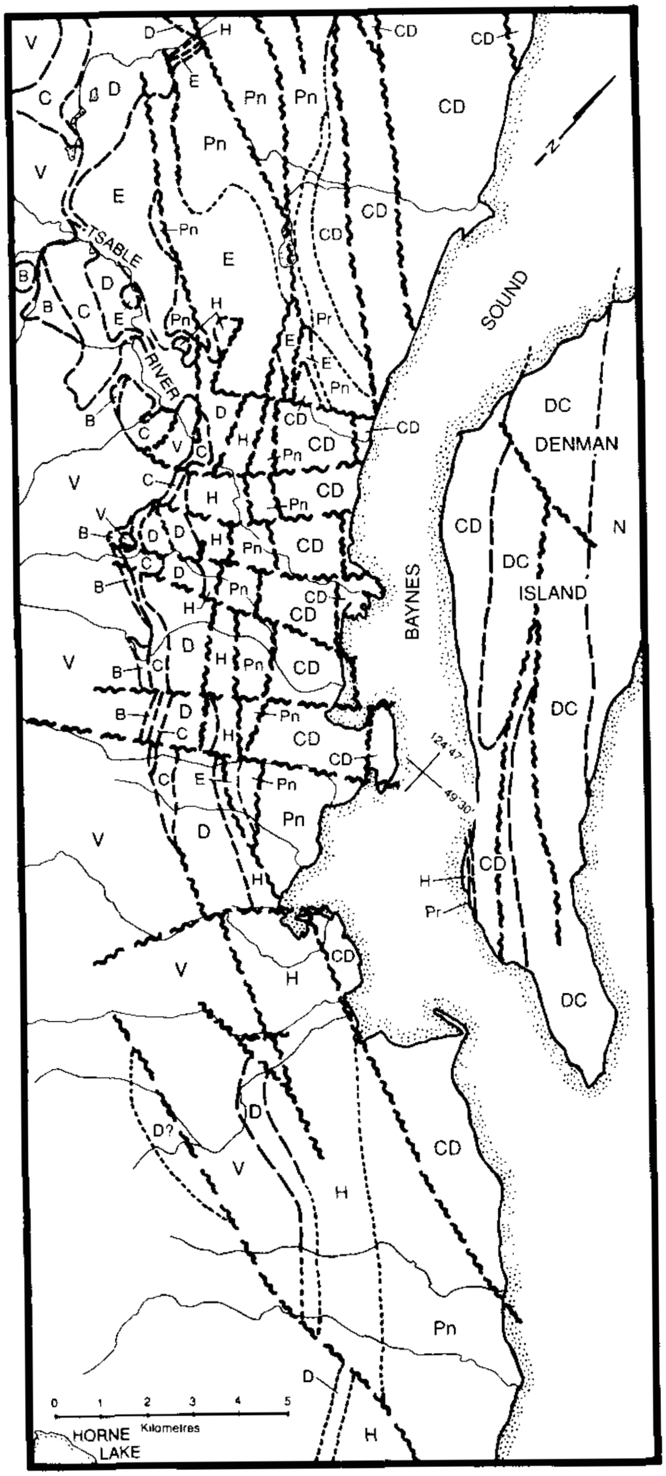

Figure 4-3-4a. Geology of the Comox sub-basin. Refer to Figure 4-3-4c for legend.

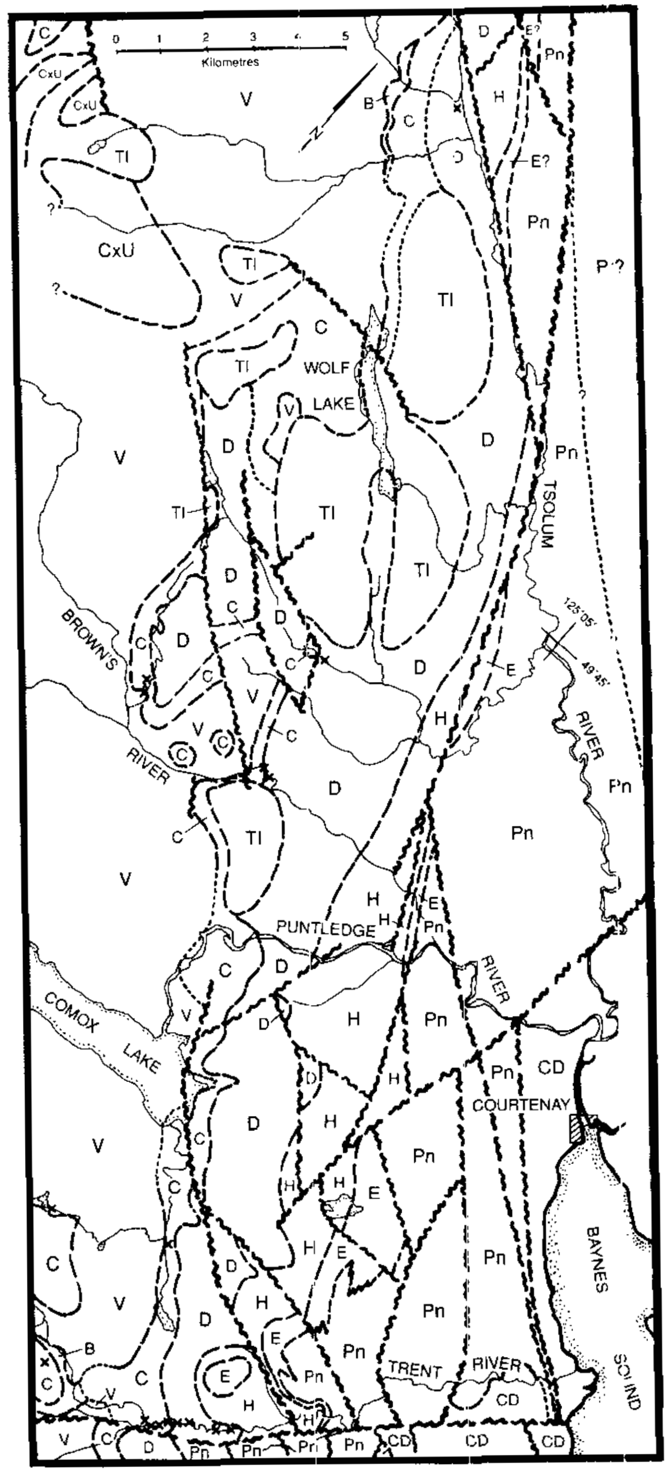

Figure 4-3-4b. Geology of the Comox sub-basin. Refer to Figure 4-3-4c for legend.

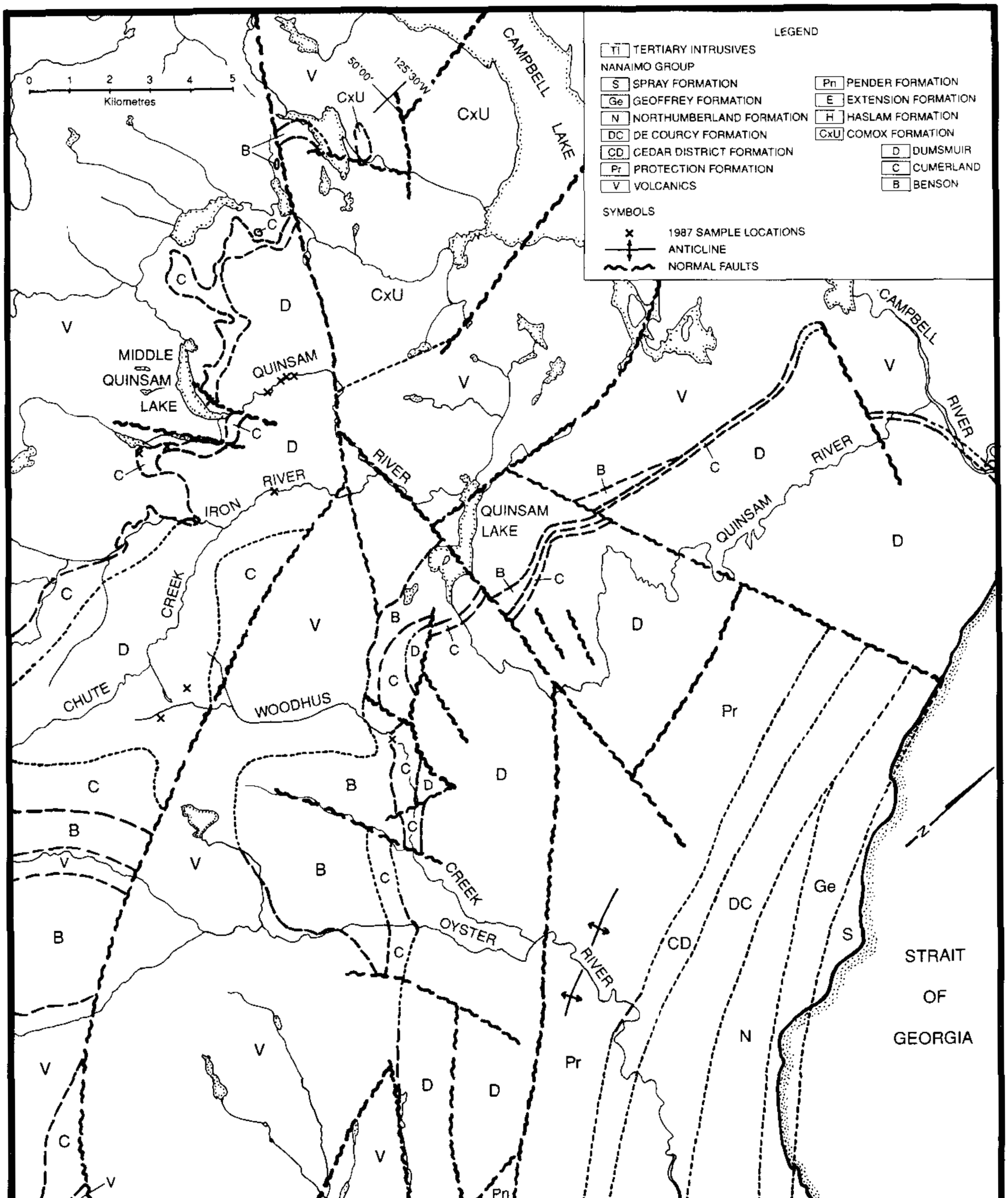

Figure 4-3-4c. Geology of the Comox sub-basin.

The Newcastle member consists of 50 to 60 metres of dark grey mudstone and coal, with thick wedges and lenses of light grey, coarse-grained quartz-lithic arenite and pebbly gritstone. Three coals are present, from top down, the River, Douglas and Newcastle beds.

The River or Douglas Rider bed is the most discontinuous of the Pender coals. It is known to be mineable only at South Wellington and Cassidy, where it consists of up to 2.1 metres of dirty coal with numerous bands of black coaly mudstone.

The Douglas coal bed varies laterally in thickness from a few centimetres to over 18 metres. Bands of black coaly shale are difficult to distinguish from clean coal. The coal is generally sheared and broken.

The Newcastle or Lower Douglas coal bed marks the base of the Newcastle member. It maintains a consistent thickness of about 1 metre, and consists of several thin coal leaves separated by bands of black coaly dirt and hard grey mudstone. A white-weathering ash band forms a persistent marker near the top of the coal bed.

The Cranberry member consists of 150 to 195 metres of dark green, coarse-grained volcanic wacke and green and grey sandy siltstone. Lenses of greenish grey chert-pebble conglomerate are a minor component; they are concentrated in the basal third of this unit. Occasional thin (approximately 10-centimetre) coals have been intersected by drilling, however they are not laterally persistent and may be merely coalified driftwood.

Extension Formation

The Extension Formation (Clapp, 1912a) may be mapped as two new units: the upper, barren Millstream conglomerate and the basal Northfield coal measures.

The Millstream member consists of 120 to 150 metres of thick-bedded to massive, quartz-chert-volcanic conglomerate, ranging from pebbly grit to cobbles. It is well exposed along the northeast side of the Millstream River, near Wellington, and also crops out on either side of the Extension Valley and at Wolf Mountain. Several thin coal beds are locally present, accompanied by lenses of greenish grey siltstone. The base of the Millstream is often a scour surface.

TABLE 4-3-2
CORRELATION OF COMOX COALS, COMOX SUB-BASIN

MEMBER	DEPOSIT Quinsam	Chute Creek	Woodhus Creek	Cumber-land	Tsable River
Dunsmuir member				W	
				X	
				Y	
	4	A, B		Z	
	3	C, D		1 (Upper)	30
Cumberland member	2		Upper	2 (Farm)	20 (2)
	1 Rider		Lower	2a	15
	1			3	10 (3)
				3a	
				4 (Lower)	

The Northfield member consists of 10 to 30 metres of brownish grey sandy siltstone and fine quartz volcanic sandstone, bounded at the top by the No. 2 coal bed, and at the base by the Wellington coal bed.

The No. 2 or Little Wellington coal bed is usually thin and dirty, with an average thickness of 0.7 metre.

The Wellington coal bed is the thickest and cleanest of the Nanaimo coals, averaging about 1.9 metres in thickness, inclusive of minor dirt bands. Its floor is marked by a distinctive rooty bed. Detailed mapping suggests that the Wellington is a composite of three thin coal leaves, each of which displays great lateral persistence. The workable section is determined by the thickness of the intervening dirt bands, as well as by relict floor topography.

COMOX SUB-BASIN

In the Comox sub-basin, known mineable coal is confined to the Comox Formation. The younger coarse clastic units, which are coal bearing at Nanaimo, are mostly barren due to a northward facies change from paralic to open marine. Thin coals have been reported in water wells in the Spray Formation near Campbell River. but more work will be needed before their mineability can be accurately assessed. The Comox coals have been extensively worked in the Cumberland and Tsable River coalfields, prospected at Ash River and Port Alberni, and are currently being test-mined at Quinsam.

A correlation chart of the Comox coals, based on lithological and geophysical data, is presented as Table 4-3-2.

Comox Formation

The Comox Formation may be subdivided into three mappable units; from top down, they are the Dunsmuir sandstone, Cumberland coal measures and Benson conglomerate (Figure 4-3-4). The top two units are new.

The Dunsmuir member is well exposed along the canyons of the Trent and Browns rivers, and crops out over the old Dunsmuir mines at Cumberland. It consists of 120 to 150 metres of thick-bedded, medium-grained, white, quartz feldspar arenites with widely spaced and thin but persistent interbeds of dark grey shale and coal. From top down, the coals are dsignated the W, X, Y, Z and No. 1 seams.

The W, X, Y and Z coal beds are spaced roughly equally through the top two-thirds of the Dunsmuir. They are typically about 30 centimetres thick. The No. 1 coal bed is about 25 metres above the base of the Dunsmuir. Its thickness is consistent (0.75 to 2.1 metres). The roof is a strong massive sandstone and the floor is a dark grey shale.

The Dunsmuir appears to thicken northward into the Quinsam and Campbell River areas. Here it is finer grained, containing more siltstone and shale interbeds and fewer thick sandstones. Numerous thin coals have been found by drilling, but coals of mineable thickness appear to be confined to the westernmost areas such as Quinsam (Quinsam No. 3 and No. 4 beds) and Chute Creek ('A' bed). The base of the Dunsmuir is locally marked by a bed of coarse, dark green, volcanic-pebble conglomerate. The top contact of the Dunsmuir in the Campbell River area is still under investigation, hampered by lack of continuous outcrop sections.

The Cumberland member is well exposed along the canyons of Perseverance (Coal) Creek near Cumberland, and the Trent and Browns rivers. It consists of 30 to 150 metres of dark grey siltstone, carbonaceous shale, sandstone and coal. The sandstones are markedly lenticular, and pinch out or interfinger with the siltstones. The carbonaceous shales and coals form fairly persistent coal zones. In the Cumberland coalfield the major coal beds, from the top down, are numbered 2, 3a and 4. Minor beds are the 2a and 3. The following coal bed descriptions focus on the Cumberland coalfield with comments on correlation with the other coalfields.

The No. 2 bed is the most persistent of the Cumberland member coals. It consists of 0.75 to 1.5 metres of dull and bright coal with thin bands of hard, black carbonaceous shale. Its roof is a hard, but fissile, dark grey carbonaceous siltstone, and its floor is a strong, light grey, rooty, sandy siltstone. A correlative bed in the Tsable River coalfield has a thickness of 1.8 to 4.2 metres. Coal occurs at this horizon in the Quinsam coalfield, as the Quinsam No. 2 (averaging 1.5 metres) and Woodhus Creek Upper (averaging 1.6 metres) beds.

The No. 2a bed consists of 0.3 to 0.6 metre of coal, with a roof and floor of siltstone. It thickens to the north and is best developed north and west of the Oyster River. It is correlated with the Woodhus Creek Lower (up to 3.6 metres thick) and the Quinsam No. 4 (averaging 2.9 metres thick) beds.

The No. 3 bed consists of 0.9 to 1.5 metres of coal and black shale. The roof and floor vary from siltstone to massive sandstone. It thickens to the south of Cumberland and attains a thickness of up to 4.2 metres in the Tsable River coalfield.

The No. 3a bed consists of 1.3 to 1.6 metres of coal and partings of dirty coal and sandstone. It has a hard sandstone or shale roof and a sandstone floor.

The No. 4 bed is the thickest coal at Cumberland, but its distribution is interrupted by basement paleohighs projecting up as hills above the level of the coal bed. It consists of 1.2 to 2.4 metres of dull and bright coal, with thin dirt bands, chiefly of black coaly shale. Its roof is a weak carbonaceous shale and its floor varies from pale green seat-earth mudstone to brown ferruginous siltstone.

The Benson member (Clapp, 1912a; as revised by Muller and Jeletzky, 1970) is a basal conglomerate unit which infills the irregularities of the basement surface. It consists of up to 300 metres of dark green and brown, basaltic cobble to boulder conglomerate with lenses of red, green and brown shale, siltstone, volcanic wacke and rare thin coals (probably of drift origin). It does not contain mineable coal beds. Its age is uncertain, owing to the lack of diagnostic fossils, although its baked appearance in some exposures suggests that it might be markedly older than the overlying coal measures.

COAL QUALITY

The majority of the Comox and Nanaimo coals are of high-volatile A bituminous rank, although local variations do occur.

Proximate analyses ran on "as received basis" samples for run-of-mine coals have yielded the following value ranges for Comox and Nanaimo coals:

Moisture content	0.6–5.2%
Volatile matter	28.1–41.9%
Fixed carbon	38.1–63.6%
Ash	6.7–26.4%
Sulphur	0.4– 3.7%
BTU	10 414–13 925

TABLE 4-3-3
1987 COAL SAMPLE LOCATIONS

NANAIMO SUB-BASIN

Sample No.	UTM Easting	UTM Northing	Elevation (m)	Source of Sample
87-01	435940	5440525	19	Reserve measures
87-02	435960	5440450	20	Reserve measures
87-03	433430	5440910	30	Douglas coal bed?
87-04	433670	5439675	60	Newcastle coal bed
87-05	433625	5439800	60	Newcastle coal bed
87-06	425575	5440625	570	Wellington coal bed, No. 1 seam
87-07	424550	5440715	670	Wellington coal bed, No. 3 seam
87-08	429100	5443475	120	Wellington coal bed, Rider seam
87-19	432850	5448925	0	Reserve measures
87-20	432700	5449400	0	Reserve measures
87-21	432180	5449900	0	Douglas coal bed?
87-22	432160	5449985	0	Newcastle coal bed
87-23	432860	5448525	0	Newcastle coal bed
87-24	431340	549480	40	Newcastle coal bed
87-25	431410	5449525	20	Newcastle coal bed
87-26	431630	5446490	10	Newcastle coal bed
87-27	433060	5439280	102	Newcastle coal bed

COMOX SUB-BASIN

Refer to Table 4-3-2. To avoid interpretation problems, coal measures outside the Cumberland area are labelled as "coal beds".

Sample No.	UTM Easting	UTM Northing	Elevation (m)	Source of Sample
87-09	351900	5493290	475	No. 4 seam
87-10	349500	5495880	555	Nos. 3 and 3a seams
87-11	351960	5497100	180	No. 4 seam
87-12	343600	5506270	478	No. 2a seam?
87-13	343620	5506180	450	No. 3a seam?
87-14	340660	5520450	90	X seam
87-15	326770	5526320	564	A coal bed?
87-16	326750	5527350	526	A or B coal bed?
87-17	331250	5530000	210	Lower coal bed?
87-18	322525	5533200	351	No. 1 coal bed
87-29	323600	5534840	238	No. 4 coal bed
87-30	323490	5534650	239	No. 4 coal bed
87-31	323365	5534550	241	No. 4 coal bed
87-32	323350	5534100	242	No. 3 coal bed
87-33	346100	5509100	195	No. 2 seam
87-34	355700	5494580	175	X seam
87-35	354610	5493900	232	No. 2 seam
87-36	354590	5493770	235	No. 2 seam
87-37	354330	5493560	240	No. 3a seam
87-38	347045	5506255	150	No. 2 seam
87-39	346870	5506410	162	No. 2a or 3 seam?
87-40	355480	5494410	190	Y seam
87-41	355090	5494290	198	Z seam
87-42	354820	5493940	228	No. 1 seam
87-43	354520	5493630	238	No. 3 seam
87-44	322280	5531420	314	No. 2 coal bed
87-45	322185	5530880	338	No. 2 coal bed
87-46	325065	5532420	274	No. 3 coal bed?
87-47	354345	5493490	255	No. 4 Rider seam
87-48	354200	5493410	270	No. 4 seam

Little is known concerning the coking potential of the Comox and Nanaimo coals, owing to the paucity of modern analyses. Free-swelling index (FSI) data are available for some coals sampled after about 1950. The Wellington coal bed has an FSI of 2 to 4, when unoxidized. The Comox No. 2 coal has an FSI of 6 to 9 at Tsable River and Cumberland. Maximum fluidities of the No. 2 coal are 400 to 12 500 dial divisions per minute, at mean vitrinite reflectances of 0.7 to 0.85. Both the Wellington and the Comox No. 2 coal have potential as components in coking-coal blends.

During the 1987 field season, 114 samples were collected from 48 locations. Sample location information is presented in Table 4-3-3. Grab, channel or ply samples were taken depending on the type of exposure. Petrographic studies of these coals are in progress. Proximate and ultimate analyses will be run on selected coal samples. The analytical results will be reported at a later date.

ECONOMIC CONSIDERATIONS

Over a 100-year period which ended in 1953, a total of 46.3 million tonnes of coal was mined in the Nanaimo area. The Comox coalfield had produced 18.6 million tonnes of coal when mining ceased in 1967. Wolf Mountain mine in the Nanaimo sub-basin produced 17 200 tonnes of clean thermal coal over a 4-month period in 1986. This mine is inactive at present. Quinsam Coal Limited is presently operating under a Limited Production Permit and is providing small shipments of coal to local markets.

Vancouver Island coals have been attracting considerable attention lately. The proximity of tidewater is a major factor in making the deposits attractive. Exploration data indicate that potentially mineable coal resources exist in the eastern coal basins, both of coking and thermal grades. Island coal deposits are being considered for uses other than traditional applications. Quinsam coals are currently being investigated for use in the area of coal gasification. Coal seam methane gas potential studies are presently being conducted in both the Nanaimo and Comox sub-basins.

On September 2, 1987, the provincial government gave approval to selectively issue coal licences within the northeast Vancouver Island licence moratorium area (*see* Figure 4-3-1) which will allow additional exploration in this district.

FURTHER WORK

Investigations of coal quality, petrographic composition and rank are continuing in Victoria. A detailed study of the Quinsam coal deposit is planned for the 1988 season.

The Wellington coal bed in the Nanaimo coalfield is the subject of an M.Sc. project at The University of British Columbia. Detailed mapping of mine workings will lead to a better understanding of the short and medium-range variation of the Wellington coal, and by analogy, certain coals of the Pender and Comox formations. It should become possible to delineate geological hazards in advance of mining, thus enhancing the safety and economics of coal mining on Vancouver Island.

Detailed geological maps of the Comox and Nanaimo coalfields are being compiled. Data available for these maps include outcrop descriptions (from both historic and current work), drill records and mine plans. Release of these maps is anticipated in early 1988.

ACKNOWLEDGMENTS

David Chamberlain and Brian Young of the Provincial Archives of British Columbia provided critically useful information. Glenn Rouse of The University of British Columbia provided coal samples from old mines. The owners and operators of Wolf Mountain colliery provided access to their mine. Steve Gardner of Quinsam Coal provided data and assistance in sampling the Quinsam area. With Peter Hacquebard, he helped define the stratigraphy of the Wellington coal bed near Extension. Georgia Hoffman, Sharon Chapman, C. Day and JoAnne Schwemler provided field assistance; the latter is doing the petrographic analysis.

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A SUMMARY OF THE RESULTS OF A PALYNOLOGICAL INVESTIGATION OF BRITISH COLUMBIA'S NORTHEAST COALFIELD*[1]

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KEYWORDS: Stratigraphy, Peace River coalfield, palynology, Gething Formation, Moosebar Formation, Gates Formation, marine transgressions.

INTRODUCTION

The strata of the Peace River coalfield, in the foothills of northeastern British Columbia (Figure 4-4-1), formed in a tectonically active region near the western margin of the craton. The complex pattern of intertonguing marine and nonmarine strata which resulted was subsequently deformed by folding and thrusting, making interpretation and correlation extremely difficult.

The present palynologic study was undertaken in an attempt to resolve some of the stratigraphic problems, where sedimentological and geophysical methods have failed. The primary aim of the study is to generate a composite palynologic section that can be used to zone, correlate and date the coal-bearing strata in the southern half of the coalfield.

Eleven drill holes, representing nearly 3000 metres of section from the Gething, Moosebar and Gates formations (Figure 4-4-2) were sampled at 15-metre intervals. The 199 samples examined for palynomorphs yielded a total assemblage containing 350 species of pollen, spores, dinoflagellate cysts, acritarchs, algal cysts and fungal spores. Of these, 256 species are restricted in their occurrence within the section, and have been used to zone and correlate the strata.

Open-marine, restricted-marine and nonmarine horizons are identified on the basis of type and relative abundance of palynomorphs. Contact relationships are examined and clarified, the palynologic section is compared with lithologic information, and a geologic age is established for the rocks.

RESULTS

Of the 197 core samples used for this study, 163 samples (83 per cent) contain indigenous palynomorphs and 34 samples (17 per cent) are barren or contain palynomorphs considered to be recycled. A total of 350 species have been identified, including 232 pollen and spore species, 96 dinoflagellate cyst and acritarch species, and 22 algal cyst and fungal spore species.

Recycled palynomorphs are present in varying amounts in a large number of samples and have been excluded from the results. Although often difficult to recognize, in this study recyclants have been identified as those specimens which exhibit a significantly higher TAI value, and/or greater corrosion (chemical degradation) or pitting (abrasion) of the wall relative to similar types of palynomorphs in the sample.

ZONATION AND CORRELATION

The edited data, when plotted on a cross-section, reveal a pattern of frequent inundations from the north by a shallow sea (Figure 4-4-3). Six major and four minor transgressions are identified in the Gething through Gates section. All of the major transgressions, as well as the intervening nonmarine deposits of the regressive phases, can be characterized by a unique palynomorph assemblage.

Although a single nonubiquitous species rarely occurs throughout a particular zone, each zone can be recognized on the basis of palynomorph type, abundance and diversity. This allows all but a few palynologic zones to be correlated through the entire length of the study area. The remaining zones can be traced to facies equivalents.

The zonation and correlation are illustrated in Figure 4-4-3. Of the 350 species identified in this study, 94 are ubiquitous. The remaining 256 species, made up of 150 pollen and spore species, 85 dinocyst and acritarch species and 21 algal cyst and fungal spore species, are restricted in occurrence[2].

Figure 4-4-3 shows the location of the drill holes used in this study and their relative position in the section. The Gething-Moosebar lithologic contact, as determined by company geologists from core and geophysical logs, has been used as the datum as there is generally good agreement on its position. Lithologic contacts (solid lines) are placed according to company drill-hole data or, where unavailable, by average thickness (dashed lines) based on measured sections or nearby drill-hole information (Stott, 1968, 1973; Duff and Gilchrist, 1981; Carmichael, 1983). The occurrence of coal, as single or multiple seams exceeding 0.5 metre in thickness, is plotted where geophysical or stratigraphic information is available.

The palynologic contacts (dotted lines) separate marine from nonmarine strata, based on the presence or absence of marine dinocyst and acritarch species. Although spores and pollen are not uncommon in marine strata, particularly re-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

[1] This paper is excerpted from an M.Sc. thesis, available through The University of British or the British Columbia Ministry of Energy, Mines and Petroleum Resources.

[2] The figure illustrating biostratigraphic ranges of the zoneable species has not been included in this report due to space constraints.

stricted-marine (or near-shore) facies, dinocysts and acritarchs are absent from terrestrial strata with the exception of occasional flood or storm-deposited specimens. In addition to recognizable marine and nonmarine (terrestrial) palynologic zones, there are parts of the section in which the samples contain only rare ubiquitous species and abundant recyclants, or no palynomorphs whatsoever. The distribution of these "barren" samples is consistent enough to allow them to be recognized as distinct palynologic units.

Two types of marine zones, open and restricted marine, are identified in this study, based on the type(s) of palynomorph(s) present and the relative abundance and diversity of each. Open-marine strata are characterized by an abundant and diverse dinocyst/acritarch assemblage and an absence of

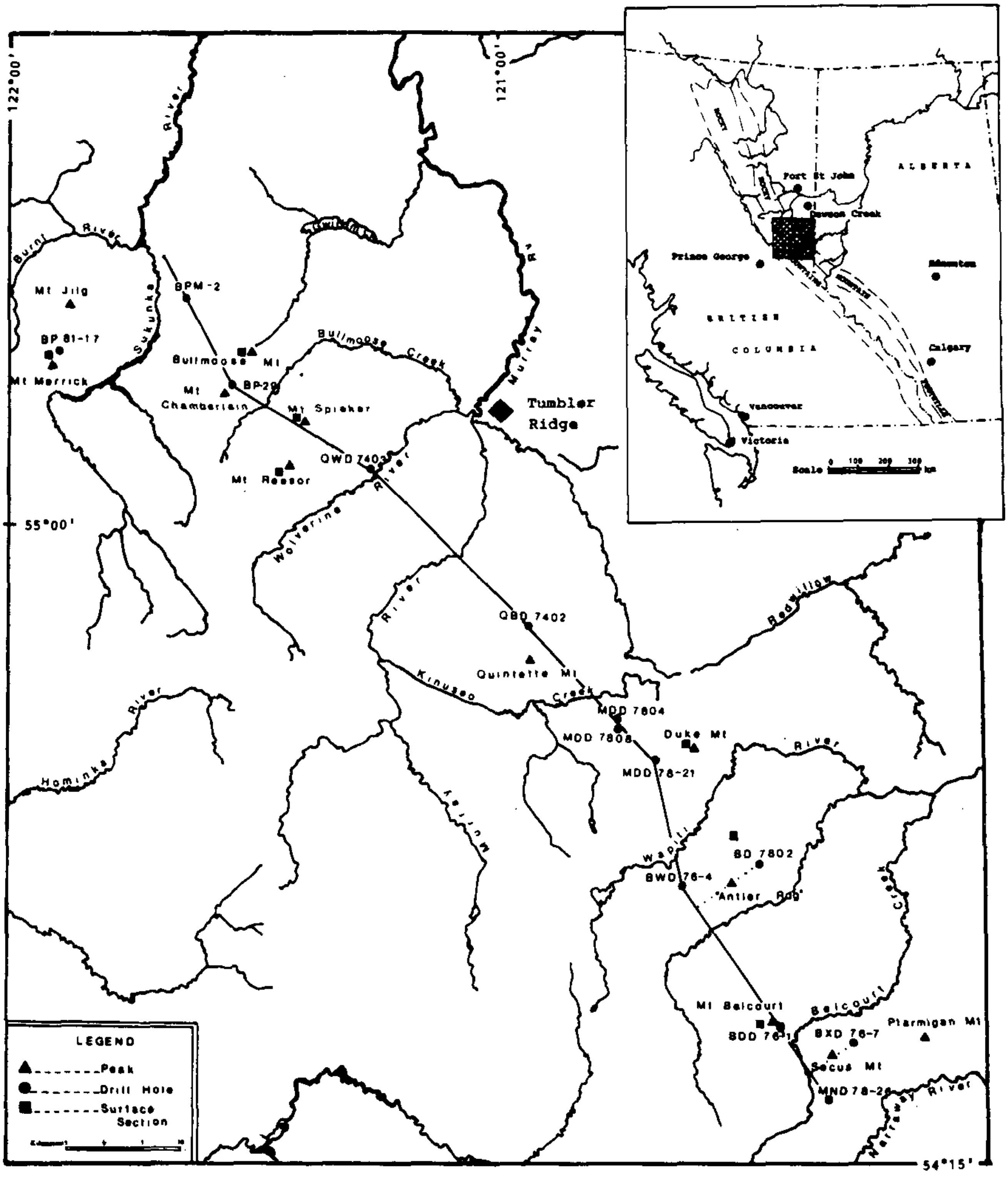

Figure 4-4-1. Map showing study area and drill-hole locations.

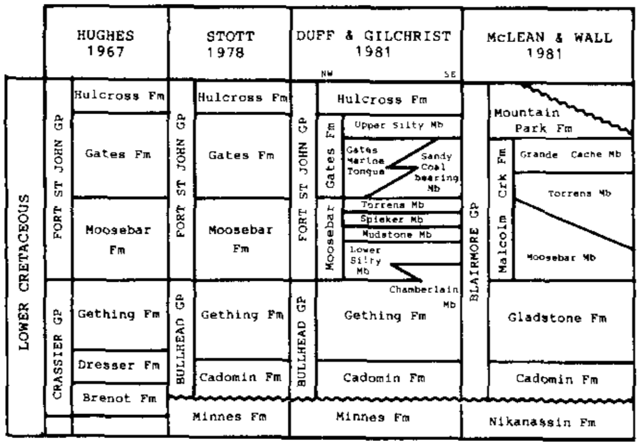

Figure 4-4-2. *Stratigraphic nomenclature of the* Peace River coalfield.

pollen and spores, algal cysts and fungal spores. Restricted-marine strata contain all types of palynomorphs in relative abundances that reflect proximity to open-marine or terrestrial environments.

Terrestrial strata are characterized by an absence of dinocysts and acritarchs (except as qualified earlier), and the presence of variable quantities of pollen and spores, plus or minus algal and fungal debris. Barren zones, considered here to be predominantly nonmarine, are characterized by an absence of diagnostic species and/or the presence of a large number of recycled specimens, or by a total absence of palynomorphs.

It should be emphasized here that the palynologic zones, as determined by the density of sampling used in this study, identify the prevailing depositional influence. Marine zones may contain nonmarine strata and vice versa.

The marine-nonmarine units have been determined solely on the basis of palynologic evidence. Placement of a palynologic boundary is somewhat arbitrary depending on the distance between samples in a vertical section. Occasionally, coal will persist along, or close to, palynologic horizons and a boundary will be placed to emphasize probable concurrent episodes of coal development without compromising palynologic data.

Six major marine transgressions, defined here as marine strata which can be correlated the entire length of the study area, and four minor marine incursions have been identified. Major transgressions occur at the base of the Gething Formation, in the lower half of the Moosebar Formation, at the base and the top of the basal Gates marine-nonmarine unit, in the upper middle Gates, and at the top of the Gates Formation. Two marine tongues are identified in the upper half of the Gething, and another two occur in the basal Gates marine-nonmarine unit, all in the northwest half of the study area.

The intervening nonmarine strata, representing marine regressions, occur in the Gething Formation above the basal marine unit and below the marine tongues and in the basal Gates marine-nonmarine unit in the southeast half of the study area. Two more are present in the upper half of the Gates Formation. Barren zones are identified above the marine tongues in the Gething, and in the upper half of the Moosebar Formation.

GETHING FORMATION

The marine unit at the base of the Gething Formation is approximately 30 metres thick from Sukunka to Monkman Pass. Southeast of Monkman Pass it splits into an upper and lower tongue. The upper tongue thins rapidly and may be absent southeast of Secus Mountain. The lower tongue maintains a thickness of 20 to 30 metres, but evidence suggests that it splits again in the vicinity of Secus Mountain, and that both tongues persist beyond the limits of the study area. The unit contains both marine and nonmarine palynomorphs, indicating a restricted-marine environment with the terrestrial influence notably stronger in the southeast. There are four spore species (*Clavatipollenites couperii*, *C. minutus*, *Cooksonites reticulatus*, *Podocarpidites naumovai*) and one dinocyst species (*dino sp. A*) exclusive to the Gething basal marine unit.

The Gething strata which lie between the basal marine unit and the lower marine tongue are considered to be terrestrial, despite poor recovery of palynomorphs. Only a single spore species (*Reticulisporites semireticulatus*), of the 12 present in the Gething Formation, is confined to the nonmarine zone. The unit contains numerous ubiquitous species and recyclants, although many of the samples are barren. The poor preservation and pervasive recycling are consistent with the interpretation by Stott (1973) of deposition in the fluctuating, moderate to high-energy conditions of an alluvial-deltaic environment.

The upper half of the Gething Formation north of Quintette Mountain contains two marine tongues. The lower tongue is approximately 30 to 35 metres thick between Sukunka North and Bullmoose Mountain, and thins to less than 10 metres at Monkman Pass. Palynologic evidence suggests that it extends as far south as the Antler Ridge–Triad Creek region. The upper marine tongue is also approximately 35 metres thick at Sukunka North, but thins rapidly and disappears just south of the Wolverine section. Of the twelve spore species and four dinocyst species found in the Gething, two spore (*Coptospora striata*, *Cicatricosisporites potomacensis*) and two dinocyst species (*Apteodinium sp.*, *Palaeoperidinium sp.*) are restricted to these marine zones. No attempt was made to distinguish the upper and lower tongues palynologically, since there are insufficient data to do this reliably.

The strata which overlie the marine tongues are also barren of palynomorphs. This zone, referred to by Duff and Gilchrist (1981) as the Chamberlain member, is an important coal-bearing unit of limited lateral extent. Approximately 25 metres thick at Bullmoose Mountain, it thins rapidly to the southeast, disappearing between Wolverine River and Quintette Mountain. Duff and Gilchrist indicate that the coal zone also thins in a northwesterly direction, cut off by marine strata. At present no palynologic data are available for the region north of Bullmoose Mountain.

The barren strata in the upper part of the Gething Formation do not differ significantly from the underlying terrestrial strata and are presumed to have been deposited under similar conditions.

MOOSEBAR FORMATION

The base of the Moosebar Formation is identified palynologically by the first major influx of marine species. A

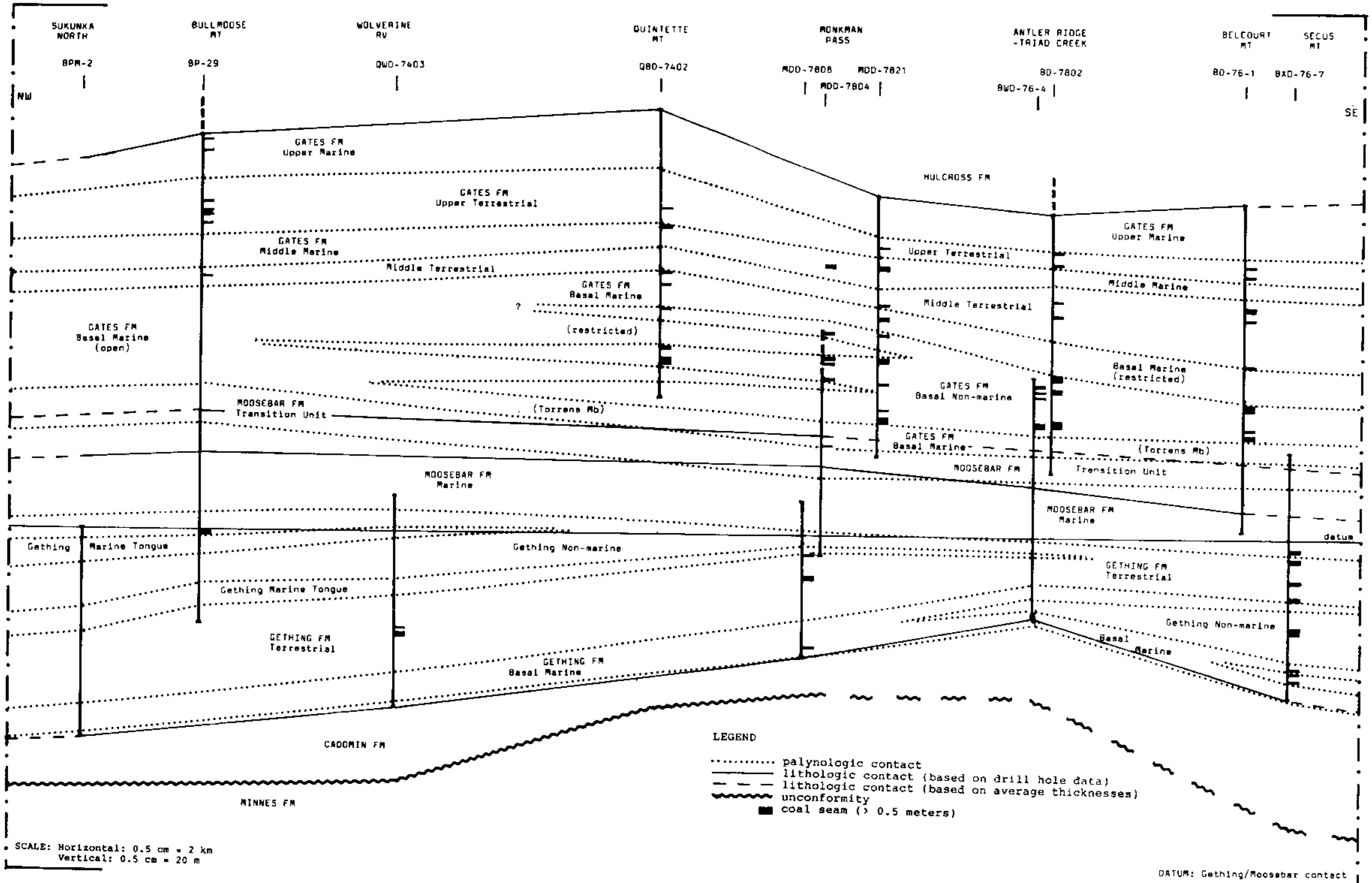

Figure 4-4-3 (a and b). Palynologic zonation and correlation of the Peace River coalfield.

lower marine zone containing 27 dinocyst and acritarch species and 30 spore species, and an upper "transition unit" completely barren of palynomorphs, make up the Moosebar Formation.

The marine unit varies in thickness from 100 metres in the northwest to 70 metres in the southeast and is characterized palynologically by nine dinocyst/acritarch species and five spore species. Although it is dominated by marine species throughout most of the study area, indicating open-marine conditions, there is an increase in terrestrial palynomorphs in the Mount Belcourt–Secus Mountain region, suggesting proximity to a terrestrial source. In addition, three of the drill holes contain a single barren sample in the middle of the marine sequence, and a fourth hole contains a sample with only a few spores, indicating a regressive or emergent phase at this level.

Lithologically, the Moosebar marine unit consists of two or three coarsening-upward cycles of fine to silty black shales (Leckie, 1981; Carmichael, 1983). At most locations the top of the second cycle corresponds to the regression identified palynologically.

Although the palynologic boundary between the Moosebar and Gething formations is fairly consistent with the lithologic contact in the southern half of the study area, it lies above the Gething-Moosebar contact in the northern half. This may be due in part to the presence of marine strata so close to the top of the Gething, and to the discontinuous nature of the Chamberlain member and the coal within it, making the lithologic contact somewhat difficult to locate accurately. Speculation by Duff and Gilchrist (1981) that their Gething marine tongue correlates with the Moosebar marine strata north of Bullmoose Mountain is not supported by palynologic evidence. Of the 32 zoneable marine species in the two formations, only a single dinocyst species was found to be common to both.

The transition unit lying above the marine shales is distinguished by a total absence of palynomorphs. The unit thins from 40 metres in the northwest to 30 metres in the southeast. Lithologically it is recognized by the introduction of bedded siltstones and sandstones into the dark shales, but the amount of coarse material is highly variable across the section. A comparison of the palynologic section with lithologs described by Carmichael (1983) indicates that between Wolverine River and Quintette Mountain in the northwest and south of the Antler Ridge–Triad Creek section, the transition unit consists of thick-bedded siltstones and sandstones overlain by thin interbeds of sandstone, siltstone and shale. In the intervening region the unit consists only of thin-bedded sandstone, siltstone and shale. Thin coals are occasionally present near the top. At Mount Spieker in the northwest, Leckie (1981) describes a section similar to the Wolverine-Quintette section, which he divides lithologically between the thick-bedded coarse material and the overlying finer sediments, placing the former at the top of one coarsening-upward cycle and the latter at the base of a second cycle. Outside his study area this division into coarsening-upward cycles is not always apparent, and would likely result in the correlation of different stratigraphic horizons. The "Spieker member" of Duff and Gilchrist (1981) "includes all strata between the mudstone member and the clean well-sorted sandstone of the upper Torrens member" and is equivalent to the transition unit with the exception of the top few metres, considered here to be palynologically part of the overlying unit (Torrens member). This is explained more fully in the following section.

Gates Formation

The base of the Gates Formation, as interpreted in this study, occurs as an influx of marine palynomorphs above the barren transition unit. The Gates contains three major palynologically distinct marine units: a basal marine unit which is divided into an upper and lower zone by a nonmarine wedge; a middle marine unit; and an upper marine unit which marks the top of the formation. Nonmarine strata are present in the basal Gates unit, immediately above the basal marine-nonmarine unit and between the middle and upper marine units.

The basal Gates unit is predominantly open marine in the northwest, rapidly giving way to a complex pattern of intertonguing marine and nonmarine strata and, further southeast, to upper and lower restricted-marine tongues, separated by 60 metres (on average) of nonmarine strata. The zone is characterized by 29 dinocyst and acritarch species, 7 of which are restricted to this unit, and 41 spore species, 9 of which are restricted.

At Bullmoose Mountain in the northwest, open-marine conditions are indicated by a 100-metre-thick succession containing an abundant and diverse dinocyst/acritarch assemblage. A few nonmarine species near the middle and top of the succession (Figure 4-4-3) indicate occasional regression. Four of the lower Gates seven dinocyst species (*Callaiosphaeridium asymmetricum*, *Gonyaulacysta* cf *cassidata*, *Gonyaulacysta* cf *episoma*, *Prolixosphaeridium* cf *mixtispinosum*) occur exclusively in the open-marine strata.

Between Bullmoose and Quintette mountains palynologic data are lacking. A somewhat simplified interpretation of the intertonguing of marine and nonmarine strata is based on a northward projection of the information from Quintette Mountain and Monkman Pass, and on comparison with lithologs from Carmichael's study. The data indicate that restricted marine conditions persist throughout the study area at the base and top of the Gates basal marine-nonmarine unit, and that at least two minor marine transgressions penetrate as far south as Monkman Pass. South of Monkman Pass, a thick succession of nonmarine strata lies between the upper and lower restricted-marine zones.

The lower restricted-marine zone is characterized palynologically by an assemblage of dinocysts, spores, algal cysts and fungal material. Of the seven dinocysts restricted to the Gates marine-nonmarine unit, two (*Fromea amphora*, *Hystrochokolpoma sp. A*) are found exlusively in this lower marine zone.

Carmichael's drill-hole lithologs indicate that this zone consists primarily of resistant, thick-bedded sandstone, containing thin interbeds of conglomerate in the southeast, becoming finer in the northwest. Lithologic and palynologic data show that the zone varies only slightly in thickness from 25 to 30 metres across most of the section, possibly reaching a minimum thickness of 20 metres in the northwest part of the study area.

This lower marine zone has been mapped in whole or in part as the Torrens member by a number of other workers. Carmichael (1983) accurately identifies the sandstone in most of his drill holes, but occasionally correlates it with thick nonmarine sandstone of the underlying transition unit. The "clean, well-sorted sands" mapped by Duff and Gilchrist (1981), using geophysical logs, are highly variable in thickness (from 5 to 20 metres), and correspond to the top of the marine sandstones identified palynologically. A closer look at the geophysical logs indicates a slight coarsening-upward cycle just below these clean sands. At most locations the combined thickness of the coarsening-upward cycle and the clean sands that overlie it ranges from 25 to 30 metres. Leckie (1981) identifies this sandstone unit at Mount Spieker at the top of his Torrens-Sukunka member. He describes an "amalgamated sandstone" which is "20 to 30 m thick and occurs as a continuous body, with occasional thick conglomeratic lenses, across the whole of the study area. Conglomerate lenses excluded, there is an overall upward increase in grain size from very fine, or fine grained to medium grained sandstone" (page 22).

Recognition of the Torrens member in the field has resulted in much confusion and likely will continue to do so. As Carmichael (1983) points out, "Coal companies working in the Foothills of northeastern British Columbia generally refer to the first thick sandstone interval beneath the lowermost economic coal seam as the Torrens Member" (page 14). Coal is present immediately above the Torrens member only in the region south of Quintette Mountain, where the sandstone is overlain by thick nonmarine deposits. North of Quintette Mountain the coal occurs above a stratigraphically higher marine sandstone, which marks the first minor transgression into the Monkman area.

The marine sandstones of the Torrens member are considered by some workers to mark the top of the Moosebar Formation (Duff and Gilchrist, 1981; Leckie, 1981), while others consider it to be equivalent to the basal Gates Formation (McLean, 1982; Carmichael, 1983). Palynologic evidence strongly supports the interpretation of the Torrens member as basal Gates. Although a distinct, restricted-marine unit in the southeast, it is palynologically inseparable from the open-marine strata of the basal Gates in the northwest. In addition, none of the eight marine species found in the Torrens member are restricted exclusively to it and Moosebar marine shales. The two units, in fact, are separated by the palynologically barren transition unit.

Above the Torrens member in the northwest half of the study area is a thickened succession of intertonguing marine and nonmarine strata. Although palynologic data are lacking between Bullmoose and Quintette mountains, the consistency of the data at Quintette and Monkman Pass allows reasonable extrapolation into this region. A marine regression lying immediately above the Torrens member over much of the study area stopped short of Bullmoose Mountain and was followed by a minor transgression into the Monkman Pass region. A second regression probably reached Bullmoose Mountain in the northwest, as evidenced by the presence of several nonmarine species in the middle of the open-marine sequence. The transgression overlying this can also be traced southward to Monkman Pass. A third regression, shown just north of Quintette Mountain, is located primarily on the basis of abundant spores, relative to dinocysts, and a persistent coal horizon at this position in the section.

The top of the basal Gates unit is marked by a second major trangression (the upper restricted-marine zone in Figure 4-4-3). A 40-metre-thick sequence of restricted-marine strata, characterized by near equal numbers of marine and nonmarine species, can be traced southward to Secus Mountain and beyond the study area. Two of the seven basal Gates dinocyst species (*Ascotomocystis maxima*, cf *Kalyptea monoceras*), and eight of the nine spore species (*Callialasporites segmentatus*, *Cerratosporites* cf *morrinicolus*, *Cibotiumspora juriensis*, *Concavissimisporites minor*, *Cooksonites variabilis*, *Densoisporites microrugulatus*, *Januasporites spiniferus*, *Polycingulatisporites sp. A*) are restricted to the upper marine unit. The upper restricted-marine unit and the open-marine strata to the northwest correspond to the Gates marine tongue of Duff and Gilchrist (1981).

The nonmarine component of the basal Gates marine-nonmarine unit lies immediately above the Torrens member. It is 30 metres thick in the southeast, increasing to 90 metres at Monkman Pass where it first begins to interfinger with marine strata. The unit contains only one characteristic spore species (*Psilatricolpites parvulus*) and is a major coal-bearing succession. It corresponds approximately to the sandy coal-bearing unit of Duff and Gilchrist (1981), which they trace as far northwest as Sukunka River using geophysical logs. Palynological evidence indicates that all strata in the lower Gates from Bullmoose Mountain northwestwards are predominantly marine.

The Gates middle terrestrial unit lies above the basal marine-nonmarine unit and contains 17 spore species, 4 of which are exclusive to this zone. It consists of 80 metres of strata at Belcourt Mountain in the southeast, but thins rapidly to 20 metres at Monkman Pass. It appears to maintain this thickness to the northwest limit of the study area, although it may pinch out or interfinger with marine strata in the vicinity of Bullmoose Mountain.

A thin restricted-marine unit overlies the middle nonmarine unit. It is identified palynologically by the presence of a few zoneable and numerous ubiquitous marine species, in a thin zone between two distinctly nonmarine zones. Of the 25 nonmarine and 4 marine species present, only 3 spores and a single dinocyst species are exclusive to this unit. It thins from 30 metres in the northwest to 10 metres in the southeast.

The Gates upper terrestrial zone is only weakly defined, both palynologically and lithologically. Palynologically, it is recognized as a thin zone, lacking marine species, between two marine units. It contains a total of 19 spore species, 2 of which are unique to the zone. The unit is thickest in the northwest (50 to 60 metres) and thins to 25 to 30 metres between Monkman Pass and Belcourt Mountain. Although this is a reversal of the normal trend, gaps in sampling of the upper Gates at Bullmoose and Quintette mountains, and the distance between the two sections, may obscure a more complex relationship between marine and nonmarine strata in this region.

The top of the Gates Formation is restricted marine, and contains a rich assemblage of 24 marine and 44 nonmarine species, including 4 species of dinocysts and 11 species of spores that are unique to this zone. The Gates upper marine unit consists of 40 to 60 metres of predominantly thick-bedded sandstone, with minor siltstones, shales and thin coals.

AGE DETERMINATION

According to Singh (1975), the appearance of early angiosperm pollen in North America follows a consistent pattern with respect to time, and allows fairly accurate dating of mid-Cretaceous rocks. Monosulcate (reticulate) grains first appear in sediments in the eastern United States in Barremian-Aptian time, but in western Canada and United States they have not been recorded in strata older than Middle Albian. Tricolpate (reticulate) grains make their appearance in Middle Albian rocks throughout North America, and tricolporate (smooth, triangular) grains mark the Albian-Cenomanian boundary.

In the present study several monosulcate pollen species (*Clavatipollenites hughesii, C. couperii, C. minutus*) have been found throughout the Gething Formation and a single tricolpate grain (*Tricolpites crassimuras*) is present near the top of the Gething terrestrial unit. Another tricolpate grain (*Psilatricolpites parvulus*) was found in the nonmarine horizon of the basal Gates unit. *Tricolpites crassimuras* was recorded by Singh (1975) from late Middle Albian to early Late Albian rocks in northwestern and central Alberta, but he notes an Albian age for the species. *Psilatricolpites parvulus* was recorded in early Late Albian rocks by Singh (1975) and given a Late Albian to Cenomanian age in North America.

The palynological evidence indicates that the entire Gething through Gates section in the Peace River coalfield is of Middle Albian to early Late Albian age.

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COAL TRENDS IN THE GETHING FORMATION–AN UPDATE

By Andrew Legun

KEYWORDS: Coal geology, Gething Formation, stratigraphic correlations, Chamberlain member, Bullmoose member, Gaylard member, Quintette mine, Babcock Mountain.

INTRODUCTION

This study focuses on the Gething Formation between the Sukunka River and Kinuseo Creek, an area in which a major marine tongue separates the Gething Formation into upper and lower coal-bearing sequences. In previous work the writer has reported on the southern limits of the marine tongue and the northern and eastern limits of the upper coal measures by a compilation of all available coal and petroleum well data. Two major lines of section were drawn in support of this work (Legun, 1987).

Work in 1987 focuses on measuring field sections and collating section data from coal assessment reports. The field sections complement lines of section based largely on geophysical log data. A computer database was compiled to permit manipulation of stratigraphic data from more than 500 locations. I am indebted to Ward Kilby of the Geological Survey Branch for facilitating this task. In addition, field mapping and seam tracing was done in the vicinity of the Teck Corporation Bullmoose mine and one diamond-drill hole (QHD 86010) was logged in detail. I was assisted in these tasks by George Walker.

STRATIGRAPHIC TERMINOLOGY

Duff and Gilchrist (1983) informally divided the Gething Formation into three units: the Upper, Middle and Lower Gething. The Middle Gething is an upward-coarsening sequence, grading from shale to sandstone, containing marine fauna. Also called the Gething marine tongue, it separates the upper and lower coal measures. Gibson (1987, in press) however revises this subdivision and formally defines three new units: the Chamberlain, Bullmoose and Gaylard members. The principal change to Duff and Gilchrist's subdivision has been to split the Middle Gething. The thick sandstone of the upper half of the coarsening-up sequence is incorporated in the Chamber member and the shale below constitutes the Bullmoose member; the Lower Gething remains intact and is renamed the Gaylard member. At its top, the Gaylard member often includes some combination of chert-pebble conglomerate, glauconitic sandstone and quartzitic arenite, in lithological contrast to the shales above (Bullmoose member) and the coal measures below. Oil company geologists correlate this unit and everything stratigraphically above it as equivalent to the Bluesky Formation of the plains. A chart showing correspondence of stratigraphic nomenclature is shown in Table 4-5-1.

STRATIGRAPHIC CORRELATIONS–PRELIMINARY RESULTS

Field sections measured during the course of fieldwork in 1987 are listed in Table 4-5-2. In general, exposure of the more recessive parts of the stratigraphy is poor, with the notable exception of sections at Mount Reesor and the Quintette mine (Eagle's Nest). Sections were also examined at Mount Collier and on the west limb of the Five Cabin Creek syncline. These sections correspond with a stratigraphic interval below the marine tongue.

For the purposes of this summary, a line of section was chosen from well BP et al Bullmoose (W.A. 4974) to well Oakwood et al Murray (W.A. 5189). Geographically this extends from near Mount Spieker in the north, through the Quintette mine area to Babcock Creek (Figure 4-5-1). It includes measured sections at Mount Reesor and the Eagle's Nest and several coal exploration boreholes (diamond and

TABLE 4-5-1
STRATIGRAPHIC NOMENCLATURE FOR THE GETHING FORMATION IN THE FOOTHILLS AND PLAINS OF NORTHEASTERN BRITISH COLUMBIA

Stratigraphic Unit	Williams (1984)	Duff and Gilchrist (1983)	Gibson (1987), Legun (1987)	Legun (1987)	Oppelt (1986)
Upper coal measures	Bluesky facies B_1	Upper Gething (Chamberlain member)	Chamberlain member	Upper Gething (Chamberlain member)	Upper Gething (Chamberlain member)
Sandstone	Bluesky facies B	Middle Gething (Gething marine tongue)		Middle Gething	Bluesky Fm. facies B
Shale			Bullmoose member		
Glauconitic sst. conglomerate, quarzitic sst.	Bluesky facies C	Lower Gething	Gaylard member		Bluesky Fm. facies C
Lower coal measures	Gething Fm.			Lower Gething	Lower Gething

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

rotary). The data were reduced to a common lithologic "denominator" as the data from the measured sections are much more complete than that which can be interpreted from well logs. The three newly defined members of the Gething Formation are discussed in the context of their correlation (Figure 4-5-2).

CHAMBERLAIN MEMBER

Toward the Quintette mine there is an increase in the thickness of channel sandstones in the Chamberlain member.

TABLE 4-5-2. MEASURED SECTIONS

	UTMN	UTME
West Wolverine 1	6094000	611000
West Wolverine 2	6094650	611650
Wolverine dump	6095650	612650
Eagle's Nest	6097250	615330
West Quintette	6080150	633500
Mt. Reesor	6104400	601100
Mt. Chamberlain	6113000	590350
Quintette Mtn.	6080900	636600

Major channel deposits are absent in BP et al Bullmoose, are about 12 metres thick in the section on Mount Reesor, and at least 30 metres thick at the Eagle's Nest between the Mesa and Wolverine pits. To the southeast, along the line of section, the channel deposits thin to 22 metres in QHD 86010, to 10 metres in QBR 8121 and to 13 metres in QBD 7102. In Oakwood *et al.* Murray (W.A. 5189) the presence of a channel deposit is uncertain as the host sandstone appears to coarsen upward rather than fine upward at its base. Data from the line of section are combined with thickness data from drill holes off the line of section.

A preliminary assessment suggests a lobe of distributary channel sands which thins in a wide arc extending from northwest to southeast and is centred near the Eagle's Nest. There is poor coal development associated with the channel sandstones and the Skeeter and Chamberlain seams, which are several metres thick in the B.P. Sukunka deposit to the north, are missing at the Quintette mine. The only coal seam of economic thickness in the Chamberlain member along the line of section is the Bird seam. At the north end of the line of

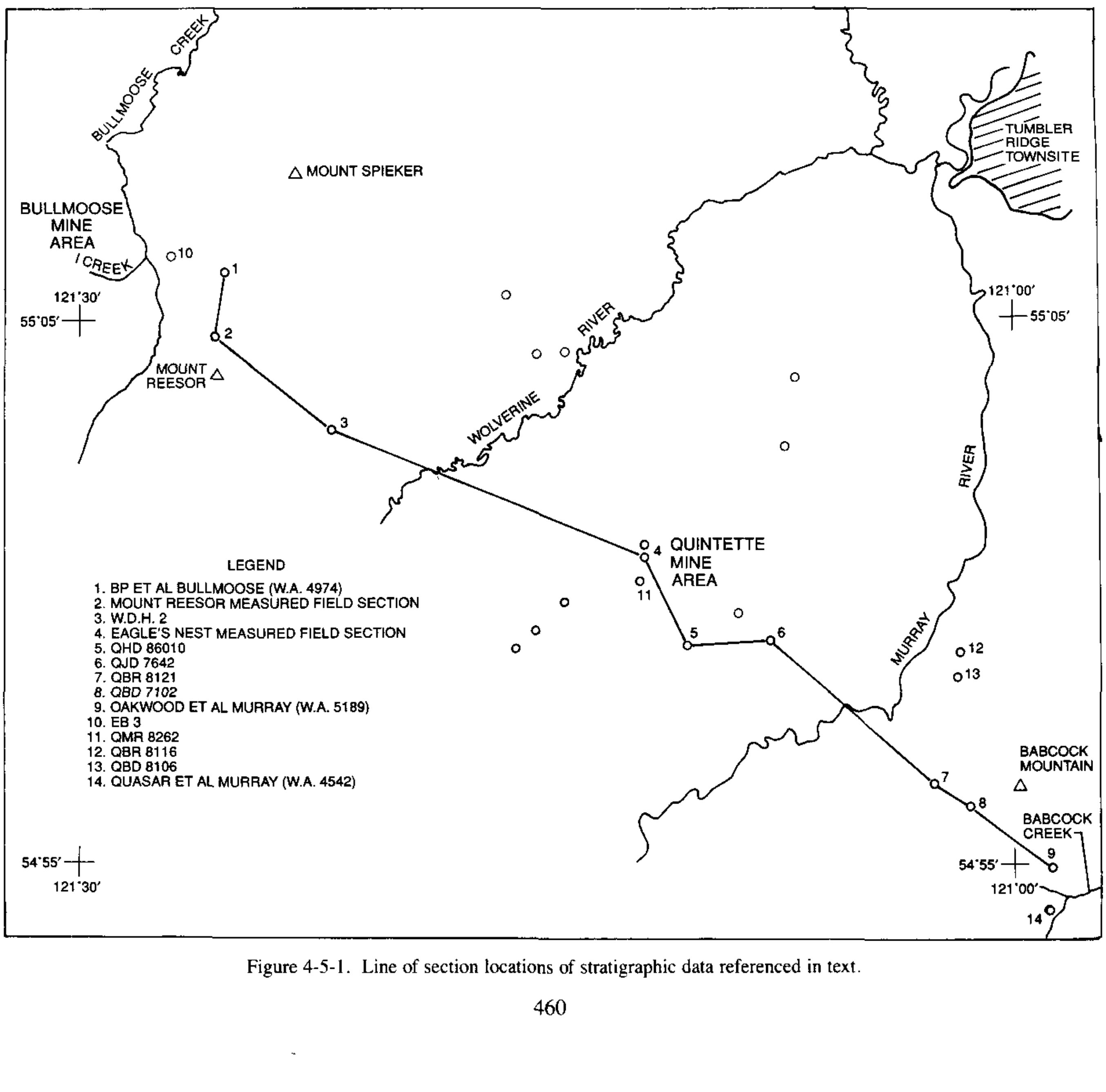

Figure 4-5-1. Line of section locations of stratigraphic data referenced in text.

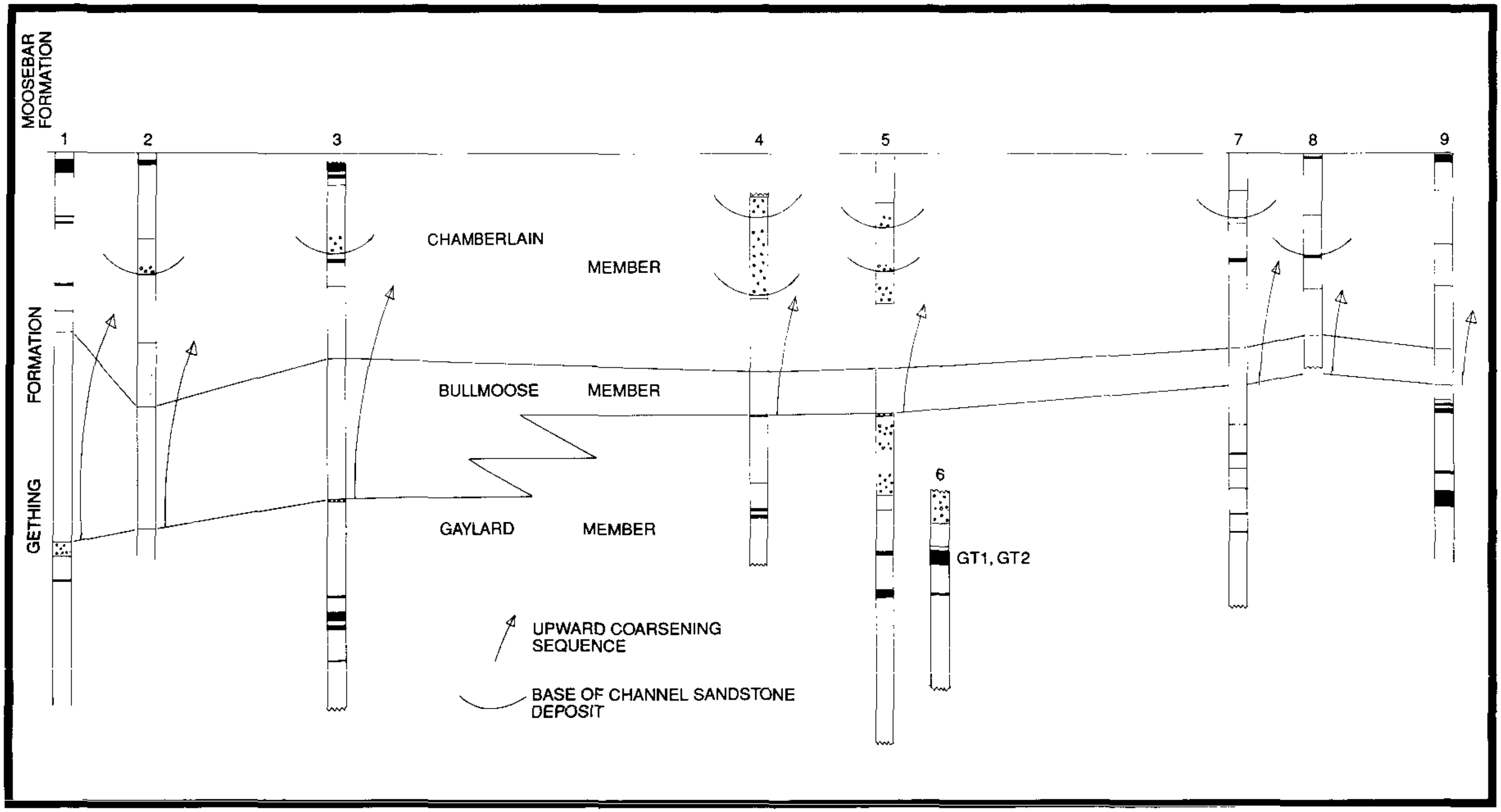

Figure 4-5-2. Correlation of the Gething Formation (*see* Figure 4-5-1 for locations).

section, near Mount Spieker, it reaches 5 metres in composite thickness. Exploration work on the Gething Formation was done in this area by Ranger Oil Ltd. in 1977 and 1982. More recently Bullmoose mine geologists exposed a composite thickness of up to 3.5 metres of coal along the southwest limb of the South Fork syncline. The writer traced the seam through a number of fold zones in the vicinity of the mine. The extrapolation of this trace indicates potential for preservation of the Bird seam in the hinge area of the South Fork syncline across I Creek (Figure 4-5-1). The area of preservation would be small (about 1 square kilometre) but close to surface. The closest drill hole to this area is EB 3 to the east, which intersected 2.5 metres of the Bird seam.

BULLMOOSE MEMBER SHALES AND BASAL SANDSTONES OF THE CHAMBERLAIN MEMBER

The Bullmoose member thins from 50 metres in the north to 15 metres at the Quintette mine. It consists of marine shale mottled with trace fossils and graded siltstones (turbidites). The shale passes stratigraphically upward into interbedded sheet sandstones and siltstones. The upward appearance of thick, parallel-laminated to low-angle crossbedded arenites marks the contact with the Chamberlain member. The entire lithological transition constitutes an upward-coarsening sequence which is marked on each drill hole along the line of section. The shale of the Bullmoose member becomes more silty to the south and the proportion of sand to shale in the upward-coarsening sequence is greater. This suggests a southward shoaling of the marine embayment represented by the shale deposits of the Bullmoose member.

The sandstone facies appears to represent wave-dominated delta-front deposits. At Mount Reesor, hummocky and swaly cross-stratification appears to represent storm activity on this front, alternating with periods of quiescence marked by horizons of intense vertical burrowing. To the south at Quintette, bioturbation is lacking and the sandstones include thin sheet-like beds of conglomerate.

GAYLARD MEMBER

South along the line of section, shales of the Bullmoose member appear to pass laterally into sandstones, then conglomerates and finally coal measures of the Gaylard member. The lateral change is first marked in the stratigraphic section at the Eagle's Nest. Here, the Bullmoose shales are apparently replaced by 22 metres of horizontally laminated and low-angle crossbedded arenites of probable shallow-marine origin. To the south, at QHD 86010, the arenites are replaced by 32 metres of clean quartzitic conglomerates and quartzitic arenite. The basal contact is marked by a rapid increase in argillaceous content and a "dirty" appearance (lithic matrix of the arenite) suggesting derivation of the upper lithology by reworking and "washing" of the pre-existing rocks. These shoreface or coastal bar deposits pass southward along the line of section into coal measures, as evidenced in QBR 8121 and the Oakwood et al Murray well (W.A. 5189).

Coals of economic thickness in the Gaylard member south of the Sukunka River include the "middle" coals of the Sukunka deposit and the Hermann Gething coals at Quintette. The Hermann Gething coals, GT1 and GT2, are shown on the line of seciton. They lie 43 metres below the top of the Gaylard member, 130 metres below the Moosebar-Gething contact and comprise 5 to 6 metres of coal. This thickness, however, does not appear to persist laterally. To the northwest, the coals thin to less than 4 metres (apparent thickness) in QMR 8262 (56 metres depth) and less than 2 metres at the Eagle's Nest, at about the same stratigraphic position. The stratigraphic position of these coals was not reached in drill holes to the east (QBD 8106, QBR 8116). To the southeast there are only very thin coals in QBR 8121, but further away, thick (up to 7 metres) coals are present about 37 metres below the top of the Gaylard member in Oakwood et al Murray (W.A. 5189) and Quasar et al Murray (W.A. 4542). These wells are located south of Babcock Mountain in an area untested for coal at this stratigraphic interval. The coal is found at depth in the petroleum wells but fold structures bring the interval close to surface nearby (for example, Waterfall Creek anticline).

FUTURE WORK

Future work will include a stratigraphic fence diagram of the three members of the Gething Formation. This is probably the best means of gaining an overview of coal thickness trends and lateral facies relationships with a minimum of effort and time.

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KINUSEO MAPPING AND COMPILATION PROJECT (93I/14, 15; 93P/03)

By W. E. Kilby and S. T. Johnston

KEYWORDS: Coal geology, Kinuseo, Bullmoose, Goodrich sandstone, Shaftesbury Formation, Kaskapau Formation, Cardium Formation, Muskiki Formation, Badheart Formation, Puskwaskau Formation.

INTRODUCTION

The Kinuseo mapping and compilation project is a continuation of the 1986 Bullmoose mapping project (Kilby and Wrightson, 1987a,b,c). The objective is to produce 1:50 000-scale geologic maps of the Kinuseo Falls and Kinuseo Creek areas, 93I/14 and 93I/15 (Figure 4-6-1). The maps will include data collected in the field during July and August 1987, together with a significant amount of data compiled from other sources. All of the data will be compiled into a computer processible format for distribution.

In addition to the compilation and mapping in the Kinuseo areas, additional work was carried out in the Bullmoose Creek area (93P/03). Several parts of the Open File 1987-6 map were modified as a result of this re-examination. This paper discusses the mapping in the Kinuseo areas and the revisions to the Bullmoose mapping.

LOCATION

The project area encompasses about 1640 square kilometres in the Northeastern British Columbia Coal Development (Figure 4-6-1). The map area straddles the Rocky Mountain foothills and overlaps onto the Front Ranges to the southwest. This study examines only those strata underlying the foothills. Elevations range from 2800 to 6800 metres. Vegetation varies from alpine tundra to mature stands of pine

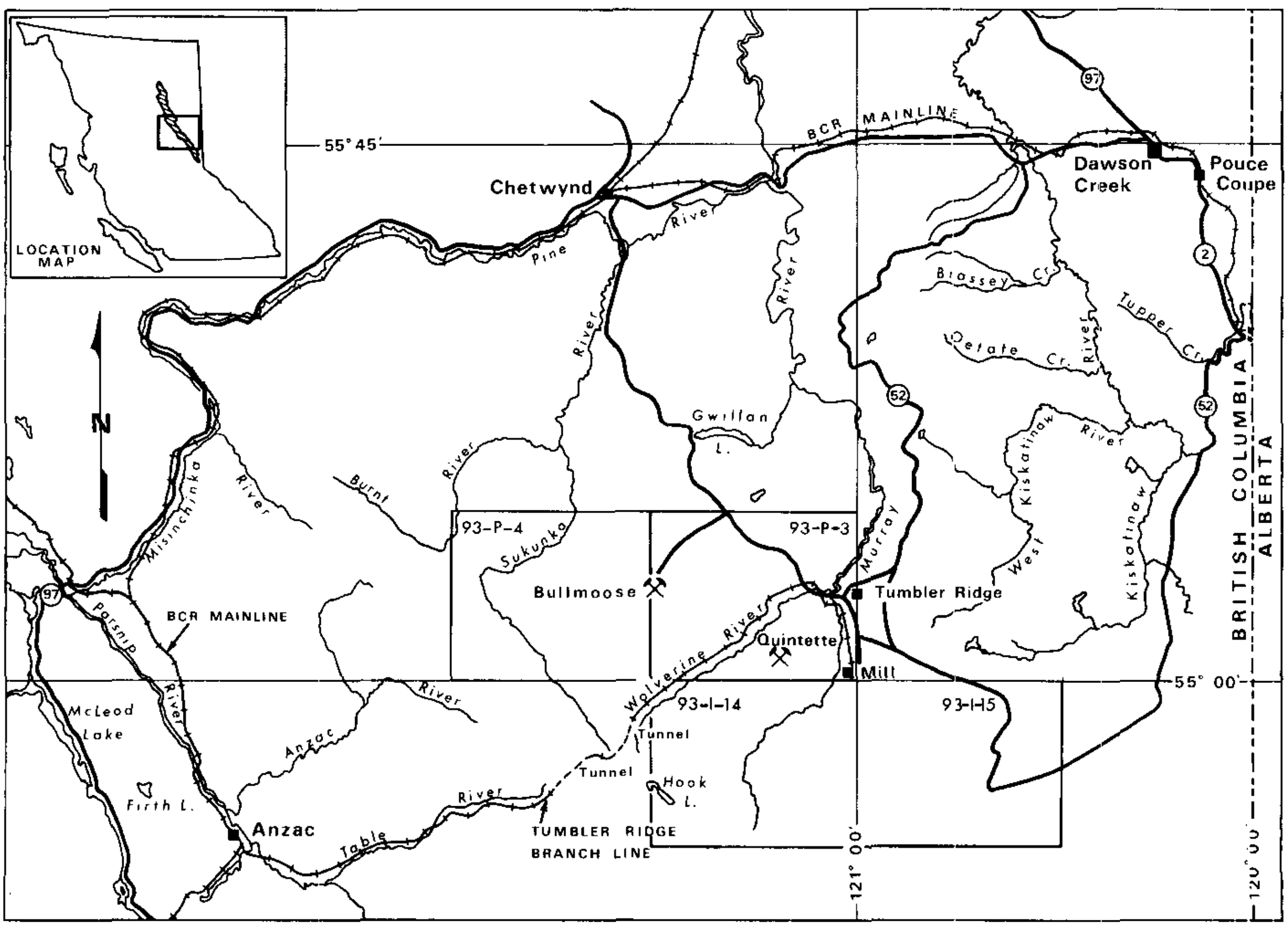

Figure 4-6-1. Study area location map.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

SERIES	GROUP	MAP SYMBOL	FORMATION	THICKNESS IN METRES	LITHOLOGY
UPPER CRETACEOUS		uKw	WAPITI	1000	Non marine interbedded conglomerate, sandstone, mudstone and coal
	SMOKY	uKp	PUSKWASKAU	210	Concretionary grey marine shale; coarsens upward to marine sandstone (Chungo)
		uKb	BADHEART	10	Marine and non marine quartz sandstone
		uKm	MUSKIKI	65	Grey marine shale; rust weathering; concretionary
		uKc	CARDIUM	40	Marine and non marine sandstone; conglomerate in upper part
		uKk	KASKAPAU	750	Dark grey marine shales; interbedded sandstone and shale in lower part
		uKd	DUNVEGAN	475	Marine and non marine sandstone, shale and coal
LOWER CRETACEOUS	FORT ST. JOHN	Ksh	SHAFTESBURY	400	Dark grey marine shale, locally silty with sideritic concretions; minor conglomerate and sandstone. Includes the Goodrich sandstone
		Kbc	BOULDER CREEK	120	Fine grained, well-sorted sandstone; massive conglomerate; non marine sandstone and mudstone and coal
		Kh	HULCROSS	100	Dark grey marine shale with sideritic concretions
		Kg	GATES	130	Fine-grained, marine and non marine sandstones; conglomerate; coal; shale and mudstone
		Km	MOOSEBAR	130	Dark grey marine shale with sideritic concretions; glauconitic sandstone and pebbles at base
	BULLHEAD	Kge	GETHING	375	Fine to coarse-grained, brown, calcareous, carbonaceous sandstone; coal, carbonaceous shale, and conglomerate
		Kcd	CADOMIN	40	Massive conglomerate containing chert and quartzite pebbles and sandstone
	MINNES	JKm	UNDIFFERENTIATED	1700	Thinly-thickly interbedded, shale, sandstone, siltstone and coals
JURASSIC		Jf	FERNIE	700	Black marine shale

Figure 4-6-2. Stratigraphic table (modified after Stott, 1983).

and spruce. Three major drainage systems, the Kinuseo Creek, the Flatbed Creek and the Murray River, crosscut the regional structural trend. These water courses follow U-shaped valleys carved during the Pleistocene glaciation. Access is provided by one paved highway (No. 24), one gravel highway (No. 52) and numerous forestry and coal company access roads.

DATA

A large amount of surface and subsurface data is available for this project. The complete database includes 13 465 outcrop stations with orientation data, 473 coal company boreholes, 45 oil and gas wells and 6858 topographic points digitized from 1:50 000 NTS maps. Much of the previously existing outcrop data was collected from coal company exploration maps on file with the ministry by contract personnel under the Canada/British Columbia Coal Data Acquisition Program. Coal exploration borehole data were obtained from assessment reports on file with the Geological Survey Branch and oil and gas well information was obtained from the Petroleum Resources Division of the Ministry of Energy, Mines and Petroleum Resources in Victoria. A portion of the Kinuseo Creek map sheet was compiled from detailed deposit modelling work conducted during the 1987 field season (Wrightson, this volume). Fieldwork concentrated on the poorly mapped regions within the study area and zones of structural complexity.

Microcomputers are being used for data storage, processing and data displays. For a review of the procedures used and a description of the hardware and software utilized during the project see Kilby and Wrightson (1987a).

STRATIGRAPHY

The foothills within the study area are underlain by Jurassic and Cretaceous marine and nonmarine strata. The

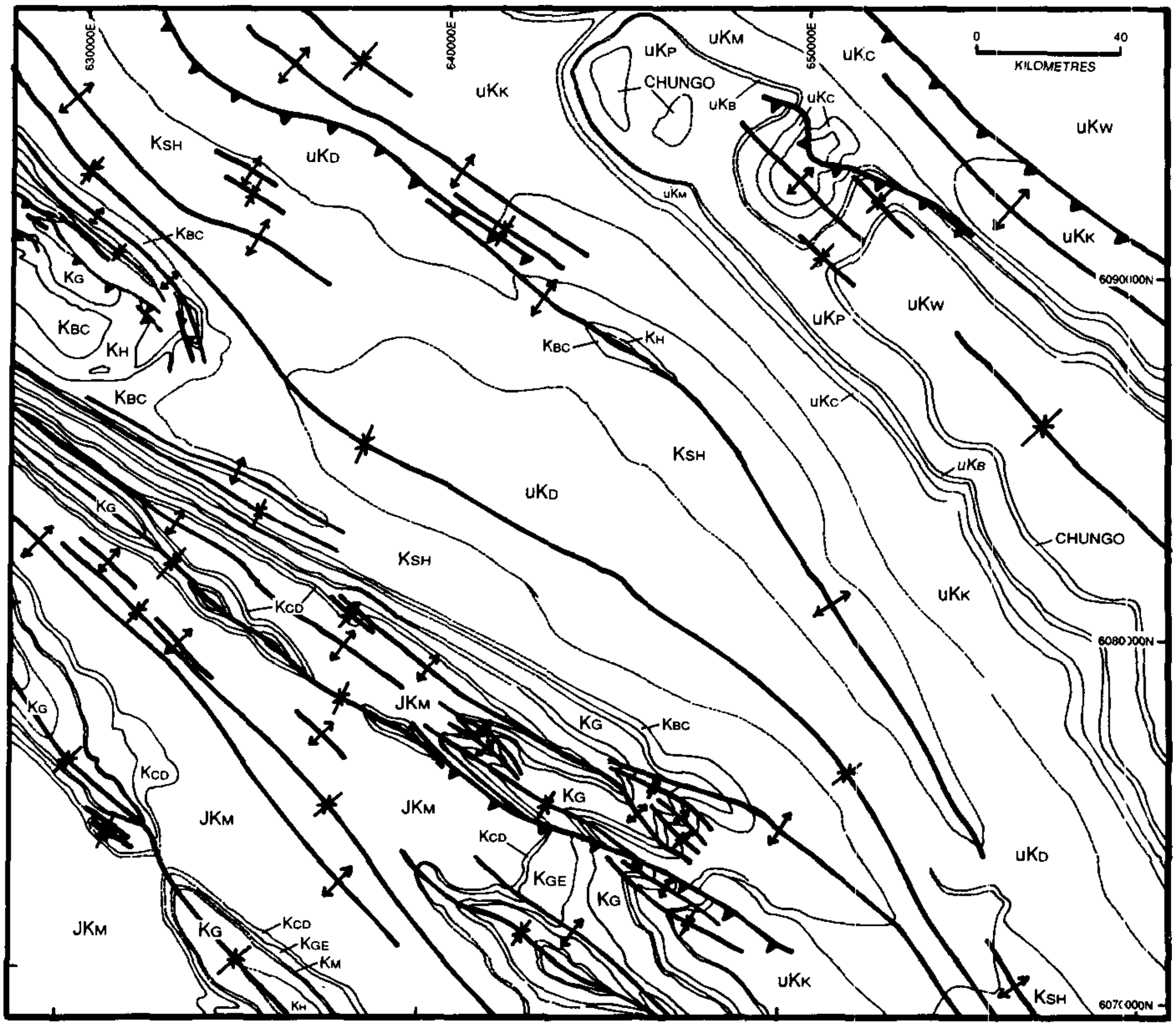

Figure 4-6-3. Kinuseo Falls map sheet (93I/14).

regional stratigraphy has been investigated by Stott (1967, 1968, 1973 and 1982). The formations and their approximate thicknesses are summarized in Figure 4-6-2. Descriptions of formations within the Minnes, Bullhead and Fort St. John groups and the Dunvegan Formation are included in Kilby and Wrightson (1987) and are not repeated here. One difference in the Fort St. John Group in the Kinuseo areas is described below.

The Goodrich sandstone, part of the Fort St. John Group, forms a mappable unit in the Bullmoose area and has formation status there (Kilby and Wrightson, 1987a). The sandstone, which separates similar marine shales of the Hasler and Crusier formations, exhibits a regional thinning to the south. In the Kinuseo areas, the Goodrich sandstone is composed of a poorly exposed thin sandstone which cannot be mapped on the surface or in the subsurface at a scale of 1:50 000. Because this sandstone is unmappable within the study area, the Hasler, Goodrich and Crusier formations have been combined as the Shaftesbury Formation.

SMOKY GROUP

Kaskapau Formation

The Kaskapau Formation is largely composed of dark grey marine shale. The contact with the underlying Dunvegan Formation is thought to be unconformable. Sandstone horizons several metres thick are present near the base of the shale. At the top of the formation, interbedded sandstones and shales grade into the overlying Cardium Formation. The Kaskapau Formation is generally recessive, outcropping only along river valleys and roadcuts.

Cardium Formation

The Cardium Formation consists of a lower marine sandstone and an upper nonmarine sandstone and mudstone sequence. Conglomerates are also locally present near the top of the formation. The sandstones often exhibit extensive bioturbation. Contact with the overlying Muskiki Formation

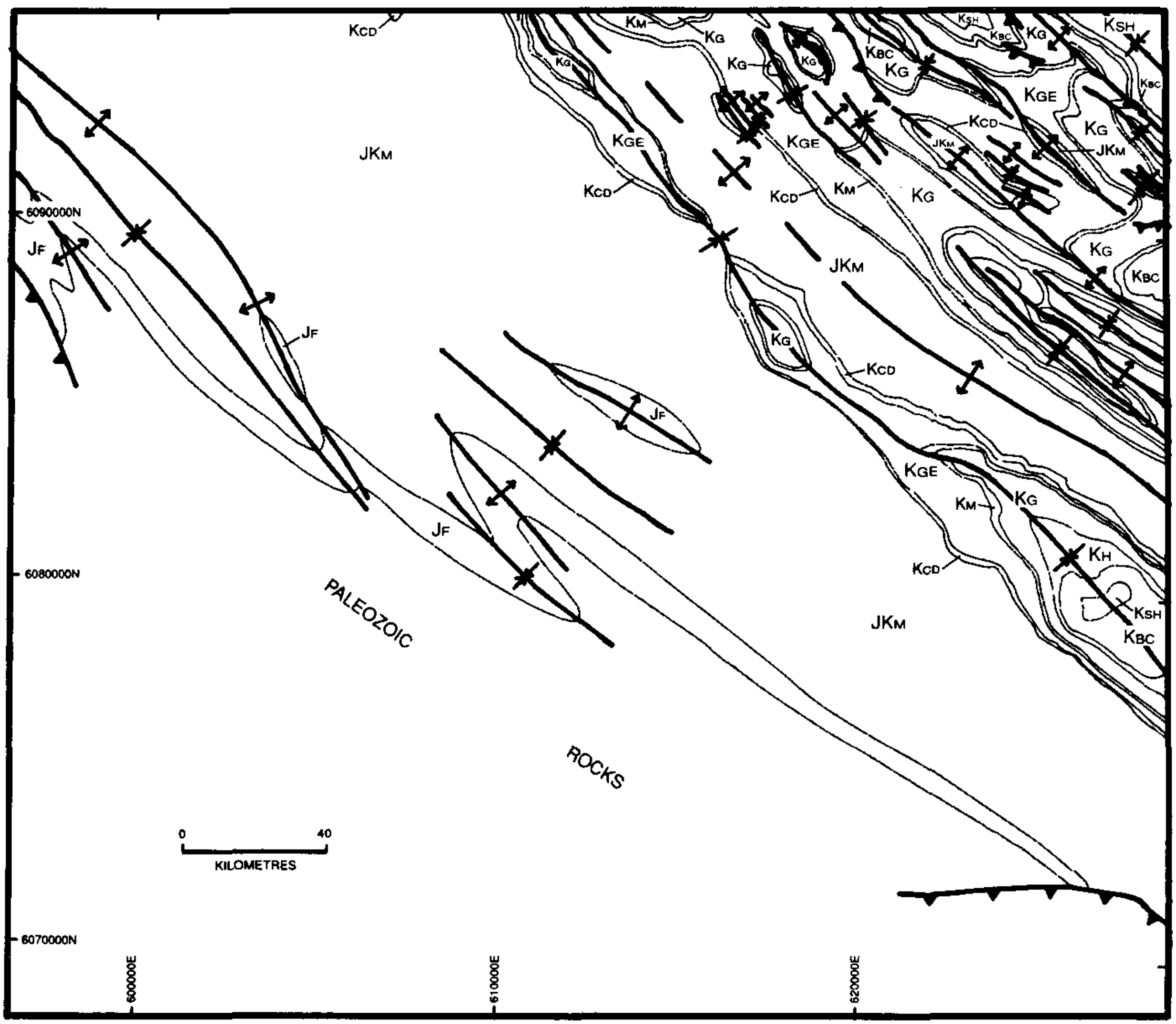

Figure 4-6-4. Kinuseo Creek map sheet (93I/15).

is abrupt and is characterized by the presence of a thin and discontinuous pebble-lag conglomerate.

Muskiki Formation

The Muskiki Formation is a monotonous sequence of rusty weathering, concretionary, grey marine shales. The shales grade upwards into siltstones which underlie the Badheart Formation.

Badheart Formation

The Badheart Formation is a marine to nonmarine sequence of sandstones which are very similar to the sandstones of the Cardium Formation.

Puskwaskau Formation

The Puskwaskau Formation is a rusty weathering marine shale unit. The shales are concretionary and coarsen upwards. The unit is locally capped by fine-grained sandstones. These sandstones, where present, are given member status within the Puskwaskau Formation and are known as the Chungo member.

Wapiti Formation

The nonmarine Wapiti Formation is composed of fining-upward sandstone sequences interbedded with mudstone and some coal.

STRUCTURE

The study area straddles the foothills structural province. Deformation and shortening have been accommodated largely by the development of northwest-trending box and chevron folds. The lack of marker horizons within the Fernie Formation and the Minnes Group prevented the detailed delineation of structure in areas underlain by these strata. In the inner foothills, large synclines characterized by steeply dipping limbs which expose strata of the Bullhead and Fort St. John Groups are separated by narrow complex anticlines (Figure 4-6-3). Folds in the outer foothills are broad open structures characterized by gently dipping limbs (Figure 4-6-4).

No major thrust faults cross the area. The Bullmoose thrust, a prominent structure to the north (Kilby and Wrightson, 1987b) dies out just north of the Murray River. Minor thrust faults, with displacements of less than 500 metres, are evident in the Babcock Mountain area and in the outer foothills near Thunder Mountain. In addition many of the shale sequences have acted as zones of detachment and exhibit complex internal folding and faulting not evident in the enclosing strata.

ECONOMIC GEOLOGY

Coal prospects within the study area, dominantly in the Gates Formation, have proved to be economically viable. Quintette Coal Mines Ltd. has recently begun mining coal seams included in the Gates Formation from the Shikano pit.

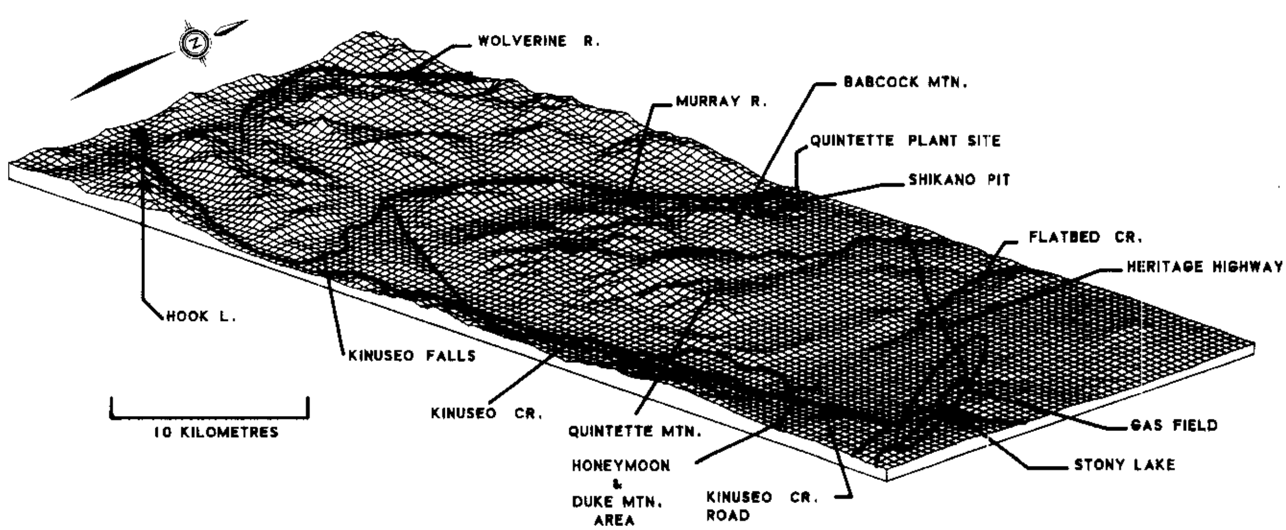

Figure 4-6-5. Isometric view of study area, showing location of infrastructure, major developments and geographic features.

Potential coal mines have been identified on Babcock Mountain and in the Honeymoon syncline – Duke Mountain area (Figure 4-6-5).

Oil and gas exploration has identified several gas pools present beneath the outer foothills. These reservoirs, apparently associated with blind thrusts, have also proved economically viable.

BULLMOOSE PROJECT — REVISIONS AND ADDITIONS

The Bullmoose project was a mapping and compilation project carried out during the 1986 field season. The areas covered in that survey were 93P/03 and 93P/04 (Figure 4-6-1). The style of the project was similar to the Kinuseo project. Due to the large areas covered and the heavy reliance on previous workers' interpretations, some problem areas were detected. These areas were addressed during the 1987 field season as part of the Kinuseo project.

A portion of the Tumbler Ridge map sheet, 93P/02, was examined to provide continuous coverage of the Upper Cretaceous Smoky Group strata between the Bullmoose and Kinuseo project areas.

The Bullmoose project emphasized mapping the Minnes Group strata, rather than the strata above the coal measures, once the coal-measure mapping was complete. Severe folding and lack of mappable units within the Minnes Group resulted in difficulties in interpretation. Little emphasis was placed on mapping the strata above the Boulder Creek Formation, which resulted in errors in the map published as Open File 1987-6; these errors have now been corrected (Figure 4-6-6).

The Kinuseo project concentrated on the strata above the coal measures to maximize useful information from the resources available.

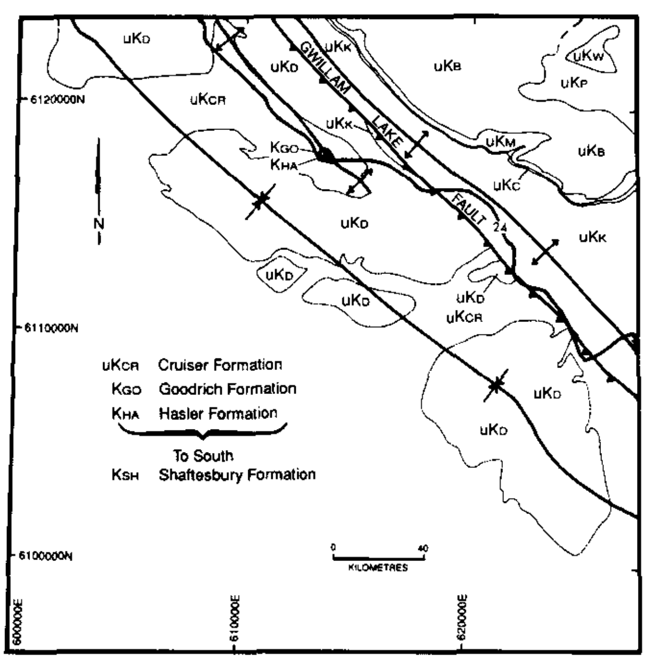

Figure 4-6-6. Eastern portion of the Bullmoose Creek map sheet (93P/3) showing revisions to Open File 1987-6.

Problems with the Bullmoose open file map were detected by the authors as well as coal industry geologists working in the area. We are grateful for the interest and attention paid to the project by these individuals and hope this style of input will continue and result in a superior final geological interpretation.

GWILLAM LAKE FAULT

The Gwillam Lake fault is a regional thrust fault which cuts across the eastern part of the Bullmoose Creek map sheet. D.F. Stott described this structure in 1968. Detailed mapping with a different interpretation of the structure was done by P. Jones in 1959. The authors have adopted the latter interpretation without field evidence of their own. Stott's interpretation was confirmed (Figure 4-6-6) by field data collected during 1987 and a different interpretation of the stratigraphy east of the fault. Along the fault trace on maps 93P/03, 93P/02 and 93I/15, Kaskapau Formation strata form the footwall, and Dunvegan and/or Kaskapau strata are found in the hangingwall. The fault is believed to terminate a short distance south of a road exposure at 6103700N 631000E in the Tumbler Ridge map area (93P/02) and is represented by broad folds in the Kinuseo Creek map area.

SMOKY GROUP STRATA

Open File 1987-6 shows a large exposure of Kaskapau Formation strata east of Bullmoose Creek. This interpretation was consistent with both major compilation sources used: Stott, 1982 and Jones, 1960. Formational thickness calculations, airphoto interpretation and field examination have resulted in a reinterpretation of the interval to include all of the Smoky Group. Cardium, Muskiki, Badheart and Puskwaskau strata are all found on Mount Bergeron. Wapiti strata are also interpreted on the eastern edge of the map sheet (Figure 4-6-6). These upper Cretaceous rocks can be traced through the Tumbler Ridge map sheet, along Tumbler Ridge, to the Kinuseo Creek map sheet where they cover much of the eastern half of the area.

BULLMOOSE THRUST - A FOLDED THRUST FAULT NEAR THE MESA PIT

Placement of the Bullmoose thrust fault through the Mesa pit on Open File 1987-6 drew valid criticism as no large displacement fault had been encountered during the extensive exploration activity in the area. Detailed examination of the area has led to a slight revision of the original interpretation (Figure 4-6-7). It is still felt that the Bullmoose fault runs through the Mesa pit area but not as one discrete fault and with less displacement than in areas to the north. The displacement in the pit area occurs along a large number of minor faults, forming a duplex zone in the coal-bearing Gates Formation. Above the Gates Formation, all the displacement is confined to a narrow fault zone, the Bullmoose thrust fault. This fault is recognized on the Mesa pit access road, a short distance east of the pit, where it is east dipping and displaces the Boulder Creek Formation. Displacement is about 425 metres which corresponds to the sum of the displacements seen along faults such as the Mesa fault zone and Sheriff faults in the Mesa pit. The upper detachment zone of the Mesa pit duplex zone was located below a competent Gates conglomerate unit. As the fault cuts up-section through this conglomerate, it remains a discrete zone with a fault to bedding angle of 30 degrees as it cuts though the Hulcross, Boulder Creek and Hasler formations.

A thin coal seam near the base of the repeated Boulder Creek Formation was sampled on either side of the thrust (Figure 4-6-7). The hangingwall sample had a significantly higher mean random vitrinite reflectance than the sample from the same seam in the footwall ($\bar{R}m$ 1.21 versus $\bar{R}m$ .79). At present the only plausible explanation for this large rank difference is tectonic heating due to the proximity of the hangingwall sample to the fault. However it must be noted that there is a significant maceral difference between the two samples. The higher rank, hangingwall sample is vitrinite rich while the footwall sample is rich in micrinite. More detailed sampling will be required to ascertain the cause of this rank and maceral variance.

COAL OCCURRENCES IN OTHER THAN GATES AND GETHING STRATA

Coal seams were sampled from the Boulder Creek, Dunvegan, Kaskapau and Wapiti formations during the field season.

A basal Wapiti seam outcrops in a roadcut along Highway 52 just east of Quality Creek in the Tumbler Ridge map area. It is 90 centimetres thick and had a $\bar{R}m$ value of .55. At this location the seam contains a 3-centimetre, altered volcanic-ash band or tonstein. X-ray diffraction mineralogical analysis has shown this rock to be kaolinite with a trace of quartz. This locality contains an excellent exposure of the Chungo member of the Puskwaskau Formation.

A 10-centimetre coal seam occurs within the marine shales of the Kaskapau Formation along Bullmoose Creek at 6118300N 615600E. The coal has a $\bar{R}m$ value of .64. Maceral examination showed it to contain vitrinite with about 1 per cent liptinite (sporinite and cutinite), 1 to 2 per cent pyrite, and much less than 1 per cent inertinite. The contacts of the seam are slightly slickensided but it is not thought to be tectonically implaced. The coal possibly originated as a raft of vegetation which was washed out to sea.

Four occurrences of lower Dunvegan coals were sampled. All occurrences are in or near the hangingwall contact with the Gwillam Lake fault in the Bullmoose Creek and Tumbler Ridge map areas. Seam thicknesses ranged from 10 centimetres to 1.5 metres. Mean random reflectance ($\bar{R}m$) values range from .67 to 1.03.

SUMMARY

The foothills within the study area are divisible into inner and outer regions. The inner foothills are characterized by large folds with steeply dipping limbs which expose the Fort St. John Group, including the economically interesting coal measures of the Gates Formation, and older strata. A folded thrust fault has been documented in this zone to the north, in the Bullmoose Creek map area. Strong evidence of tectonic heating associated with faulting is also presented. The outer foothills are characterized by broad open folds with gently dipping limbs. Blind thrust faults beneath the outer foothills area are associated with economically viable gas pools.

The *Kinuseo mapping and compilation project will* provide 1:50 000 mapping coverage of the 93I/14 and 93I/15 map sheets together with updates to Open File 1987-6. Processing of the large quantity of structural data available for this project is being facilitated by the use of microcomputers. The resulting database will aid further, more detailed studies.

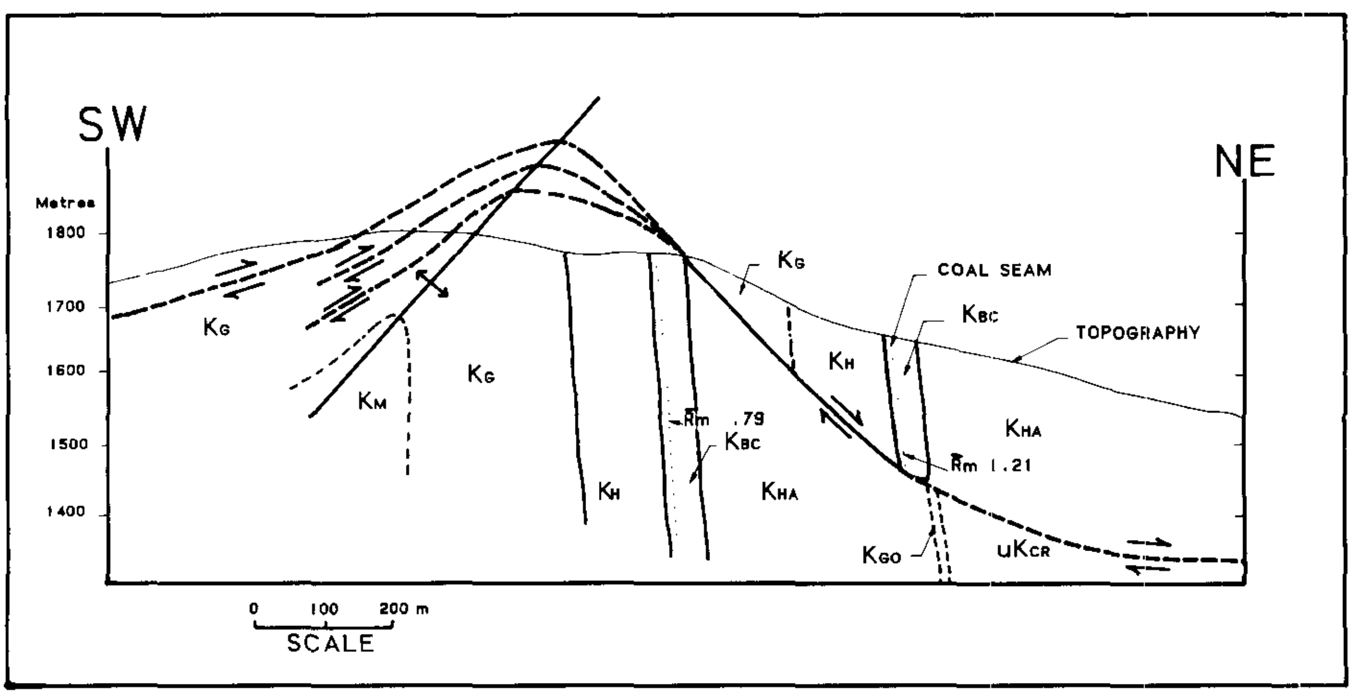

Figure 4-6-7. Cross-section through the Mesa pit area, showing folded thrust fault and Boulder Creek coal sample locations with $\bar{R}m$ values.

ACKNOWLEDGMENTS

The authors would like to thank C.B. Wrightson for his invaluable input to this project. David Thomas provided able field assistance during the field study. Joanne Schwemler provided coal petrography sample preparation and analysis and Dr. J.T.Y. Kwong provided X-ray diffraction analysis.

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GEOLOGY OF DUKE AND HONEYMOON PIT AREAS, MONKMAN COAL DEPOSIT, NORTHEAST BRITISH COLUMBIA COALFIELD*
(93I/15)

By C. B. Wrightson

KEYWORDS: Coal geology, Monkman coal deposit, computer modelling, Minnes Group, Bullhead Group, Fort St. John Group, Smoky Group.

INTRODUCTION

Coal licences were initially acquired on the Monkman property by McIntyre Mines Limited in 1970. Exploration mapping and drilling programs have been conducted over a 17-year period by McIntyre Mines Limited, Canadian Superior Exploration Ltd., Pacific Petroleums Ltd. and Petro-Canada Inc. The Monkman project is a joint venture between Petro-Canada, Mobil Oil Ltd., Smoky River Coal Ltd. and Sumitomo Corporation, with Petro-Canada acting as operator.

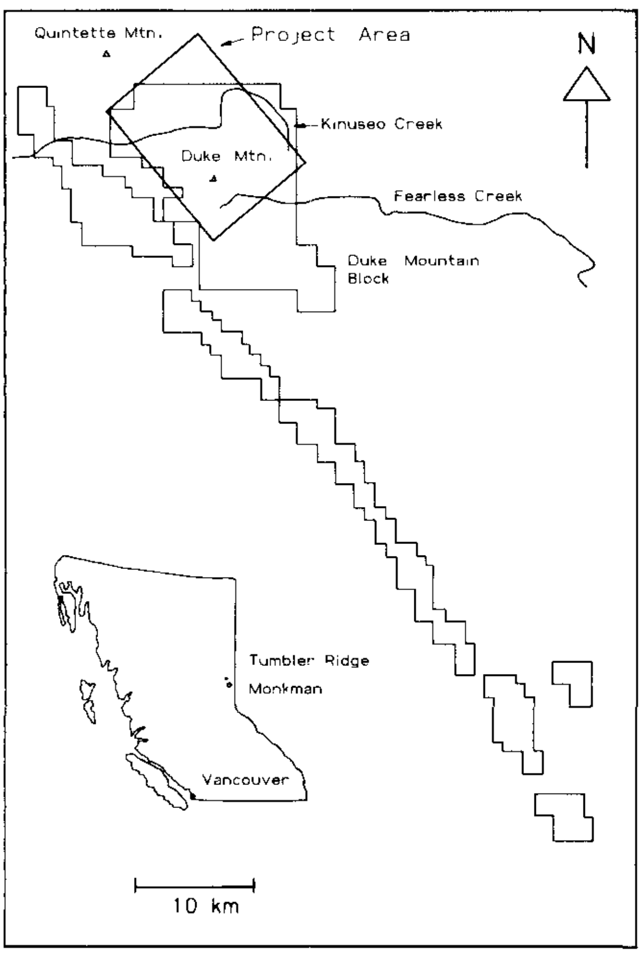

Figure 4-7-1. Study area location map with Monkman property coal licences.

The joint venture group has presented a proposal to the provincial government for an open-pit mine capable of producing 3 million tonnes per year of metallurgical coal. This proposal has obtained Stage II approval. The objectives of the author's project are to provide a detailed geological interpretation of the proposed mine area and to develop a computer-based model of the coal deposit. Information built into the model will be used to calculate coal reserves and stripping ratios. An assessment of the coal deposit will be available to the provincial government at the time that a mining project is initiated at Monkman. Methodology and computer technology developed during this project will be used to model and assess other coal deposits and to assist with the interpretation of structural geology.

LOCATION AND ACCESS

The Monkman coal deposit is located in the southern part of the Northeast British Columbia Coalfield approximately 30 kilometres southeast of the Quintette mine and 35 kilometres southeast of Tumbler Ridge (Figure 4-7-1). The project area covers 140 square kilometres in the inner foothills region of the Rocky Mountains. The Monkman property consists of 169 coal licences which cover 39 587 hectares. The Duke Mountain Block, in which Duke and Honeymoon pits are located (Figure 4-7-2), encompasses 20 745 hectares. Coal licences owned by Petro-Canada mark the northern boundary of the study area and Fearless Creek marks the southern boundary. Kinuseo Creek valley cuts across the northern part of the area. The valley contains up to 100 metres of unconsolidated overburden (Figure 4-7-2) which covers part of the proposed Duke and Honeymoon pits. Elevations vary from 950 metres in the valley floor of Kinuseo Creek to 1742 metres at the top of Duke Mountain. Vegetation ranges from spruce forests to alpine tundra.

Access into the Monkman area is via the Monkman Highway, a dry-weather road which parallels Kinuseo Creek and extends to just west of Kinuseo Falls on the Murray River. The Monkman Highway can be reached by gravel roads from Tumbler Ridge; Elmworth, Alberta; or from Dawson Creek along the Heritage Highway. An airstrip near Thunder Mountain permits access by light plane. Numerous coal exploration roads, petroleum industry access roads and seismic lines provide excellent access to most parts of the project area.

FIELDWORK

Prior to the 1987 field season, all pertinent open file coal assessment reports were examined. Geological maps of the area were used to obtain digitized outcrop information. A computer-based outcrop database was designed to store the

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

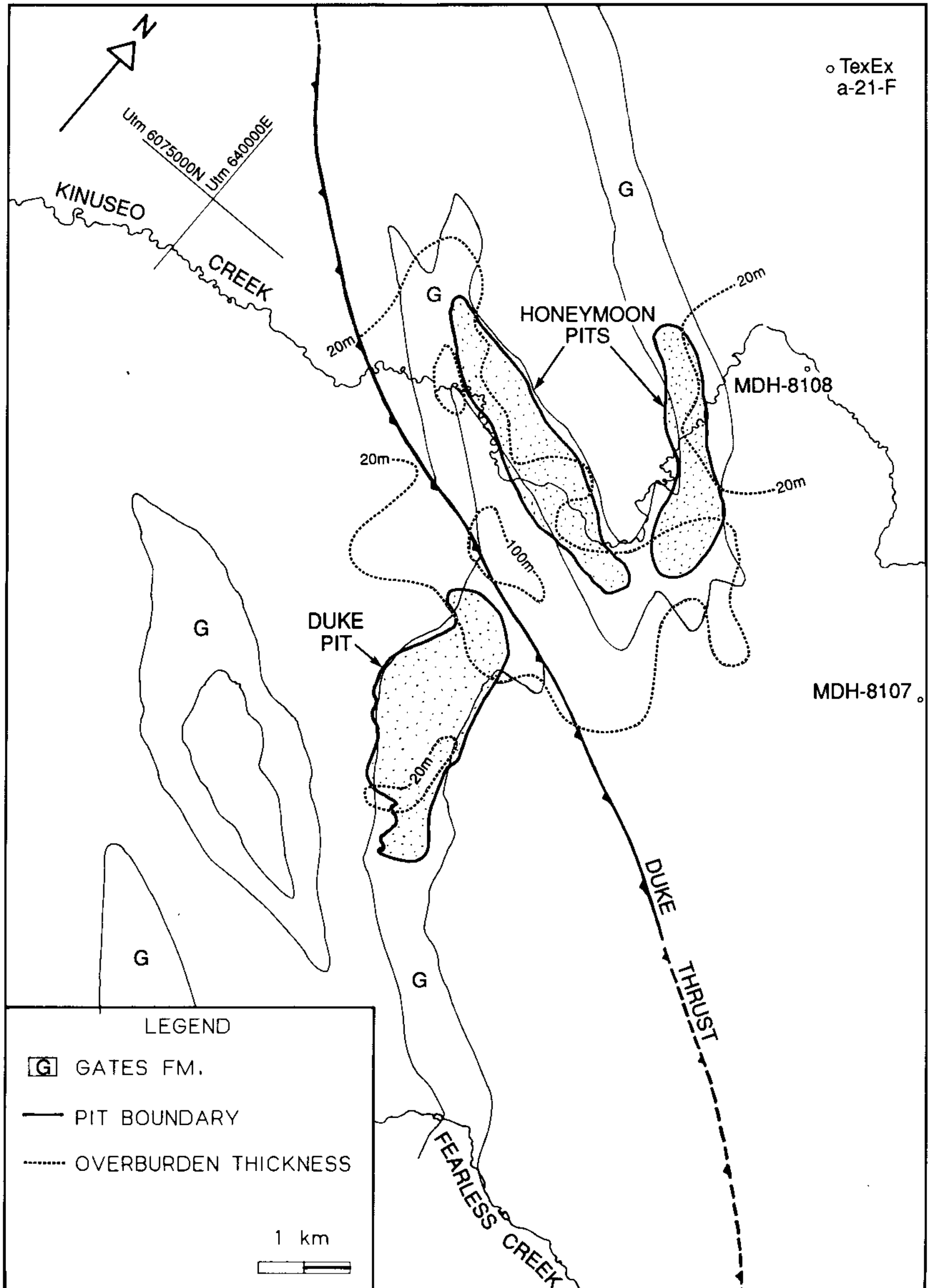

Figure 4-7-2. Subcrop map of the Gates Formation showing unconsolidated overburden thickness and Duke and Honeymoon pits.

information. Once completed, outcrop maps were produced and examined to identify areas which lacked data and to indicate areas with structural complexities or interpretation problems. Subsequent field mapping concentrated on collecting additional outcrop data at these locations and verifying the information over the remaining parts of the map sheet. New data were plotted on topographic maps at a scale of 1:5000. Airphotos at a scale of 1:40 000 were used to produce enlargements at a scale of 1:10 000. Outcrop information was also plotted on the photo enlargements.

Field mapping was conducted in conjunction with mapping carried out by W. Kilby and S. Johnston (1988) on NTS map sheets 93I/14, 93I/15 and 93P/02 at a scale of 1:50 000. Some outcrop data in the southeast corner of the geology map (Figure 4-7-3) is from this source. Information from 1955 outcrop data points and 211 drill holes was examined and incorporated into the geological interpretation.

METHODOLOGY AND DATA HANDLING

Computer-based methods have been used extensively to assist with data handling and display. Orientation parameters describing the geological structural features were calculated using computer-based numerical procedures (Charlesworth *et al.*, 1976).

Cross-sections were constructed by projecting outcrop and drill-hole data down plunge onto planes of cross-section. Assuming that the folded surfaces approximate cylindricity, the data can be reliably projected parallel to the fold axis. Lack of data, or poor distribution of orientations along both limbs and across the hinge zone of a fold, may result in unreliable fold axes orientations. In these cases an appropriate projection axis or fold axis orientation may be obtained by visually best-fitting the data by trial and error, using several different projection orientations.

Thick unconsolidated overburden covers parts of both the Duke and Honeymoon pit areas. Visual best-fit fold axes orientations were determined in these areas.

General data-handling methods are similar to those described by Kilby and Wrightson (1987). Drill-hole data have been incorporated into this study in a computer processible format. Information was divided into primary, secondary and tertiary categories and entered into three independent raw data files. Primary data consist of drill-hole identification, location (easting, northing and elevation), overburden thickness, total depth and original hole orientation measured as the hole trend and plunge. Secondary data consist of drill-hole deviation data entered as the measurement depth, the hole trend and the deviation measured in degrees from vertical. Tertiary data consist of the drilled depths and the identifying names of the horizons of interest. The raw data files were then processed to yield three additional files containing the data in formats ready to be processed or plotted on maps or cross-sections. Primary data for each drill hole are stored as separate records with indexing information used to locate the specific secondary and tertiary data for that hole. Secondary and tertiary data are stored in separate files as eastings, northings and elevations in format ready for posting to maps or cross-sections. Each entry is an independent record. Data points can be referenced and retrieved based upon locational parameters, drill-hole identification, or stratigraphic horizon.

Outcrop data were digitized using a GTCO digitizer connected to a Compaq portable 286 computer. Database maintainance and data processing and display were managed on a Wyse pc286 computer. Peripheral devices included a Houston Instrument DMP-52 plotter and an Epson FX-286e printer.

Database construction and maintainance were performed using the Geological Analysis Package of Cal Data Ltd. Display of the geological data was facilitated by the Structural Analysis module of the Geological Analysis Package, with a number of modifications by the author. Structural analysis of the outcrop data and drill-hole information processing was performed with programs written by the author. Outcrop data were digitized from geological maps using programs written by W. Kilby. Figures were produced using the ECAD computer-aided drafting program.

STRATIGRAPHY

Strata exposed in the area range from the Lower Cretaceous to Jurassic Minnes Group, to the Upper Cretaceous Kaskapau Formation. The stratigraphy in the area has been described extensively by Stott (1968 and 1982) and others. Descriptions of sedimentology and depositional environments are beyond the scope of this study and are not included here. Table 4-7-1 summarizes each formation in terms of a general description and the thickness specific to the Monkman location. Thicknesses and descriptions were obtained from outcrop information, coal exploration drill holes and petroleum industry exploration wells. Texaco Exploration Canada Ltd. drilled an exploration well, TexEx Flatbed a-21-F/93-I-15, in the northeast corner of the map area (Figure 4-7-3). The entire stratigraphic sequence, from the Minnes to the Kaskapau, is penetrated by this hole. Brief descriptions of the stratigraphy follow.

MINNES GROUP

The Minnes Group consists of both marine and nonmarine strata ranging in age from Jurassic to Early Cretaceous. Lithologies include interbedded sandstones, siltstones and shales with minor coal seams.

BULLHEAD GROUP

CADOMIN FORMATION

The Cadomin Formation unconformably overlies the Minnes Group. It is approximately 45 metres thick and consists of two bands of chert and quartzite conglomerate separated by sandstone. The conglomerate framework is poorly sorted and ranges from grit to cobble-size fragments. The Cadomin Formation is easily mappable with prominent ridges often indicating its outcrop.

GETHING FORMATION

Gething strata consist of 140 metres of interbedded sandstone, siltstone, shale and coal. Lenticular conglomerate

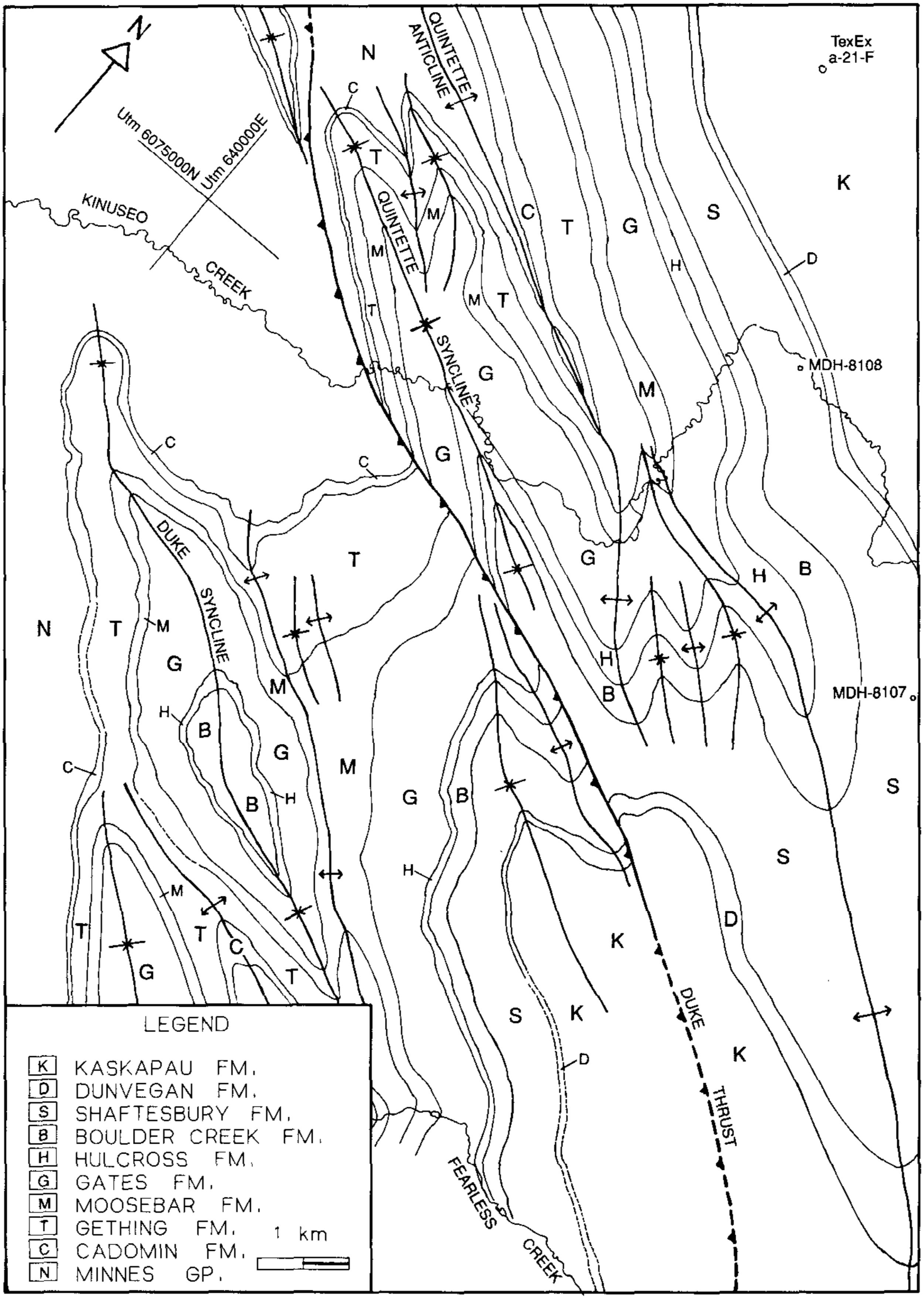

Figure 4-7-3. Geology of the Monkman coal deposit in the Duke and Honeymoon area.

TABLE 4-7-1
STRATIGRAPHIC COLUMN, MONKMAN AREA

SERIES	GROUP	FORMATION	THICKNESS IN METRES	LITHOLOGY
UPPER CRETACEOUS	SMOKY	KASKAPAU	400	Dark grey marine shales; interbedded sandstone and shale in lower part
UPPER CRETACEOUS	SMOKY	DUNVEGAN	30	Non-marine sandstone, some shale and coal
UPPER CRETACEOUS / LOWER CRETACEOUS	FORT ST. JOHN	SHAFTESBURY	250	Dark grey marine shale, locally silty with sideritic concretions; minor conglomerate and sandstone. Includes the Goodrich sandstone
LOWER CRETACEOUS	FORT ST. JOHN	BOULDER CREEK	90	Fine-grained, well sorted sandstone; massive conglomerate; non-marine sandstone and mudstone and coal
LOWER CRETACEOUS	FORT ST. JOHN	HULCROSS	80	Dark grey marine shale with sideritic concretions
LOWER CRETACEOUS	FORT ST. JOHN	GATES	250	Fine-grained, marine and non-marine sandstones; conglomerate; coal; shale and mudstone
LOWER CRETACEOUS	FORT ST. JOHN	MOOSEBAR	120	Dark grey marine shale with sideritic concretions; glauconitic sandstone and pebbles at base, coarsens up, Torrens member at top
LOWER CRETACEOUS	BULLHEAD	GETHING	140	Fine- to coarse-grained, brown, calcareous, carbonaceous sandstone; coal, carbonaceous shale, and conglomerate
LOWER CRETACEOUS	BULLHEAD	CADOMIN	45	Massive conglomerate containing chert and quartzite pebbles and some sandstone
LOWER CRETACEOUS / JURASSIC	MINNES	UNDIFFERENTIATED	1700	Thinly-thickly interbedded, shale, sandstone, siltstone and coals

bands are often found in the lower third of the Gething. In the Monkman area the coal seams are generally poorly developed and are of little economic interest.

FORT ST. JOHN GROUP

Moosebar Formation

The Moosebar Formation is about 120 metres thick. A thin glauconitic conglomeratic band marks the lower contact. This is overlain by bioturbated marine mudstone followed by a series of coarsening-up cycles. The Torrens member, which lies at the top of the Moosebar Formation, is a well-sorted beach sand 20 metres thick.

Gates Formation

The Gates Formation is comprised of approximately 250 metres of interbedded sandstone, siltstone, shale, coal and some conglomerate. Twelve coal seams, identified from oldest to youngest as B1 to B12, are distributed throughout the formation. Well-developed coal seams are present in the Gates Formation from just north of Bullmoose Creek southwards into Alberta.

Potentially mineable coal reserves have been identified in seams B1 to B9 in the Monkman area. Seams B3 and B4 are of most economic interest and constitute the majority of the coal reserves estimated by Petro-Canada in Duke and Honeymoon pits.

Hulcross Formation

Interbedded marine shale and siltstone, with some fine-grained sandstone, make up the Hullcross Formation. It is approximately 80 metres thick.

Boulder Creek Formation

The Boulder Creek Formation compises from 70 to 90 metres of conglomerate, sandstone, siltstone, shale and minor coals. The lowermost 30 metres consist of pebble conglomerate which is overlain by a finer grained interval. The upper 5 metres may be either pebble conglomerate or sandstone.

Shaftesbury Formation

To the northwest, the Shaftesbury Formation is differentiated into the Hasler, Goodrich and Cruiser formations, but these divisions have not been recognized in the vicinity of the Monkman deposit (Stott, 1982). The Shaftesbury Formation may be closely examined with outcrop data in the southeastern quadrant of the map sheet, in coal exploration drill holes MDH-8107 and MDH-8108 and in TexEx Flatbed a-21-F/93-I-15. The Boulder Creek Formation is overlain by 35 to 65 metres of marine shales, silty shales and thin fine-grained sandstones. Above this lies up to 18 metres of marine sandstone. TexEx a-21-F intersects two coarsening-up offshore-bar sandstones which are probably a marine equivalent to the Goodrich Formation. Marine sandstones in a similar stratigraphic position were located at several outcrops. Drill holes MDH-8107 and MDH-8108, however, did not intersect a recognizable sandstone horizon even though they are interpreted to have penetrated the lower portion of the Shaftesbury Formation. The sandstone interval is overlain by about 170 metres of marine shales. The top of these shales marks the top of the Shaftesbury Formation. Discontinuity of the marine sandstone interval makes mapping difficult and prevents division of the Shaftesbury Formation.

SMOKY GROUP

Dunvegan Formation

The Dunvegan Formation consists of 30 metres of argillaceous fluvial sandstones with minor amounts of shale and coal.

Kaskapau Formation

The Kaskapau Formation is comprised of about 400 metres of recessive, dark, marine shales with minor sandstone interbeds near the base.

STRUCTURE

Folds in the Monkman area generally display narrow hinge zones and planar limbs. Major structures are continuous along strike for several kilometres. Along strike the folds are characterized by variations in fold axis trend and plunge. Fold structures tend to die out with abrupt terminations. Duke syncline, Quintette syncline and Quintette anticline (Figure 4-7-3) display these characteristics.

At the north end of the map sheet Quintette anticline has a calculated trend and plunge of 113°/5°. Along strike to the southeast the fold axis orientation changes to 118°/2° and then to 125°/5°. Further south, outcrop data are rare where thick overburden covers Kinuseo Creek valley. Calculated fold axis orientations cannot be determined in this area. Numerous coal exploration drill holes are present in the valley and the continuation of the anticline was examined using these data. Visual best-fit fold axis orientations continue to increase in both trend and plunge to the southeast to maximums of 141°/11°. Rapid but consistent changes in trend, accompanied by an increase in plunge of macroscopic folds, may be indicative of a termination of the fold. Cross-sections further south show no indication of the continuation of Quintette anticline. Fold terminations will be examined in the next field season and outcrop data will be numerically analysed to determine if the folds display conical geometry.

At the northern end of Quintette syncline, the orientation of the fold axis is 121°/20°. To the southeast, the orientation gradually changes to 130°/2°. With the exception of the north end, orientation data are poorly distributed around the syncline.

Outcrop information is abundant along both limbs and across the hinge zone of Duke syncline. Calculated fold axis orientations were determined for four distinct segments or domains along the trend of the structure. At the north end, the fold axis trend and plunge are 313°/0°. The trend and plunge change to 125°/5° in the north-central part of the structure and shallow slightly to 124°/2° in the south-central portion of the fold. At the south end of Duke syncline the fold axis orientation changes dramatically to a trend of 290° and a plunge of 15°.

In the extreme northwest corner of the map sheet Duke thrust fault displaces Minnes strata over the Cadomin Formation in Quintette syncline. The western limb of the syncline is vertical to slightly overturned. Along strike to the southeast the fault cannot be traced by outcrop data, due to the overburden in Kinuseo Creek valley. Drill-hole information indicates continuity of the thrust to the southeast, where it is indicated by the positions of Dunvegan outcrops.

ECONOMIC GEOLOGY

Major economic interest in the area is in the Monkman coal deposit which contains large reserves of metallurgical coal. The deposit has reached an advanced stage of exploration and engineering planning and has received Stage II approval from the provincial government. Further development awaits tightening in the slack world coal markets.

Gas from Mississippian to Jurassic sediments is exploited to the east and north of the study area.

AKNOWLEDGMENTS

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Applied Geochemistry

APPLIED GEOCHEMISTRY SUBSECTION, OVERVIEW OF THE FIRST TWO YEARS*

by P. F. Matysek

KEYWORDS: British Columbia, applied geochemistry, Regional Geochemical Surveys, sampling procedures, analytical methods, orientation surveys, platinum, gold.

INTRODUCTION

British Columbia has challenging problems in the application of exploration geochemical techniques in Canada because of its complex geological history, mountainous terrain and mantle of glacial deposits. Baseline geochemical surveys, complimentary research and orientation surveys are essential prerequisites for the successful application of exploration geochemistry. Since 1976, the Geological Survey Branch has provided regional geochemical sediment and water data, largely with the cooperation of the Geological Survey of Canada. The Applied Geochemistry Subsection was formed in 1986 to provide better direction to the branch's geochemical surveys and to initiate research and development projects to promote more effective use of geochemistry by industry. It is committed to a spectrum of programs designed to aid, stimulate and promote the growth of the exploration and mining industry in British Columbia. This paper summarizes the status of the branch's 1986 and 1987 geochemical programs, and projects funded by the branch undertaken by Dr. W.K. Fletcher at The University of British Columbia.

To ensure that the branch's geochemical projects are timely and appropriate, an advisory group of six geochemists has been assembled from the exploration community (four), The University of British Columbia (one) and the Geological Survey of Canada (one). The purpose of this group is to obtain industry, university and federal contributions to the conception and formulation of the branch's geochemical programs. The committee meets with the branch at least twice a year to comment on proposed geochemical projects, review results and comment on their effectiveness.

1986-1988 GEOCHEMICAL PROGRAMS

RESPONSIBILITIES AND RESOURCES

The Applied Geochemistry Subsection is responsible for: (1) providing baseline geochemical data by conducting Regional Geochemical Surveys (RGS); (2) conducting field orientation studies and complimentary geochemical research; (3) demonstrating the usefulness of geochemical techniques; (4) developing methods in the processing and assessment of geochemical data by statistical and computer techniques; and (5) providing assistance and scientific leadership to the Geological Survey Branch, and the academic and exploration communities.

Staffing and funding of the subsection increased in 1987 to include contract geochemists Stephen Day and John Gravel and an operating budget of approximately $500 000. Funding for subsection activities comes in part from the enhanced Geological Survey Branch budget and the Canada/British Columbia Mineral Development Agreement. The bulk of 1987 funds (75 per cent) was spent on reconnaissance multi-element stream sediment and water surveys; the remainder was allocated to orientation surveys, research and development. Figure 5-1-2 and the accompanying Table 5-1-1 summarize 1987 geochemical projects that involved the subsection. Relevant details and highlights of these and earlier projects are described in this paper.

REGIONAL GEOCHEMICAL SURVEY PROGRAMS (RGS)

Since 1976, the Geological Survey Branch, in cooperation with the Geological Survey of Canada, has conducted regional geochemical surveys as part of the National Reconnaissance Program. This database represents multi-element determinations and field observations of reconnaissance sediment and water sampling of twenty-eight 1:250 000 National Topographic System (NTS) map areas (Figure 5-1-1). High quality analytical results are ensured by using specific and sensitive determination techniques and by monitoring analytical variation by duplicates and standards. Results from the RGS program are used by the exploration industry to assist in area selection and target identification and, in the longer term, as an indicator of regional geological or geochemical provinces that contain favourable exploration targets. To date, 41 per cent of British Columbia (approximately 390 00 square kilometres) has been sampled at an average density of one sample per 13 square kilometres (31 000 samples). Complete reconnaissance coverage of the province is anticipated by 1997 at current sampling rates. Details of the RGS Program are described by Matysek (1987). In an ongoing effort to improve the quality of the RGS Program, the Applied Geochemistry Subsection has introduced a number of enhancements in field procedures, data management, presentation and interpretation.

FIELD ENHANCEMENTS

Beginning in 1986, thanks to improved funding for the program, the branch was able to re-establish the policy of having a staff member responsible for quality control of the sampling program on a day-to-day basis. A ministry presence ensured that all aspects of sample collection, data recording, drying, packing and shipping were in accordance with standards set by the National Geochemical Reconnaissance Program.

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

TABLE 5-1-1
ACTIVITIES OF THE APPLIED GEOCHEMISTRY SUBSECTION, 1987

Number	Location	Description	Objectives	Results/Status
1	93L, E	Release of RGS 1986 stream and lake sediment data.	Provide baseline geochemical data. Results are used to identify both regional metallogeny and as a guide to locating mineral occurrences.	Over 100 data packets sold. Tabulation and assessment of new staking being compiled by D. V. Lefebure and M. H. Gunning in Exploration in British Columbia, 1987 (in preparation).
1a	93E	Evaluation of an ICP-ES geochemical package using 1986 RGS data.	Make recommendations concerning the selection of the most cost-effective and reliable technique for future RGS programs.	Preliminary analysis by Day, Matysek and Johnson in Geological Fieldwork, 1987.
2	104K, F, G, B, C	RGS 1987. Collection of stream sediments.	Provide baseline geochemical data.	Sampling completed over 35 000 km^2 area. 2726 samples collected at a density of one sample per 13 km^2. All samples will be analysed for gold plus 19 other elements. Further details by Gravel and Matysek in Geological Fieldwork, 1987. Release date, summer 1988.
3	92E, L, 102I	Orientation studies for RGS 1988.	Define appropriate sampling, preparation and analytical techniques for successful application of exploration geochemistry on Vancouver Island.	Samples currently being prepared and analysed. Preliminary results discussed by Matysek and Day in Geological Fieldwork, 1987.
4	Giant Nickel	Platinum in stream sediments.	Define exploration geochemical guidelines for the search for platinum and palladium in soils and stream sediments.	Samples currently being prepared and analysed.
5	Tulameen ultramafic complex	Platinum in soils and stream sediments (with UBC).	As above.	As above.
6	Franklin Camp	Platinum in soils and stream sediments (with UBC).	As above.	As above.
7	Scottie Creek	Platinum in soils and stream sediments (UBC).	As above.	As above.
8	Harris Creek	Gold in stream sediments (UBC).	Examine seasonal variations in gold content of sediments.	Full discussion by Fletcher and Day in Geological Fieldwork, 1987.
9	Mount Washington	Gold in stream sediments (UBC).	On-going study of distribution and behaviour of gold in stream sediments.	Samples currently being prepared and analysed. Results will be available by March 1988.
10	82F/11, 14	Detailed geochemical sampling by 1:50 000 mappers — Kokanee.	Integrate geochemical and geological data, to aid in the assessment of the mineral potential of the survey area.	141 conventional stream sediment and 12 bulk heavy mineral samples collected. Geochemical results will be released with 1:50 000 mapping open file.
11	93N/09	Detailed geochemical sampling by 1:50 000 mappers — Manson Creek.	As above.	23 conventional stream sediment and 21 bulk heavy mineral samples collected. Geochemical results will be released with 1:50 000 mapping open file.
12	104M/15	Detailed geochemical sampling by 1:50 000 mappers — Atlin.	As above.	93 conventional stream sediment and 24 bulk heavy mineral samples collected. Geochemical results will be released with 1:50 000 mapping open file.
Office	Province	RGS data on floppy diskettes.	To ensure a complete and consistent database. To make RGS data more readily accessible to the exploration community.	17 full sets (22 map sheets) and a number of single map sheets have been sold. Diskettes for 1986 and 1987 releases will be available by February 1988.
Office		Software development of a geochemical plotting and statistical package.	To develop internal geochemical open file production capabilities.	System to be completed by March 1988.

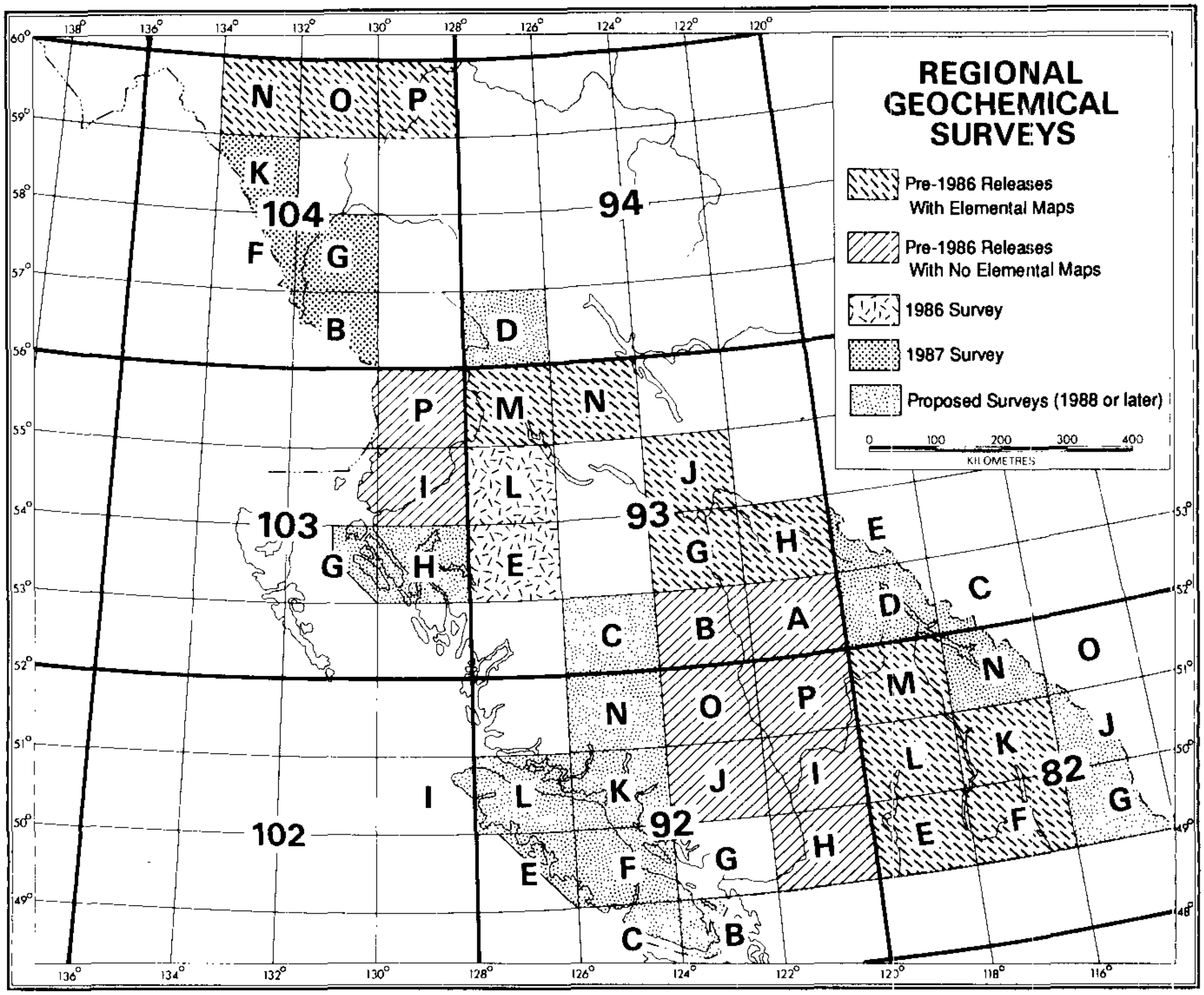

Figure 5-1-1. Areal distribution of the Regional Geochemical Survey Program.

A number of field enhancements were introduced in this year's sampling program to ensure that the samples are of a very high quality.

- Sample efficiency, in terms of site selection and ease of access in glacier-fed streams, increased, due in part to the use of neoprene dry-suits.
- To ensure that a sufficient amount of sediment was collected for at least two (10-gram) gold analyses, all samples were dry-seived in the field to –18 mesh (<1 millimetre) to assess fines content. Samples suspected to be rich in organic material or consisting predominantly of gravel were dry-sieved to the analytical size, –80 mesh (<177 microns). If they contained less than 40 grams of fine sediment, a new sample was collected. Sample quality was routinely checked by sieving one sample in each block of twenty to –80 mesh.
- To aid in the follow-up of survey results, highly visible aluminum tags (5 centimetres by 10 centimetres) bearing a unique RGS sample number were used to mark every sample site.

ANALYTICAL ENHANCEMENTS

Since 1976, most trace element concentrations in RGS have been determined by atomic absorption spectroscopy (AAS) samples after a Le Fort aqua regia digestion. However, inductively coupled plasma emission spectroscopy (ICP-ES) may represent an inexpensive alternative to AAS if the high standards of the RGS database can be maintained. As a preliminary test of the quality of ICP-ES data, two sets of similarly prepared and digested stream and lake sediment samples from the Whitesail Lake area (1987 release) were analysed by commercially available ICP-ES and AAS packages for a number of comparable elements. Preliminary results show that elements copper, zinc, iron, manganese, lead, cobalt and nickel could be determined by ICP-ES without reducing the quality of the database. Further details of this study (Day, Matysek and Johnson, 1988) are outlined in this volume.

DATA PREPARATION AND DATABASE ENHANCEMENTS

In an effort to develop in-house expertise in the data processing of results of RGS surveys for publication, data preparation services that have traditionally been provided by the Geological Survey of Canada, such as cartography, data entry and digitizing of sample site locations, are now the responsibility of the Applied Geochemistry Subsection. Microcomputer software is currently being developed and appropriate hardware has been purchased so that in-house computing, plotting and text production capabilities will be available. These capabilities will not only provide the subsection flexibility in selection of release dates, data presentation and interpretation of results, but will also streamline management of the program.

In 1986, British Columbia became the first province to make regional geochemical survey data publicly available on floppy diskettes. All previous RGS data were edited, systematically formatted and downloaded from magnetic tapes onto standard MS-DOS, double-sided, double-density, 5¼-inch floppy diskettes on a map sheet basis. This ensures that the RGS database is stored in a complete and consistent manner and makes the data more readily accessible to a wider segment of the exploration industry. The increased accessibility will promote a more thorough and refined assessment, and bring about a closer realization of the data's potential. Delineation of regional geochemical trends, a geochemical base for remote sensing studies and incorporation of the RGS database into private sector computerized geochemical databases are some of the applications that have been attempted by industry. Floppy diskette versions of 1986 (93G, 93H and 93J) and 1987 (93E and 93L) survey data are presently available.

1986 RGS RELEASES

Data from the joint federal-provincial reconnaissance Regional Geochemical Survey completed in the summer of 1986 were released on 29 July 1987 in Smithers, Vancouver and Victoria as the following open files [Figure 5-1-2, (1)]:

		Geological Survey of Canada Open File	British Columbia
93E	Whitesail Lake	1360	BC RGS 16
93L	Smithers	1361	BC RGS 17

Each map sheet covers approximately 14 500 square kilometres with an average sample density of one sample per 13 square kilometres. A total of 1848 stream and 457 lake sediment samples were analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, arsenic, molybdenum, iron, mercury, loss on ignition, uranium, cadmium, antimony, tungsten and barium. Corresponding stream and lake waters were analyzed for uranium, fluorine and pH. Addition of tin, vanadium, fluorine and especially gold analyses on samples collected from the Smithers map sheet were of considerable interest to the exploration industry.

Each open file consists of a sample location map, a current mineral inventory map, individual maps for each element analysed, and a text of field, analytical and statistical data. A total of 101 data packages has been sold to October 31, 1987, with nearly equal sales for each of the two map sheets. The high mineral potential, relatively good access, recent 1:50 000 geological mapping and inclusion of gold analyses in the survey data probably contributed to the high level of interest.

1987 RGS SURVEYS

In 1987, the British Columbia Geological Survey and the Geological Survey of Canada cooperated to systematically sample and analyse stream sediments and waters from a 35 000-square-kilometre rugged and remote region of northwestern British Columbia [Figure 5-1-2, (2)]. In total, 2726 sites were sampled at a density of one sample per 12 square kilometres. All stream sediments will be analysed for gold and the routine RGS 19-element suite (zinc, copper, lead, nickel, cobalt, silver, manganese, cadmium, iron, molybdenum, vanadium, arsenic, uranium, antimony, loss on ignition, tungsten and barium) and stream waters will be analysed for uranium, fluorine and pH. Survey results will be released in midsummer in a format similar to the 1986 RGS. Further details of this year's sampling program are outlined in this volume by Gravel and Matysek.

FUTURE DEVELOPMENTS

In the next 5 years, the Geological Survey Branch proposes to complete Regional Geochemical Surveys in the following areas (Figure 5-1-1): Vancouver Island (92B, 92C, 92E, 92F, 92G, 92K, 92L and 102I), Rocky Mountain Trench area (82G, 82J, 82N, 83D and 83E), central Coast Mountains (103G and 103H), Toodoggone camp (94E) and Cariboo area (92N and 93C). The sequence and selection of sampling areas will be dependent upon a number of factors such as available funding, feedback from the exploration community to proposed areas, and integration with the 1:50 000 geological mapping program. Assuming funding continues at the present level, sampling is planned for northern Vancouver Island (92E, 92L and 102I) in 1988.

Due to funding and logistical constraints during the period 1979 to 1981, data from nine 1:250 000 Regional Geochemical Surveys (Figure 5-1-1) were released with only a sample location map, a text containing detailed listings with no elemental maps and a statistical summary of the analytical data. This form does not allow identification of anomalies on the ground or resolution of geochemical trends, without first plotting individual points on an overlay or having access to computer plotting facilities. One project that the subsection will carry out is to produce elemental maps for these survey areas in 1988.

To encourage mineral exploration in previously sampled RGS areas, the branch is considering adding other elements to the existing RGS database through nondestructive analysis (Instrumental Neutron Activation Analysis, INAA) of archived RGS pulps. The RGS pulp and reject library contains approximately 31 000 samples, representing sampling from twenty-nine 1:250 000 map sheets. Most of these sediment samples have only been analysed for 12 elements (zinc,

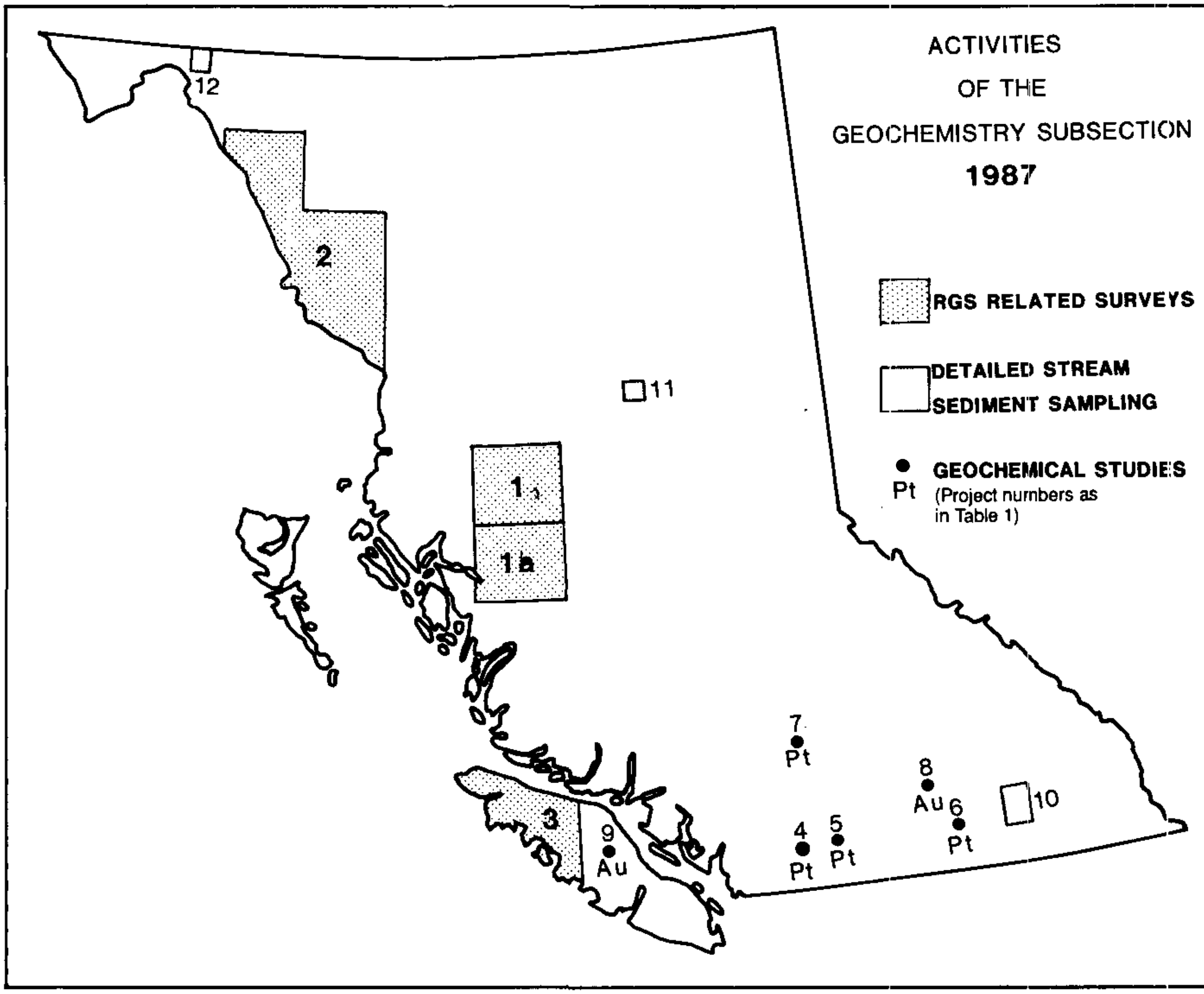

Figure 5-1-2. Locations of 1987 Applied Geochemistry Subsection Programs.

copper, lead, nickel, cobalt, silver, manganese, iron, molybdenum, mercury, uranium and tungsten) therefore addition of gold, arsenic, antimony and the rare earths is planned. A decision on funding and priorities is expected shortly.

RESEARCH PROJECTS

The branch's geochemical research projects aim is to provide guidelines in applying exploration geochemistry in the province. Results from these studies should provide effective methods for using geochemical techniques in the complex British Columbia setting.

VANCOUVER ISLAND

In preparation for RGS sampling on northern Vancouver Island in 1988, an orientation survey [Figure 5-1-2, (3)] was conducted in 1987 which included collection of 320 sediment samples from 30 streams draining areas with a variety of precious and base metal occurrences. Barren areas were included in the orientation to provide an indication of geochemical background. Four types of samples (conventional RGS sediment samples, moss-mat samples, sieved –10 mesh 10-kilogram heavy mineral samples and 10-kilogram unsieved sandy to fine sediment samples) were collected from one sampling station on all 30 streams. On selected streams draining mineralized areas, conventional RGS and moss-mat samples were collected at 500-metre intervals and unsieved bulk sediment samples were collected at 1000-metre stations to determine dispersion characteristics for 3 to 4 kilometres downstream from mineralization. Standard RGS sample preparation and digestion techniques will be used for analysing moss-mat, conventional RGS and unsieved samples. The relative merit of using other than the usual –80-mesh fraction for determination of base and precious metals is being tested by means of bulk fine sediment samples. Further details of sample locations, collection, processing, analytical methods and preliminary results are provided in Matysek and Day in this volume.

PLATINUM IN SOILS AND STREAM SEDIMENTS

There are few geochemical guidelines to assist exploration companies in the search for platinum group elements in British Columbia. The subsection, in cooperation with Dr. W.K. Fletcher at The University of British Columbia, is undertaking a study of the dispersion of platinum and palladium in stream sediments and soils. Four geologically distinct platinum occurrences were visited in August and September 1987 [Figure 5-1-2; Table 5-1-1; (4-7)]. Five types of sample were collected from 11 streams using the same methods as for the northern Vancouver Island project. Bulk-sieved samples were collected at up to six locations on three streams to determine downstream dispersion of platinum and related elements. Due to uncertainty about the mode of occurrence of platinum in the samples, duplicate-sieved samples were collected at several sites to provide an indication of within-site variability. Soil samples were collected from two or three pits over anomalous zones defined by exploration companies. Each soil horizon was sampled in duplicate, including the surface LFH organic layer, typically yielding six samples per station.

Both soils and –10 mesh field-sieved stream sediments are being processed by wet sieving followed by heavy mineral separation in heavy liquids and finally magnetic and electrostatic separations, to determine the speciation of platinum and palladium. Conventional fine-sediment samples (sieved to several fractions including –80 mesh) will provide a useful comparison with heavy mineral sampling techniques. The study also includes an evaluation of lead collection fire assay followed by a graphite furnace atomic absorption for determination of platinum and palladium.

Sample preparation and analytical work are in progress with results expected in early March. A preliminary open file report can be anticipated by late spring, with a full discussion of the results in Geological Fieldwork, 1988.

GOLD IN STREAM SEDIMENTS

Geochemical data from a detailed study of gold in stream sediments by Matysek and Saxby (1987) will be available as an open file in mid-1988. This study, carried out in the Smithers area (93L), includes dispersion and replicate sampling studies for nine streams draining several types of gold mineralization. Eighty sieved bulk sediment samples were processed by wet sieving and heavy mineral separation and analysed by instrumental neutron activation. Results from this study will address the reliability of conventional stream sediment and heavy mineral samples for various sizes of gold particles.

Several branch-funded stream sediment sampling projects [Figure 5-1-2; Table 5-1-1; (8, 9)] are currently in progress at The University of British Columbia under the direction of Dr. W.K. Fletcher. A study of the seasonal variation of gold concentrations in sediments collected from a single bar of Harris Creek (82L/02) is in its second year. Interpretations are still tentative but show that gold concentrations are greatest following the spring meltwater flood, then steadily decrease over the summer and autumn. Samples collected are also being used in comparative studies of three analytical methods (fire assay with atomic absorption spectroscopy finish, instrumental neutron activation analysis, and cyanidation followed by graphite furnace atomic absorption). Stream sediments are also being collected on Mount Washington (92F/14), from nine sites on McKay, Murex, Tsolum and Piggott creeks, to study gold dispersion downstream from mineralization. Results will be available by March 1988. For details of the work completed to date *see* Day and Fletcher (1987), Fletcher and Day in this volume and Fletcher and Horsky (in press).

DETAILED STREAM SEDIMENT SAMPLING

Under the guidance of section geochemists, geologists mapping 1:50 000 map sheets in three areas of British Columbia [Figure 5-1-2; Table 5-1-2; (10-12)] collected conventional RGS samples (2 kilograms of fine sediment) and field-sieved –10 mesh bulk sediment samples. The former will be analysed for gold and by a standard 30-element ICP-ES package with selected elements determined by hydride generation techniques. Concentration of gold, tungsten and rare earth elements in bulk samples will be determined by instrumental neutron activation analysis. In areas previously covered by the Regional Geochemical Surveys (82F, 93N) these programs will increase sample density and provide information on the distribution of heavy minerals. The number of samples collected in each project is summarized in Table 5-1-1. Sample locations are given by Brown and Logan, Ferri and Melville and Mihalynuk and Rouse in this volume. Geochemical results will be released as open files.

FUTURE RESEARCH AND DEVELOPMENT

Future research and development will be directed toward:

- Refinement of field and analytical techniques used in reconnaissance and detailed surface geochemical surveys of all types, but especially those based on stream sediments, lake-bottom sediments, soils and heavy minerals.
- Delineation of geochemical provinces in British Columbia and their relationship to tectonic terranes, metallogenic provinces and mineral deposits.
- Elucidation of the nature of primary and secondary dispersion halos and trains associated with mineral deposits.
- Refinement of regional and detailed geochemical exploration techniques in glaciated terranes of British Columbia.
- Development of more efficient methods for the processing and assessment of geochemical data by statistical and computer techniques.
- Improved understanding of the factors controlling the migration of elements in the surficial environment.
- Integration of remote sensing techniques and regional geochemical data.

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REGIONAL GEOCHEMICAL SURVEYS RGS 18–ISKUT RIVER (104B) RGS 19–SUMDUM (104F) AND TELEGRAPH CREEK (104G) RGS 20–TULSEQUAH (104K)*

By J. Gravel and P. F. Matysek

KEYWORDS: Regional geochemical surveys, stream sediments, stream waters, Iskut River, Sumdum, Telegraph Creek, Tulsequah.

INTRODUCTION

During July and August 1987 the British Columbia Ministry of Energy, Mines and Petroleum Resources conducted three regional geochemical stream sediment and water sampling surveys (RGS 18, 19 and 20) covering the Iskut River, Sumdum, Telegraph Creek and Tulsequah map sheets (Figure 5-2-1).

Since 1976, the Geological Survey Branch, in cooperation with the Geological Survey of Canada, has carried out regional geochemical surveys as part of the National Reconnaissance Program.

To date, twenty-eight 1:250 000 map areas, covering approximately 40 per cent of the province (approximately 390 000 square kilometres), have been sampled at a density

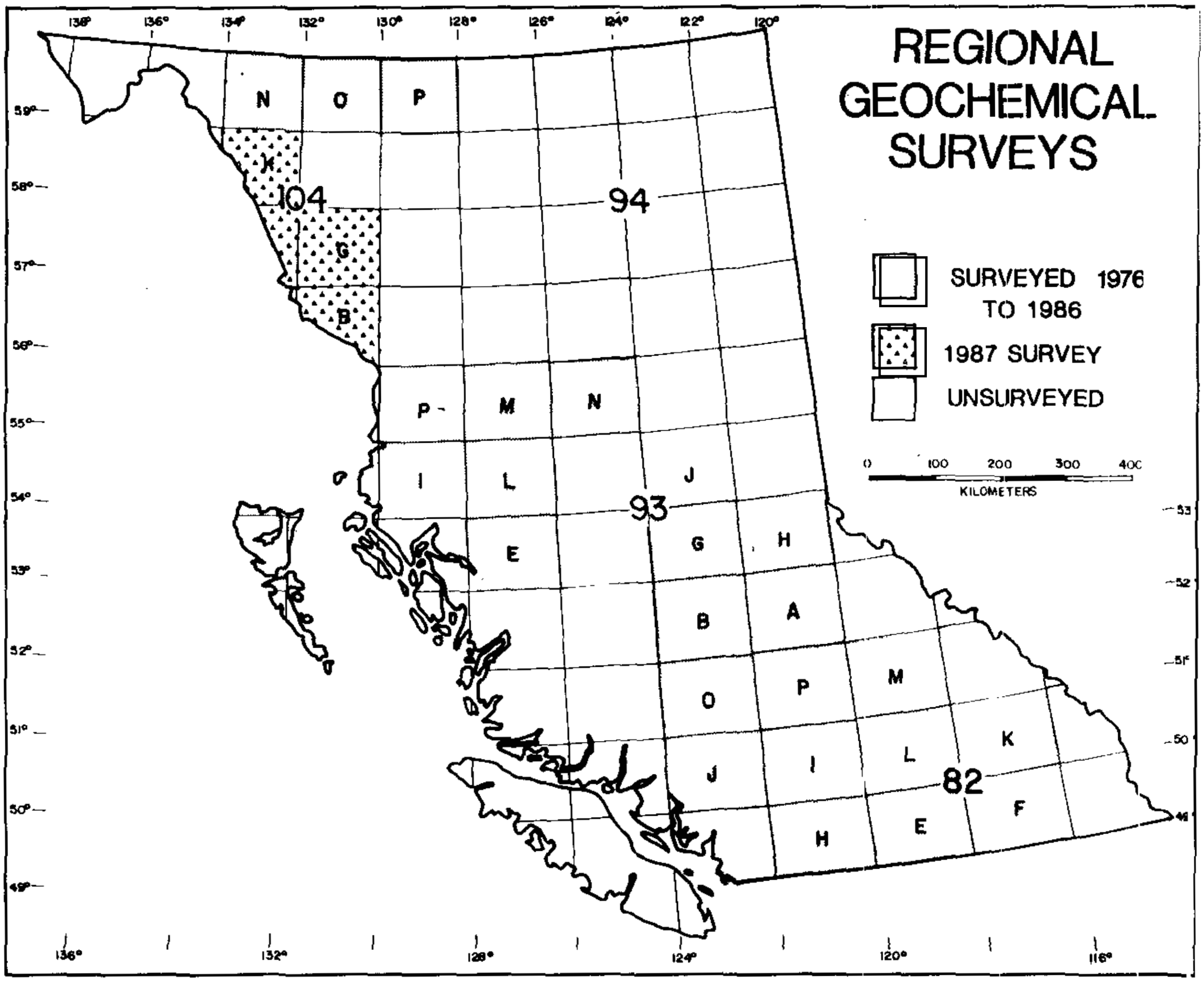

Figure 5-2-1. Present status of the British Columbia Regional Geochemical Surveys (RGS).

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

of one sample per 13 square kilometres (31 000 samples). Complete reconnaissance coverage of the province will not be attained before 1997 at current rates.

The objectives of these surveys are to provide:

- High quality geochemical data at the reconnaissance level in regions of active exploration.
- A regional geochemical database conforming to national standards.
- Information of environmental and mineral potential importance for provincial land status evaluations.

The ministry organized and supervised all components of RGS 18 and 20. Sampling, analysis, data processing and floppy diskette production were funded in part from the third year of the Canada/British Columbia Mineral Development Agreement (MDA). For RGS 19 the ministry funded organization, supervision, sample collection, data processing and floppy diskette production while Energy, Mines and Resources Canada (E.M.R.) funded sample preparation and analysis. Field supervision for all three surveys was provided by J. Gravel under the direction of P. Matysek. Open file production for all surveys will be handled by E.M.R.

1987 SAMPLING PROGRAM

The 1987 sampling program represents the ministry's largest and most ambitious regional geochemical survey to date. Systematic sediment sampling over 35 000 square kilometres of rugged and remote northwestern British Columbia required helicopter-supported sampling in 97 per cent of the survey area. Truck and floatplane support was used in the remainder of the area. McElhanney Engineering Services Ltd. of Vancouver, the sampling contractor, employed a crew of seven and successfully operated two shifts to optimize use of long daylight hours. Frontier Helicopters Ltd. provided a Bell 206B helicopter with long-range fuel tanks, two experienced pilots and an on-site mechanic. Operations were staged out of the Tel Air Services base in Telegraph Creek which provided occasional floatplane transportation, meals and sample handling and drying facilities (Plate 5-2-1).

Considerable interaction and cooperation between the ministry, McElhanney Engineering Services and Frontier Helicopters in the project planning and personnel training aspects of the program resulted in definite improvement in the production and efficiency from previous programs. In total, 2726 sites were sampled in 34 days giving an average of over 80 sites per day (Table 5-2-1). Productivity averaged 7.5 samples per hour of helicopter work.

Sampling crews, comprising a pilot, sampler and sampler-navigator, proved to be the optimum configuration for rapid sampling and site access. To guide sample collection, the ministry provided 1:50 000 topographic maps identifying preferred sample sites and alternative site locations. Dressed in neoprene waders to allow comfortable sampling in glacial meltwater streams (Plate 5-2-2), samplers collected 200 millilitres of water and 2 to 4 kilograms of sand-sized sediment from active portions of selected stream channels. Sample sites were marked by highly visible aluminum tags (5 by 10 centimetres) bearing a unique RGS sample number to aid in follow-up surveys.

Sediment samples were initially placed on open air racks to drain excess water, then dried for 4 to 7 days at 50°C in a wooden shelter. Dried samples were sieved to − 18 mesh (<1

Plate 5-2-1. Stream sediment samples sitting on racks within the drying shack.

TABLE 5-2-1
BREAKDOWN OF SAMPLING ACCORDING TO RGS NUMBER

RGS No.	Map Sheet	Sites Sampled	Area km^2	Density 1 site/km^2
18	104B Iskut River	661	8 200	12.5
19	104F Sumdum and	142	3 750	26.4
	104G Telegraph Creek	1 076	13 100	12.2
20	104K Tulsequah	847	9 900	11.7
	Total	*2 726*	*34 950*	*12.8*

millimetre) to reduce sample weight and assess the fines content. Suspect samples, considered to be organic rich or predominantly gravel, were sieved to −80 mesh (<177 microns); samples deficient in fines (<40 grams) were rejected and those sites resampled. Sample quality was routinely checked by sieving one sample in each block of twenty to −80 mesh.

Field-prepared sediment and water samples were placed in plastic pails and shipped to Kamloops (104B, F and K) or Ottawa (104G) where sediment samples are sieved to −80 mesh and control standards and blind duplicates are inserted as a check on laboratory accuracy and precision. Prepared samples are then shipped to a commercial laboratory for multi-element analysis.

Plate 5-2-2. Samplers wearing neoprene dry suits were able to collect samples from otherwise inaccessable sites.

All stream sediment samples will be analysed for gold, silver, arsenic, barium, cadmium, cobalt, copper, iron, mercury, manganese, molybdenum, nickel, lead, antimony, uranium, tungsten, zinc and organic content by loss on ignition (LOI). Stream waters will be analysed for uranium, fluoride and their pH level.

Survey results will be released in midsummer 1988. A data packet, consisting of a sample location map, detailed listings, statistical summaries and 1:250 000 maps for individual elements showing range symbols and concentrations on a geological and topographic base, will be available for purchase. Due to the size of the survey region, two separate releases are anticipated. To further a more thorough and refined assessment of the RGS data by the exploration community, survey results will also be available on floppy diskettes.

PHYSIOGRAPHY AND GEOLOGY

In the project area, the northwesterly trending contact between the Intermontane Belt and Coast plutonic complex forms a major geologic divide that roughly conforms to the boundary between the Coast Range and the Stikine Plateau physiographic terrains (Holland, 1976).

Within the Coast Range, granodiorite to quartz monzonite plutons of Triassic to Cretaceous age (Souther *et al.*, 1979) form jagged peaks with a mean elevation of 2000 metres, rising to 3160 metres at Mount Ratz. Icefields, covering tens to hundreds of square kilometres, blanket the upper slopes while talus, till and moraines deposited during the final ablation stages of the Pleistocene glaciation, cover the middle to lower slopes. Regionally derived stratified drift covers valley bottoms. Glacial meltwater streams describing a herringbone pattern, flow into either the Taku, Stikine or Iskut rivers which cut through the Coast Range before emptying into the Pacific Ocean.

The Stikine Plateau is largely comprised of sub-provinces of the Intermontane Belt. The Whitehorse belt, Stikine arch and Iskut belt consist of volcanic and sedimentary rocks of the Hazelton, Laberge, Takla and Stuhini groups. These are bounded by Hazelton sediments of the Bowser basin along the eastern margin and by Mississippian metabasalts and ultramafics of the Atlin terrane to the north. Granodiorite to quartz monzonite intrusions of Triassic to late Cretaceous age are exposed throughout the survey area. Flood basalts of Tertiary to recent age formed shield volcanoes at Level Mountain and Edziza Peak. A Tertiary peneplane averaging 1600 metres in elevation is developed on the Stikine Plateau. A variable degree of dissection has produced regional north-trending flat-topped mountain ranges and highland plateaus. Rugged peaks cored by plutonic rocks occasionally rise above 2300 metres. Tills and moraines deposited by the Cordillerian ice sheet indicate north, west and south ice-flow directions controlled by an area of accumulation on the Central Plateau. Thick, exotically derived stratified drift floors the larger valleys like the Taku, Stikine and Iskut. Streams in this region define a dendritic or disturbed pattern.

Sources of the geologic base compiled for the 1988 RGS release are Map 1418A by Souther *et al.* (1979) and Open File 1565 by Wheeler and McFeely (1987) with revisions by

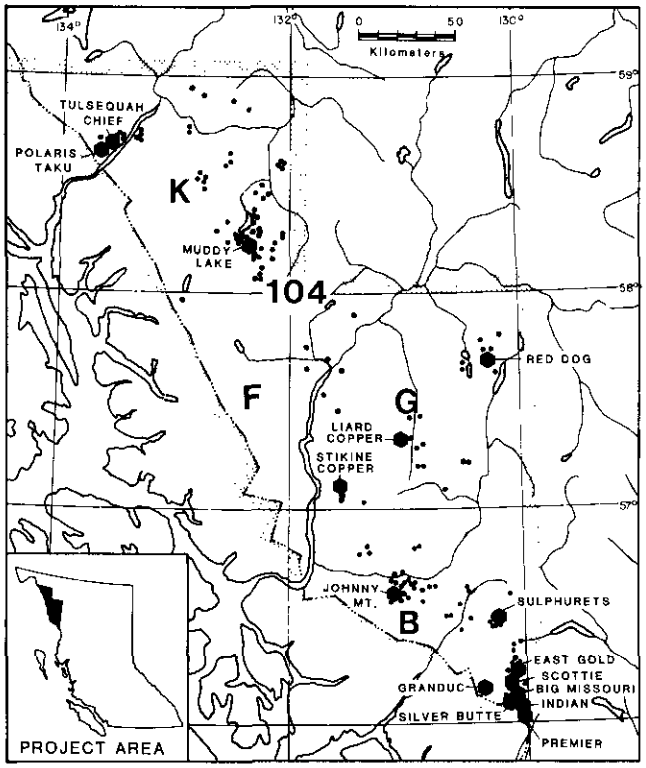

Figure 5-2-2. Activity in the area covered by RGS 18, 19 and 20. Dots represent assessment reports filed between 1981 and 1985; hexagons define mines or major prospects.

D.J. Alldrick. Other large-scale mapping projects are cited in the references.

EXPLORATION POTENTIAL

The present level of exploration activity in the study area is fairly high, centred on mines and known prospects in the region (Figure 5-2-2; Table 5-2-2). Exploration for gold in epithermal, mesothermal and vein replacement deposits is concentrated on the Silbak Premier, Sulphurets, Johnny Mountain, Red Dog, Muddy Lake and Polaris Taku deposits. Porphyry copper has been an important target in the Liard Copper and Stikine Copper areas while volcanogenic massive sulphides are searched for around Tulsequah Chief. The highly favourable response by the exploration industry to gold analyses in the 1987 release has convinced the ministry to include gold in the upcoming releases. The 1988 release, with complete gold coverage, should result in a sharp increase in exploration activity.

TABLE 5-2-2
GOLD-BEARING DEPOSITS IN THE 104B, F, G AND K MAP AREAS

Deposit Name	Au:Ag Ratio	Other Elements	Deposit Type
Tulsequah Chief	1:36	Cu, Pb, Zn	Volcanogenic massive sulphide
Polaris Taku	20:1	Cu	Vein, replacement
Muddy Lake			Vein, unclassified
Red Dog			Vein, unclasssified
Liard Copper	1:9	Cu, Mo, Ag	Porphyry
Stikine Copper	1:20	Cu, Ag	Porphyry
Johnny Mountain	1:2	Cu, Pb, Zn	Vein, replacement
Sulphurets	50:1	Cu, Ag	Vein, replacement and porphyry
East Gold	1:3	Cu, Pb, Zn	Vein, unclassified
Scottie	2:1		Vein, mesothermal
Granduc	1:55	Cu	Volcanogenic massive sulphide
Big Missouri	1:1	Pb, Zn	Vein, unclassified
Silver Butte			Vein, unclassified
Indian	1:40	Pb, Zn	Vein, shear
Premier	1:26	Cu, Pb, Zn, Cd	Vein, epithermal

(After Schroeter and Panteleyev, 1986)

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GEOCHEMICAL ORIENTATION SURVEYS: NORTHERN VANCOUVER ISLAND, FIELDWORK AND PRELIMINARY RESULTS

By P. F. Matysek and S. J. Day

KEYWORDS: Applied geochemistry, northern Vancouver Island, orientation surveys, multi-element geochemistry, Goldvalley, Red Dog, stream sediments, moss-mat samples.

INTRODUCTION

Stream sediment Regional Geochemical Surveys (RGS) are planned by the Geological Survey Branch in 1988 to assess the mineral potential of northern Vancouver Island. However, very little is known about the geochemical responses of sediments to typical geological and environmental influences within the sampling area. Successful application of stream sediment techniques will be challenged by the unique surficial, physiographic and climatic conditions characteristic of Vancouver Island such as: (1) a thick and diverse blanket of glacial deposits; (2) intense mechanical weathering, due to high rainfall; (3) lack of fine sediments in granitic and carbonate terranes; and (4) widespread logging.

In order to assess the effectiveness of drainage geochemistry for reconnaissance multi-element surveys, a study was implemented to compare the relative merits of a variety of stream sediment sampling and sample preparation techniques. Orientation studies were conducted in a variety of geological and physiographic environments to determine the characteristics of stream sediment anomalies associated with five modes of mineralization on northern Vancouver Island.

Results from this study will be used to: (1) define background and threshold levels; (2) identify those factors that influence dispersion and are thus criteria for the interpretation of survey results; (3) recognize those features that must be noted and reported by the samplers; and (4) define optimum survey procedures.

This paper describes the sampling, sample preparation and analytical procedures and discusses some preliminary results from sampling in the Zeballos and Nahwitti Lake areas.

DESCRIPTION OF THE STUDY AREA

LOCATION

The study area is located on northern Vancouver Island from 126° to 128°50′ west longitude and 49°10′ to 50°57′ north latitude. It encompasses an area of 15 655 square kilometres, which is equivalent to about sixteen 1:50 000 map sheets.

PHYSIOGRAPHY

Northern Vancouver Island consists of two major physiographic units, the Nahwitti Lowland and Vancouver Island Mountains (Holland, 1964). The Nahwitti Lowland is composed of low mountains and coastal plains, while Vancouver Island Mountains are characterized by a more rugged terrain where elevations range between sea level in the deeply penetrating inlets, or 100 metres in several northerly trending finger lakes, to 2300 metres for the higher peaks. Howes (1981) further subdivided these units according to the underlying bedrock and its response to depositional and erosional processes. Descriptions and locations of these subunits are given in Table 5-3-1 and Figure 5-3-1.

CLIMATE

The survey area is characterized by cool, very wet winters and mild, wet summers. Mean annual precipitation varies from 1400 millimetres to greater than 4600 millimetres with 70 to 80 per cent occurring between October and March (Howes, 1981). Three distinct precipitation zones (Figure 5-3-1) have been suggested by Howes (1981): (1) Western Zone with mean annual precipitation increasing from about 2000 millimetres on the west coast to greater than 4600 millimetres along its eastern margin; (2) Southeastern Zone with mean annual precipitation (1550 to 3000 millimetres) considerably less than the Western Zone as result of the rain shadow effect of the western mountains; and (3) Northeastern Zone the driest of the three, with mean annual precipitation ranging from 1400 to 2000 millimetres.

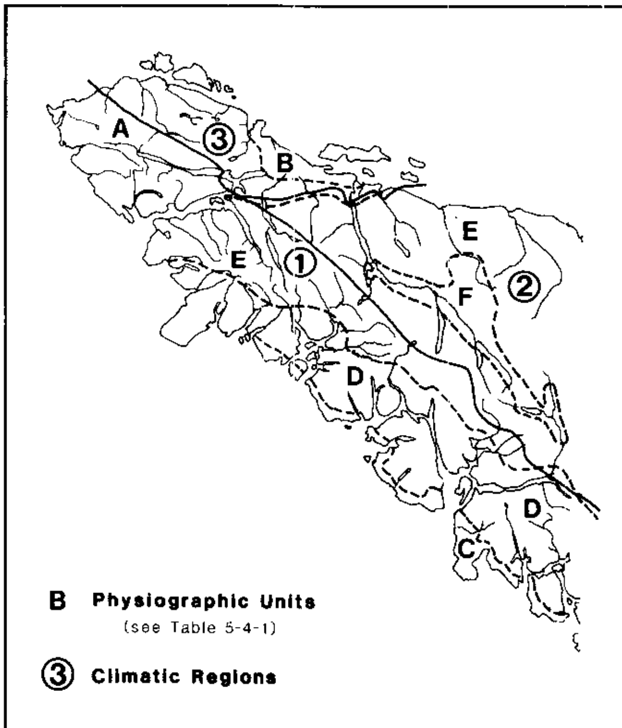

Figure 5-3-1. Physiographic and climatic regimes (*see* Table 5-3-1 and text, respectively), described by Howes (1981).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

TABLE 5-3-1
ABRIDGED DESCRIPTIONS OF PHYSIOGRAPHIC UNITS AS DESCRIBED BY HOWES (1981).

Unit	Subunit	Location	Bedrock Geology	Quaternary Geology	Description
Nahwitti Lowland	(A) Nahwitti Plateau	Northern tip of Vancouver Island	Dominantly Karmutsen with some Island intrusives	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
	(B) Suquash Basin	Eastern margin of the Nahwitti Lowland	Cretaceous sediments	As Nahwitti Plateau	Rolling to level topography below 300 m a.s.l.; scattered rounded hillocks and uplands
Vancouver Island Mountains	(C) Estevan Coastal Plain	Three-kilometre strip along west coast	Flat to gently dipping Tertiary clastic sedimentary rocks, scattered Island intrusives	Mantle of bedrock-derived colluvium (glacio-)fluvial, sediments, till and marine sediments on coast	Flat, featureless, rock cliffs and platforms, pocket beaches
	(D) Fiord-land	Islands and peninsulas along western coast	South of Esperanza Inlet, mostly granitic; north of inlet Bonanza volcanics, Brooks Peninsula is West Coast complex	Colluvial materials on steep valley walls and on summits; minor till on lower valley sides and slopes	Land rises abruptly to 600 to 900 m a.s.l.; rounded, timbered hill tops
	(E) Vancouver Island Range	Zones of NW/SE-oriented mountain ranges separated by the Nimpkish River Valley	Eastern zone underlain by Karmutsen volcanics, some Island intrusives; Karmutsen and Bonanza to west, with narrow belt of Quatsino and Parsons Bay	Very similar to fiord-land; fluvial and glacio-fluvial deposits in valley	Very rugged; U-shaped valleys, dissected Tertiary surface.
	(F) Nimpkish River Valley	Located in the south-central portion of the Vancouver Island Mountains	Predominantly underlain by Island intrusives	Dominantly till on valley sides and bottoms, mantling bedrock	Broad, U-shaped valleys; valley floor broken by a few peaks.

BEDROCK GEOLOGY

Northern Vancouver Island is underlain mainly by Mesozoic volcanic and sedimentary rocks which were intruded, during Jurassic time, by granitic plutons. Details of the bedrock geology have been described by Muller *et al.*, (1974) and Muller (1977). The various bedrock formations have been grouped into six units according to their origin and lithology (Table 5-3-2 and Figure 5-3-2).

QUATERNARY AND SURFICIAL GEOLOGY

The landscape was extensively modified by glaciation during the Pleistocene. Most of the surficial materials were deposited either during the last glacial episode or as a result of nonglacial processes during the past 10 000 years.

Coast Mountain ice appears to have radiated across the Island, flowing in a southwesterly direction across the southern part of the study area and in a northwesterly direction across the Nahwitti Lowland. At the glacial maximum, about 15 000 years ago (Armstrong *et al.*, 1965), most of northern Vancouver Island was buried by ice.

Radiocarbon dates indicate that glacial recession commenced about 13 000 years ago. Two patterns of deglaciation have been distinguished (Howe, 1981). On the northern part of the Island, ice probably separated into discrete stagnant masses which occupied lowland sites. Meltwater flowed from these masses, depositing fluvioglacial materials in the valleys. In the Vancouver Island Mountains, an episode of valley glaciation produced U-shaped valleys, moraines and outwash deposits. During the last 10 000 years, post-glacial modification of slopes by intense weathering and mass wasting has resulted in the formation of talus and debris-avalanche deposits.

Studies of the distribution of surficial materials by Howes (1981) in the survey area indicated that colluvial (40 to 50 per cent) and morainal materials (30 to 35 per cent) account for the bulk of the total surface cover. The remainder of the region consists of bedrock outcrops (10 to 12 per cent), usually occurring in alpine areas and fluvial and fluvioglacial materials (8 to 10 per cent) which are principally distributed on the valley bottoms. Organic materials (1 per cent) and minor amounts of marine, glaciolacustrine and eolian deposits (less than 1 per cent) account for the remainder.

SAMPLING TECHNIQUES AND ANALYTICAL PROCEDURES

SAMPLE COLLECTION

Three hundred and twenty sediment samples were collected by the authors from 30 streams in northern Vancouver Island (92E and 92L). For the most part, sampling was restricted to single stations on secondary and tertiary streams draining basins averaging 8 to 15 square kilometres in area. Eleven of the sampled catchments are characterized by one of five types of mineralization (Table 5-3-3) and are undisturbed by large-scale placer or bedrock mining activity. Up to ten

TABLE 5-3-2
TABLE OF MAJOR BEDROCK UNITS ENCOUNTERED IN THE SURVEY AREA (MULLER *et al.*, 1973)

Name	Age	Characteristic Lithologies
7. Intrusives (e.g., Zeballos Stock)	Eocene	Quartz diorite
6. Sediments	Cretaceous	Conglomerate, greywacke, siltstone, shale, coal
5. Island Intrusions West Coast complex	Jurassic	Quartz diorite, granodiorite, quartz monzonite, quartz feldspar porphyry, gneiss, metaquartzite, marble, agmatite, amphibolite
4. Bonanza Group	Lower Jurassic	Andesitic to rhyodacitic lava, tuff breccia
Vancouver Group		
3. Parson Bay Formation	Upper Triassic	Calcareous siltstone, shale, limestone, greywacke, conglomerate, breccia
2. Quatsino Formation	Upper Triassic	Limestone, marble
1. Karmutsen Formation	Upper Triassic	Basaltic pillow lava, breccia, minor limestone

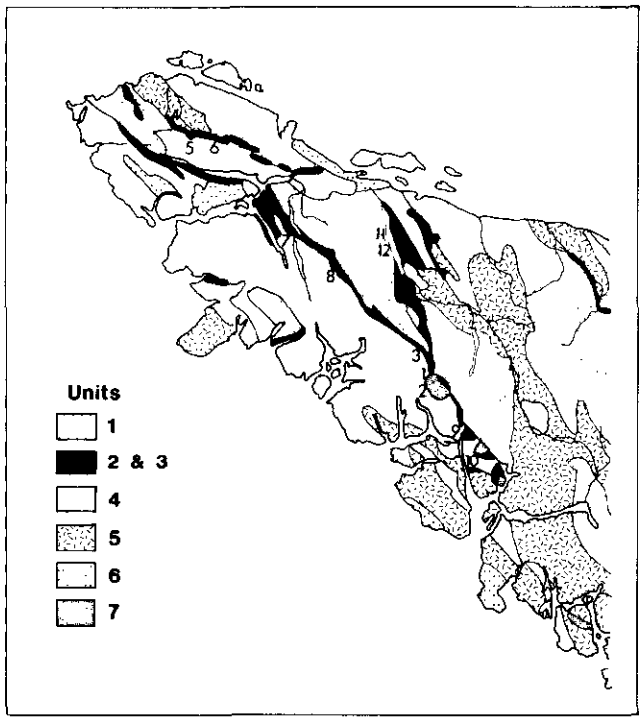

Figure 5-3-2. Simplified geology (after Muller *et al.*, 1974) and locations of anomalous streams. *See* Table 5-3-2 for descriptions of the geological units. Key to creeks: 1 = Goldvalley Creek; 2 = Spud Creek; 3 = Toray Creek; 4 = Red Dog Creek; 5 = Hepler Creek; 6 = HPH Creek; 7 = Jeune Creek; 8 = Merry Widow Creek; 9 = Extravagant Creek; 10 = Tsowwin River; 11 = Storey Creek; 12 = Kinman Creek.

additional sampling stations were established at 500-metre intervals along each anomalous stream to examine downstream dispersion characteristics for a number of sampling

TABLE 5-3-3
MINERALIZATION TYPES ENCOUNTERED ON NORTHERN VANCOUVER ISLAND

Type	Deposit Examples (Sampled Creeks)	Commodities	Mineralogy
A. Tertiary Mesothermal Veins	Zeballos (Gold-valley, Spud Creek)	Au, Ag, Cu, Pb, Zn	Gold (coarse), chalcopyrite sphalerite, galena, pyrite, arsenopyrite, quartz, calcite
B. Epithermal	Hep (Hepler Creek)	Au, Ag	No data
C. Stockwork	Expo (Hepler Creek) Red Dog (Creek)	Cu, Mo	Chalcopyrite, molybdenite, pyrite
D. Base metal skarn	HPH (Creek)	Pb, Zn, Ag	Galena, sphalerite, chalcopyrite, tetrahedrite, pyrite, calcite
E. Iron skarn	Hiller (Toray Creek) Nimpkish Copper (Kinman Creek) Merry Widow area (Merry Widow Creek)	Fe, Cu, Pb, Zn, Cu, Ag, Au	Magnetite, chalcopyrite, bornite, arsenopyrite, pyrite, garnet, epidote, actinolite, calcite

methods. Locations (Figure 5-3-2) and the geology of the anomalous drainages are summarized in Table 5-3-4. The remaining sampled drainages (19) represent background concentrations of ore elements, based on the absence of reported occurrences of any economic minerals in a readily accessible, well-explored area.

At the lowermost sampling station on every stream, five types of samples were collected: (1) a coarse sample comprising 10 kilograms of wet-sieved, −20-mesh (1 millimetre) material collected from a high energy environment (sandy gravels); (2) a fine sample comprising 10 kilograms of wet-sieved, −20-mesh material collected from a low energy environment (sands); (3) a bulk sediment sample comprising 10 kilograms of nonsieved sand; (4) a moss sample comprising 1 to 2 kilograms of sediment-laden moss-mat scraped off logs, boulders or outcrop within the active stream channel; and (5) an RGS-style, 1 to 2-kilogram fine sand sample. On selected streams draining mineralized areas, conventional RGS and moss-mat sediment samples were collected at 500-metre intervals and unseived bulk sediment samples were collected at 1000-metre stations to determine dispersion characteristics 3 to 4 kilometres downstream from mineralization. Field site duplicates of moss-mat and conventional RGS samples were collected at one in five stations.

Moss-mat samples were collected because of their abundance and exceptional ability to scavenge fine sediment material in generally fines-poor Vancouver Island streams. Sieved and unseived bulk sediment samples were collected to compare elemental responses from various sizes and densities of sediment particles. Standard RGS samples were collected to be used as a baseline for interpreting results from other sampling and preparation methods.

Each site was photographed and a number of standard observations were recorded on RGS sediment field cards, as well as site specific observations on moss-mat samples such as host type and competency, position relative to the stream bank and active channel, estimated mat thickness, textural composition and moisture content. For heavy mineral samples, weight of material processed and elapsed time were recorded. Maps depicting sample media abundance, logging activity, bank materials, channel features and precipitates were prepared from traverses between sample stations on anomalous creeks.

PREPARATION

Preparation and analysis of unseived bulk, moss-mat and conventional stream sediment samples were carried out under contract by Acme Analytical Laboratories, Vancouver. Sieved bulk sediment samples were prepared under contract by C.F. Minerals and Research Laboratory, Kelowna.

Sample preparation for standard RGS and moss-mat samples involved standard RGS methods which consist of field drying, disaggregation and dry-seiving to obtain a −80-mesh (<177 microns) fraction. Bulk sediment samples were also field-dried, dissaggregated and dry-sieved into three size fractions: −60 to 100-mesh, −100 to 200-mesh and −200-mesh (ASTM units).

Field-sieved bulk samples were wet-sieved through a −60-mesh screen, followed by density separation by a two-stage heavy liquid treatment (tetrabromoethane, S.G. = 2.96 and methylene iodide, S.G. = 3.3) and then sized to prepare three intermediate and three heavy mineral concentrates (−60+100-mesh, −100+200-mesh and −200-mesh).

SAMPLE ANALYSES

Prepared density (heavy and intermediate) and size fractions were analysed by non-destructive instrumental neutron activation under contract to Nuclear Activation Services Ltd., Hamilton, Ontario.

TABLE 5-3-4. SUMMARY OF ALL STREAMS SAMPLED

Creek	NTS Sheet	UTM Coords		Physiography[1]	Lithology[2]						Deposit[3]						Samples[4]			
		East	North		1	2	3	4	5	6	A	B	C	D	E	N	H	B	S	M
Spud	92L/02	656100	5544100	D				x		x	x						2	4	9	10
Tsowwin	92E/15	672900	5517100	D		x	x	x			x						2	4	9	9
"Red Dog"	92L/12	570600	5618300	A		x		x	x				x				2	5	11	10
Goldvalley	92L/02	657600	5544800	D						x	x		x				2	4	8	9
Hepler	92L/12	579200	5617200	A		x		x	x			x	x				2	5	10	10
"HPH"	92L/12	584500	5516700	A	x	x	x							x			2	3	6	6
Toray	92L/02	651700	5555300	D		x	x	x	x						x		2	4	7	7
Merry Widow	92L/06	625700	5579200	E		x	x	x	x						x		2	2	4	4
Extravagant	92E/15	667800	5532700	D		x	x	x							x		2	1	2	2
Kinman	92L/07	648700	5578600	E		x	x	x	x				x		x		2	2	4	4
Jeune	92L/06	613200	5587500	E		x	x		x					x	x		2	3	5	5
Storey	92L/07	647100	5580400	E	x		x	x	x					x	x		2	1	2	2
Little Zeballos	92E/15	661200	5537700	D		x	x	x		x						A	2	1	2	1
"TB"	92E/15	660500	5538200	D				x		x						A	2	1	2	1
Nomash	92L/02	664700	5541100	D	x		x			x						A	2	1	2	1
Malaspina	92E/15	674300	5525700	E		x	x	x		x						A	2	1	2	2
"T3"	92E/15	673000	5516500	E		x		x								A	2	1	2	2
"T2"	92E/15	678000	5521600	E		x	x	x								A	2	1	2	2
Perry	92E/15	674700	5527100	E	x											A	2	1	2	1
Nahwitti	92L/12	588100	5616100	A	x	x	x									C	2	1	2	2
"N1"	92L/07	645700	5584900	E	x				x							CDE	2	1	1	1
"N9"	92L/07	645500	5592000	E	x	x	x	x								CDE	2	1	1	1
"N6"	92L/07	658400	5582600	E	x				x							CDE	2	1	1	1
"N7"	92L/07	650200	5592600	E		x		x								CDE	2	1	1	1
Mead	92L/12	584100	5616500	A	x	x	x									D	2	1	2	1
Rainier	92L/06	626200	5577500	E		x	x	x	x							E	2	1	1	1
"Akery"	92L/06	610400	5578600	E				x	x							E	2	1	2	2
"Vieux"	92L/06	611800	5585700	E		x			x							E	2	1	1	1
"Upper Toray"	92L/02	651700	5553700	D		x		x	x							E	2	1	1	1
Artlish	92L/02	654500	5552500	D		x	x		x							E	2	1	1	1
Craft	92L/06	622900	5581200	E				x	x							E	2	1	1	1
Yootook	92L/06	617000	5585400	E		x	x	x								E	2	1	1	1

[1] *See* Table 5-3-1.
[2] *See* Table 5-3-2.
[3] *See* Table 5-3-3, N = background to mineralization type indicated.
[4] Number of samples of each type.
H = sieved bulk samples.
B = nonsieved bulk samples.
M = moss-mat samples.
S = stream sediment samples.
Note: Creek names in quotations are informal designations made by the authors.

Conventional RGS, Moss-Mat and Bulk Sediment Samples

A 0.50-gram portion of each sample was digested with 3 millilitres of 3:1:2 $HCL:HNO_3:H_2O$ at 95°C for one hour and then diluted to 10 millilitres with water. Elemental concentrations of molybdenum, copper, lead, zinc, silver, nickel, cobalt, manganese, iron, strontium, vanadium, calcium, phosphorus, lanthanum, chromium, magnesium, barium, titanium, boron, aluminum, sodium, potassium and tungsten were determined by inductively coupled plasma emission spectroscopy (ICP-ES). This digestion is almost total for base metals, partial for rock-forming elements such as sodium, aluminum, calcium, phosphorus, magnesium and titanium, partial for iron, manganese and barium, and very weak for refractory elements such as chromium, boron and tungsten.

Arsenic, antimony, bismuth, germanium, selenium and tellurium in the above solution were reduced to their hydrides and determined by ICP-ES. Mercury was determined by cold vapour atomic absorption spectroscopy using an F and J Scientific mercury assembly after adding stannous chloride/ hydrochloric acid solution to an aliquot of the digested sample solution.

Loss-on-ignition (LOI) was determined using a 500-milligram sample. The sample was weighed, placed in a furnace and heated to 500°C over a period of 2 to 3 hours. The sample was left at this temperature for 4 hours, then allowed to cool to room temperature for weighing.

For the majority of samples a 10-gram sample was ignited at 600°C, digested with hot aqua regia, extracted by methyl isobutylketone and analysed for gold by graphite furnace atomic absorption spectroscopy. The reported detection limit of this method is 1 ppb.

Background elemental values obtained from collected samples are generally well above the contracted laboratory's reported detection limits, except for determinations of molybdenum, silver, cadmium, germanium, bismuth and tungsten.

PRELIMINARY RESULTS AND DISCUSSION

The following discussions focus on comparing and contrasting analytical results obtained from the collection of 107 standard RGS stream sediment and 103 moss-mat sediment samples, and a detailed examination of their effectiveness in detecting and characterizing two mineral occurrences.

COMPARISON OF MOSS-MAT AND STREAM SEDIMENT DATA

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 problem, collection of moss-mats was initiated because they are relatively ubiquitous in the survey area and can be quickly and easily sampled. More importantly, moss-mats contain large amounts of fine-grained particulate matter.

Physical Differences

Comparison of weights of −80-mesh sediment obtained from moss-mat samples and conventional sediment samples shows that a high proportion (44 per cent) of standard RGS sediment samples do not yield enough sediment for both an ICP-ES analysis and a 10-gram gold analysis, despite collecting close to 2 kilograms of sandy material in the field. Sixteen per cent of samples yielded less than 5 grams of the material needed for analysis. In sharp contrast, only 5 per cent of moss-mat samples yielded insufficient material for an ICP-ES analysis and the two 10-gram gold analyses which would normally be required for the purpose of quality control. All moss-mat samples yielded at least 22 grams of −80-mesh sediment with the average sample yielding more than 60 grams. Consequently, if gold is to be determined with appropriate duplicates, samples up to 10 kilograms of fine sediment maybe required, alternatively samples should be field-sieved. Moss-mat samples may be an attractive alternative provided that the chemical differences are not overwhelming.

Chemical Differences

Direct comparison of analyses of moss-mat sediments and stream sediments shows some significant differences. For example, stream sediments returned consistently higher values of zinc, nickel, manganese, strontium, calcium, magnesium, barium, aluminum and sodium, whereas moss-mat sediments have higher values for vanadium, phosphorus, lanthanum, potassium and antimony. There are no significant differences for molybdenum, copper, lead, cobalt, iron, arsenic, chromium, titanium, boron, mercury and selenium or loss-on-ignition. Figure 5-3-3 illustrates some of the above relationships. At present, there is insufficient data to classify gold. At this early stage of the project, it is not clear what factors may be important in determining differences, but possible mechanisms are.

- Uptake of mobile elements by the moss, that is transfer of metals from the particulate phase (analysed) to the organic phase (not analysed).
- Incorporation of particulate material from the moss-mat host.
- Different size and/or density distributions of sediment in moss-mat sediments and stream sediments, resulting from morphological characteristics of moss-mats and their location in the stream flow.

These factors will be resolved as the study progresses, with chemical analyses of the organic fraction, detailed site-specific studies and textural analyses of moss-mat and stream sediments.

RED DOG COPPER-MOLYBDENUM STOCKWORK

The Red Dog copper-molybdenum stockwork deposit is located approximately 8 kilometres north of Holberg in till-blanketed, rolling hills of the Nahwitti Plateau physiographic region. Chalcopyrite and molybdenite mineralization is hosted in lapilli tuff and brecciated tuff of the Bonanza Group and Parsons Bay Formation (Muller *et al.*, 1974) adjacent to a Jurassic diorite stock. The deposit crops out on a low hill in the headwaters of Red Dog Creek (name coined by authors),

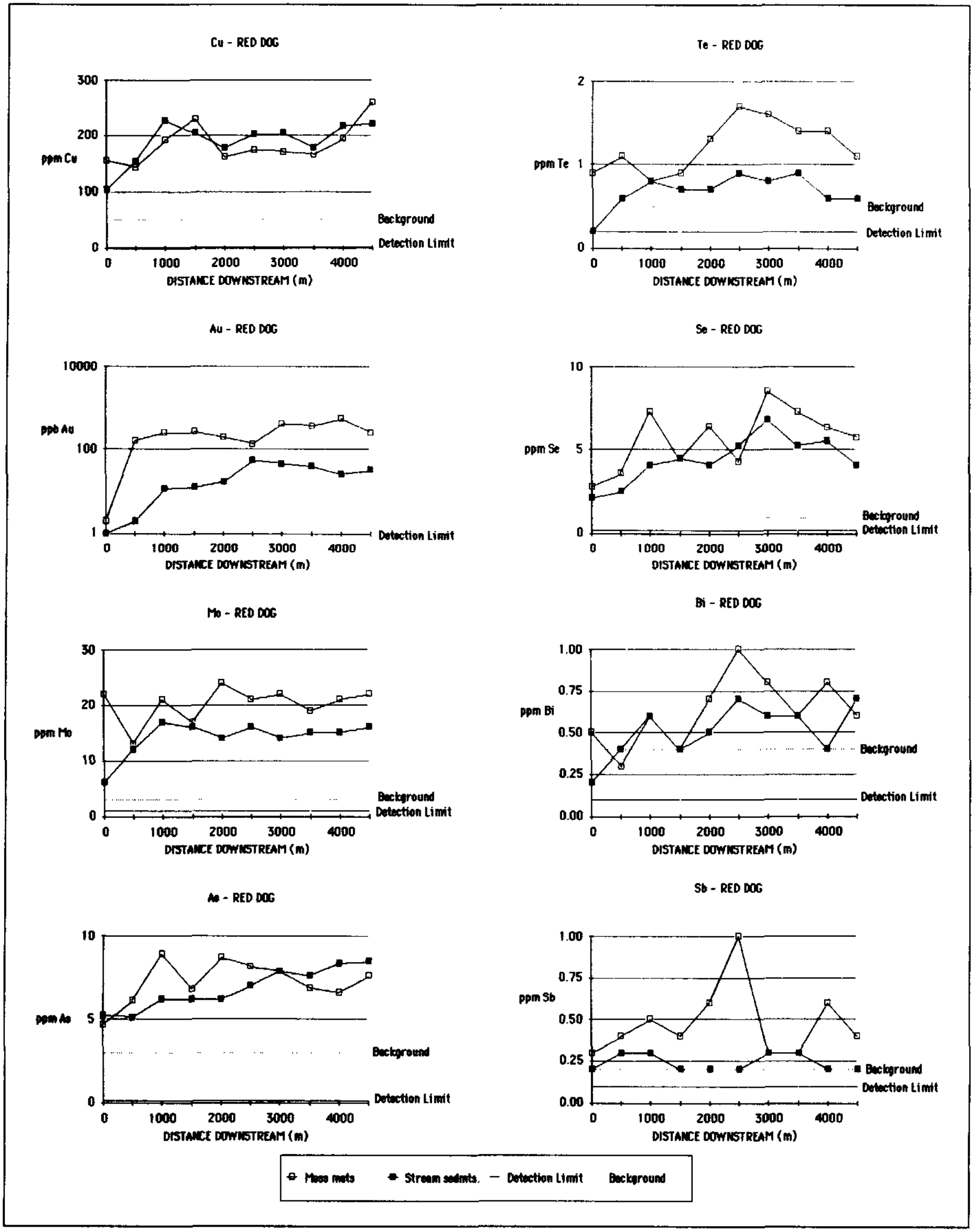

Figure 5-3-5. Downstream dispersion patterns for Au, Mo, Cu, As, Sb, Bi, Se and Te in Red Dog Creek moss-mat and stream sediment samples. Detection limits are from the analytical company's brochure, regional background level determined as described in the text. *See* Figure 5-3-4 for sample locations.

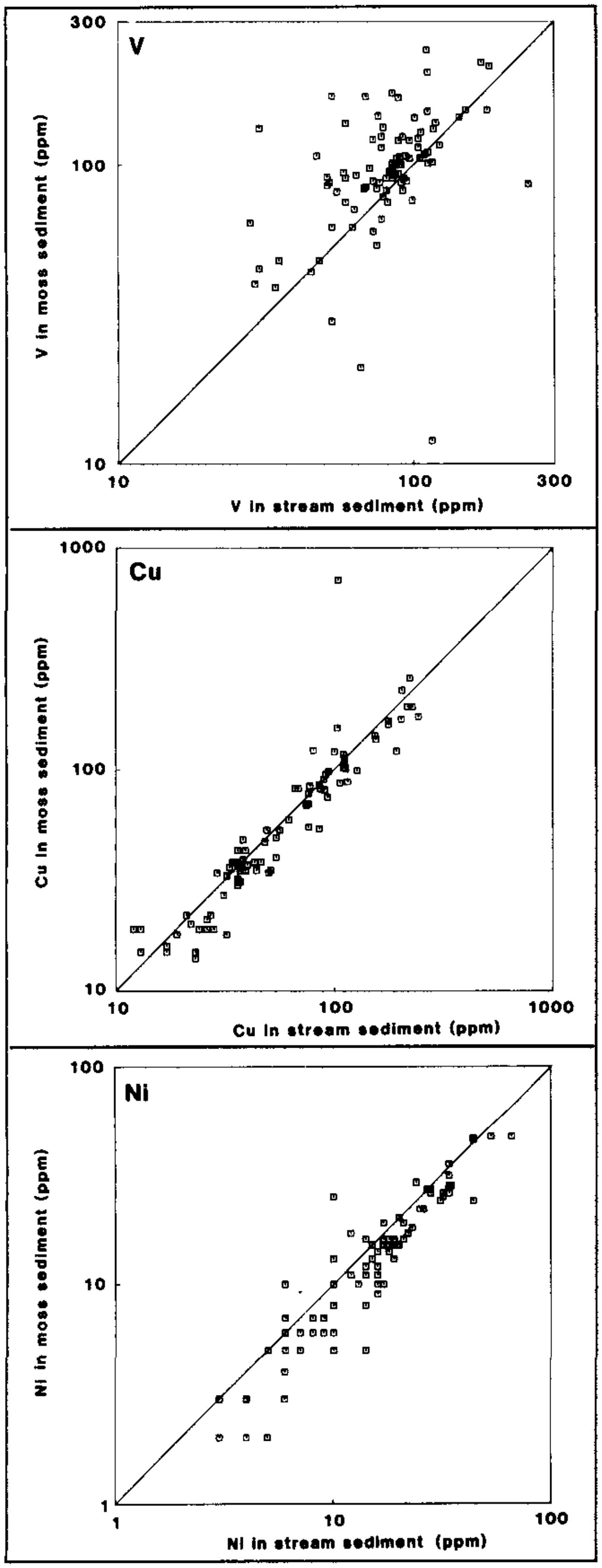

Figure 5-3-3. Some examples of results for moss-mat and standard RGS stream sediment samples taken at the same sampling station. The diagonal line represents the case where both media return the same value.

however alteration and quartz veining were observed up to 2 kilometres downstream from the main mineralized zone.

Red Dog Creek rises at an elevation of some 500 metres, falling 300 metres over a distance of 4500 metres, with a drainage basin area of approximately 13 square kilometres (Figure 5-3-4). In the upper reaches, the stream flows through logjams producing localized sand and gravel deposits. Toward the lowest sampling location, near the confluence with the Goodspeed River, the stream meanders between point bars occasionally reaching bedrock below till up to 10 metres thick. Moss mats, typically growing on logs, and stream sediments were sampled from 10 stations at 500-metre intervals. The highest sampling location is several hundred metres upstream from the surface expression of mineralization.

Results

Geochemical Background

Locally, copper-molybdenum mineralization is commonly associated with Jurassic diorite stocks, thus definition of geochemical background is difficult. Other samples collected from streams draining Jurassic diorite intrusions (creeks N1 and N6, Table 5-3-4) in the Nimpkish Lake area provide a preliminary indication of regional trace element background values, though weathering and lithological characteristics are likely to be different in the Vancouver Island Ranges. In addition, the uppermost sampling point probably represents local background. Assuming these samples represent background levels, copper, molybdenum, silver, gold, arsenic, antimony, bismuth, selenium and tellurium show anomalous values in both moss-mat sediments and stream sediment samples (Figure 5-3-5).

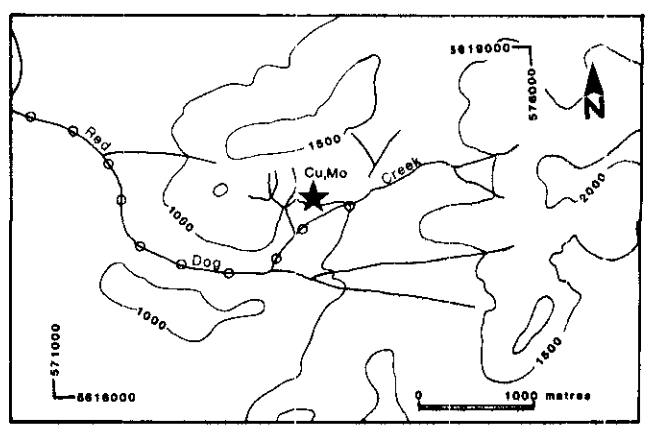

Figure 5-3-4. Sample locations (circles) on Red Dog Creek draining Red Dog copper-molybdenum deposit (star). The contour interval is 500 feet.

Gold

Gold analyses on 10 pairs of 5-gram splits of stream sediments are reasonably consistent (Table 5-3-5) suggesting that gold is present as numerous small inclusions rather than one or two coarse particles. Highly erratic results related to the nugget effect are typical of the latter case.

Five hundred metres downstream from the highest sampling location, gold concentrations in moss-mat sediments increase from 2 ppb to over 100 ppb. This level is maintained even to the lowest sampling location 4 kilometres downstream (Figure 5-3-5). In comparison, anomaly contrast is lower for stream sediments with concentrations never rising above 50 ppb, though values are greater than 10 ppb for most of the section. Dilution of the anomaly is not apparent in either moss-mat sediments or stream sediments despite erosion of till in the banks. This is perhaps due to gold input from quartz veins and alteration observed in the stream bed, or anomalous gold concentrations in the till derived from the deposit.

Other Anomalous Elements (Molybdenum, Copper, Silver, Arsenic, Antimony, Bismuth, Selenium, Tellurium)

There are marked similarities between results for molybdenum, copper, arsenic, selenium and tellurium, and gold results. After initially rising to anomalous levels, concentrations of these elements do not decay downstream (Figure 5-3-5). Concentrations of antimony and silver are anomalous in both moss-mat sediments and stream sediments though levels are very close to the detection limit. However, concentrations in moss-mat sediments are greater than in stream sediments resulting in slightly greater anomaly contrast. Results show that for this particular geological and physiographic setting, a standard RGS sediment sample collected up to at least 4 kilometres from known mineralization would detect the anomaly. Because anomaly contrast is greater in moss-mat samples, these may represent an improvement over the conventional samples.

GOLDVALLEY CREEK, ZEBALLOS CAMP

The Zeballos gold camp is located in the fiord-land physiographic region of the west coast of Vancouver Island. Gold mineralization is demonstrably associated with the granitic Tertiary Zeballos stock (Hansen and Sinclair, 1984) intruded into Bonanza Group, Karmutsen Formation, Quatsino Formation and a Jurassic Island Intrusions pluton. Mesothermal gold and silver-bearing veins with minor lead and copper have been mined at two locations in Goldvalley (Spud Valley mine, CD mine).

Elevations in the camp vary from sea level to 1300 metres at the summits of very rugged peaks. Goldvalley Creek rises in a logged cirque and initially meanders over a very gently sloping area that was possibly the site of a tarn. The stream gradually steepens, flowing over bedrock and then, toward the confluence with the Zeballos River, becomes choked by

TABLE 5-3-5
GOLD CONCENTRATIONS OBTAINED FROM 5-GRAM SPLITS OF GOLDVALLEY AND RED DOG STREAM SEDIMENTS

Sample Number	Gold concentrations (ppb) Split 1	Split 2
RED DOG SAMPLES		
RD-SS-01	13	50
RD-SS-02	18	31
RD-SS-03	26	52
RD-SS-04	45	NSS[1]
RD-SS-05	35	30
RD-SS-06	85	60
RD-SS-07	24	9
RD-SS-08	13	10
RD-SS-09	7	15
RD-SS-10	2	2
RD-SS-11	1	1
GOLDVALLEY SAMPLES		
GV-SS-01	1950	NSS[1]
GV-SS-02	12480	32950
GV-SS-03	26	30
GV-SS-04	30	245
GV-SS-05	640	2580
GV-SS-06	12	420
GV-SS-07	25	290
GV-SS-08	27	905

[1] Not sufficient sample for analysis.

very large granite boulders. In addition to known mineralization, chalcopyrite and molybdenite stringers were found 2250 metres downstream from the uppermost sampling station. Moss-mat samples from boulders and stream sediment samples were collected at seven stations 500 metres apart (Figure 5-3-6). Drainage basin area to the lowest sampling station is approximately 8 square kilometres.

RESULTS

Geochemical Background

Background levels were determined for moss-mat and standard RGS stream sediment samples collected from three streams (Table 5-3-4) assumed to be draining unmineralized portions of the Zeballos stock. However, concentrations of gold (69 ppb in a moss-mat sediment sample), and several other trace elements (molybdenum, copper, zinc, nickel, cobalt, arsenic and antimony) obtained from Little Zeballos

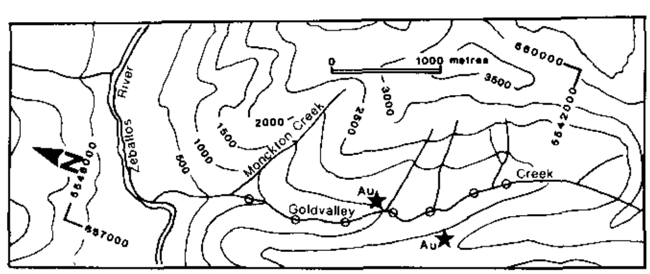

Figure 5-3-6. Sample locations (circles) on Goldvalley Creek in the Zeballos camp. Gold occurrences are indicated by stars. The contour interval is 500 feet.

River moss-mat and stream sediments, were considerably higher than the other two basins assumed to be barren (TB Creek and Nomash River). This is perhaps due to undiscovered mineralization upstream from the sampling location or the result of this stream also draining Bonanza volcanics, which typically have high background base metal values. Based on background levels obtained from samples collected from Nomash River and TB Creek, gold, silver, arsenic and lead concentrations are anomalous in Goldvalley sediments. As was the case for the Red Dog example, anomalous concentrations are reflected in both moss-mat and standard RGS sediment samples. Conspicuously, copper, which has been produced in the camp and molybdenum, which was observed in streambed outcrops, are characterized by background concentrations for both sample media.

Gold

In contrast to Red Dog Creek results, gold concentrations in stream sediment duplicate splits are high (up to 33 ppm) but very erratic (Table 5-3-5) indicating that gold is present as coarse free particles which are not partitioned evenly between splits. Nonetheless, downstream dispersion patterns for moss-mat sediments and stream sediment samples are comparable (Figure 5-3-7), both showing very high values 2500 metres downstream and a distinctive low at 500 to 1000 metres.

Other Anomalous Elements (Silver, Arsenic and Lead)

Silver concentrations are well correlated with gold concentrations and consequently are very erratic. Moss-mat sediment silver concentrations vary from the detection limit (two samples) to greater than 10 ppm, whereas only one stream sediment sample is above the estimated background for the region. Arsenic concentrations show very similar trends with peaks at 0 metre and 2500 metres and a low point at 500 to 1000 metres (Figure 5-3-7). Trends in lead concentration are above background in the area of small-scale mining near 1500 metres and increase to the same peak as observed for gold, silver and arsenic at 2500 metres (Figure 5-3-6). As in Red Dog Creek, the gold anomaly would be detected at the lowest sampling location using a conventional stream sediment sample, though of the three other elements that characterize the deposit, only arsenic shows clearly anomalous values.

SUMMARY

Preliminary results indicate that the lack of fine sediment in northern Vancouver Island streams is likely to be a severe problem in regional drainage sediment projects. Much larger samples must be collected to satisfy the analytical requirements for gold. Moss-mat sediments may be a satisfactory alternative for many important elements (molybdenum, copper, lead, cobalt, iron, arsenic, mercury) because the fine-sediment yield is very high. However, questions remain about significant differences for other elements, in particular, zinc, nickel, manganese, antimony, vanadium and phosphate. Further research will be initiated.

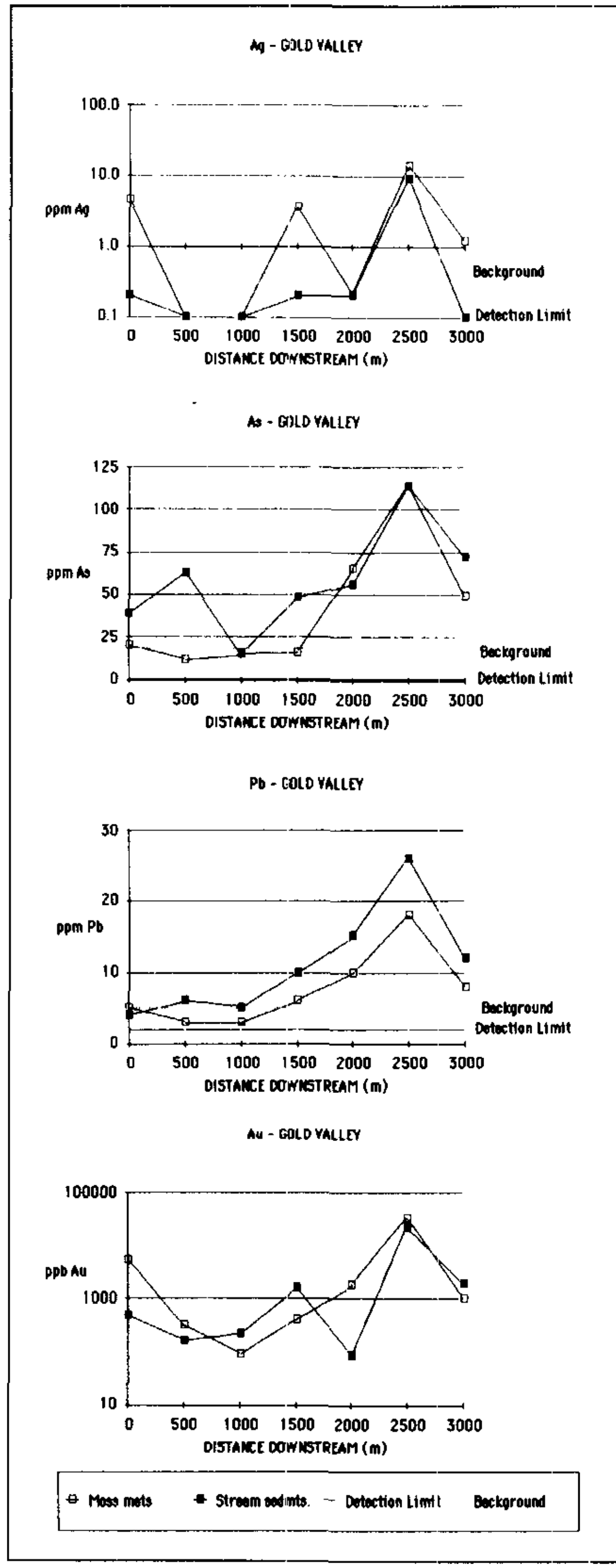

Figure 5-3-7. Downstream dispersion patterns for Au, Ag, As and Pb in Goldvalley Creek moss-mat and stream sediment samples. Detection limits are from the analtyical company's brochure, regional background level determined as described in the text *See* Figure 5-3-6 for sample locations.

Results from contrasting streams in the Nahwitti Lowlands and the coastal mountains show that anomalous gold and base metal concentrations can be determined satisfactorily at regional scale sampling density in conventional stream sediments. Moss-mat samples reflect similar results and often provide better contrast. Additional information on the effectiveness of conventional stream sediment samples will be available as soon as results from bulk nonsieved and sieved samples become available.

ACKNOWLEDGMENTS

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THE REGIONAL GEOCHEMICAL SURVEY: EVALUATION OF AN ICP-ES PACKAGE*

By S. J. Day, P. F. Matysek and W. M. Johnson

KEYWORDS: Applied geochemistry, analysis of variance, atomic absorption spectroscopy, duplicate data, inductively coupled plasma, lake sediments, stream sediments, quality control.

INTRODUCTION

In 1975, the Geological Survey of Canada (G.S.C.) established analytical methods for the British Columbia Regional Geochemical Survey (RGS) program (Garrett, 1974). These methods are consistent with those established for the National Reconnaissance program, facilitate national and provincial comparison by ensuring the data are of similar precision for a particular element and consistent with some relative baseline level in terms of accuracy. As a result, the G.S.C. and the British Columbia Geological Survey Branch have continued to use the same analytical system (that is, the same sample preparation and decomposition methods, with atomic absorption spectroscopy as the final determination step) to determine 13 elements in stream and lake sediments collected for the RGS program. In the early 1980s, simultaneous determination of 30 elements or more by inductively coupled plasma emission spectroscopy (ICP-ES) provided superior cost performance and has since replaced atomic absorption spectroscopy (AAS) as the popular method for determining concentrations of trace and major elements in sediments, soils and rocks. Inductively coupled plasma-emission spectroscopy also offers technical advantages over AAS (Fletcher, 1981; Thompson, 1986), namely:

- Virtually simultaneous multi-element analyses.
- Determination of trace and major elements in the same solutions, without dilution.
- Fewer molecular interferences and lack of interference due to formation of refractory compounds.

These cost and technical advantages suggested that a study was needed to determine if ICP-ES analyses might replace AAS determinations for many of the elements in the routine 13-element package. If findings were positive, future RGS surveys could benefit from the determination of many more elements with no increase in analytical costs. Accordingly, as part of the 1986 RGS program in the Whitesail Lake area (93E), one set of samples was analysed by standard RGS methods and a second set similarly prepared and digested but analysed by ICP-ES at the same commercial laboratory in order to test analytical quality. This preliminary report examines elemental responses from the ICP-ES determinations with respect to analytical sensitivities and reproducibility. Comparisons with standard RGS analytical methods are also discussed where appropriate. The results from this study enable preliminary recommendations to be made concerning the use of ICP-ES as the final determination step in future RGS programs.

PURPOSE OF STUDY

Fundamentally, we must determine if lower cost simultaneous determination of elements by ICP-ES is a suitable alternative to standard AAS determinations following the same type of digestion. In the case of the RGS, the provincial geochemical database must continue to conform to national standards, permitting exploration companies and governments to make informed policy decisions based on consistent data (Matysek, 1987; Gravel and Matysek, 1988). In this study the following questions are addressed:

- How do a pair of analyses obtained from the two approaches differ, and what biases are present?
- What are the precision characteristics of the two methods, at concentrations typical of stream and lake sediments?
- Which additional major and trace element concentrations reported as part of the ICP-ES package are adequately sensitive and precise?
- For which elements can regional trends be distinguished?

STUDY DATA: 1986 RGS-16 93E, WHITESAIL LAKE

A total of 1169 sediment samples were collected at a density of one sample per 13 square kilometres from streams (82 per cent) and lakes (18 per cent), of which 65 pairs of samples were field-site duplicates. All samples are field dried and sieved to –80-mesh for subsequent analysis. Included in the data set were 65 samples made from laboratory splits (analytical duplicates) of randomly selected sediment samples and 65 samples representing control standards. One field duplicate, one analytical duplicate and one control reference were randomly inserted into each batch of 20 samples. The locations of duplicates in the batches were unknown to the commercial laboratory contracted for the analytical work.

ANALYTICAL PACKAGES

CONVENTIONAL RGS — ATOMIC ABSORPTION SPECTROSCOPY

Most elements were determined following Lefort aqua regia digestion ($3HNO_3$:HCl). Three millilitres of concentrated nitric acid was added to 1 gram of each sample and heated in a boiling water bath for 30 minutes. The sample was then cooled to room temperature and 1 millilitre of concentrated hydrochloric acid added. Finally, following reheating

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

for 30 minutes in the water bath and cooling, the solution was made up to 25 millilitres with demineralized water and concentrations determined for zinc, copper, lead, nickel, cobalt, manganese, iron, silver and cadmium by flame AAS. Arsenic and antimony in solution were reduced to their hydrides and determined by flame AAS. Mercury was determined by flameless AAS following reduction to Hg^0 (vapour). Molybdenum was released from 0.5 gram of sample in a separate Lefort aqua regia digestion and barium was liberated from a 0.25 gram of sample with a hydrofluoric-perchloric-nitric acid (5:8:2) mixture. Both elements were determined by flame AAS.

INDUCTIVELY COUPLED PLASMA — EMISSION SPECTROSCOPY

Half a gram of each sample was treated with Lefort aqua regia using the procedure described above. Concentrations of 28 elements were determined by ICP-ES (Table 5-4-1). The extent to which the Lefort aqua regia liberates many of these elements from resistant silicates and oxides is not well known though conventional aqua regia (HNO_3:3HCl) only weakly attacks these minerals.

LIMITATIONS OF THE COMPARISON

Only two multi-element packages from one laboratory are compared in this study, due to the following limitations:

- Splits of samples were used for each package, possibly resulting in subsampling errors.
- Different split weights were used for the AAS and ICP-ES determinations (1 and 0.5 gram, respectively) resulting in different sample to solution ratios.
- Although similar decomposition solutions (Lefort aqua regia) were used for most elements, other variables, such as the exact length of time the sample was digested, may result in significant differences.

TABLE 5-4-1. SUMMARY STATISTICS FOR ALL ELEMENTS DETERMINED IN THIS STUDY

Element/ Unit	ELA	AAS IDL	AAS ≤DL (%)	AAS Mean	AAS CV (%)	ICP-ES IDL	ICP-ES ≤DL (%)	ICP-ES Mean	ICP-ES CV (%)
A. Elements with ICP-ES and AAS determinations that are comparable									
Cu/ppm	12	1.0	0.0	25.2	23	1.0	0.4	28.6	21
Pb/ppm	*18*	*1.0*	*16.5*	*5.5*	*61*	2.0	17.2	8.6	36
Zn/ppm	51	1.0	0.0	78.5	12	2.0	0.3	71.0	13
Cd/ppm	0.1	0.1	70.3	0.2	38	0.5	91.4	0.6	92
Mo/ppm ...	1.3	1.0	61.1	1.5	155	1.0	81.7	2.2	114
Ni/ppm.....	4.5	1.0	0.9	12.4	35	1.0	1.0	12.3	35
Co/ppm	1	1.0	0.6	8.0	29	1.0	1.8	8.1	28
Fe/%	1.4	0.05	0.0	3.0	43	0.01	0.3	3.0	44
Mn/ppm .	390	5.0	0.0	619.3	10	1.0	0.3	585.5	11
Ag/ppm	0.04	0.1	84.4	0.1	22	0.2	89.2	0.3	37
As/ppm	2.1	1.0	34.3	3.2	96	5.0	73.4	8.8	30
Sb/ppm	0.2	0.2	57.6	0.4	88	5.0	100.0	5.0	0
B. Elements with ICP-ES and AAS determinations that are not comparable									
Ba/ppm	840	10.0	0.0	608.5	8	10.0	0.3	104.2	13
C. Elements determined by ICP-ES or AAS only									
Hg/ppb ..	40	5.0	0.0	30.6	16				
*Al/% ...	—					0.01	0.5	1.5	104
*K/%	4.2					0.01	0.9	0.1	28
*Ca/%	—					0.01	0.3	0.6	94
*Mg/%	—					0.01	0.3	0.5	95
*Na/% ...	—					0.01	11.1	0.03	35
*Ti/%	—					0.01	4.0	0.1	30
P/ppm	600					10.0	0.3	735.0	5
*Sr/ppm ...	100					1.0	0.3	46.0	12
V/ppm	3.9					1.0	0.3	63.0	12
*Tl/ppm ...	—					10.0	100.0		
*Be/ppm ..	3					0.5	96.2	1.1	1090
Bi/ppm ...	0.3					2.0	99.9	2.1	24
*Cr/ppm ...	4.1					1.0	0.3	24.2	21
*La/ppm ..	—					10.0	56.9	14.3	17
*Ga/ppm .	—					10.0	99.3	10.2	5

+ For both analytical packages, Lefort aqua regia was used to liberate the elements.

* Elements very poorly liberated by conventional aqua regia.

ELA—lithological abundance estimated from average for felsic rocks (Wedepohl, 1969). Data not available for all elements.

IDL—instrument detection limit.

≤DL—percentage of all samples (1299) less than or equal to the detection limit.

Mean—geometric mean of all samples above detection limit.

CV—coefficient of variation (standard deviation/mean) for all samples above the detection limit.

Blank—element not determined.

COMPARISON OF THE AAS AND ICP-ES PACKAGES (Zn, Cu, Pb, Ni, Co, Mn, Fe, Ag, Mo, Cd, As, Sb)

REPORTED DETECTION LIMITS

The detection limits reported by the laboratory for both AAS and ICP-ES packages are considered in relation to average crustal abundances of the elements (Table 5-4-1). The number of samples reported as equal to or below detection limit shows important differences between analytical instruments and can be used to eliminate certain elements from further consideration. For example the considerable difference in detection limits for antimony (0.2 ppm for AAS, 5.0 ppm for ICP-ES) results in all samples being below the ICP-ES detection limit, versus 58 per cent for AAS. The proportion of determinations either below or equal to the ICP-ES detection limit is 91 per cent for cadmium, 89 per cent for silver, 82 per cent for molybdenum and 73 per cent for arsenic. Similarly, the proportion of determinations at or below the AAS detection limit is 70 per cent for cadmium, 84 per cent for silver, 61 per cent for molybdenum and 34 per cent arsenic. Both methods provide adequate sensitivity for the remainder of the elements. However, it is clear that neither analytical method provides adequate sensitivity for all elements that might reasonably be expected to be of interest in these surveys. Although not necessarily requireu for exploration purposes, reliable estimation of background concentrations of these elements can be attained by preliminary preconcentration, or by using a more sensitive analytical method.

BIVARIATE SCATTER PLOTS

Scatter plots of ICP-ES versus AAS data (Figure 5-4-1) permit visual evaluation of differences by checking departures from the 45° $X_{ICP} = X_{AAS}$ line (X = concentration of element X). All data were log transformed so that departures from the line are shown with respect to the concentration of the element. For example, a 1 ppm departure at a concentration of 10 ppm appears the same as a 10 ppm departure at 100 ppm. In most cases, scatter is about the line (for example, X = Fe, Figure 5-4-1) though it is not clear what significance can be attached to a slight tendency for scatter

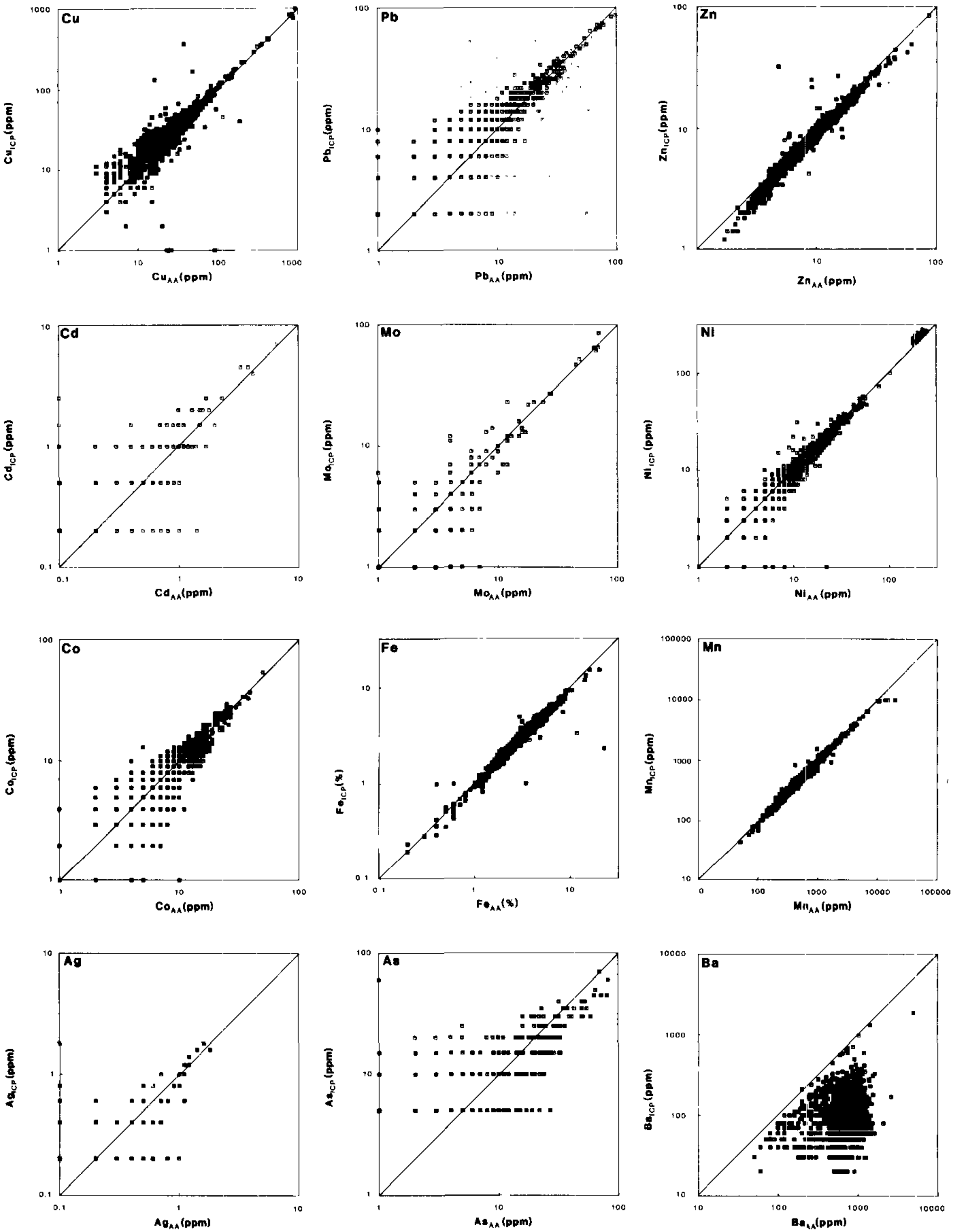

Figure 5-4-1. Scatter plots of concentrations determined by ICP-ES and AAS packages. Diagonal line shows $X_{ICP} = X_{AA}$. All 1299 samples are plotted on each diagram.

toward either the $X_{ICP} > X_{AAS}$ or the $X_{ICP} < X_{AAS}$ regions (for example, X = Cu and X = Zn). Regression analysis was used to quantify differences between results.

REDUCED MAJOR-AXIS REGRESSION

The extent and sign of the difference between the ICP-ES and AAS packages are determined by calculating regression equations from the duplicate data. Ideally the regression equations would have slopes (B_1) of 1 and y-axis intercepts (B_0) of zero:

$$X_{ICP} = B_1 X_{AAS} + B_0.$$

The reduced major axis regression method is used to give a regression fit close to that indicated by visual evaluation of the data, as well as 95 per cent confidence limits about the slope and intercept, to test departure from the ideal case. Nine categories of results are recognized (Table 5-4-2) involving deviations of slope (rotational or proportional bias, Figure 5-4-2) and intercepts (translational or fixed bias, Figure 5-4-3) from the model. Cobalt is the only element where $X_{ICP} = X_{AAS}$ ($B_1 = 1$, $B_0 = 0$, with 95 per cent confidence, Figure 5-4-4). The five chalcophile elements arsenic, silver, lead, copper and cadium are in a group where $B_1 > 1$ and $B_0 > 0$ whereas molybdenum, nickel and manganese are in the opposite group. Zinc and iron are transitional cases.

TABLE 5-4-2. SUMMARY OF BIASES DETERMINED BY REGRESSION (All results are at 95% confidence level.)

Rotational Cases	Translational cases $b_0<0$	$b_0=0$	$b_0>0$
$b_1<1$	Mo, Ni, Mn		
$b_1=1$	Fe	Co	
$b_1>1$	Zn		Cu, Pb, Cd, Ag, As

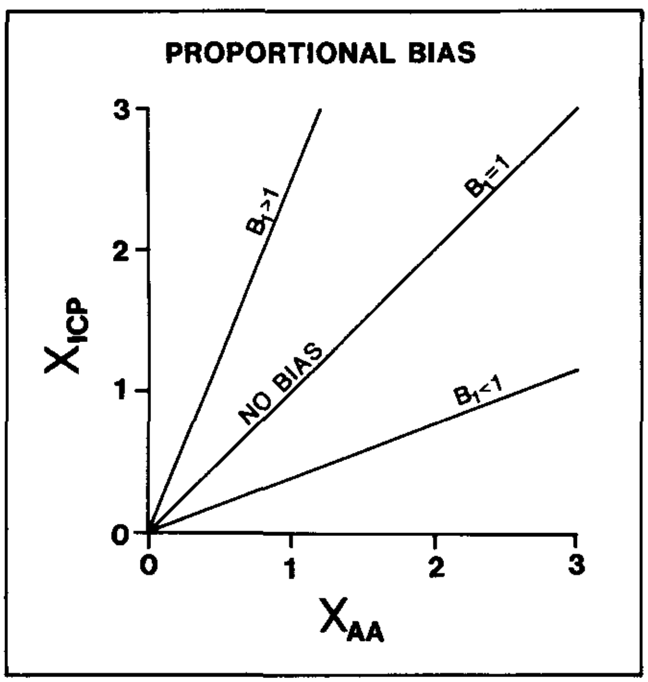

Figure 5-4-2. Examples of proportional (or rotational) bias. X_{AA} and X_{ICP} are concentrations of element X determined by AAS and ICP-ES, respectively. Units are arbitrary.

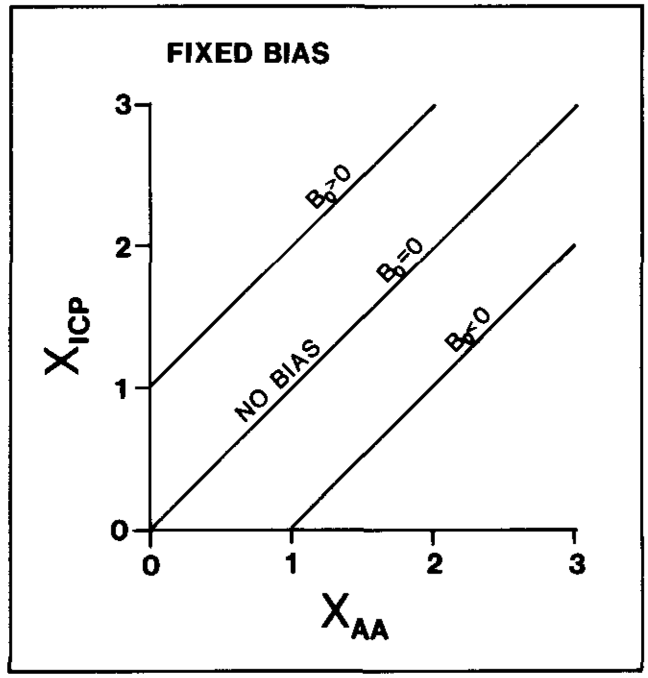

Figure 5-4-3. Examples of fixed (or translational) bias. X_{AA} and X_{ICP} are concentrations of element X determined by AAS and ICP-ES, respectively. Units are arbitrary.

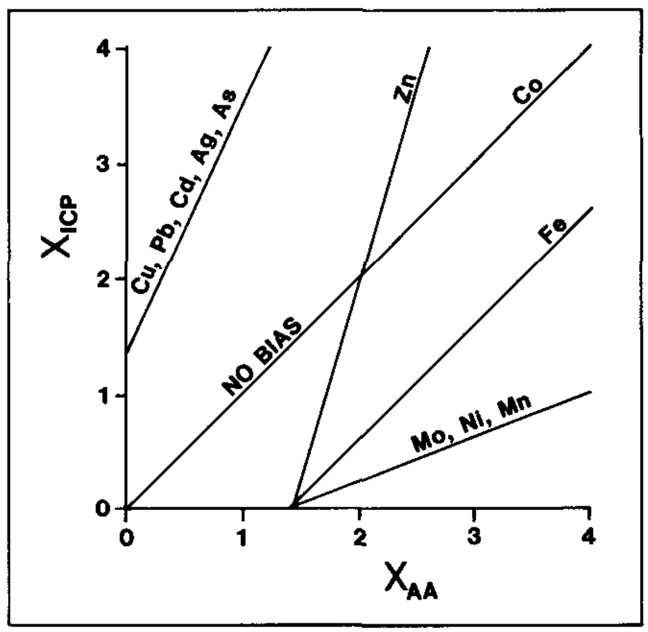

Figure 5-4-4. Diagrammatic summary of results presented in Table 5-4-2 showing types of bias. X_{AA} and X_{ICP} are concentrations of element X determined by AAS and ICP-ES, respectively. The relative position of lines and axis units are arbitrary.

PRECISION

Variation of precision may indicate that element determinations by the ICP-ES package are more or less precise than the conventional package at the levels encountered in stream sediments. Precision (P_C), given by:

$$P_C = \frac{2s_c}{C} \cdot 100$$

where s_c is the estimated standard deviation at concentration C, can be determined by repeated re-analysis of a few samples. Four control reference standards were analysed 12 to 18 times. At concentrations greater than 10 times the detection limit P_C is 15 per cent or less for both ICP-ES and AAS determinations of copper, zinc, nickel, cobalt, iron and manganese, a level generally considered satisfactory (Table 5-4-3).

TABLE 5-4-3. PRECISION CHARACTERISTICS FOR SELECTED ELEMENTS

Control Std./ Method	N	Cu Mean (ppm)	Cu P_C (%)	Zn Mean (ppm)	Zn P_C (%)	Ni Mean (ppm)	Ni P_C (%)	Mn Mean (ppm)	Mn P_C (%)	Fe Mean (ppm)	Fe P_C (%)
1/AAS	12	81	7	150	8	49	13	490	9	5.2	9
ICP	12	89	9	130	5	46	7	430	6	4.7	6
2/AAS	17	49	16	120	11	230	11	670	13	3.5	10
ICP	17	51	11	110	5	270	5	640	6	3.5	7
3/AAS	18	35	13	94	8	200	8	580	9	3.1	6
ICP	18	35	15	87	7	230	7	560	8	3.2	8
4/AAS	17	80	12	110	8	190	9	1100	10	3.4	7
ICP	17	87	7	110	8	210	8	1100	8	3.4	8

OTHER ELEMENTS

BARIUM

Barium concentrations determined by AAS are significantly greater than those determined by ICP-ES (Figure 5-4-1) due to the difference in strength of digestions used. Barite is not vigorously attacked by Lefort aqua regia (ICP-ES) but was completely decomposed by the stronger digestion used for the AAS determination.

ELEMENTS DETERMINED BY ICP-ES OR AAS ONLY (TABLE 5-4-1)

Of the 10 trace and minor elements determined only by ICP-ES, titanium, vanadium, phosphorus, strontium, lanthanum and chromium have high percentages of samples above the detection limit. Conversely, the sensitivity levels for gallium, thallium, beryllium and bismuth determined by the ICP-ES package are so poor that less than 0.5 per cent of samples had concentrations greater than the detection limit. Five major elements were also determined as part of the ICP-ES suite (aluminum, potassium, calcium, sodium, magnesium) and, with the exception of sodium, almost all samples were reported as above the detection limits (Table 5-4-1). Mercury was determined uniquely by AAS, and all samples reported above the detection limit (5 ppb) with an average of 31 ppb.

DETERMINATION OF REGIONAL TRENDS

It is essential to test if data determined by different analytical methods can be used to recognize similar regional trends. Ideally, this would involve a detailed analysis of the published RGS maps to determine if the same mineral exploration decisions would be made with data from either package. The problem can be tackled directly by asking the question: Is the variability introduced during sample collection, preparation, digestion and analysis insignificant when compared to the regional variability of interest to the mining industry and governments? The question can be answered to a limited extent by using analysis of variance (ANOVA) for blind and field duplicates.

ANALYSIS OF VARIANCE

For this study, field and analytical duplicates were separated into stream (53 pairs) and lake (12 pairs) data sets. Elements exhibiting the majority (greater than 75 per cent) of their values near the detection limit such as silver, molybdenum and cadmium were eliminated from the data sets. The summary of AAS results determined at the 95 per cent confidence level, presented in Table 5-4-4, shows that regional variability for cobalt, iron, nickel, manganese, copper, lead, zinc, barium and arsenic is not obscured by within-site or laboratory variability. Conversely, regional zinc and lead values in lake sediments determined by AAS are difficult to interpret because within-lake sampling variability is significant.

TABLE 5-4-4. SUMMARY OF BALANCED TWO FACTOR ANALYSIS OF VARIANCE

Analytical Method	Regional trends not significant with respect to field site variability: Streams (n=53)	Lakes (n=12)	Regional trends not significant with respect to laboratory sub-sampling variability: Streams (n=53)	Lakes (n=12)
AAS	—	Zn, Pb	—	—
ICP-EX	—	Pb	Pb	—

n = The maximum number of duplicate pairs available for each sampling media. Pairs containing detection limit values were omitted.

Elements evaluated:

AAS: Zn, Cu, Pb, Ni, Co, Mn, As, Fe, Ba.

ICP-ES: Zn, Cu, Pb, Ni, Co, Mn, As, Fe, Ba, Al, Ca, Cr, Mg, P, K, Na, Sr, Ti, V.

A comparison of ICP-ES ANOVA results for the same suite of elements, shows that only lead determinations in stream sediments are characterized by significant laboratory subsampling variability, perhaps partly due to poor precision near the detection limit. All the major elements (potassium, calcium, magnesium, aluminum, sodium) as well as the trace and minor elements (phosphorus, titanium, lanthanum, strontium, vanadium and chromium) determined only by ICP-ES have insignificant within-site and laboratory subsampling errors compared to regional variability.

SUMMARY

Despite the stated limitations of this study, the following results are applicable to future British Columbia Regional Geochemical Surveys:

- Determinations of copper, zinc, cobalt, nickel, manganese and iron by Lefort aqua regia digestion followed by ICP-ES appear to satisfy the standards of the RGS, that is, results are sufficiently sensitive and precise and are well correlated with AAS determinations. In addition, within-stream sample site and laboratory variabilities are relatively small and insignificant for the majority of these elements determined by ICP-ES. Concentration differences between sample sites account for most of the survey variability.

- The ICP-ES package evaluated in this study should not be used to determine antimony, cadmium, silver, molybdenum or arsenic in the RGS stream and lake sediment surveys due to their high detection limits. Antimony and arsenic can be analysed by ICP-ES if they are first reduced to their hydrides as in the conventional RGS package (Thompson, 1986).
- Although AAS provided better sensitivity characteristics than ICP-ES for silver, cadmium, molybdenum, antimony, arsenic and lead, they are only marginally adequate for silver, cadmium and molybdenum. Research should be initiated to lower detection limits for these elements.
- Statistically different concentrations for all comparable elements (except cobalt) are obtained with the two analytical packages. In a future study, elemental maps will be asssessed to evaluate whether concentration differences between methods are geochemically significant.
- The ICP-ES package provides adequate sensitivity and precision across concentration ranges normally encountered for major elements (sodium, potassium, aluminum, calcium, magnesium) as well as several trace and minor elements (barium, vanadium, strontium, titanium, chromium). However, the usefulness of data for elements contained in resistant minerals not attacked by LeFort aqua regia (barium, titanium, chromium, sodium, potassium, aluminum, calcium, magnesium) should be determined.
- Certain additional trace elements routinely determined as part of the ICP-ES package (gallium, lanthanum, bismuth, beryllium, thallium) do not completely satisfy the standards of the RGS since their detection limits are much greater than concentrations normally encountered in stream sediments.
- The cost of determining seven elements (zinc, copper, lead, cobalt, nickel, manganese, iron) of the standard RGS 12-element suite by ICP-ES is 18 per cent less than the same group determined by AAS. In addition, 12 other elements (barium, aluminum, potassium, calcium, magnesium, sodium, strontium, titanium, phosphorus, vanadium, chromium, lanthanum) are reported as part of the ICP-ES package and are of satisfactory quality. The geochemical significance of these additional elements will be investigated in future studies.

CONCLUSION

Despite some inherent limitations to the study, it is clear that the use of ICP-ES as the final determination step for routine RGS determinations of copper, lead, zinc, nickel, manganese and iron is significantly cheaper and as precise and sensitive as RGS methods currently employed, and provides information on additional elements.

ACKNOWLEDGMENTS

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DETERMINATION OF GOLD IN HEAVY-MINERAL CONCENTRATES: FIRE ASSAY AND ATOMIC ABSORPTION SPECTROSCOPY (FA-AAS) VERSUS INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS (INAA)*

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KEYWORDS: Applied geochemistry, gold analysis, heavy-mineral concentrates, fire assay, atomic absorption, neutron activation, sampling bias.

INTRODUCTION

Fire assay, followed by analysis of the resulting precious metal bead by atomic absorption spectroscopy (FA-AAS) or some other "finish", is widely used in determination of the total gold content of heavy-mineral concentrates. Direct instrumental neutron activation analysis (INAA) of the concentrate, which has the advantage of being a nondestructive multi-element technique, is also used. The objective of this study was to compare gold results obtained by the two methods on typical heavy mineral concentrates from streams in southern British Columbia.

METHODS

Bulk stream-sediment samples were collected from five streams draining gold occurrences in southern British Columbia and screened to give five size fractions between 50 and 270 mesh (ASTM). Heavy-mineral concentrates were then prepared for each fraction by density separation in methylene iodide (S.G. = 3.3). Full details of sample locations and laboratory procedures are given by Day and Fletcher (1986).

Concentrates were dried, weighed, loaded into vials and submitted to a commercial laboratory for analysis by INAA after irradiation in a flux of 5×10^{12} neutrons per square centimetre per second. Samples were then stored until their radioactivity had fallen sufficiently for them to be handled safely. Sixty-three samples, covering a concentration range of approximately 5 to 25 000 ppb gold, were then submitted to a second laboratory for analysis by FA-AAS. Samples weighing more than 10 grams were divided and weighed into two or more pots as required. After fusion, parting and cupellation, the precious metal beads for each sample were either treated individually or combined in pairs for digestion in aqua regia and determination of gold by flame atomic absorption. Gold content of the original sample was then calculated.

RESULTS AND DISCUSSION

In comparing gold values, 15 samples giving results close to or below the INAA detection limits (between 5 and 22 ppb gold) have been omitted. Seven of these also gave concentrations below the FA-AAS detection limit of 5 ppb gold.

Results for the 45 remaining samples (after excluding three outliers) are summarized in Figure 5-5-1. It is apparent that despite the very strong correlation (r = 0.99) between the two sets of data, there is some scatter and results by FA-AAS tend to be somewhat higher than those obtained by INAA. Fitting a line to the data points by reduced major axis regression gives:

$$\log \text{gold}_{FA\text{-}AAS} = 0.1801 + 0.9799 \log \text{gold}_{INAA}$$

that is, a positive intercept and a slope very close to one. The difference between the two data sets thus appears to be translational rather than rotational or a combination of the two. [A rotational bias would give an intercept of zero and a slope greater or less than one (Thompson, 1982)].

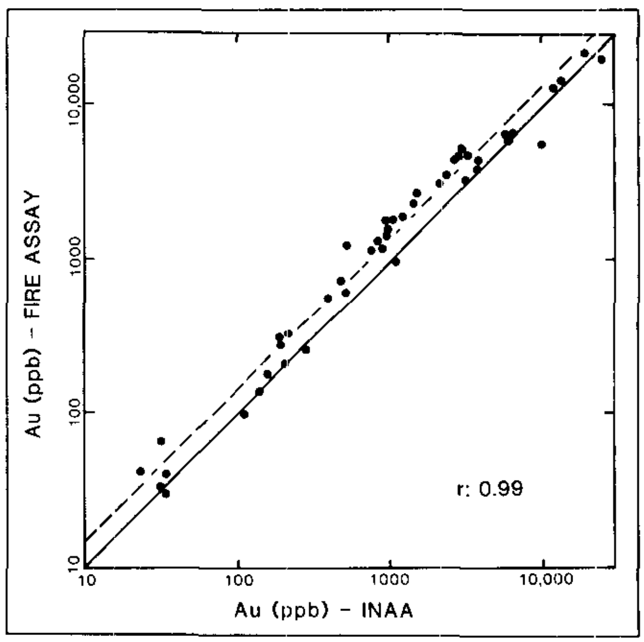

Figure 5-5-1. Log gold concentrations determined in 45 heavy-mineral concentrates by fire assay and atomic absorption (FA-AAS) and instrumental neutron activation analysis (INAA). The ideal line of equal values is shown by the solid diagonal with the reduced major axis regression to the data as the broken line ($\log \text{gold}_{FA\text{-}AAS} = 0.1801 + 0.9799 \log \text{gold}_{INAA}$).

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

To investigate the discrepancy further, recovery of gold by INAA ($R\%_{INAA}$) where:

$$R\%_{INAA} = (gold_{INAA}/gold_{FA\text{-}AAS}) \times 100$$

was examined in relation to sample weight after arranging results in groups of nine by weight (Figure 5-5-2). It is apparent that recovery systematically decreases as weight increases. This is most obvious with weights greater than about 10 grams and leads to recoveries as low as 50 per cent with concentrates weighing 50 grams. There is also considerable variability in recovery within each weight group superimposed on this systematic trend. This variability is not obviously related to either sample composition (concentrations for 21 other elements are available from the INAA) or grain size. The latter, however, requires further investigation.

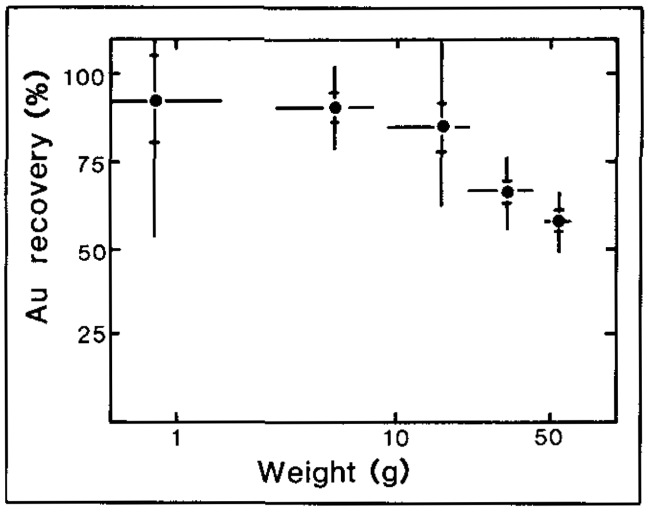

Figure 5-5-2. Per cent recovery of gold by INAA [$R\%_{INAA} = (gold_{INAA}/gold_{FA\text{-}AAS}) \times 100$] versus weight of heavy-mineral concentrate analysed. Each point represents the average weight and recovery of a group of nine samples. The vertical line through a point shows the one standard deviation limit for recovery and the horizontal line indicates the range of sample weights in the group. Small horizontal ticks on the vertical line indicate the standard error of the mean for recovery.

It is difficult to envisage an effect whereby the FA-AAS procedure could introduce a positive bias to gold values as sample weight increases. Low concentrations are therefore believed to reflect a systematic bias in the INAA method. This need not be a serious problem in exploration geochemistry, where relative rather than absolute concentrations may be acceptable (Fletcher, 1981), providing the bias remains constant. However, in routine surveys the yield of heavy minerals can vary considerably between samples from different bedrock sources and in sediment samples from adjacent sites on the stream bed (Day and Fletcher, 1986, 1987). In the determination of gold by INAA this variability could become an additional source of noise. Sample collection procedures should therefore be designed to keep variations in the weight of heavy-mineral concentrates to an acceptable minimum consistent with the goals of the survey.

Many parameters (for example, sample type and the INAA calibration procedures) may influence the magnitude of the bias between FA-AAS and INNA gold determinations. Results obtained in this study may not be typical. They do, however, indicate the need to evaluate weight-related effects in situations where there are likely to be large variations in the amounts of heavy-mineral concenrate available for analysis.

CONCLUSIONS

Instrumental neutron activation determination of gold content of heavy-mineral concentrates gave lower values than the fire assay and atomic absorption spectroscopy technique, with the difference increasing with increasing sample size. Where its multi-element nondestructive analytical capabilities make INAA the method of choice, survey design and sample collection procedures should attempt to minimize variations in heavy-mineral yield between sites as a source of unwanted variability in data for gold.

ACKNOWLEDGMENTS

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SEASONAL VARIATION OF GOLD CONTENT OF STREAM SEDIMENTS, HARRIS CREEK, NEAR VERNON: A PROGRESS REPORT* (82L/02)

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KEYWORDS: Applied geochemistry, stream sediments, gold concentration, seasonal variations.

INTRODUCTION

Results of a preliminary study of seasonal variations of gold content in Harris Creek were given by Day and Fletcher (1987a). Subsequently, Day and Fletcher (1987b) presented a model for transport of gold in Harris Creek and suggested that heavy-mineral concentrates collected from bar-head gravels could provide a good exploration medium. To study seasonal variations at such sites, bar-head gravels at a single site have been sampled five times between July 1986 and July 1987. Results for these samples are presented and discussed in relation to the transport model developed by Day and Fletcher (1987b).

LOCATION

Harris Creek rises in the Okanagan Highlands east of Vernon and flows north through Lumby (Figure 5-7-1). It was selected for study because it has exceptionally high gold concentrations and is easily accessible. The study reach, which has no major confluences, is approximately 2 kilometres long and 25 kilometres from the watershed (Figure 5-7-2). It has an energy slope of 0.03 and gravel point-bars are well developed in a typical sequence of alternating riffles and pools. Bulk sediment samples for this study were collected near the head of a gravel bar, site M1, at the downstream end of the reach.

SAMPLING METHODS

Previous studies of gold in Harris Creek (Day and Fletcher, 1986, 1987b) have shown that very large samples are nec-

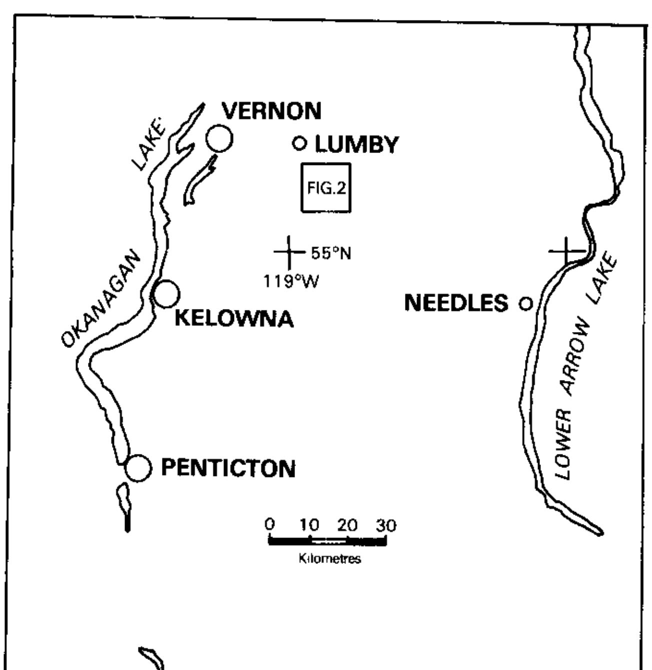

Figure 5-6-1. Location of Harris Creek.

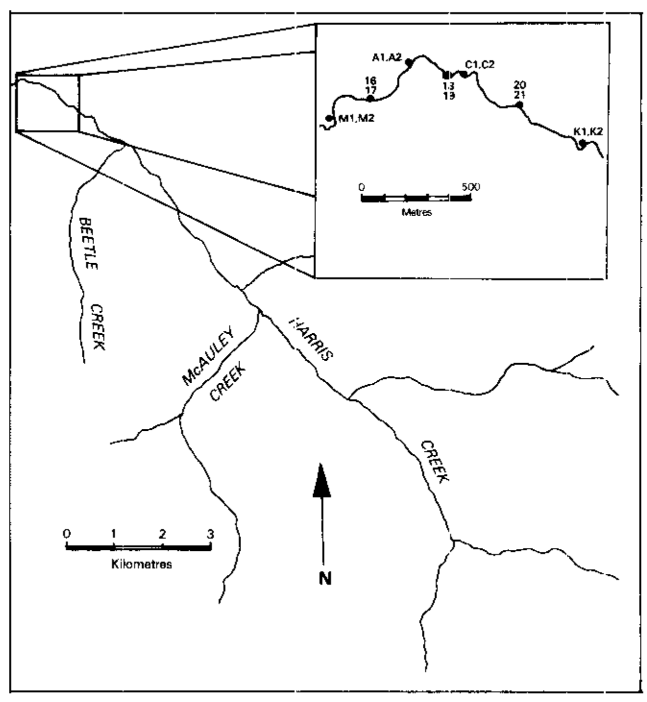

Figure 5-6-2. Catchment basin of Harris Creek, upstream from the study reach. Inset, sampling sites on the study reach — all samples used in this study were taken near the upstream head of the gravel bar at site M1.

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

cessary to ensure sample representivity. Samples therefore consisted of approximately 50 kilograms of –10-mesh (2-millimetre) sediment obtained by field screening up to 300 kilograms of gravel dug from a square metre area of the active stream bed. Samples were obtained in this way from adjoining 1-square-metre areas of the bar on July 28 and October 1, 1986 and April 7, 1987. This resulted in three shallow pits that only disappeared after the stream bed had been reworked by high discharges associated with the 1987 freshet. Two additional samples were then collected from the restored bed of the stream, at the site of the original pits, on June 20 and July 11, 1987.

Samples were dry-sieved to eight fractions, using a Rotap, and then manually wet-sieved to clean up the finer fractions. Heavy-mineral concentrates were prepared for the −150+200 and −200+270-mesh (ASTM) fractions using methylene iodide (S.G. = 3.3) and analysed for gold by instrumental neutron activation.

RESULTS

Results are summarized in Table 5-6-1. Between July 1986 and April 1987 heavy mineral concentrations on the bar declined, with the greatest decrease (approximately 40 per cent) in the finer size fraction. Concentrations then showed an increase on June 20, shortly after the 1987 freshet, before declining to their final value.

Gold concentrations in the −200+270-mesh heavy-mineral fraction show similar but much stronger trends than the heavy-mineral fraction. Thus concentrations initially decrease from 3900 ppb in July 1986 to only 53 ppb in April 1987. A post-1987 freshet increase to 830 ppb in June then fell to 130 ppb over a three-week period. Gold concentrations in the −150+200-mesh fraction also decreased between July 1986 (1600 ppb) and April 1987 (260 ppb). However the decrease then continued with concentrations falling below the detection limit (5 ppb) in June and July following the 1987 freshet.

TABLE 5-6-1
SEASONAL VARIATIONS IN CONCENTRATIONS OF HEAVY MINERALS AND GOLD IN BAR-HEAD GRAVELS AT SITE M1, HARRIS CREEK

Date	Heavy Minerals (%)[1]		Gold (ppb)[2]	
	Size Fraction			
	−150+200	−200+270	−150+200	−200+270
1986				
July 28	9.83	8.40	1600 (1070-2275)	3900 (3390-4470)
October 1	7.56	5.78	140 (15-440)	1000 (690-1360)
1987				
April 7	7.49	4.97	260 (90-600)	53 (5-200)
June 20	8.19	6.77	<5 (0-260)	830 (520-1240)
July 11	7.09	6.30	<6 (0-260)	130 (35-350)

[1] Weight per cent heavy minerals S.G. >3.3.

[2] Concentration of gold in the heavy mineral fraction; 80% confidence limits shown in parentheses.

DISCUSSION

The limited size of the bar and large sample size prevents use of replicate sampling to establish confidence limits to the gold content of the gravels at any one time. However, the sampling variability of discrete grains of a very rare mineral can be approximated by the Poisson distribution (for example, Fletcher, 1981; Ingamels, 1974; Phillips, 1971). Confidence limits have therefore been calculated using the Poisson distribution[1] and an estimate of the number of particles of free gold in each sample. This was obtained by assuming that the minimum mass of gold (that is, gold concentration times weight of heavy-mineral fraction) in a series of samples of the same size fraction corresponds to the mass of a single particle of free gold in that fraction. Calculated (80 per cent) confidence limits (Table 5-6-1 and Figure 5-6-3) only overlap with those of samples collected on adjoining dates for the low gold contents found in the −150+200-mesh fraction from October 1986 on. It is therefore believed that the major trends in gold concentration versus time are probably real, rather than random variations in gold content of the gravels.

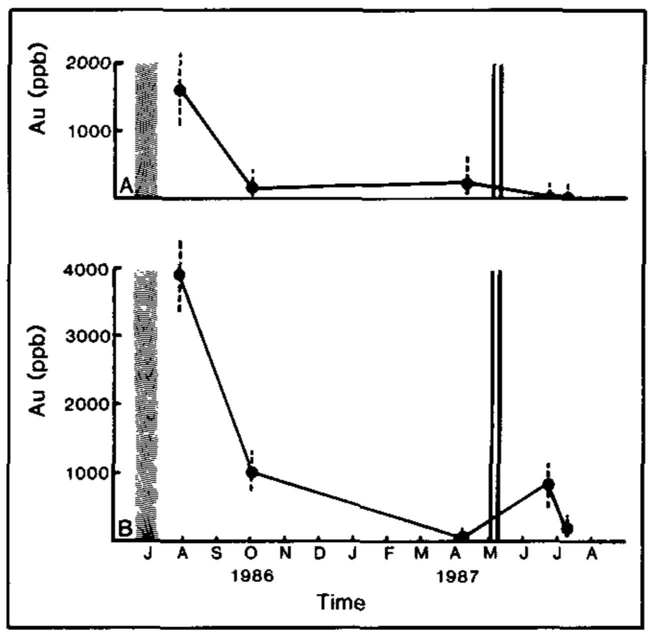

Figure 5-6-3. Gold concentrations in heavy mineral fraction (S.G. = 3.3) versus time at site M1, A: −150+200 mesh; B: −200+270 mesh. Vertical dashed lines indicate the 80 per cent confidence limits on the gold concentrations. Shaded areas indicate the periods (June 19-July 11, 1986, and April 30-May 2 and May 7-May 10 1987) when stream discharges at Environment Canada Station 08LC042, near Lumby, exceeded 10 cubic metres per second (unpublished data, Environment Canada). Note: This station is downstream from the now inoperative Station 08LC005 and discharges at this site are typically twice as large as those shown in Figure 5-6-4.

[1] A table of the confidence limits of expectation of a Poisson variable is given by Pearson and Hartley (1966) or can be calculated from the χ^2 distribution (Zar, 1984).

Heavy-mineral concentrations can develop on a stream bed in response to either their selective deposition as sediment is transported over the bed or winnowing of lighter minerals from the bed. For Harris Creek, Day and Fletcher (1987b) have suggested that the accumulation of gold in bar-head gravels results from its preferential deposition and entrapment at these sites as stream discharge falls after the freshet. In contrast, lighter minerals and very fine heavies are more likely to be swept over bars and collect in back-bar eddy pools. In this model, concentrations of gold in the bar-head gravels would be expected to decline with time as stream discharge continues to fall after the freshet and less dense minerals are progressively deposited in the voids of the gravel pavement to dilute the gold. [Infilling of voids in gravels by finer sediment has been described by Einstein (1968), Beschta and Jackson (1979) and Frostick *et al.* (1984).]

A typical hydrograph for Harris Creek (Station 08LC005, Environment Canada, 1984) shows a short period in May (or June) when discharge increases by about an order of magnitude due to the snowmelt freshet (Figure 5-7-4). Discharge then falls rather smoothly and asymptotically over a two-month period to reach baseline discharges of less than 1 cubic metre per second by early August. Unfortunately monitoring at station 08LC005 was discontinued in 1984. Gold and heavy mineral abundances in this study cannot, therefore, be directly related to stream discharge for 1986-87. Nevertheless, the association of high concentrations of gold with periods of high discharge is consistent with the model of Day and Fletcher (1987b) for its early preferential entrapment in the gravels as the freshet subsides. In this respect, it is interesting that the heavy mineral and gold concentrations found during and shortly after the strong freshet of 1986 were appreciably higher than those found after the very weak freshet of May 1987.

Despite the dramatic fall in gold concentrations with time, absolute abundance of heavy minerals in the samples remains relatively constant (10-20 grams and approximately 5 grams in the $-150+200$ and $-200+270$-mesh fractions, respectively) in all the samples. Simple dilution, as voids in the gravels are filled with less dense minerals, is therefore not responsible for the decreases observed in relative concentrations of gold. Alternative possibilities are that free gold gradually works its way down through the voids until it is below the sampled depth or as voids in the gravels are filled with fine sediment, a smaller volume of the stream bed (and thus a shallower depth) is sampled to obtain the requ red amount of -10-mesh sediment.

With respect to exploration geochemistry, the large variability in gold concentrations with values ranging from strongly anomalous to less than the detection limit within a 3-square-metre area of the stream bed, is extremely disturbing, whatever its cause. However, assuming that the seasonal trends are real, there is a considerable dilemma in recommending an optimum time for sampling. Enhanced concentrations of gold (and presumably anomaly contrast) are associated with periods of high discharge. Sampling at such times should therefore improve the chances of identifying catchments containing gold mineralization. However, high discharge events are typically of short duration (hours to days) and unpredictable. They are therefore likely to become a source of unwanted noise in geochemical or heavy mineral surveys that must often be undertaken over much longer periods of time. Conversely, samples collected when stream discharge is lower and more stable may give less variable gold values, but fail to detect the presence of anomalous concentrations in the catchment.

Clearly more studies are needed to establish the cause of the seasonal variations in gold concentrations and to avoid this as a problem in the design and interpretation of geochemical and heavy mineral surveys. Nevertheless, it is already apparent that, insofar as gold concentrations appear to be at least partly related to the seasonal cycles of stream erosion and deposition, the stream hydrographs published by the Water Resources Branch of Environment Canada (and similar agencies in other countries) could be useful in planning such surveys.

The size of the bar at site M1, and the need to take very large samples to ensure representivity, make adequate experimental replication difficult. The authors intend to continue the study through at least one more freshet in order to confirm the present observations and resolve their interpretation.

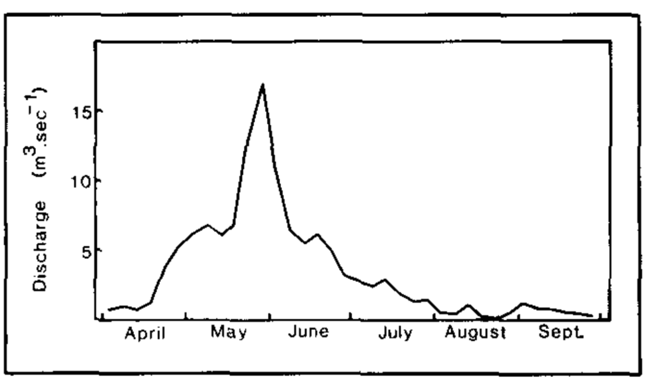

Figure 5-6-4. A typical hydrograph for Harris Creek; 5-day average discharges based on data for 1983 at Station 08LC005 (Environment Canada, 1984).

CONCLUSIONS

Gold content of stream sediments collected from gravel head-bars can show considerable seasonable variability. In Harris Creek maximum gold concentrations were found at or shortly after the periods of maximum discharge.

ACKNOWLEDGMENTS

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PRELIMINARY LITHOGEOCHEMICAL STUDY OF SLOCAN GROUP

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KEYWORDS: Lithogeochemistry, Slocan Group, genetic models, epigenetic veins, stratabound sulphides, metal abundances, mass balance.

INTRODUCTION

Lithogeochemistry is being used increasingly as a basis for examining genetic models of ore deposition and characterization of hydrothermal affects that extend beyond such features as megascopically recognizable mineralization and alteration zones.

Here we present results of a preliminary lithogeochemical study of the Slocan Group, motivated by (1) the prior recognition of syngenetic sulphides in the clastic sequence, and (2) an earlier, restricted lithogeochemical study by Cox (1979) on the basis of which he rejected the likelihood that the Slocan Group provided the metals for the silver-lead-zinc-gold veins of the Slocan mining camp.

SAMPLING ANALYSES AND DATA

Rock samples were collected from outcrops representative of parts of both the Slocan Group and the Rossland Group. Cox (1979), on the basis of lithogeochemistry, suggested that these sedimentary units were an unlikely source for metals in contained vein deposits. Our sampling was therefore directed toward potential source beds and should not be construed as representative of the units in their entirety. Sampling included carbonaceous units, pyritic horizons, tuffaceous intervals and volcanic units. Sample descriptions and locations are given by Logan (1986). All samples were examined closely and any crosscutting mineralized fractures were removed prior to crushing and grinding. Thus, it was hoped, each sample represented metal abundances of the original sedimentary rocks (± diagenetic ± metamorphic changes) with little or no epigenetic additions.

Sample analysis (n = 69) by atomic absorption spectrophotometry with an aqua regia extraction was carried out in North Vancouver by Vangeochem Labs Limited. The geochemical data for lead, zinc, silver, cobalt, nickel, barium, cadmium and sulphur, together with means, standard deviations and standard errors of the means, are tabulated in stratigraphic order (Table 5-7-1). Duplicate analyses of samples were undertaken to test the analytical precision. Precisions, estimated as the mean relative error in per cent for each element, are as follows: silver, 5 per cent; lead, zinc and nickel, 20 to 30 per cent; cobalt and cadmium, 30 to 40 per cent; sulphur, 65 per cent; and barium, 121 per cent.

Total carbon was determined for a set of five pyritic and carbonaceous slate samples (Table 5-7-2). These samples were crushed and ground to −200-mesh and analysed by Canadian Microanalytical Service Ltd. of Vancouver.

DATA ANALYSIS

Histogram and probability plots of both arithmetic and $\log_10$ transformed values for all variables were computer-generated and show multiple lognormal distributions for all elements except cobalt. The probability plots were partitioned graphically (compare Sinclair, 1976) into separate populations. Three populations are indicated for lead, silver, cadmium and sulphur; two for zinc, nickel and barium; and one for cobalt. Means, standard deviations and threshold values for the partitioned populations are listed in Table 5-7-3.

Three populations are evident in the probability plot for silver (Figure 5-7-1). The upper population (A) with a lower threshold of 0.49 ounce silver per ton corresponds to epigenetic mineralization. Population B (lower threshold = 0.04 ounce silver per ton) has been divided petrographically into two subsets: B_1 is characterized by stratabound sedimentary sulphides accompanied by remobilized, possibly epigenetic features, and B_2 corresponds to the slate belt which contains stratabound sulphides but little evidence of remobilization. The lower population (C) represents the remaining 45 samples from other rock units sampled.

The upper populations for lead, nickel and cadmium also correspond to samples exhibiting signs of epigenetic mineralization. The upper population for zinc corresponds to samples containing both epigenetic and stratabound sulphide textures. The upper population of barium represents samples of stratiform sulphide mineralization. Table 5-7-4 compares mean metal abundances of Slocan lithologic units, Rossland Group, Nelson plutonic rocks and average shale values. Of these, the slate belt (n = 11) shows the most significant enrichment in silver, barium and sulphur relative to average shale (Vine and Tourtelot, 1970). Sulphur values show a large variability, are high relative to other units and clearly correlate with the amount of pyrite. Mean barium values in slate belt samples indicate enrichment by a factor of 10 over average shales and, interestingly, are comparable to barium in the weakly mineralized samples reported here. Silver may be enriched in "Unit-1", although this could be an artifact of the small data set.

Variation of the cobalt and nickel abundances is greater within individual "lithologic units" than for averages among units. Weakly mineralized samples here are enriched in nickel by an order of magnitude compared with unmineralized rock. Cobalt(%)/nickel(%) ratios also indicate

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

this enrichment. Cobalt/nickel ratios (calculated from means) for the various Slocan lithological units range from 0.5 to 0.95, are 0.84 for the Rossland Group, but are 0.15 for epigenetic mineralized rocks.

TRIANGULAR PLOTS

Metal ratios for deposits in four polymetallic vein camps in southeastern British Columbia have been characterized using triangular plots (Sinclair, 1979; Goldsmith and Sinclair, 1984). One of these is the Slocan camp. For the Slocan, production plots of silver, lead and zinc best describe the vein mineralogy. These three variables also permit comparison with lithogeochemical data of the present study.

Figure 5-7-2(a) shows average production information plotted for 128 vein deposits from the Slocan camp (from Goldsmith and Sinclair, 1984). Silver(oz)/lead(%) ratios for the deposits are greater than 0.7. A group of zinc-rich deposits cluster within this high silver/lead field close to the zinc vertex with lead(%)/zinc(%) ratios of less than 0.25. The remaining deposits have lead/zinc ratios mostly greater than

TABLE 5-7-1
SLOCAN REGIONAL ROCK-GEOCHEMISTRY DATA AND STATISTICS
(*See* Logan, 1986, for sample locations and descriptions.)

SLOCAN GROUP (Fine-grained clastics)
Lithological Unit 1

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
WW W2202A	0.0016	0.0104	0.071	0.0025	0.0050	0.176	0.00026	2.13
WW W2202B	0.0012	0.0019	0.062	0.0005	0.0010	0.016	0.00006	0.12
Arithmetic mean	=0.0014	0.0062	0.066	0.0015	0.0030	0.096	0.00016	1.13
Std. deviation	=0.0002	0.0060	0.006	0.0014	0.0028	0.113	0.00014	1.42
Std. error mean	=0.0001	0.0042	0.004	0.0010	0.0020	0.079	0.00010	1.00

Lithological Unit 2

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
CC 1501B	0.0030	0.0105	0.021	0.0030	0.0065	0.016	0.00018	1.34
CC 1502	0.0025	0.0135	0.006	0.0035	0.0040	0.096	0.00029	0.67
CC 1504A	0.0027	0.0115	0.026	0.0045	0.0035	0.096	0.00022	1.03
CC 1515	0.0030	0.0098	0.044	0.0035	0.0080	0.016	0.00019	1.10
CC 1516	0.0020	0.0110	0.017	0.0040	0.0040	0.016	0.00032	1.32
BO B1003	0.0034	0.0110	0.021	0.0060	0.0040	0.016	0.00030	1.31
BO B1004	0.0014	0.0114	0.012	0.0035	0.0050	0.056	0.00037	0.96
BO B1005	0.0018	0.0255	0.017	0.0035	0.0055	0.056	0.00062	1.48
BO B1006	0.0026	0.0140	0.029	0.0050	0.0040	0.005	0.00022	1.35
BO B1007	0.0023	0.0127	0.006	0.0050	0.0030	0.056	0.00026	0.91
BO B1008	0.0020	0.0130	0.015	0.0040	0.0025	0.096	0.00021	0.91
BO 2004	0.0024	0.0105	0.017	0.0055	0.0040	0.056	0.00026	1.24
BO B2009	0.0023	0.0139	0.006	0.0045	0.0030	0.096	0.00018	0.68
Arithmetic mean	=0.0024	0.0129	0.018	0.0043	0.0044	0.052	0.00028	1.14
Std. deviation	=0.0005	0.0040	0.011	0.0009	0.0015	0.036	0.00012	0.33
Std. error mean	=0.0001	0.0011	0.003	0.0002	0.0004	0.010	0.00003	0.09

Lithological Unit slate belt

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
PA 606	0.0023	0.0105	0.082	0.0025	0.0050	0.256	0.00019	8.42
PA 606A-4	0.0010	0.0073	0.109	0.0035	0.0090	1.272	0.00022	8.83
PA 606A-11	0.0005	0.0081	0.006	0.0010	0.0015	0.376	0.00022	0.29
PA 606A-14	0.0024	0.0083	0.074	0.0080	0.0080	0.136	0.00031	16.27
CD 1404C	0.0065	0.0090	0.044	0.0040	0.0075	0.576	0.00044	10.23
CD 1405C	0.0052	0.0500	0.053	0.0025	0.0080	0.422	0.00109	1.58
CD 1406C	0.0060	0.0135	0.065	0.0040	0.0045	0.096	0.00044	2.15
CD 1408C	0.0052	0.0111	0.038	0.0020	0.0030	0.096	0.00066	0.30
CD 1410C	0.0016	0.0014	0.032	0.0005	0.0010	0.136	0.00007	0.26
PR 1902	0.0019	0.0085	0.015	0.0030	0.0060	0.096	0.00035	0.96
PR 1904	0.0022	0.0099	0.106	0.0040	0.0155	0.196	0.00012	5.00
Arithmetic mean	=0.0031	0.0125	0.057	0.0032	0.0063	0.333	0.00037	4.94
Std. deviation	=0.0020	0.0120	0.032	0.0020	0.0041	0.349	0.00029	5.33
Std. error mean	=0.0006	0.0036	0.009	0.0006	0.0012	0.105	0.00009	1.61

Lithological Unit 3

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
NB 1408	0.0058	0.0104	0.017	0.0030	0.0050	0.096	0.00017	0.81
ID 1707	0.0028	0.0190	0.012	0.0055	0.0030	0.216	0.00018	1.13
ID 1708	0.0045	0.020	0.024	0.0040	0.0030	0.005	0.00027	0.96
ID 1709	0.0021	0.0110	0.012	0.0050	0.0030	0.016	0.00013	0.71
ID 1709C	0.0015	0.0084	0.012	0.0035	0.0050	0.056	0.00019	1.05
RD 2003	0.0011	0.0310	0.017	0.0030	0.0065	0.056	0.00102	1.03
RD 2004	0.0017	0.0170	0.009	0.0035	0.0045	0.016	0.00043	1.46
RD 2005	0.0011	0.0119	0.015	0.0030	0.0035	0.016	0.00021	1.52
RD 2006	0.0017	0.0120	0.015	0.0035	0.0050	0.005	0.00043	1.35
Arithmetic mean	=0.0025	0.0015	0.015	0.0038	0.0043	0.054	0.00034	1.11
Std. deviation	=0.0015	0.0066	0.004	0.0009	0.0012	0.068	0.00028	0.28
Std. error mean	=0.0005	0.0022	0.001	0.0003	0.0004	0.022	0.00009	0.09

TABLE 5-7-1—*Continued*
SLOCAN REGIONAL ROCK-GEOCHEMISTRY DATA AND STATISTICS
(*See* Logan, 1986, for sample locations and descriptions.)

ROSSLAND GROUP (volcanic and clastic rocks, undivided)

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
CU CU8201	0.0015	0.0068	0.003	0.0055	0.0065	0.036	0.00015	0.35
CU CU8204	0.0019	0.0126	0.012	0.0045	0.0065	0.096	0.00026	0.06
CU CU8206	0.0018	0.0099	0.006	0.0050	0.0060	0.096	0.00019	0.07
CU CU8207	0.0015	0.0035	0.006	0.0030	0.0020	0.076	0.00014	0.79
CU CU8207A	0.0022	0.0040	0.006	0.0025	0.0020	0.036	0.00010	2.07
SS J8404S	0.0020	0.0240	0.017	0.0020	0.0025	0.176	0.00011	0.07
SS J8406S	0.0018	0.0061	0.003	0.0030	0.0020	0.056	0.00007	6.43
SS J8407S	0.0020	0.0164	0.006	0.0045	0.0075	0.016	0.00022	0.10
SL 8201	0.0021	0.0045	0.009	0.0055	0.0035	0.056	0.00017	0.05
SL 8202	0.0022	0.0096	0.006	0.0050	0.0050	0.176	0.00018	.06
SL 8203A	0.0027	0.0190	0.015	0.0070	0.0110	0.096	0.00038	0.45
SL 8203B	0.0020	0.0072	0.006	0.0065	0.0021	0.176	0.00019	0.17
SL 8203C	0.0022	0.0119	0.009	0.0060	0.0075	0.036	0.00022	0.25
SL 8204	0.0020	0.0085	0.003	0.0050	0.0065	0.005	0.00016	0.79
SL 8205	0.0022	0.0084	0.012	0.0055	0.0080	0.056	0.00019	0.95
SL 8206	0.0016	0.0055	0.009	0.0050	0.0060	0.016	0.00015	0.31
SL 8207	0.0018	0.0128	0.006	0.0060	0.0085	0.016	0.00015	0.47
SL 8208	0.0025	0.0062	0.006	0.0055	0.0060	0.056	0.00030	0.34
SL 8209	0.0019	0.0137	0.009	0.0055	0.0085	0.056	0.00020	0.04
SL 8210	0.0018	0.0065	0.006	0.0035	0.0045	0.036	0.00018	0.10
SL 8218	0.0016	0.0089	0.001	0.0035	0.0055	0.016	0.00018	0.02
Arithmetic mean	=0.0019	0.0098	0.007	0.0047	0.0056	0.066	0.00019	0.71
Std. deviation	=0.0003	0.0052	0.004	0.0013	0.0025	0.053	0.00007	1.40
Std. error mean	=0.0007	0.0011	0.001	0.0003	0.0005	0.012	0.00001	0.31

EPIGENETIC MINERALIZATION (undivided)

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
NB 14-B	0.1600	1.140	0.629	0.0030	0.0040	0.276	0.0118	3.04
NB 1401A	3.6000	0.0040	4.694	0.0051	0.0035	0.016	0.00054	22.68
NB 1409	0.5600	0.9600	1.576	0.0020	0.0035	1.176	0.0088	.70
NB 1410	0.0035	0.0780	0.141	0.0055	0.0300	0.176	0.00192	5.42
PA 606A-6	0.0019	0.4400	0.092	0.0030	0.0140	0.216	0.00590	3.48
PA 606A-8	0.0045	0.0960	0.129	0.0065	0.0300	0.336	0.00144	12.31
CD 1402C	0.172	0.0138	0.147	0.0065	0.0085	0.176	0.00049	7.96
CD 1403C	0.0251	0.0548	0.071	0.0025	0.0065	0.096	0.00112	2.13
CD 1409C	0.0088	0.345	0.088	0.0055	0.0450	0.016	0.0056	0.12
SS J8401S	0.0091	0.2500	0.582	0.0050	0.0400	0.096	0.0057	0.65
SS J8402S	0.0047	0.2900	0.965	0.0050	0.0450	0.456	0.0064	1.17
SS J8403S	0.0020	1.4500	0.144	0.0045	0.0950	0.296	0.00154	0.82
SS J8405S	0.0024	0.5500	0.188	0.0035	0.0500	0.016	0.00035	0.29
Arithmetic mean	=0.3503	0.4363	0.727	0.0044	0.0288	0.253	0.00397	4.20
Std. deviation	=0.9888	0.4681	1.270	0.0015	0.0266	0.309	0.00366	5.44
Std. error mean	=0.2739	0.1297	0.353	0.0004	0.0074	0.086	0.00101	1.78

0.7. In comparison, Figure 5-7-2(b) shows the silver(oz)-lead(%)-zinc(%) plot of rock geochemical data. The most obvious difference between Figures 5-7-2(a) and 2(b) is the relative depletion of rocks in lead. Silver(oz)/lead(%) ratios of the lithogeochemical data are mostly greater than 2.5 and lead(%)/zinc(%) ratios less than 1.0. This restricts data to less than half the area of the plot area. Symbols in Figure 5-7-2(b) separate lithologic units and epigenetic mineralization and indicate higher relative silver for the slate belt data. A cluster of mineralized samples near the zinc vertex corresponds to the zinc-rich deposits of Figure 5-7-2(a). The remaining mineralized samples (except two) are close to the silver-zinc line indicating low relative lead abundances.

The silver-nickel-cobalt plot (Figure 5-7-3) shows data extending outward from the silver vertex about the 1:1 Co(%)/Ni(%) ratio line. Mineralized samples cluster near the silver vertex and extend along the silver-nickel line suggestive of an enrichment of nickel relative to cobalt. Slate belt data plot closest to the silver vertex. Distribution of samples about the 1:1 cobalt-nickel line suggests a sympathetic variation for the two.

DISCUSSION

Three main stages of sulphide formation (diagenetic, metamorphic, hydrothermal) have been defined for the sediments on the basis of texture (Logan, 1986). There is an increased abundance of copper, nickel, zinc and lead sulphides with each successive stage of sulphide formation (that is, hydrothermal > metamorphic > diagenetic). The total content of trace metals is assumed to have remained unchanged during diagenesis.

Trace metal distribution within the sedimentary rocks is as important as total metal concentration in assessing whether the sedimentary units were capable of providing metals to mineralizing solutions. Analysis of organic matter from the carbonaceous mudstones hosting the XY deposit at Howards Pass, Yukon–Northwest Territories boundary, indicates that less than 22 per cent of copper, nickel, cobalt, zinc and silver is bound in the organic component and that the bulk of trace metals occurs within the sulphides (Goodfellow *et al.*, 1983). Trace elements in pyrite separates from Black Sea carbonaceous sediments (Bulugara, 1969, referred to in Good-

TABLE 5-7-2
TOTAL CARBON AND HYDROGEN, SLATE BELT SAMPLES, SLOCAN DISTRICT
(*See* Logan, 1986, for sample locations and descriptions.)

Sample	Lithology	Element (%) C	H
San 01	slate	5.25	<0.02
WW 2B	slate	2.10	<0.02
PA 606	slate	4.52	<0.02
PA 606	slate	4.51	<0.02
CD-1	slate	5.25	<0.02
W1-1	greywacke	1.82	<0.02

TABLE 5-7-3
STATISTICAL PARAMETERS AND THRESHOLDS FOR PARTITIONED POPULATIONS, SLOCAN ROCK-GEOCHEMICAL DATA
(*See* Sinclair, 1976, for methodology.)

Element Units	Populations %	B[1]	b+s[2]	b−s[3]	Thresholds
Pb	A(0.06)	0.70	6.0	0.009	0.015
%	B(0.15)	0.007	0.01	0.0049	0.0055
					0.0033
	C(0.79)	0.0021	0.0033	0.0014	
Zn	A(0.15)	0.45	0.80	0.25	0.05
%	B(0.85)	0.01	0.019	0.0056	
Ag	A(0.07)	0.94	1.25	0.7	0.49
oz/ton	B(0.27)	0.10	0.20	0.048	0.04
					0.022
	C(0.66)	0.01	0.02	0.0052	
Co[4]	A(1.0)	42.0	56.0	29.0	67.5
ppm					
Ni	A(0.10)	440.0	540.0	360.0	370
ppm					200
	B(0.90)	44.0	80.0	25.0	
Ba	A(0.03)	1.2	1.35	1.10	0.65
%	B(0.97)	0.07	0.21	0.025	
Cd	A(0.08)	64.0	80.0	50.0	38
ppm	B(0.10)	18.0	26.0	13.0	8.5
	C(0.82)	2.3	4.2	1.4	
S	A(0.15)	9.3	10.3	6.2	2.5
%	B(0.65)	0.90	1.4	0.57	0.35
	C(0.20)	0.10	0.18	0.053	

% of data in population.
[1] Antilog of mean of lognormal population.
[2] Antilog of mean plus one standard deviation of lognormal population.
[3] Antilog of mean minus one standard deviation of lognormal population.
[4] Normal distribution.

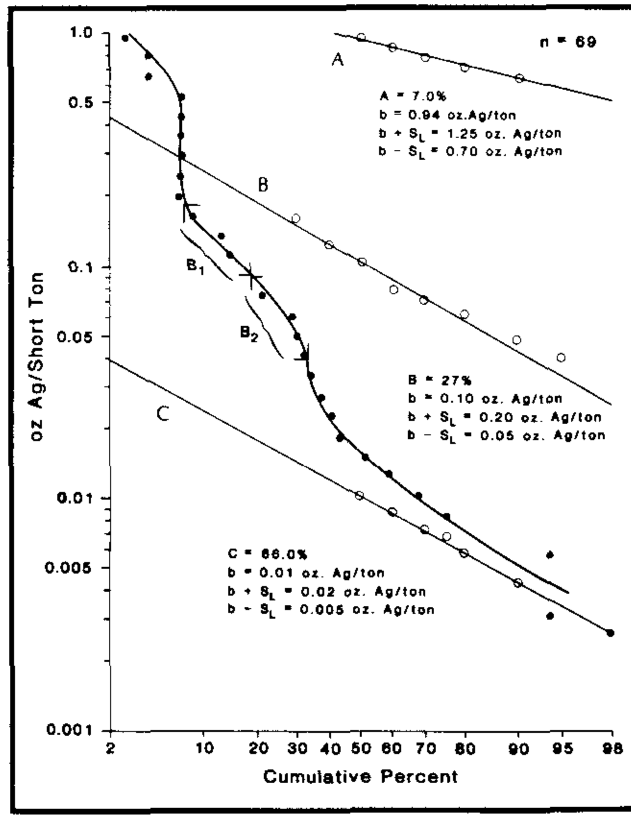

Figure 5-7-1. Probability graph of 69 Ag values for samples from sedimentary and volcanic rocks in the Sandon area, Slocan mining camp. Black dots are original data, open circles are estimated partitioning points. Procedure after Sinclair (1976).

fellow *et al.*, 1983) and black shales from Amjhore, India (Pandalai *et al.*, 1983) show that most of these metals are incorporated in iron sulphides (Co^{2+} and Ni^{2+} substitute isomorphously for Fe^{2+} in the pyrite lattice owing to similar ionic radii, other elements probably occur as discrete sulphide phases).

Reflected light microscopy combined with scanning electron microscope energy dispersive spectroscope studies of the Slocan sedimentary samples indicates the presence of inclusions of sphalerite, chalcopyrite, millerite and galena in pyrite, and less commonly in pyrrhotite. Discrete silver

TABLE 5-7-4
COMPARATIVE ROCK GEOCHEMISTRY, SLOCAN DATA VERSUS OTHERS

Element	Lithologic Units Slocan Group 1 n=2	2 n=13	2 n=20[1]	Slate Belt =11	3 n=9	3 n=63[1]	Rossland Group n=21	Nelson Batholith n=19[1]	Black Shale[2]
Pb (ppm)	14	24	32	31	25	31	19	33	20
Zn (ppm)	62	129	58	125	156	175	98	101	<300
Ag (oz/ton)	0.066	0.018	n.c.	0.057	0.015	n.c.	0.007	n.c.	<0.029
Co (ppm)	15	43	n.c.	32	38	n.c.	47	n.c.	10
Ni (ppm)	30	44	n.c.	63	43	n.c.	56	n.c.	50
Ba (%)	0.096	0.052	n.c.	0.333	0.054	n.c.	0.0066	n.c.	0.030
Cd (ppm)	1.6	2.8	n.c.	3.7	3.4	n.c.	1.9	n.c.	n.c.
S (%)	1.13	1.14	n.c.	4.94	1.11	n.c.	0.71	n.c.	n.c.

[1] Cox (1979).
[2] Vine and Tourtelot (1970).

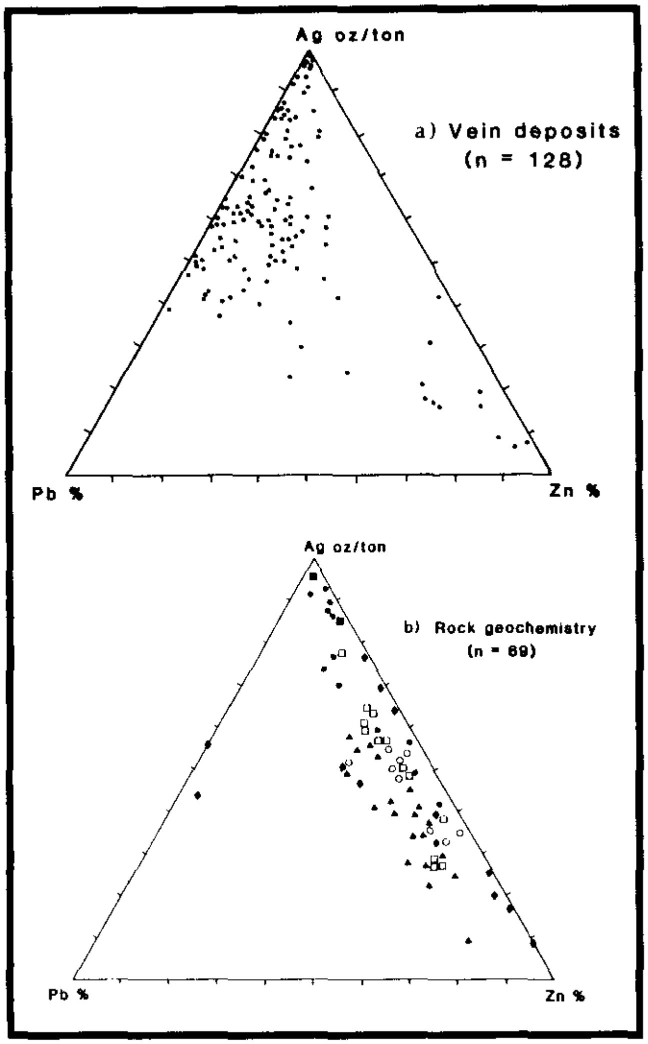

Figure 5-7-2. Ag-Pb-Zn triangular plots: (a) average production grades, Slocan mining camp (Goldsmith and Sinclair, 1984), (b) regional lithogeochemical data, this study. Solid squares are Slocan Unit 1, open squares are Unit 2, solid circles are slate belt and open circles are Unit 3. Triangles represent Rossland Group and diamonds denote mineralized samples.

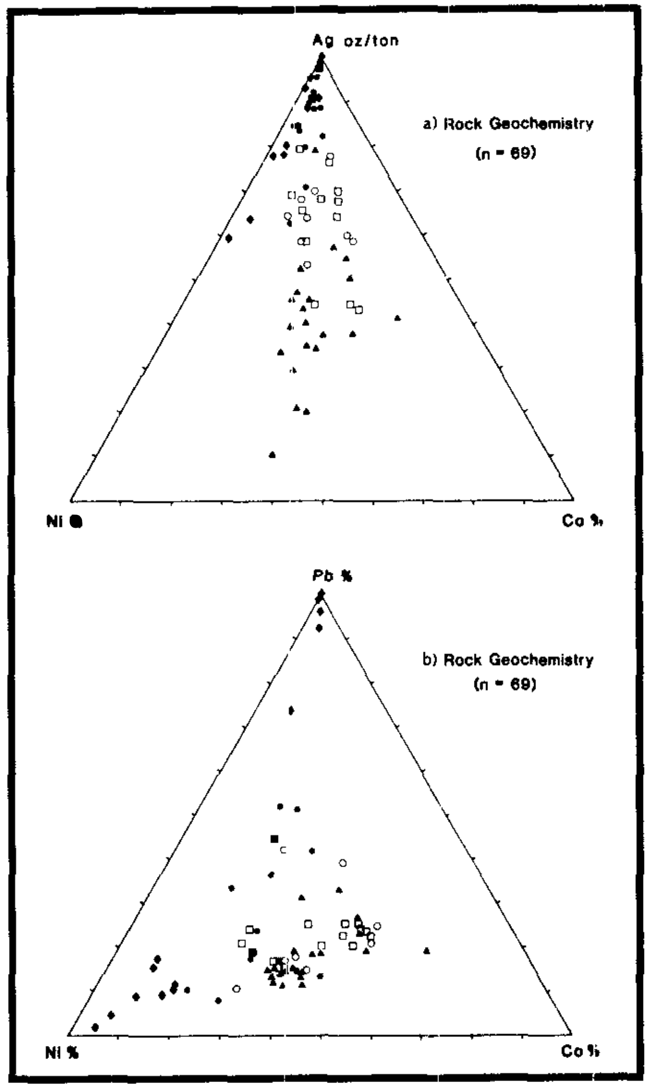

Figure 5-7-3. Ag-Ni-Co and Pb-Ni-Co triangular plots of regional rock geochemistry, Sandon area, Slocan mining camp. Symbols as described in Figure 5-7-2.

sulphide minerals could not be identified in the sedimentary rocks.

Boyle (1968) has emphasized that for silver, the degree of diagenesis and metamorphism determines trace metal sites. Where only slightly metamorphosed, the trace metals are associated with clays, carbonaceous substances (bitumen, humic and fluvic acids) and fine-grained, nearly colloidal sulphides (Boyle, 1968). Increased metamorphism causes localization of trace metals, commonly as inclusions within iron sulphides. In Slocan sedimentary rocks, pyrrhotite is associated spatially with hornfels aureoles around intrusive bodies. This suggests regional/contact metamorphism of pyritic sediments has released sulphur during the conversion of pyrite to pyrrhotite. Sulphur isotope studies of vein minerals define an S^{34} spread of -11.0 to -1.0 per mil, averaging -7.0 (Brame, 1979). These values are characteristic of sulphur in sedimentary sulphides. During replacement of pyrite by pyrrhotite or simple recrystallization, the impurities (trace metals and sulphide inclusions) migrate to crystal edges where precipitation or dissolution occurs, depending upon the ambient temperature, pressure and chemical activities. The solubilities of most sulphides are greatest in the bisulphide (HS^-) stability region (Fyfe *et al.*, 1978) and sulphur released during metamorphism would increase the activities of the aqueous sulphur species. Sulphide complexes of silver, lead, zinc and copper are more stable than chloride complexes in the temperature range suggested by fluid inclusions, (Reinsbakken, 1968) for vein formation. Chloride complexes are more stable for silver above 300°C and for lead below 300°C (Barnes, 1979). The paragenetic sequence and mineralogic zonal pattern for lode deposits results from changing solution chemistry (pH, Eh, sulphur activity), temperature and pressure during vein deposition.

The general paragenetic sequence of ore deposition is pyrite – sphalerite – tetrahedrite – galena – silver sulphosalts and native silver (Cairnes, 1934). The age of mineralization is believed to be related to intrusion and therefore equivalent in age to the Nelson batholith (Reynolds and Sinclair, 1971; Andrew *et al.*, 1984). Metamorphogenic hydrothermal fluids, either generated or modified through additions during contact metamorphism by intrusion of the Nelson batholith, were likely sulphide-rich solutions. The relative solubilities for lead, zinc and copper sulphide complexes, and the release of sulphur coincident in time with the initial mineralizing fluids, are compatible with vein paragenesis. Fluid inclusion studies of late-stage minerals (12 deposits) suggest that ore fluids were dilute brines (Reinsbakken, 1968). Limited fluid inclusions in quartz from the Scranton deposit contain daughter crystals, and up to 40 NaCl equivalent per cent salinity (Brame, 1979). Saline solutions such as these are capable of transporting lead and silver as chloride complexes. Assuming precipitation during decreasing fluid temperatures, late-stage silver deposition suggests changing from an initial Cl^--dominated hot brine to a less saline HS^--rich system. Factors such as decreasing temperature of fluids, the batholith, or the ambient temperature, longer pathlines for fluid circulation that facilitates more thorough sediment buffering of solutions, and decrease in activity of specific chemical species such as sulphur could produce this change in solution chemistry. Flow rate versus reaction rate determines whether the wallrock can buffer fluid compositions. If the flow rate is greater than the reaction rate, disequilibrium mass transport results (Fyfe *et al.*, 1978). This characterizes conditions of near-surface vein formation. The lack of wallrock alteration and the fact that the mineralization occupies large continuous through-going structures suggests that temperature is the factor controlling precipitation. Throttling or boiling can provide a pressure decrease resulting in deposition, but fluid inclusion studies (Reinsbakken, 1968) show no evidence of fluid boiling.

Comparisons between lithological units of the Slocan and Rossland groups indicate enrichments of silver, barium and sulphur concentrations for only the slate belt (Figure 5-7-4). This northwesterly trending zone coincides spatially with quadratic trend highs established for trace inclusions of silver in galena, tin in sphalerite and arsenic in pyrite (Sinclair, 1967). Sinclair (1967) suggests the distribution pattern of trends reflects a temperature gradient with the relatively high-temperature centre located near Sandon. Sulphide textures establish the syn/diagenetic nature of the slate belt sulphides. The coincidence of high metal concentrations centred on the highest spatial density of deposits and those with relatively more silver suggests this unit may have acted as a source for vein metals. Carbonaceous parts of the slate belt are enriched in trace metals but recognizable metallic minerals other than pyrite are not common. The abundance of sulphides in modern sediments has been shown to be directly proportional to the organic content of the sediments (Berner, 1970). A mean value of 4.2 per cent total carbon ($n=5$) places the slate belt rocks in the black shale category of Vine and Tourtelot (1970). These may represent "metal sinks" where metals have been trapped in immobile organic or sulphide phases rather than likely source beds.

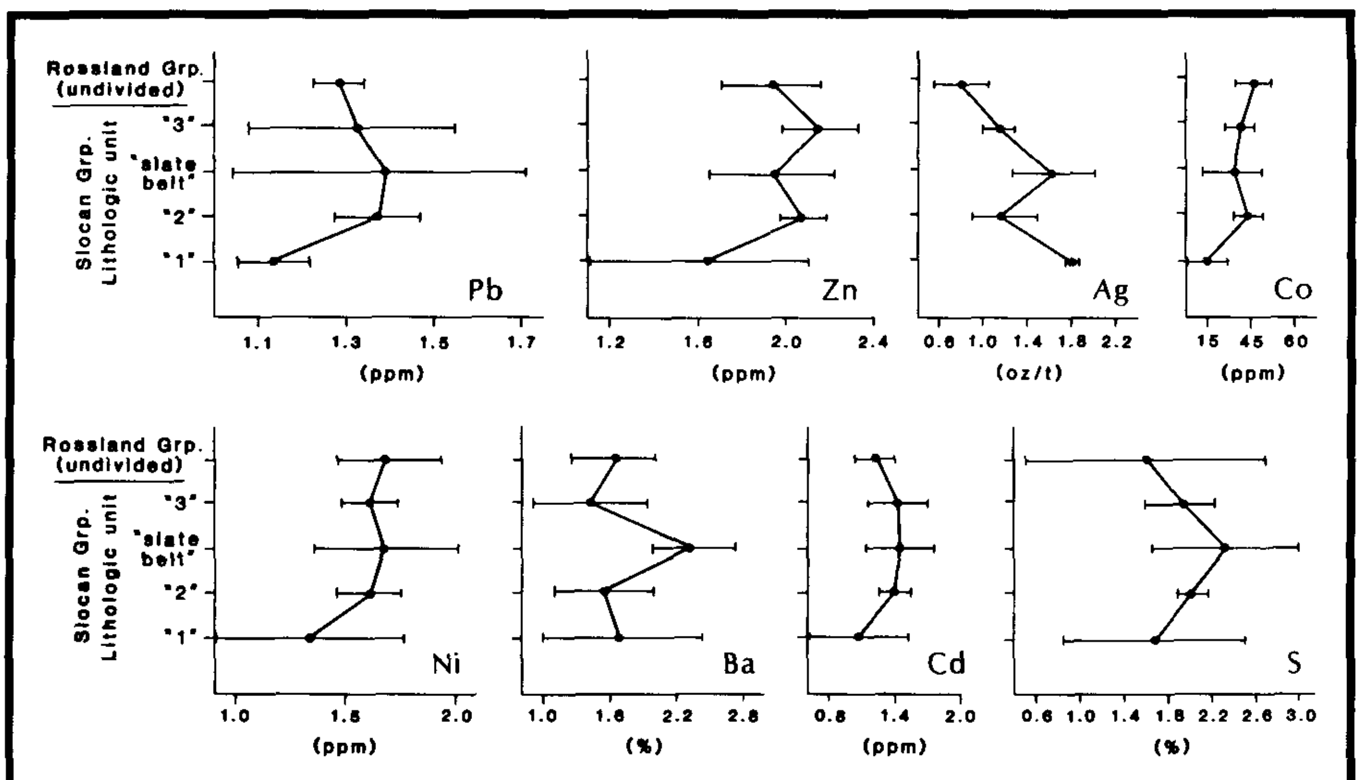

Figure 5-7-4. Variations in means and standard deviations of trace element concentrations for Slocan and Rossland units arranged in the assumed stratigraphic order. All abscissa scales are log (base 10) transforms of original data except for Cd which is log (base 10) of 10 × original data.

The validity of comparing absolute metal abundances for samples which contain variable amounts of carbonaceous material and pyrite is uncertain. Triangular diagrams display data as relative amounts and thus provide a means of comparing metal ratios in various substrates. Silver-lead-zinc plots for lithogeochemical data show that slate belt samples contain relatively high silver abundances. The rock geochemical ratios differ from ratios for average production figures for the camp only in the relative amount of zinc. The sedimentary rocks are enriched by a factor of two relative to the veins. A genetic model involving a sedimentary source for metal requires a 50-per-cent preferential depletion of zinc relative to both lead and silver to produce the ratios now found in veins from those now existing in the slate belt unit.

Source rock volumes can be determined using total production figures from the Slocan mining camp (Goldsmith *et al.*, 1986) to test the plausibility of sediment derivation for silver, lead and zinc in veins. The following calculations use mean metal values for slate belt rocks and assume 10 per cent extraction of metals from the source rock.

For silver, total production of 64×10^6 ounces and a mean metal value of 0.057 oz/ton:

$$\text{Amount of source rock} = \frac{64 \times 10^6 \text{ oz}}{0.1 \text{ (extraction)} \times 0.057 \text{ oz/ton}}$$

$$= \frac{11\ 228 \times 10^6 \text{ tons} \times 0.905 \text{ tonne/ton}}{2.7 \text{ tonne/m}^3 \text{ (volume conversion)}}$$

$$= 3.76 \times 10^9 \text{m}^3 \text{ or } 3.7 \text{ km}^3.$$

Calculations for lead, with a total production of 0.22×10^6 tonnes, requires $2.7 \times 10^8 m^3$ and for zinc with total production of 0.24×10^6 tonnes, $7.0 \times 10^7 m^3$ of source rock are required. From these calculations a sedimentary source seems a viable possibility for silver, lead and zinc in veins.

CONCLUSIONS

A variety of analytical data combined with crude mass balance calculations suggest that fine-grained clastic rocks of the Slocan Group could have been the source for metals in the spatially related silver-lead-zinc-gold veins. The geochemical data do not prove the genetic relationship but are permissive in terms of metal ratios, metal concentration ratios and estimated source rock volumes of 3 to 4 cubic kilometres, as well as other independent isotopic data (Logan, 1986).

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MINERAL POTENTIAL OF THE WOKKPASH RECREATION AREA

By Andrew Legun

KEYWORDS: Applied geochemistry, stream sediments, Wokkpash Creek, mineral potential.

INTRODUCTION

In 1985 a five-day stream sediment sampling program was undertaken in the Wokkpash Creek watershed. The area, currently classified as a Recreation Area by the Parks Branch, is located 32 kilometres due south of Mile 400 on the Alaska Highway. The results of the stream sediment sampling are reported here with minimal comment. Previous work dealt with geological observations (Legun, 1984) and details of sampling (Legun, 1985).

TABLE 5-8-1

I.D.	Sample Au (ppb.)	Ag (ppm)	Cu	Pb	Zn	Co	Ni	F	Ba
1	61	0.3	8	8	42	2	8	730	1120
2	90	0.3	11	10	58	3	13	1810	510
3	66	0.3	8	11	70	2	15	700	3300
4	49	0.3	8	21	51	2	7	690	3330
5	49	0.3	8	17	59	2	10	690	2490
6	45	0.3	8	18	80	3	10	980	1260
7	74	0.3	10	64	380	3	9	2070	5180
8	90	0.3	8	71	285	4	9	2050	5560
9	20	0.3	6	8	34	2	4	445	340
10	20	0.3	15	7	10	5	8	740	550
11	45	0.3	13	6	9	4	7	770	610
12	78	0.3	14	6	18	2	8	700	740
13	20	0.3	11	17	98	2	12	770	970
14	40	0.3	9	17	83	2	10	670	2680
15	20	0.3	12	21	45	2	11	950	810
16	37	0.3	5	3	12	2	4	890	240
17	40	0.3	11	15	28	2	8	590	380
18	57	0.3	53	21	42	10	18	1070	720
19	33	0.3	13	4	20	4	7	520	850
20	33	0.3	43	8	19	4	8	570	670
21	20	0.3	15	4	23	7	8	450	790
22	50	0.3	11	12	19	3	9	540	870
23	20	0.3	15	5	19	5	8	500	780
24	20	0.3	17	3	10	6	11	520	910
25	32	0.3	23	9	45	10	13	500	1580
26	20	0.3	19	6	20	8	8	510	640
27	20	0.3	11	11	15	3	6	510	1450
28	20	0.3	18	11	19	4	10	550	650
29	53	0.3	9	4	15	2	5	420	500
30	28	0.3	13	4	9	4	7	580	660
31	20	0.3	45	16	49	13	18	1240	750
32	20	0.3	21	7	11	5	8	880	560
33	20	0.3	14	8	19	6	7	515	540
34	40	0.3	26	13	43	11	13	930	730
35	28	0.3	9	9	22	2	4	430	1460
36	123	0.3	33	14	31	12	19	910	930
37	37	0.3	7	8	17	2	3	360	690
38	74	0.3	35	19	315	25	110	620	740
39	24	0.8	43	34	67	10	27	930	800
40	61	0.3	28	12	223	13	97	840	440
41	24	0.3	55	12	285	12	105	730	1420
42	70	0.3	73	17	425	24	220	770	5350
43	20	0.3	30	15	39	4	10	950	682
44	20	0.3	12	10	24	3	8	620	340

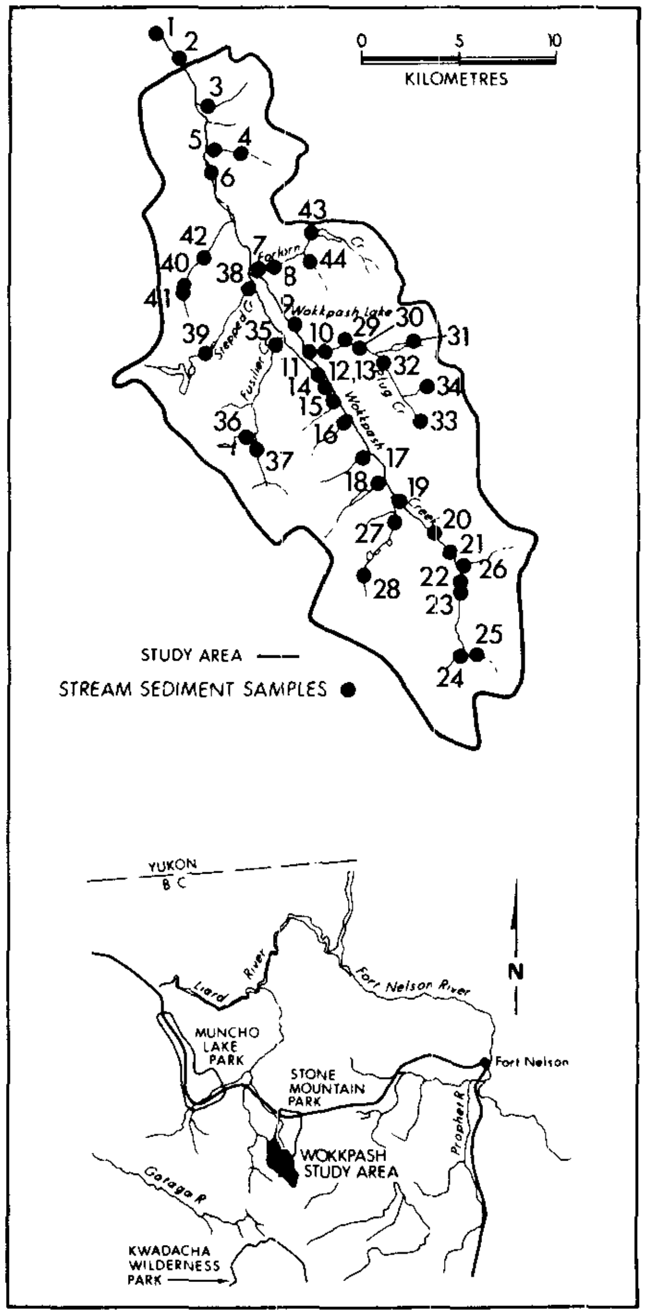

Figure 5-8-1. Location map and stream sediment sampling sites, Wokkpash Park Proposal area.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

RESULTS

A total of 44 samples were collected and analysed for gold, silver, copper, lead, zinc, cobalt, nickel, barium and fluorine. Barium was analysed by atomic absorption after fusion of the sample, gold was by fire assay with an atomic absorption finish. The rest of the samples were done by atomic absorption after acid digestion of the sample. Sampling sites are located and numbered in Figure 5-8-1. Analytical results for each sampling site are listed in Table 5-8-1. Concentrations are in parts per million except for gold which is given in parts per billion.

As the number of samples is small for statistical purposes, the results have been compared to regional geochemical values to determine their significance. This comparison shows the high end of values for copper, lead, cobalt and nickel are within the regional background range. This would tend to eliminate the following types of regional mineralization from consideration:

(1) Disseminated copper in Proterozoic quartzites.
(2) Copper veins associated with gabbro dykes that cut Proterozoic rocks (Churchill mine, Carr, 1971).
(3) Copper in Ordovician limestones and sandstones of the Ketchika Group (Cup claims, Assessment Report 12594).

Of the remaining elements, one sample is anomalous for silver, three for zinc, one for gold and three for barium. A value is considered anomalous if it corresponds to the top 2 per cent of values of the regional sample. Elements with anomalous values are discussed below.

GOLD

Sample 36 (123 ppb gold) was obtained in Proterozoic terrane west of a major fault. There is no coincident anomalous value in silver and nearby values are low.

SILVER

A rock sample from a breccia-conglomerate (regolith ?) at the Proterozoic-Paleozoic contact on Fusilier Creek returned an analysis of 10 ppm silver (Legun, 1984). A stream sediment sample downstream from this site gave background results (0.3 ppm). The only stream sediment sample anomalous in silver (39) is on Stepped Creek, just downstream from the faulted Proterozoic-Paleozoic contact. It is not associated with any other elements.

ZINC AND LEAD

The anomalous zinc values are clustered at the north end of Wokkpash Lake in well-exposed Paleozoic terrain. The highest value (425 ppm) coincides with an area of black shale rather than limestone. Associated lead values in limestone terrain are rather weak and erratic (for example, samples 7, 38, 41). The only area where there is an association of lead, zinc, barium and fluorine values typical of lead-zinc deposits in limestones is in Forlorn gorge. The rock walls here have superb exposure and only traces of fluorite were visible on examination. According to Taylor and Stott (1973) the dolomitic breccia facies typical of the Robb Lake deposits is not present within the proposed park boundary. The writer's fieldwork supports this. The potential for lead-zinc mineralization in Devonian limestones (particularly along the contact of the Stone and Dunedin formations) is considered to be low.

BARIUM

Regionally, barite deposits occur in crosscutting buttress-like structures as at Sulphur Creek or 110 Creek (MacQueen and Thompson, 1978). No such structures were visible from the air in well-exposed terrain. Potential remains, however, for stratiform bedded barite deposits. They are similar to their host rocks and not easily recognized. Some of the anomalous barite values (for example, 5350 ppm in sample 42) may have significance in this regard.

MAGNESIUM

Magnesite nodules occur in the Chischa Formation just outside the recreation area boundary (Grant, 1987). At the time of the study the writer was unaware of this showing. The Chischa Formation does extend into the park; however, as for barite, any sizeable deposit of magnesite would be difficult to miss from the air.

CONCLUSIONS

Anomalous values in stream sediment samples seem to be erratic and without any strong elemental associations. Highest values for several elements come from a sample taken in the vicinity of a black shale — a lithology typified by high background values for many elements.

Based on analytical results, geologic field observations and the eastern platformal and sedimentary setting of the study area, it is concluded that the prospects for discovery of a major mineral deposit are low.

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GEOCHEMICAL AND ASSAY RESULTS, JENNINGS RIVER MAP AREA (MIDWAY AREA)* (104O/16)

By J. Nelson, J. A. Bradford and H. Marsden

KEYWORDS: Jennings River map area, analytical data, showings, sedex, Cassiar batholith, manto deposits, epigenetic veins, Midway deposit.

INTRODUCTION

Complete analytical results for rock samples collected in the course of regional mapping of the area around the Midway deposit, northern British Columbia (Nelson and Bradford, 1987) are presented in Table 5-9-1. Samples from known showings were analysed for a variety of elements in order to constrain genetic models and highlight commodities of economic interest. Reconnaissance targets were also sampled. The second column in Table 5-9-1 shows the occurrence type, after the classification used in Nelson and Bradford (1987). The categories are as follows:

I. Sedex-type, hosted by Earn Group clastic sediments (Upper Devonian-Lower Mississippian).

II. Deposits related to the main phase of the Cassiar batholith (probably mid-Cretaceous).

III. Deposits of Late Cretaceous to Eocene age:
   A. Manto lead-zinc-silver.
   B. Lead-zinc-silver veins.

IV. Other.

HIGHLIGHTS

Silver analyses of 1452 and 3802 ppm were returned from grab samples of selected sulphide-rich ore from the Amy property (No. 17) and a quartz vein in the southwestern corner of the map area (No. 47) respectively (Figure 5-9-1). The latter was previously reported in Nelson and Bradford (1987). Gold analyses are generally low, with the exception of 562 ppb in a skarn from the Nancy occurrence (No. 10). A grab sample from a massive sulphide lens near the Blue Light showings (104O-005) in 104O/09 contains 0.89 per cent tin (No. 77). Significantly anomalous tin (Nos. 11, 14, 30) and fluorine values (Nos. 19, 23, 24, 32, 34) are associated with Late Cretaceous felsic dykes (Bradford and Godwin, this volume) and epithermal vein and manto mineralization. Fluorine in particular should be considered as a pathfinder element for these types of deposits.

KNOWN SHOWINGS

GUNNAR BERG (104O-032)

Samples from a quartzite breccia zone, 25 metres in diameter, adjacent to the Cassiar batholith contain significant amounts of silver, lead, arsenic, antimony (No. 2) and molybdenum (No. 3), suggestive of an intrusive-hydrothermal origin.

BERG (104O-015)

Oxidized mineralization in a stratigraphic setting similar to the Midway deposit contains significant zinc (Nos. 7, 8) and elevated lead, barium, mercury and gold values. High barium is typical of oxidized carbonate-hosted mineralization and does not necessarily signify exhalative origin.

NANCY (104O-013)

Pyrrhotite-bearing skarn adjacent to molybdenum mineralization in the Cassiar batholith contains anomalous gold values (No. 10).

SILVERKNIFE (104O-048)

Epigenetic silver-lead-zinc mineralization in Rosella Formation carbonates contains anomalous tin (No. 11), which may be indicative of a cryptic intrusion, as at the Midway deposit.

AMY/MARBACO (104O-004)

In this Kechika carbonate-hosted replacement deposit, high concentrations of silver correlate with high lead and

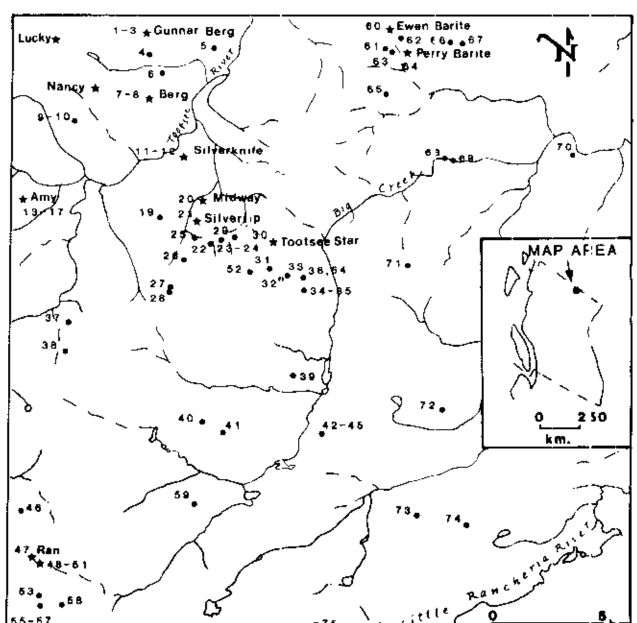

Figure 5-9-1. Locations of analysed samples, map area 104O/16.

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

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

TABLE 5-9-1
GEOCHEMICAL AND ASSAY RESULTS
MAP AREA 104O/16

Samples Taken From Known Mineral Showings 104O-16

Samp. No.	Showing Name	Type	Au ppb	Ag	Cu	Zn	Pb	Ni	Mo	Hg	As	Sb	Ba	Sn	Bi	Te	F	Sr	Description
				(All values in ppm unless indicated as per cent.)															
1	Gunnar Berg	IV	<15	<10	29	260	10	—	6	—	25	40	<56	—	—	—	—	114	Pyrrhotite in shear zone, Tapioca ss.
2	Gunnar Berg	IV	<15	30	82	249	0.41%	—	27	—	0.29%	295	360	—	—	—	—	33	Skarn: diopside-tremolite-wollastonite-calcite.
3	Gunnar Berg	IV	<15	<10	39	166	327	—	77	—	187	34	114	—	—	—	—	42	Rusty quartz breccia
4	Gunnar Berg	IV	<15	<10	48	22	16	—	5	—	<25	<10	255	—	—	—	—	99	Quartz breccia.
7	Berg	IV	<30	<10	3	620	620	62	3	0.403	33	11	887	—	<5	<5	—	2	Smithsonite, calcite and hydrozincite in brecciated Earn shale.
8	Berg	IV	52	10	56	5.55%	3.34%	153	20	5.38	136	233	>10 000	—	<5	<5	—	79	Fe-Mn oxides with hematite and jarosite.
9	Nancy	II	<15	<0.5	50	26	55	—	0.59%	0.020	<20	<10	383	—	—	—	—	103	Molybdenum and pyrite in quartz veins in altered granite.
10	Nancy	II	562	—	48	271	18	—	32	—	<25	<10	333	—	—	—	—	362	Garnet-idocrase-quartz-diopside skarn with pyrrhotite veinlets.
11	Silverknife	IIIA	103	32	120	5.7%	0.43%	—	<5	—	760	<10	—	350	—	—	155	—	Disseminated galena-sphalerite-pyrite in laminated dolomite.
12	Silverknife	IIIA	32	125	72	5.4%	3.0%	—	<5	—	534	171	—	64	—	—	70	—	Disseminated galena-sphalerite-pyrite in marble.
13	Amy	II	18	10	0.13%	126	140	—	17	0.020	<20	202	<56	46	—	—	—	297	Pyrrhotite-chalcopyrite in marble.
14	Amy	II	18	816	540	17.2%	1.25%	—	4	0.162	<20	28	188	180	—	—	—	80	Hydrozincite-smithsonite
15	Amy	II	43	383	60	860	8.81%	—	—	0.020	<20	202	<56	30	—	—	—	297	Layered galena-sphalerite-siderite.
16	Amy	II	36	280	220	0.22%	380	—	2	0.021	<20	77	63	—	—	—	—	106	Sphalerite-galena-siderite
17	Amy	II	67	1 452	0.14%	2.09%	17.0%	—	6	0.039	<20	0.25%	56	100	—	—	—	20	1.5-metre-wide galena-Fe-oxide zone in marble.
20	Midway	I	<15	4	143	240	56	—	19	—	25	<10	10 000	—	—	—	345	116	Laminated silica-barite exhalite.
21	Silvertip	I	<15	5	126	106	480	—	<5	—	773	52	162	—	—	—	—	43	Siliceous exhalite
30	Tootsee Star	IIIB	74	320	310	600	6.0%	15	3	0.020	0.10%	124	1 400	230	<5	<5	—	7	Galena, plumbojarosite in quartz veins in shear zone.
48	Ran	IIB	<15	5	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	Quartz pods with pyrite boxwork in granite.
49	Ran	IIIB	17	10	—	—	—	—	—	—	<25	<10	—	—	—	—	—	—	Quartz veins with pyrite in granite.
50	Ran	IIIB	<15	13	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	Quartz veins with pyrite.
51	Ran	IIIB	<15	1	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	Quartz veins.
60	Ewen barite	I	<30	<10	5	52	<3	7	<3	<0.020	<25	<5	<10 000	—	<5	<5	—	1751	Grey baritic exhalite.
64	Perry barite	I	<30	<10	5	36	3	6	<3	<0.020	<25	<5	<10 000	—	<5	<5	—	1159	12 × 20-metre baritic exhalite.

Samples Taken From Known Mineral Showings 104O-16

Samp. No.	Showing Name	Type	Au ppb	Ag	Cu	Zn	Pb	Ni	Mo	Hg	As	Sb	Ba	Sn	Bi	Te	F	Sr	Description
				(All values in ppm unless indicated as per cent.)															
5	Sylvester 7A		<15	0.7	15	23	10	—	<5	—	<25	<10	—	—	—	—	—	—	Shear zone in chert-argillite.
6	McDame		<15	2	15	42	69	—	<5	—	<25	<10	—	—	—	—	—	—	Quartz veining associated with pyrrhotite-rich dyke.
18	Sylvester 7E		—	—	220	137	21	21	<3	0.02	<25	<5	998	—	<5	5	—	—	Malachite in vug in microdiorite.
19	McDame		<30	10	63	573	29	46	<3	0.224	33	<5	>10 000	—	—	—	345	116	Fe-Mn oxides along dyke contact.
22	Earn		<15	1	21	840	14	—	<5	—	733	52	162	—	—	—	—	43	Fe-oxides in trench.
23	Earn		<15	29	173	124	0.26%	—	9	—	156	<10	—	—	—	—	790	—	Quartz veins with galena; strong alteration.
24	Earn		<15	1	42	108	106	—	12	—	—	—	323	—	—	—	—	34	Quartz veins: sericite-pyrite alteration.
25	McDame/Earn		<15	2	129	0.64%	217	—	5	—	40	<10	—	—	—	—	—	—	Fe-oxides on fault contact.
26	Earn		<30	<10	37	65	16	45	<3	0.092	<25	<5	>10 000	—	<5	<5	—	133	Siliceous, baritic, pyritic exhalite.
27	Earn		<30	<10	19	92	10	33	<3	0.046	<25	<5	1 066	—	<5	<5	—	4	Siliceous exhalite.
28	Earn		<30	<10	49	150	12	25	<3	0.066	<25	<5	>10 000	—	<5	<5	—	80	Siliceous, baritic exhalite.
29	Sylvester 7A		103	<10	52	0.27%	117	12	<3	0.507	166	<5	>10 000	—	<5	<5	—	1 167	Fe-Mn oxides adjacent quartz veins in limestone.
31	Sylvester 7A		21	—	260	32	15	51	<5	—	<25	10	—	—	—	—	—	—	Pyrrhotite-rich dyke.
32	Sylvester 7A		<15	3	80	124	21	—	13	—	<25	<10	—	—	—	—	415	—	Sericiet-pyrite-altered cherty argillite.
33	Sylvester		<15	<10	—	29	25	—	—	—	<20	—	—	—	—	—	—	—	6-centimetre-wide quartz vein with pyrite and galena.
34	Dyke		—	—	—	—	—	—	—	—	—	—	—	—	—	—	1 220	—	Quartz-orthoclase-biotite dyke with 10% pyrite.
35	Sylvester 7A		<15	<0.6	—	—	—	—	—	—	25	—	—	—	—	—	—	—	Fe-stained pyrrhotite-rich chert.
36	Earn		—	—	—	—	—	—	—	—	—	—	—	25	—	—	—	—	Siliceous exhalite.
37	Road River		<30	<10	19	58	40	25	10	<0.02	33	<5	—	—	<5	<5	—	—	Pyrrhotite-bearing chert.
38	Road River		<30	<10	36	60	11	10	<3	0.023	30	<5	912	—	<5	<5	—	228	Pyrrhotite-bearing chert.
39	Sylvester 7A		<15	0.5	—	—	—	—	—	—	20	<10	—	—	—	—	—	—	3- to 4-metre-wide quartz breccia vein.
40	McDame		<30	<10	3	0.24%	15	500	<3	0.02	72	89	—	—	5	17	—	—	Gossanous sinter.
41	McDame		<30	<10	48	124	192	63	12	0.04	<25	<5	—	—	5	5	—	—	Rusty quartz veins.
42	Sylvester 7B		<15	1	0.37%	—	—	—	—	—	<20	<10	—	—	—	—	—	—	Pyrite and chalcopyrite in altered diabase.
43	Sylvester 7B		15	0.5	—	—	—	—	—	—	<20	<10	—	—	—	—	—	—	Pyrrhotite and calcite veinlets in diabase.
44	Sylvester 7C		15	0.5	—	—	—	—	—	—	<20	—	—	—	—	—	—	—	Pyrrhotite in talc-altered serpentinite.
45	Sylvester 7C		127	1	202	—	—	—	—	—	<20	—	—	—	—	—	—	—	2-centimetre-wide quartz-pyrite-chalcopyrite vein.
46	Cassiar		<15	<0.5	—	—	—	—	—	—	<20	<10	—	—	—	—	—	—	Cockscomb quartz, limonite in sericitized granite.
47	Cassiar		49	3 802	—	—	—	—	—	—	<20	10	—	—	—	—	—	—	Quartz vein with pyrite, argentite.
52	McDame		—	2	87	40	—	—	—	—	—	—	—	—	—	—	—	—	Gossan.
53	Cassiar		<15	5	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	Quartz vein rubble.
54	Sylvester		<15	1	—	—	—	—	—	—	<20	—	—	—	—	—	—	—	Quartz-carbonate alteration with quartz veins.
55	Cassiar		15	6	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	20-centimetre-wide quartz-molybdenum-pyrite vein.
56	Cassiar		<15	114	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	5 to 10-centimetre-wide quartz veins with 20% pyrite, 5% molybdenum.
57	Cassiar		<15	22	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	Quartz vein parallel to dyke.
58	Cassiar		<15	<0.6	—	—	—	—	—	—	<25	—	—	—	—	—	—	—	10-centimetre-wide hematite-stained quartz vein.
59	Atan (Boya)		—	—	—	219	10	—	—	—	—	—	>10 000	—	—	—	—	222	Pyritic bands in siltstone (exhalite?).
61	Sylvester 7A		<30	<10	107	109	13	49	10	—	<25	<5	—	—	5	5	—	1 751	Mn-oxide band (layer?).
62	Earn		<30	<10	95	230	62	43	16	0.076	110	7	3 353	—	5	5	—	158	Gouge zone.
63	Sylvester 7A		90	<10	3	37	58	<5	5	0.020	0.11%	8	7 267	—	<5	<5	—	114	Quartz breccia veins with pyrite molds.
65	Sylvester 7A		—	0.5	—	84	10	—	—	—	—	—	—	—	—	—	—	—	Pyritic chert.
66	Tapioca		<30	<10	350	140	272	<2	<3	0.094	<25	<5	—	—	<5	<5	—	—	Quartz vein with Fe-oxides.
67	Dyke		<30	<10	119	480	0.20%	10	57	0.155	306	58	—	—	12	<5	—	—	Quartz-clay-altered porphyry dyke.
68	McDame		<30	<10	4	114	27	<3	<3	0.090	<25	<5	>10 000	—	<5	<5	—	1 167	Barite vein.
69	McDame		78	<10	31	0.17%	320	87	<3	0.430	55	53	—	—	<5	<5	—	—	Goethite in dolomite.
70	McDame (?)		<15	2	—	—	—	—	—	—	110	—	—	—	—	—	—	—	Gossanous beds in sooty dolomite.
71	Sylvester 7A		<15	19	—	—	—	—	—	—	68	—	—	—	—	—	—	—	Gossan in altered serpentinite.
72	Sylvester 7E		73	<10	0.12%	3.8%	1.78%	<3	3	1.53	42	8	—	—	<5	<5	—	—	Quartz vein with pyrite, malachite stain.
73	Sylvester 7E		<30	<10	34	71	25	95	<3	<0.02	46	<5	—	—	<5	<5	—	—	Carbonate alteration with mariposite, quartz veins.
74	Sylvester 7E		<30	<10	7	14	10	9	3	0.022	52	<5	—	—	<5	<5	—	—	Altered gossan in siltstone
75	Atan		<30	<10	19	34	21	28	5	<0.02	85	<5	>10 000	—	<5	<5	—	—	Massive sulphide vein.

antimony (tetrahedrite). Low tin contents relative to Midway and Silverknife are consistent with the Amy's association with the S-type Cassiar batholith, as opposed to a younger A-type or differentiated S-type granite (Bradford and Godwin, this volume).

BLUE LIGHT (104O-005)

This set of occurrences, beryl in pegmatite, fluorite in open spaces, skarns and massive sulphide lenses, is associated with an Eocene granite body that shows a regional fluorine geochemical signature (NGR-41-1978, Geological Survey of Canada, Open File 561). The presence of nearly 0.89 per cent tin in a massive pyrite-magnetite lens (No. 77) is consistent with the probable A-type or differentiated S-type affinity of the granite. Because these occurrences are located in map-area 104-09, the samples are not shown on Figure 5-9-1.

EARN GROUP EXHALITES

These siliceous to baritic exhalative units are geochemically distinct from unoxidized epigenetic mineralization (Types II and III); they contain significant barium and low lead and silver values (Nos. 20, 21, 26, 27, 28, 60, 54).

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GALENA LEAD ISOTOPE RESEARCH AT THE UNIVERSITY OF BRITISH COLUMBIA*

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KEYWORDS: Lead isotope, Canadian Cordillera, metallogeny, deposit models, LEADTABLE.

The senior author directs research by the Lead Isotope Research Group at The University of British Columbia (U.B.C.), in collaboration with R.L. Armstrong's Geochronology Laboratory. Emphasis is on interpretation of galena lead isotopes to support decisions in mineral exploration. Research also contributes to more theoretical understanding of metallogeny in British Columbia.

Projects continuing from previous years are: (1) acquiring a library and computer-based file of galena samples from as many deposits as possible in the Canadian Cordillera, (2) developing case histories with application to exploration, and (3) continuing research in models relevant to the study of metallogeny. A. Andrew was recently appointed as a Research Associate with funding from LITHOPROBE, and is continuing her isotopic studies of Wrangellia. Four papers from her completed doctoral thesis (Andrew, 1987) have been submitted for publication (Andrew and Godwin, 1988a, b, c, d).

Over the past year our research group has completed a computer-based 'LEADTABLE' for publication by the British Columbia Ministry of Energy, Mines and Petroleum Resources (Godwin *et al.*, in preparation). LEADTABLE is a (dBase III+) file containing: sample numbers; deposit names; details of collector; location by latitude and longitude, NTS and MINFILE number; details of deposit type, age of host rock and tectonic terrane; geological comments; details of analyst and analytical quality; and galena lead isotope ratios with errors. Most of the analyses listed are from U.B.C., at various times and with varying degrees of precision. About 800 of these are new, high-precision analyses by Gabites. The remainder are from the literature. Our library of galena currently consists of over 1700 samples, about three quarters of which are from more than 600 deposits in British Columbia. Individuals with galena samples from deposits, particularly from recently discovered or remote showings, are urged to submit them to the authors.

Approximately 250 galena samples have been analysed during the year. These isotope data complete several case histories, continue ongoing projects, and provide preliminary results for new projects. The projects for which analyses have been completed (but not yet published) include interpretation of galena lead isotopes from deposits in (1) the Stewart area, northwestern British Columbia (with D.J. Alldrick; *see* Alldrick *et al.*, 1987), (2) the Bridge River gold camp, southwestern British Columbia (with C.H.B. Leitch, in conjunction with K.M. Dawson, Geological Survey of Canada; *see* Leitch and Godwin, 1988), and (3) the Toodoggone camp (with T.G. Schroeter).

Ongoing camp projects involve galena lead isotope analyses from:

(1) The Gambier Group centred on the International Maggie Mines Ltd. property in southwestern British Columbia (with D.G. Reddy, *see* Reddy *et al.*, 1987, 1988). He will compare Gambier Group deposits with those in the Harrison Lake Group. Old data indicate much similarity between these areas.

(2) The silver-zinc-tin deposits in the Midway area, northern British Columbia (with J.A. Bradford, J.L. Nelson and K.M. Dawson). Preliminary work by Dawson, Godwin and Gabites (1985) suggests that Cretaceous-Tertiary deposits generated within the Cassiar-Pelly platform are distinctly different from those generated by events related to the Cassiar batholith.

(3) The Dome Mountain area, central British Columbia (with D.G. MacIntyre and P.J. Desjardins). The galena here should have a lead isotopic fingerprint similar to galena in the Stewart area (*see* Alldrick *et al.*, 1987), as the deposits are hosted in the same Hazelton Group volcanic rocks.

(4) The Oliver area, southern British Columbia (with J.K. Russell). A hypothesis was put forward (Russell, personal communication, 1987) that metamorphism and deformation in the Permian Kobau Group and formation of vein deposits in the Oliver camp preceded intrusion of the Jurassic Oliver granodiorite. If this is the case, deposits related to the batholith should have a different lead isotope signature from deposits in the metamorphic rocks. In fact, preliminary isotopic analysis of galena shows only minor differences between the deposits, indicating that all of the mineralization is related to the intrusives.

Two new, related projects were initiated this summer. These involve galena lead isotope analysis and interpretation of mineralization from deposits in the Rossland Group (with T. Höy and K.P.E. Andrew), and in veins in the Nelson batholith (with D.A. Brown and J.M. Logan). Partial results from the latter are reported in this volume (Logan *et al.*, 1988, this volume).

Research undertaken by our group covers a wide range of projects, many in collaboration with U.B.C. students, and geologists with the Geological Survey Branch of the Ministry of Energy, Mines and Petroleum Resources and Geological Survey of Canada. There is a growing acceptance and recog-

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

nition of the use of lead isotope research in both regional and detailed studies. Analysis of lead isotopes in galena is increasingly accepted as a tool in regional mapping and in studies of metallogeny.

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British Columbia Geological Survey
Geological Fieldwork 1987

GEOLOGY AND GEOCHEMISTRY OF CARBONATE-HOSTED LEAD-ZINC DEPOSITS OF THE KOOTENAY ARC (82F/East Half)

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KEYWORDS: Economic geology, Kootenay arc, lead-zinc, carbonate hosted, lead isotopes.

INTRODUCTION

Fieldwork for this study consisted of a preliminary investigation and sampling of carbonate-hosted lead-zinc deposits within the Kootenay arc. Lead isotope data from galena were also determined at The University of British Columbia.

Carbonate-hosted lead-zinc deposits in the Kootenay arc have been characterized as either concordant or transgressive types based on field characteristics (Fyles, 1966). In general, the transgressive mineralization occurs as vein or replacement deposits that are enriched in silver. The concordant deposits are stratiform and contain a simple base metal sulphide mineral suite with little or no precious metals. The concordant deposits have also been referred to as the Salmo or Remac-type, after several large deposits in the Salmo camp.

Lead isotope data from deposits in the Kootenay arc have been used to interpret and explain the source of lead and the ore-forming processes responsible for these deposits. Lead isotope plots for the Remac-type deposits do not conform to lead growth curves constructed for lead-zinc deposits from this region, nor can they be adequately interpreted as the result of lead mixing or lead inheritance.

A thorough analysis and comparison of the ore and gangue mineralogy, stratigraphy, and trace element and isotope geochemistry from these conformable Remac-type deposits and the younger Metaline-type deposits will provide an improved understanding of the regional ore-forming process.

BACKGROUND

The Kootenay arc is a thin, arcuate band of complexly deformed and metamorphosed volcanic and sedimentary rocks. It extends from Revelstoke, British Columbia, south along Kootenay Lake, and into Washington State, where it is covered by the Columbia Plateau flood basalts (Figure 5-11-1). The arc forms a portion of the Omineca crystalline belt.

Carbonate-hosted lead-zinc deposits are contained in Lower Cambrian Reeves/Badshot and Middle Cambrian Metaline limestone. These strata have been described as both platformal and deep-water carbonate deposits; their base metal mineralization has been variously attributed to Mississippi Valley-type processes, to exhalative processes, and to epigenetic processes superimposed on previously exhaled, stratiform sulphide accumulations (Fyles, 1966; Sangster, 1970; Höy, 1982).

LEAD ISOTOPE RESEARCH

Lead isotope analyses of galena from these deposits were investigated from the 1960s onward (Russell and Farquhar, 1960; Sinclair, 1966; P.C. LeCouteur, unpublished report, 1973; Godwin and Sinclair, 1982; Andrew *et al.*, 1984; C.I. Godwin *et al.*, unpublished report, 1987). Recent applications of lead isotopes, utilizing the ideas of "plumbotectonics", have elucidated regional lead isotope relationships. The theory of plumbotectonics is that a deposit's lead isotopic systematics are, to a degree, a function of its tectonic setting (Doe and Zartman, 1979).

Godwin and Sinclair (1982) established a "shale curve" using lead isotope data derived from stratiform, shale-hosted, massive base metal sulphide deposits in British Columbia and the Yukon Territory (Figure 5-11-2). It is assumed that lead isotope ratios that plot on this curve evolved in a similar tectonic environment; the shale curve can be a useful reference for upper continental and upper crustal lead in the Canadian Cordillera (C.I. Godwin *et al.*, unpublished report, 1987).

Andrew *et al.* (1984) noted that lead isotopic ratios from the Bluebell deposit plot below the shale curve and describe what has been called the "Bluebell curve". They interpreted this curve to represent a mixing of upper crustal (that is, shale-curve lead) with lower crustal lead.

Current investigations by C.I. Godwin, A. Andrew, J. Gabites and others at The University of British Columbia are focusing on lead isotope analyses of western Canadian tectonic belts. Remac-type deposits and the silver-rich transgressive deposits, such as those in the Ainsworth-Bluebell camp, all lie within the Omineca Belt.

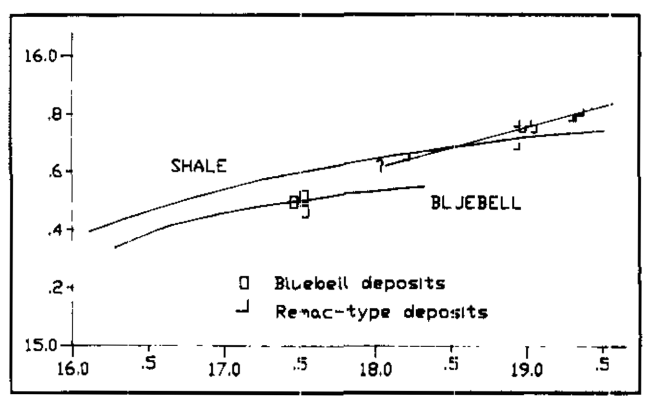

Figure 5-11-2. Lead isotope data: Bluebell curve, shale curve, and Kootenay arc, carbonate-hosted lead-zinc deposit data.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.

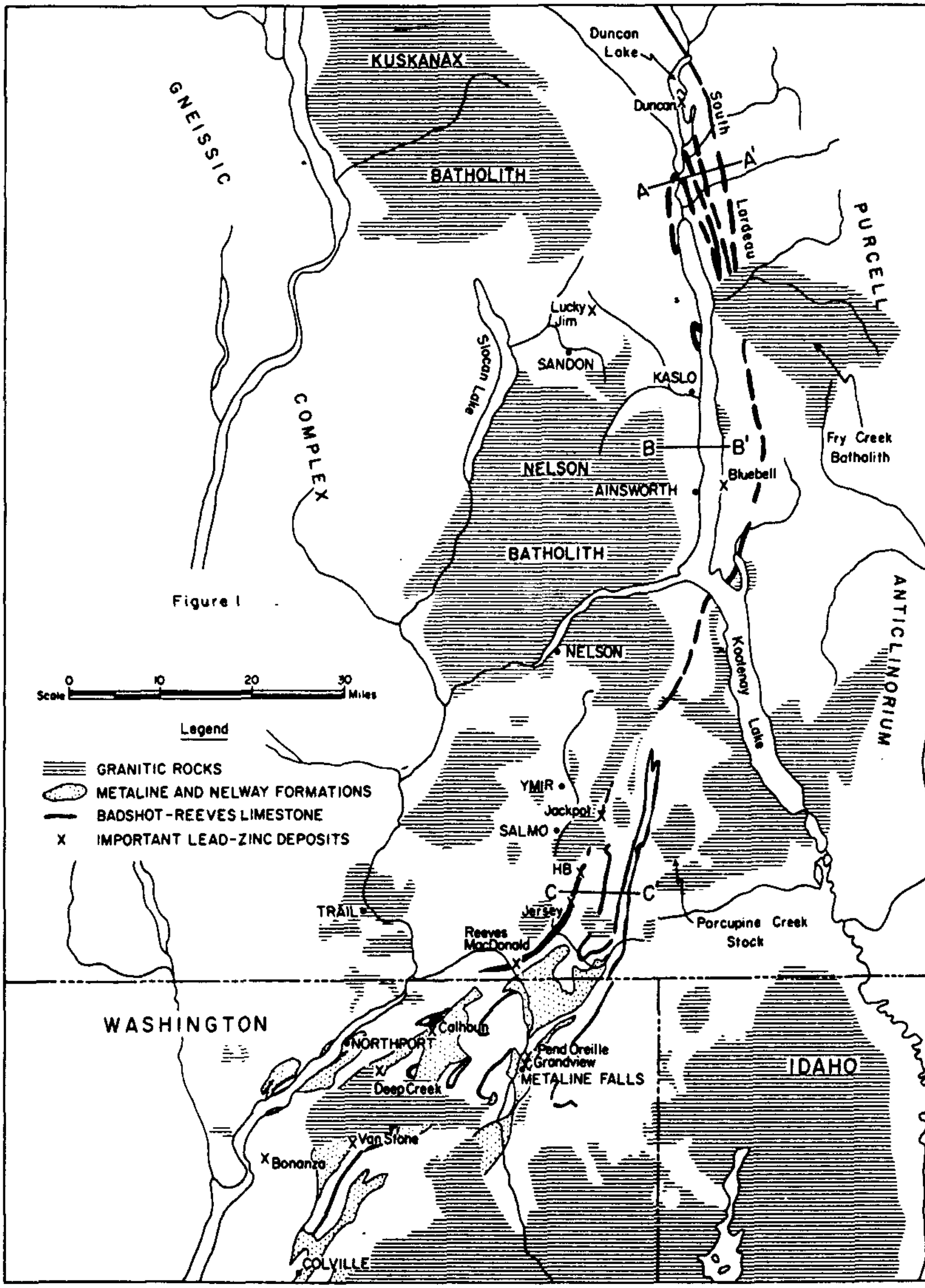

Figure 5-11-1. Geologic map of the southern Kootenay arc (after Fyles, 1970).

LEAD ISOTOPE DATA

Tables 5-11-1 and 5-11-2 are compilations of much of the data used to construct the Bluebell and shale curves. Shale curve data are applicable to the Omineca, Foreland and Selwyn belts of the Canadian Cordillera (C.I. Godwin *et al.*, unpublished report, 1987).

Table 5-11-3 is a compilation of lead isotope data from carbonate-hosted lead-zinc deposits in the Kootenay arc; Figure 5-11-2 illustrates the poor fit for the Remac-type deposits compared to the shale and Bluebell curves.

All data were precisely plotted using a Calmtech computer-aided drafting system. This system allows for easily accessed and reproducible data; all future data will be stored and plotted using this system.

PURPOSE OF STUDY

The purpose of this research is to investigate the geology of several carbonate-hosted lead-zinc deposits in the Kootenay arc, in order to identify and assess similar and contrasting geologic and geochemical features. As illustrated in Figure 5-11-2, lead data from Remac-type deposits do not fit established growth curves representative of deposits in the Omineca Belt. Relationships of Remac-type lead isotopic data with other data from the belt will be investigated.

It has been suggested that the Remac-type deposits (Jersey, Reeves MacDonald, HB, Duncan Lake and others) may be of sedimentary exhalative origin. This research will investigate the probability that they are exhalative, or at least closely associated with exhalative processes, and whether a quantification of geologic and geochemical features supports this contention. A carbonate-hosted lead-zinc exhalite analogue has been described by Russell (1978, 1986), and Hitzman and Large (1986) among others.

TABLE 5-12-1

LEAD ISOTOPE DATA: BLUEBELL CURVE[1]

	Normalized Pb Ratios		
206/204	207/204	207/206	208/206
18.347	15.532	0.847	2.130
18.144	15.522	0.855	2.139
17.982	15.513	0.863	2.146
17.817	15.503	0.870	2.154
17.695	15.496	0.876	2.160
17.587	15.488	0.881	2.166
17.288	15.465	0.895	2.181
16.694	15.436	0.910	2.200
16.630	15.401	0.926	2.219
16.285	15.358	0.943	2.241

[1] C.I. Godwin *et al.*, unpublished report, 1987.

TABLE 5-12-2

LEAD ISOTOPE DATA: SHALE CURVE[1]

	Normalized Pb Ratios		
206/204	207/204	207/206	208/206
16.101	15.385	0.956	2.222
16.341	15.425	0.944	2.206
16.809	15.494	0.922	2.176
17.263	15.551	0.901	2.148
17.704	15.598	0.881	2.123
18.132	15.636	0.863	2.101
18.402	15.657	0.851	2.089
18.525	15.666	0.846	2.082
18.667	15.676	0.840	2.076
18.728	15.680	0.837	2.073
18.828	15.686	0.833	2.069
18.967	15.694	0.827	2.063
19.045	15.699	0.824	2.059
19.123	15.703	0.821	2.056
19.259	15.710	0.816	2.050
19.394	15.717	0.810	2.045
19.526	15.723	0.805	2.040

[1] C.I. Godwin *et al.*, unpublished report, 1987.

TABLE 5-12-3

LEAD ISOTOPE DATA FROM CARBONATE-HOSTED KOOTENAY ARC LEAD-ZINC DEPOSITS[1]

Sample				Normalized Pb Ratios		
No.	Deposit	Host Rock	206/204	207/204	207/206	208/206
448	Reeves MacDonald	Reeves	19.072	15.731	0.825	2.064
623	Bluebell	Badshot	17.478	15.481	0.886	2.170
639	HB	Reeves	19.085	15.720	0.824	2.067
640	Jackpot	Reeves	18.988	15.737	0.829	2.069
641	Jersey	Reeves	19.089	15.729	0.824	2.065
827	Blue Star	carbonate	17.529	15.642	0.892	2.178
828	Highlander	Reeves(?)	17.553	15.504	0.883	2.177
842	Rainbow	Reeves	19.277	15.749	0.817	2.149
651	Wigwam	Badshot	18.236	15.623	0.857	2.093
653	Duncan Lake	Badshot	19.413	15.779	0.813	2.055
655	Sal A	Badshot	19.343	15.760	0.815	2.052
[2]	Van Stone	Metaline	19.390	15.791		
[2]	Pend d'Oreille	Metaline	19.486	15.789		

[1] C.I. Godwin *et al.*, unpublished report, 1987; this is a compilation of Pb isotope data with text; designed for Canadian Cordillera exploration activities.

[2] From P.C. LeCouteur, unpublished report, 1973; data normalized to absolute ratios of the Broken Hill standard.

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GALENA LEAD ISOTOPE CHARACTERISTICS OF MINERALIZATION IN KOKANEE GLACIER PROVINCIAL PARK, SOUTHEASTERN BRITISH COLUMBIA (82F/11, 14)

By J. M. Logan, J. E. Gabites* and D. A. Brown

KEYWORDS: Lead isotopes, Kokanee Glacier Park, Nelson batholith, shale curve, pericratonic curve, Bluebell curve, epigenetic veins.

INTRODUCTION

This paper presents new galena lead isotope data from 22 mineral deposits located in and around Kokanee Glacier Provincial Park and is part of a 2-year mineral evaluation being conducted by the Geological Survey Branch (Brown and Logan, this volume). The study was undertaken to determine lead isotope characteristics of a variety of mineral occurrences. Deposits were selected on the basis of past production, mineralogy and vein orientation, to insure all types were represented. Lead isotope ratios cluster in three groups. The groupings suggest three separate lead sources; two show mixing with Nelson batholith leads. The majority of deposits have lead signatures close to Nelson batholith potassium-feldspar leads and a few have old nonradiogeneic leads. Lead isotope ratios, when interpreted with a geological database, provide a framework within which to evaluate the park's mineral potential, in particular its potential for gold-bearing deposits.

GEOLOGY

Much of Kokanee Glacier Provincial Park is underlain by rocks of the Nelson batholith. The batholith can be divided into six phases (Brown and Logan, this volume). The main phase is potassium-feldspar porphyritic granite and was intruded during the Middle Jurassic. Zircon uranium-lead dates range from 165 to 170 Ma (Carr *et al.*, 1987; Ghosh, 1986; Parrish, personnal communication, 1987). A rubidium-strontium isochron of 162 ± 6 Ma is reported by Duncan and Parrish (1979). Potassium-argon dates range from 171 to 49 Ma (Duncan and Parrish, 1979) and indicate a prolonged and complex thermal history. Tertiary potassium-argon dates from biotite indicate a thermal event, but no intrusions, except narrow dykes, were mapped within the park. It is speculated that Tertiary intrusives are present, in the southwest corner of the map area.

The northern end of the batholith intrudes Late Triassic Slocan Group argillite, siltstone and minor limestone. The eastern edge is a moderate west-dipping sequence of Lower Cambrian to Late Triassic rocks (Brown and Logan, this volume; Fyles, 1967). The western boundary is the Slocan Lake fault zone and Cretaceous to Tertiary gneissic intrusions of the Valhalla complex (Carr *et al.*, 1987).

Lithoprobe seismic reflection profiles are interpreted to illustrate that the Nelson batholith is about 8 to 10 kilometres thick (Cook *et al.*, 1987). Stratigraphy east of the map area, near Ainsworth, projects down dip beneath it. The Tertiary age Slocan Lake fault extends eastward from Slocan Lake under the batholith and continues eastward below Kootenay Lake. The fault is shown to be about 12 kilometres below the central part of the park on Lithoprobe profiles (Cook *et al.*, 1987).

ANALYTICAL METHODS

Analysis of galena lead isotopes at The University of British Columbia was carried out by J.E. Gabites. Two milligrams of pure galena were hand-picked from each sample. Pure lead chloride solution was obtained by dissolution of the galena in pure 2-normal hydrochloric acid and evaporation to dryness. Lead chloride crystals so formed were cleaned by washing several times in 4-normal hydrochloric acid. The cleaned lead chloride crystals were dissolved in ultrapure water. One microgram of lead in the lead chloride solution was loaded with phosphoric acid and silica gel onto a cleaned, single rhenium filament. Lead isotope ratios were measured on a Vacuum Generators Isomass 54R solid source mass spectrometer linked to a Hewlett-Packard HP-85 computer.

Within-run precision is better than 0.01 per cent standard deviation. The variation observed in duplicate analyses is less than 0.05 per cent. Isotope ratios are normalized to the values of Broken Hill Standard lead (BHS-UBC1) given in Richards *et al.* (1981). Analytical precision is monitored by repeated measurement of BHS-UBC1 and systematic duplicate analyses of samples.

Two errors in mass spectrometric measurement of lead isotopes are ^{204}Pb-error and fractionation error (Godwin *et al.*, in preparation). The trends of these errors are shown on data plots so that trends in data can be assessed as being real or due to analytical problems.

FRAMEWORK FOR INTERPRETATION

Different sources of lead within the earth (mantle, lower crust, upper crust, orogene) have different characteristic lead isotopic signatures (Doe and Zartman, 1979). These signatures are dependant on the relative amounts of uranium and thorium in the source, and the length of time of isolation from other sources. Thus galena lead isotopic analyses cannot be used to date mineralization absolutely. Lead growth model

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curves, however, provide a reference framework within which lead isotope data can be interpreted. The three growth curves used in this paper have been derived empirically from lead data from mineral deposits in the Canadian Cordillera.

The data for the curve of Godwin and Sinclair (1982) was mainly from shale-hosted sedimentary exhalative deposits in the Canadian Cordillera (Carne and Cathro, 1984). The shale curve reflects an upper crustal environment of lead evolution (Zartman and Doe, 1981). Goutier's (1986) curve was modified from the shale curve to more accurately fit data from deposits in the Eagle Bay assemblage, Adams Plateau. The deposits that Goutier analysed are volcanogenic but have an upper crustal signature. The Adams Plateau area is in the pericratonic terrane (Wheeler *et al.*, in preparation), as is the Nelson batholith. Thus the model of Goutier is used here because it is more appropriate. In the rest of this paper, Goutier's curve is referred to as the pericratonic curve. The Bluebell curve of Andrew *et al.* (1984) approximates the evolution of nonradiogenic, probably mantle and/or lower crust-derived lead, for deposits in the Canadian Cordillera. This curve was modelled by assigning the Bluebell deposit an assumed age at the base of the Cambrian.

Previous lead isotope studies of the Nelson batholith (Sinclair 1964, 1966; Reynolds and Sinclair, 1971), Slocan Group (Logan, 1986; Ghosh, 1986) and vein deposits (LeCouteur, 1973; Andrew *et al.*, 1984) led to interpretation of the anomalous nature of Slocan leads by various models which involve mixing of components from two separate lead reservoirs. In these models the batholith, which is of uranium-depleted upper mantle/lower crustal derivation, supplied the nonradiogenic component, which mixed during emplacement with upper crustal leads to produced the observed Slocan data array (Reynolds and Sinclair, 1971; Andrew *et al.*, 1984). By approximating a lower crustal growth curve, Andrew *et al.* show Slocan lead isotope data to lie along a mixing isochron that corresponds to the age of mineralization and presumbaly to the time mixing occurred.

RESULTS

The lead isotope database for the map area is extensive. However, comparison with previous studies is complicated by inaccurately located samples and old data of poorer quality. Therefore, only new analyses from the Kokanee Park mineral evaluation are discussed (Table 5-12-1).

Table 5-12-1.
Galena lead isotope data[1, 2] for mesothermal veins, Kokanee Park, southeastern British Columbia

Leadfile[3] No.	Minfile No.	Deposit Name	Run No.	Run Quality	$^{206}Pb/^{204}Pb$	% error	$^{207}Pb/^{204}Pb$	% error	$^{208}Pb/^{204}Pb$	% error	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
GROUP A												
30033-001	082/F/NW-120	Smuggler	1	good	17.590	0.00	15.492	0.01	38.187	0.00	0.88074	2.17102
30037-001	082/F/NW-119	Slocan Chief	1	fair	17.783	0.00	15.522	0.02	38.354	0.00	0.87289	2.15673
30040-001	082/F/NW-118	Blackburn	1	good	17.719	0.00	15.520	0.01	38.317	0.00	0.87590	2.16252
30053-001	082/F/NW-121	Molly Gibson	1	good	17.587	0.00	15.489	0.01	38.177	0.00	0.88072	2.17078
30053-002	082/F/NW-121	Molly Gibson	1	good	17.599	0.00	15.494	0.00	38.191	0.00	0.88035	2.17002
30053-AVG	082/F/NW-121	Molly Gibson	1	good	17.593	0.00	15.492	0.01	38.184	0.02	0.88053	2.17045
GROUP B												
30029-001	082/F/NW-106	Revenue	1	good	18.968	0.00	15.657	0.00	39.158	0.00	0.82545	2.06444
30030-001	082/F/NW-099	BNA	1	good	18.873	0.00	15.647	0.00	39.033	0.00	0.82904	2.06812
30031-001	082/F/NW-109	Baltimore	2	good	18.981	0.00	15.655	0.01	39.177	0.00	0.82481	2.06406
30032-001	082/F/NW-141	Marmion/Maryland	1	good	18.859	0.00	15.631	0.01	39.026	0.00	0.82884	2.06934
30036-001	082/F/NW-114	Silver Cup	1	fair	19.031	0.00	15.668	0.02	39.111	0.00	0.82334	2.05515
30046-001	082/F/NW-077	Comstock	1	fair	18.693	0.00	15.618	0.01	38.961	0.00	0.83552	2.08426
30046-001R	082/F/NW-077	Comstock	2	good	18.704	0.00	15.628	0.01	38.998	0.00	0.83556	2.08499
30046-001A	082/F/NW-077	Comstock		good	18.698	0.01	15.623	0.02	38.980	0.01	0.83554	2.08463
30625-001	082/F/NW-152	Arlington	1	good	18.853	0.00	15.629	0.00	39.091	0.00	0.82901	2.07346
GROUP C												
30025-001	082/F/NW-127	Alpine	1	good	19.171	0.00	15.666	0.00	38.937	0.00	0.81718	2.03102
30026-001	082/F/NW-111	Pontiac	1	good	18.974	0.00	15.655	0.01	38.770	0.00	0.82507	2.04329
30027-001	082/F/NW-113	Sunrise	1	good	18.881	0.00	15.653	0.02	38.702	0.00	0.82905	2.04981
30038-001!	082/F/NW-122	Oro Fino	1	fair	19.130	0.00	15.654	0.02	38.446	0.01	0.81834	2.00971
30038-001R	082/F/NW-122	Oro Fino	2	good	19.144	0.00	15.667	0.02	39.047	0.00	0.81837	2.03961
30039-001	082/F/NW-105	Para	1	good	19.007	0.00	15.653	0.00	38.789	0.00	0.82353	2.04074
30039-002	082/F/NW-105	Para	1	good	19.011	0.00	15.647	0.00	38.768	0.00	0.82306	2.03928
30039-AVG	082/F/NW-105	Para	1	good	19.009	0.00	15.650	0.00	38.779	0.00	0.82330	2.04001
30042-001	082/F/NW-215	Silver Ranch	1	good	19.044	0.00	15.654	0.02	38.822	0.00	0.82201	2.03856
30043-001	082/F/NW-253	Al	1	good	18.980	0.00	15.644	0.01	38.762	0.00	0.82422	2.04219
30044-001	082/F/NW-256	King Solomon	1	good	19.185	0.00	15.674	0.02	38.995	0.00	0.81697	2.03256
30045-001	082/F/NW-208	Jumbo/Mary	1	good	19.069	0.00	15.650	0.01	38.810	0.00	0.82071	2.03520
30048-001	082/F/NW-212	East of LH	1	good	19.041	0.00	15.666	0.01	38.809	0.00	0.82275	2.03816
30059-001	082/F/NW-113	Granite/Sunrise	1	good	18.959	0.01	15.644	0.03	38.739	0.01	0.82513	2.04331

[1] Analyses by J.E. Gabites.
[2] Analyses normalized to Broken Hill lead standard values of Richards et al. (1981); $^{206}Pb/^{204}Pb$ = 16.004, $^{207}Pb/^{204}Pb$ = 15.390, $^{208}Pb/^{204}Pb$ = 35.651.
[3] Suffixes on Leadfile numbers are: 00x = sample number, ! = poor analysis, not used in average.
R = rerun analysis. A = arithmetic average of rerun analyses, plotted on figures. AVG = arithmetic average of analysis from the same deposit, plotted on figures.

Galena lead isotope ratios from new analyses are plotted on $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ (Figure 5-12-1A), $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ (Figure 5-12-1B) and $^{206}Pb/^{208}Pb$ versus $^{206}Pb/^{207}Pb$ (Figure 5-12-2) diagrams, and compared to the shale curve of Godwin and Sinclair, the *pericratonic, curve of Goutier and the Bluebell curve of* Andrew *et al.* The deposit name, location, host lithology, MINFILE number and deposit type are documented in Table 5-12-2. Property descriptions and bibliography for each sample location are available in MINFILE records.

INTERPRETATION

The lead isotope ratios from epigenetic vein deposits in Kokanee Park fall into three groups labelled A, B, and C. The grouping is most apparent on the $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot (Figure 5-12-1B). The groups are assigned distinct symbols, that have been used in Figure 5-12-3 to show the distribution of deposits. Group A deposits lie along a northwest linear whereas Groups B and C are distributed *randomly throughout the map area.*

Group A data are relatively nonradiogenic and lie on the Bluebell curve on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot. The model age implied by this curve is Cambrian to Ordovician. Two points are just above the Bluebell curve. These data come from four batholith-hosted deposits, the Blackburn, Molly Gibson, Slocan Chief and Smuggler. The Molly Gibson was the largest past producer (Table 5-12-2). They lie along a northwesterly striking joint set west of Kokanee

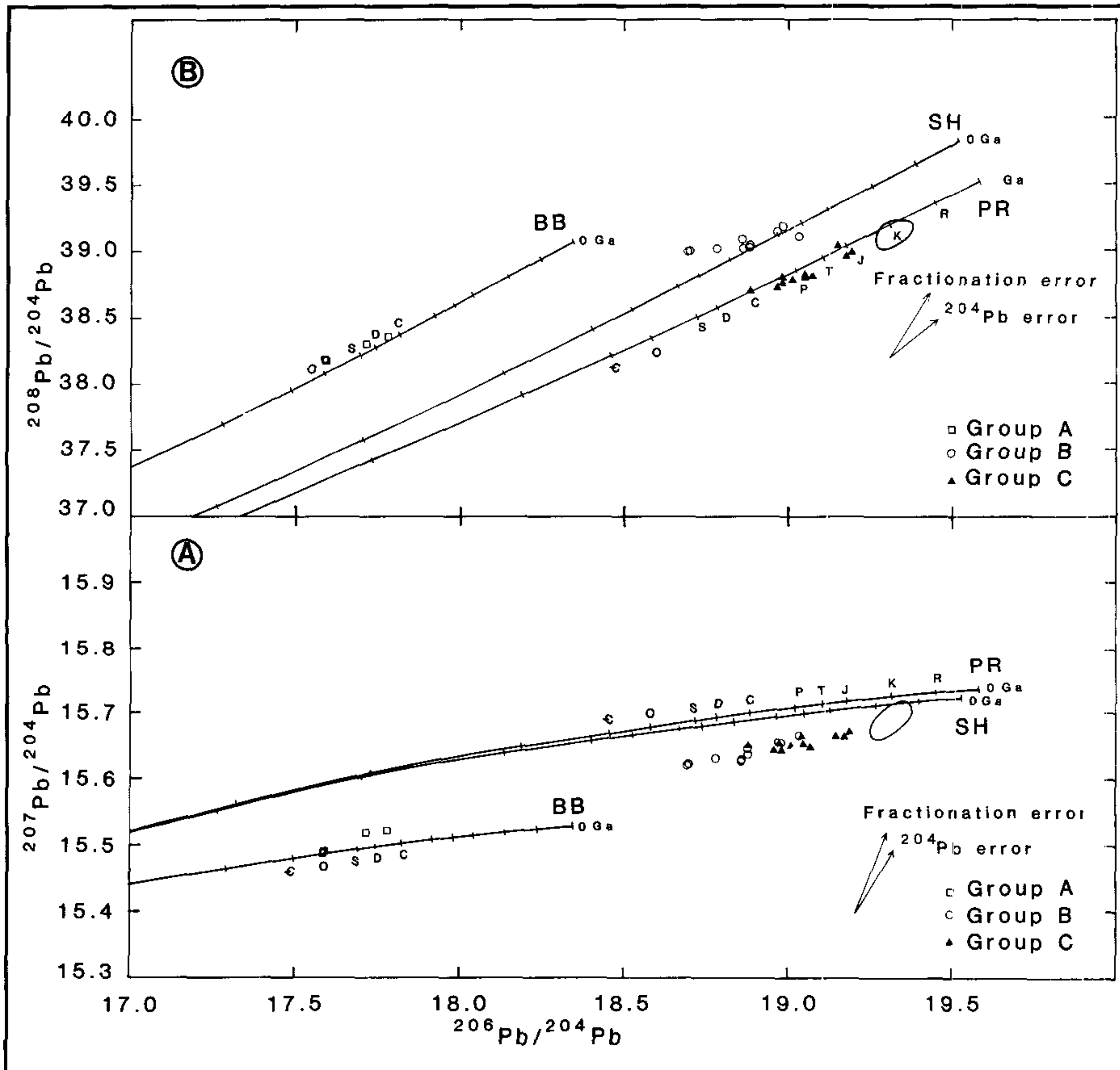

Figure 5-12-1. Galena lead isotope ratio diagram for mesothermal quartz veins in Kokanee Glacier Provincial Park, southeastern British Columbia. Model growth curves are: PR = pericratonic (Goutier, 1986), SH = shale (Godwin *et al.*, 1982), and BB = Bluebell (Andrew *et al.*, 1984). Time intervals are marked with standard abbreviations.

Table 5-12-2.
Location and host lithology for mesothermal veins, Kokanee Park, southeastern British Columbia

Minfile No.	Deposit Name	UTM Location Easting	UTM Location Northing	Host Lithology[1]	Deposit Type	Production (tonnes)
GROUP A						
82F/NW-118	Blackburn	485563	5513364	K-spar	vein	0
82F/NW-119	Slocan Chief	486953	5512505	K-spar	vein	4
82F/NW-120	Smuggler	487559	5511750	K-spar	vein	13
82F/NW-121	Molly Gibson	489035	5508600	K-spar	vein	55 860
GROUP B						
82F/NW-077	Comstock	483296	5526295	Qtz monz/lamp	vein	456
82F/NW-099	BNA	492000	5523600	Pel/psa/lst	vein	173
82F/NW-106	Revenue	491131	5519134	Hb por gn	vein	244
82F/NW-109	Baltimore	495950	5517754	Hb por gn	vein	60
82F/NW-114	Silver Cup	487625	5511666	Hb por gn	vein	4
82F/NW-141	Marmion/Maryland	476241	5514056	Hb por gn	vein	50
82F/NW-152	Arlington	473981	5515135	K-spar	vein	19 217
GROUP C						
82F/NW-105	Para	482390	5520617	K-spar	vein	15
82F/NW-111	Pontiac	496325	5515133	Hb por gn	vein	1160
82F/NW-113	Granite/Sunrise	495114	5523532	Hb por gn	vein	145
82F/NW-113	Sunrise	494714	5514283	Hb por gn	vein	145
82F/NW-122	Oro Fino	485356	5507733	K-spar	vein	4
82F/NW-127	Alpine	481934	5503399	Qtz monzonite	vein	15 551
82F/NW-208	Jumbo/Mary	479651	5516615	K-spar	vein	25
82F/NW-212	East of LH	477354	5526027	Metavol/skarn	vein	0
82F/NW-215	Silver Ranch	483690	5514368	K-spar	vein	0
82F/NW-253	Al	498281	5511798	K-spar	vein	0
82F/NW-256	King Solomon	481420	5501622	Qtz monzonite	vein	0

[1] Abbreviations are: K-spar = potassium-feldspar porphyritic granite, Qtz monz/lamp = quartz monzonite and lamprophyre, Pel/psa/lst = pelite, psammite and limestone, Hb por gn = hornblende-porphyritic granite, Qtz monz = quartz monzonite, Metavol/skarn = metavolcanic rocks and skarn.

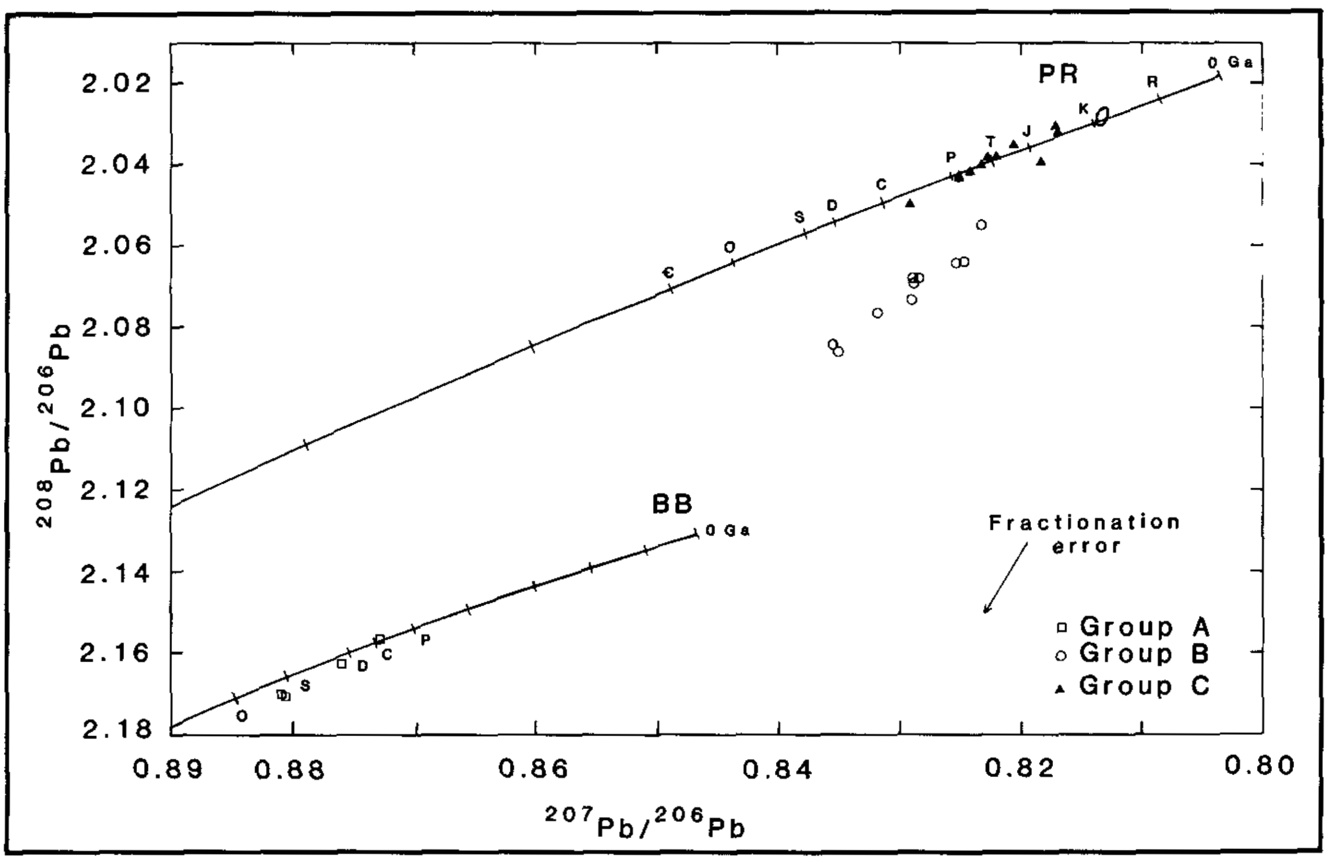

Figure 5-12-2. Galena lead isotope ratio diagram for mesothermal quartz veins in Kokanee Glacier Provincial Park, southeastern British Columbia. Model growth curves are: PR = pericratonic (Goutier, 1986), SH = shale (Godwin *et al.*, 1982), and BB = Bluebell (Andrew *et al.*, 1984). Time intervals are marked with standard abbreviations.

Glacier (Plate 5-12-1). Vein mineralogy of the four deposits comprises galena, sphalerite, arsenopyrite, pyrite and minor chalcopyrite in a gangue of brecciated buff to pink siderite. Manganese-rich siderite gangue, coated with black manganese oxide, is unique to the batholith-hosted deposits which are typically quartz-rich. Arsenopyrite is only reported from one other deposit in the Slocan camp, the LH. These characteristics emphasize the unusual nature of these four deposits. The presence of this anomalous lead, with a Cambro-Ordivician Bluebell curve model age, from veins that crosscut the Middle Jurassic batholith is enigmatic.

A possible interpretation for Group A lead is that it represents a hydrothermal event during the Jurassic to Tertiary, involving fluids derived from either the lower crust/upper mantle, or from Precambrian basement. However, this requires that the Bluebell deposit be of the same age and epigenetic (Sinclair, 1964; LeCouteur, 1973). Deposits near Ainsworth, 15 kilometres to the east, have been interpreted to be either epigenetic or syngenetic stratiform veins (Hoy *et al.*,1981). These deposits have similar lead isotope ratios (LeCouteur, 1973) to Group A.

An alternative explanation is that Group A is directly derived from a Bluebell-type Cambrian or older deposit. Incorporation by the batholith of a large mineralized inclusion of miogeocline, Lardeau Group or older rocks is implied. Mineralization in the Lardeau Group near Ainsworth contains lead with similar isotope ratios. The siderite gangue of Group A is typical of sediment-hosted deposits in the Slocan camp, 15 kilometres to the north, and suggests a sediment-derived component to the mineralizing fluids. However, there is no surface expression of sedimentary inclusions near Group A deposits. Remobilization of lead from the supposed "inclusion" by fluids during the Jurassic-Tertiary could produce the observed shift from Cambrian age, assigned to the Bluebell deposit. However, mixing of lead with the younger mineralizing fluids would be expected to pro-

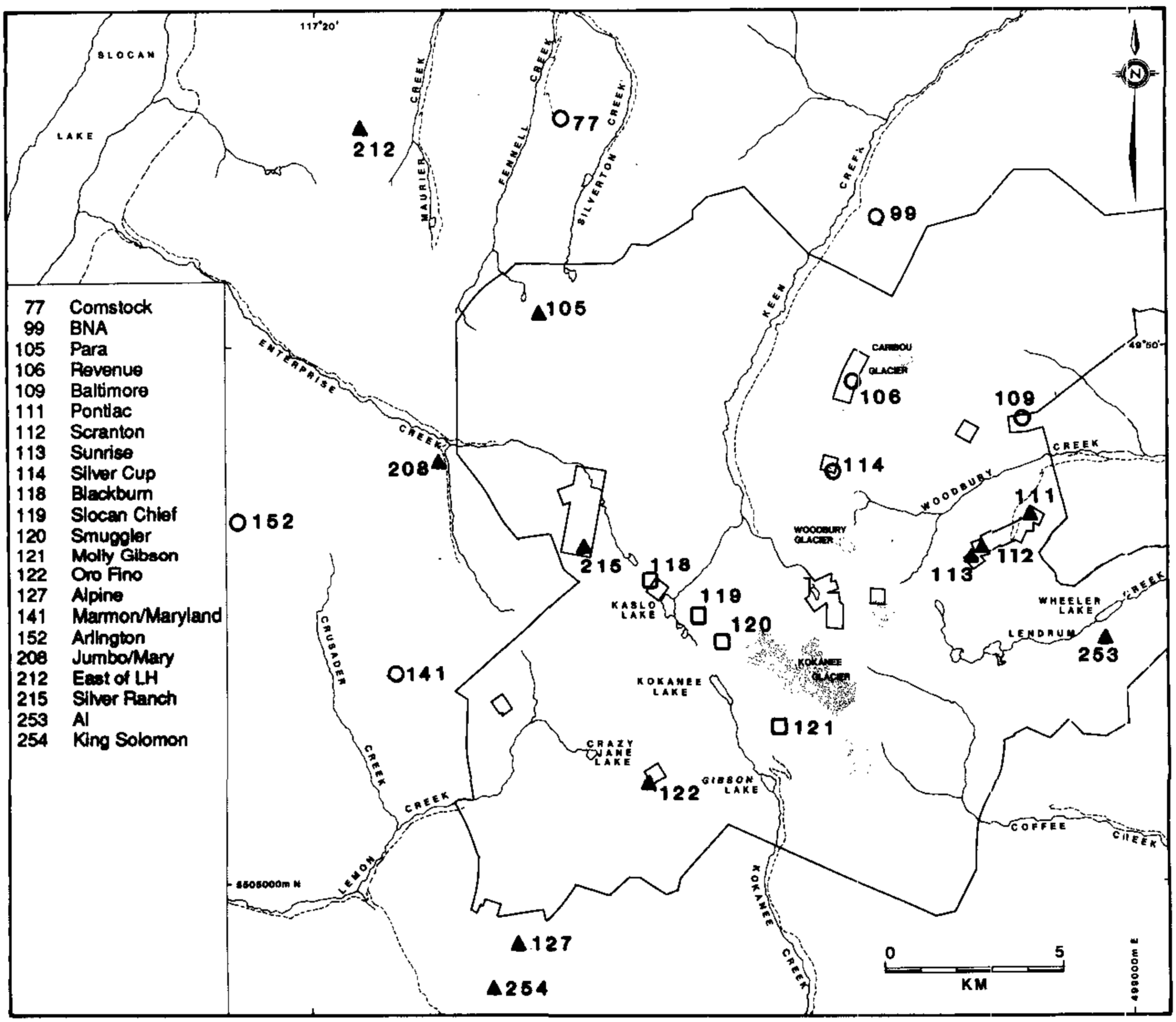

Figure 5-12-3. Vein deposit locations and MINFILE numbers for those galena lead isotope samples analysed.
Symbols distinguish 3 groups: □ = Group A, ○ = Group B, ▲ = Group C.

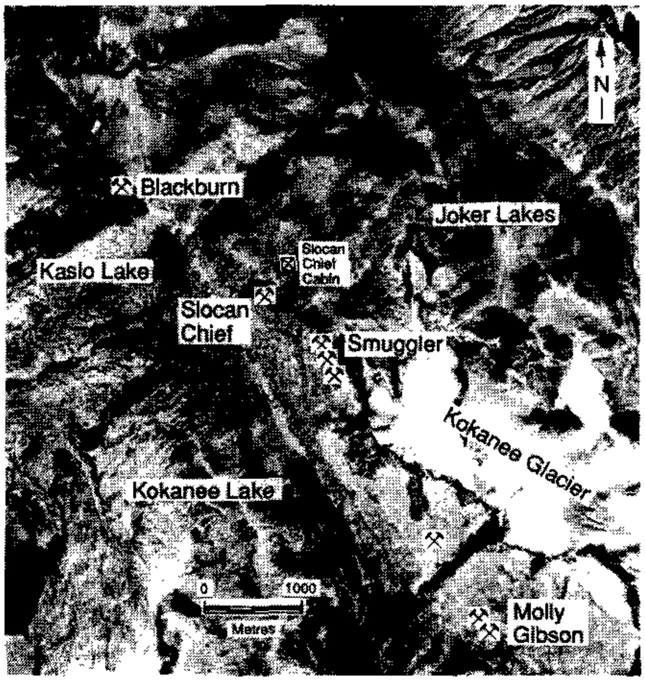

Plate 5-12-1. Group A deposits parallel a prominent northwest-trending linear located west of Kokanee Glacier. The Molly Gibson, Smuggler, Slocan Chief and Blackburn are steep southwest-dipping veins that are coplanar with the northwest-striking joint set.

duce a more significant shift in lead ratios, generating ratios transtitional between Groups A and B.

Groups B and C data overlap on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot (Figure 5-12-1A), between the pericratonic and Bluebell curves. However, plots of $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$, and $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ clearly distinguish Groups B and C (Figures 5-12-1B, 5-12-2). Group B is more thorogenic (^{208}Pb) and less radiogenic (^{207}Pb and ^{206}Pb) than Group C and forms a linear array between the Bluebell and pericratonic curves. Mineralogically, these deposits are mesothermal silver-lead-zinc-bearing quartz veins. The exception, Marmion/Maryland, recorded appreciable gold recovery, more typical of Group C. On the $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ plots, the spread of data may reflect mixing in the batholith between pericratonic and Bluebell-type leads in the Jurassic. Thus, the spread of data is representative of the mixed source for the plutonic rocks and associated mineralizing fluids that has been described from other isotope systematics (LeCouteur, 1973; Andrew *et al.*, 1984; Ghosh, 1986).

Group C data are more uranogenic and less thorogenic than Group B data. They form a linear array along the pericratonic curve in Figures 5-12-1B and 5-12-2. These data suggest a source distinct from Group B. On the $^{206}Pb/^{204}Pb$ diagram, Group C data plot with younger model ages than Group B. Mineralogically Group C deposits cannot be distinguished from Group B, gold has been recovered from the majority and is the only economic mineralization in some deposits. Lead isotope analysis of feldspar concentrates from the Nelson batholith (Ghosh, 1986) cluster at the radiogenic end of Groups B and C on Figure 5-12-1A. On Figures 5-12-1B and 5-12-2 the batholith leads plot on the pericratonic curve coincident with the projected intersection of the Group B and C linear clusters. Mixing in the batholith is inferred from both linear arrays and suggests an equivalent age for Groups A and B. Three deposits in Group C plot at the more radiogenic end of the linear arrays in Figures 5-12-1A and 5-12-2. They are characterized by high-grade gold mineralization. They are located in the southwest corner of the map area, where Tertiary potassium-argon dates from biotite have been obtained (Parrish, personnal communication, 1987). It is not known whether these dates reflect either a Tertiary thermal resetting of a Jurassic monzonite, or Tertiary intrusion. The low thorium content suggests that the bulk of the lead source is not the batholith.

CONCLUSIONS

Lead isotope ratios in the mineral occurrences in Kokanee Park fall into three groups. All deposits analysed are epigenetic veins in and near the Middle Jurassic Nelson batholith. Three separate lead sources are necessary to produce the data arrays. These are a lower crustal/upper mantle Bluebell-type, pericratonic type and an unknown source. Mixing of these three reservoirs occurred in the batholith during the Middle Jurassic. Group A deposits are surrounded by deposits of Groups B and C near the centre of the batholith. A subset of Group C represents occurrences in the southwest corner of the map area with more radiogenic lead and a gold-enriched mineralogy and may correlate with a Tertiary intrusive event.

FUTURE WORK

A regional synthesis of all previous lead isotope data is in progress. Establishing the characteristics of the three source regions is necessary to understand the metallogenic processes operative throughout the Kootenay arc. Fluid inclusion and stable isotope studies of deposits from each group are planned. Two unknowns inherent in the common lead isotope age-modelling equations are the source age of lead (t_1) and the age of mineralization (t_2). Potassium-argon isotopic age determinations of sericite wallrock alteration from two deposits are underway to date the age of mineralization. A sample for zircon uranium-lead dating should be collected from the biotite quartz monzonite in the southwest corner of the map area, where gold mineralization occurs and where Tertiary potassium-argon dates have been obtained.

ACKNOWLEDGMENTS

Support from the British Columbia Science Council in a grant to C.I. Godwin, The University of British Columbia, is gratefully acknowledged. The Ministry of Energy, Mines and Petroleum Resources provided support for lead analyses. Discussions with Dr. R.L. Armstrong and a review of the manuscript by Dr. C.I. Godwin have improved the text.

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RECONNAISSANCE STUDY OF $\delta^{34}S$ VALUES OF SULPHIDES FROM MESOTHERMAL GOLD DEPOSITS OF THE EASTERN CANADIAN CORDILLERA

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University of Alberta

KEYWORDS: Sulphur isotopes, Cordilleran mesothermal gold deposits, genetic models, exploration geochemistry.

INTRODUCTION

Studies incorporating $\delta^{34}S$ analyses of sulphides have been conducted on a variety of gold deposits ranging from Tertiary epithermal deposits of the western United States to Archean deposits of Canada and Australia (Kerrich, 1987; Field and Fifarek, 1986). However, to the best of our knowledge, there are no published data on results of $\delta^{34}S$ studies of sulphides from similar gold deposits in the Canadian Cordillera. The results of a preliminary reconnaissance survey of $\delta^{34}S$ variations in sulphides from gold deposits of the eastern Canadian Cordillera are reported here. The objectives of this study are: to better define similarities and differences between various types of gold deposits in the Canadian Cordillera; to provide additional constraints on genetic models for these deposits; and to investigate the potential for using sulphur isotope analyses as an aid to exploration. Even though the actual number of analyses in the study was limited due to financial constraints, the results of this study provide important information related to these objectives.

All three districts studied, Cassiar, Cariboo and Sheep Creek, are situated in allochthonous or suspect terranes, which adjoin autochthonous units of the North American craton (Monger *et al.*, 1982). The deposits are characterized by large, continuous quartz veins which contain variable amounts of carbonate, pyrite, arsenopyrite, graphite and scheelite. Host units for the deposits are carbonate-altered basalts at Cassiar, quartzites and marbles at Cariboo and quartzites at Sheep Creek.

EXPERIMENTAL TECHNIQUES

Preparation of sulphide separates was accomplished by standard magnetic, heavy liquid and hand-picking techniques. $\delta^{34}S$ analyses were performed by the Sulphur Isotope Unit of the Department of Chemistry, McMaster University. The results are reported in the standard ‰ notation, relative to the Canon Diablo meteorite (Ohmoto and Rye, 1979).

RESULTS

The results of analyses of samples from the gold deposits of the Cassiar district can be divided into two categories: samples from ore-grade veins and samples from low-grade veins. The two samples from ore-grade veins are quite close in value, $\delta^{34}S = +13.2$ and $+13.7$‰ (Table 5-13-1), even though they are from veins which are approximately 6 kilometres apart. The two samples from low-grade veins have an average $\delta^{34}S$ value of $+10.7$‰, which is distinctly lower than the 13.5‰ average for the ore-grade veins. With the limited number of analyses available at this time, it is not possible to discern if this difference in $\delta^{34}S$ values is a reproducible feature. Additional analyses are needed to test the possibility of distinguishing ore-grade from low-grade veins using sulphur isotope analyses.

The results of $\delta^{34}S$ analyses of two pyrite samples from the Mosquito Creek mine in the Cariboo district average $+9.2$‰ (Table 5-13-1). One $\delta^{34}S$ analysis of an arsenopyrite from the ores yielded $+8.8$‰. Though the fractionation of sulphur isotopes between pyrite and arsenopyrite has not been calibrated, the close correspondence of the results for the two sulphides suggests that equilibrium was attained. One analysis of a pyrite separate from Sheep Creek ore yielded a value of $+12.7$‰.

TABLE 5-13-1

Sample Location	Mineral	$\delta^{34}S_{Py}$	$\delta^{34}S_{H_2S}$
Cassiar			
Ore-grade vein, Maura	Py	+13.2	+12.0
Ore-grade vein, Taurus	Py	+13.7	+12.5
Low-grade vein	Py	+11.7	+10.5
Low-grade vein	Py	+9.6	+8.4
Cariboo			
Ore-grade vein	Py	+10.1	+8.9
Ore-grade vein	Py	+9.1	+7.9
Ore-grade vein	AsPy	+8.8	+7.6
Sheep Creek			
Ore-grade vein	Py	+12.7	+11.5

DISCUSSION

It has been shown in various studies that, if the oxidation state of the ore-forming fluid is low, most of the sulphur is in S^{2-} state. In such a situation, the $\delta^{34}S$ values of sulphides can be used to estimate the $\delta^{34}S$ values of the ore-forming fluids (Ohmoto and Rye, 1979). Low oxidation states for the ore-forming fluids are indicated for all three districts examined, since iron oxides are rare to absent and carbonaceous material is common in the veins. Calculations using the sulphur isotope fractionation equation for pyrite-H_2S from Ohmoto and Rye (1979) and a temperature of 300°C indicate that the $\delta^{34}S$ values for the ore-forming fluids were +12.3‰ at Cassiar, +8.4‰ at Cariboo and +11.5‰ at Sheep Creek.

The use of $\delta^{34}S$ values as indicators of the source of ore-forming components is complicated by the effects of oxidation-reduction reactions on the fractionation of sulphur isotopes (Ohmoto and Rye, 1979). However, given the reducing nature of these fluids, the $\delta^{34}S$ values of the fluids are most likely indicative of the $\delta^{34}S$ values of sulphides in the source area. Magmatic sulphides typically have $\delta^{34}S$ values within 3‰ of 0‰. Due to various oxidation-reduction processes, sedimentary sulphides possess a wide variation in $\delta^{34}S$ values within ± 20‰ of 0‰ (Ohmoto and Rye, 1979). Given the range of +8.4‰ to +12.3‰ for the $\delta^{34}S$ values of the ore-forming fluids in the deposits studied, it is probable that the sulphur in the fluids was derived from fluid interactions with sedimentary units. This interpretation is consistent with recent results from investigations involving radiogenic isotopes and other stable isotopes at Cassiar (Nesbitt *et al.*, in preparation). Studies of $\delta^{34}S$ values of sedimentary sulphides in the vicinity of all three deposits, as well as additional analyses of sulphides from the deposits, are required to confirm these preliminary conclusions.

The small variation in $\delta^{34}S$ values between districts may result from the limited number of analyses. Alternatively, if the differences are real, they probably indicate either minor differences in the $\delta^{34}S$ values of sulphides in the sedimentary source-units or variations in chemical parameters in the ore-forming fluids.

Comparison of the $\delta^{34}S$ values for pyrite from this study with values for pyrite from other gold deposits indicates that the results from the Canadian Cordilleran deposits are similar to slightly heavier than results from most other gold deposits. The geologically and geochemically similar Mother Lode deposits of California have $\delta^{34}S$ values for pyrite of 0 to +5‰ (Figure 5-13-1; Taylor, 1986) which are somewhat depleted in $\delta^{34}S$ relative to the Canadian Cordilleran deposits. The range of values observed in the Mother Lode district is believed to reflect derivation of the sulphur from meta-igneous rocks (Taylor, 1986). East of the Mother Lode district, in the sediment-hosted Carlin deposit, $\delta^{34}S$ values for pyrite range between +4 and +16‰. This range in values is similar to that observed in the eastern Canadian Cordilleran deposits and is also believed to indicate a sedimentary source for the sulphur (Radke *et al.*, 1980). In Archean gold deposits the general range for $\delta^{34}S$ in pyrite is +1 to +6‰ which, as with the results from the Mother Lode district, is probably a reflection of the greater abundance of meta-igneous rocks in the associated units (Kerrich, 1987).

In conclusion, the data from this investigation of $\delta^{34}S$ values from sulphides in mesothermal deposits of the eastern Canadian Cordillera indicate: relatively uniform, $\delta^{34}S$-enriched values for $\delta^{34}S$; probable derivation of the sulphur from a sedimentary source; and a possible difference between high and low-grade veins at Cassiar of roughly 2‰.

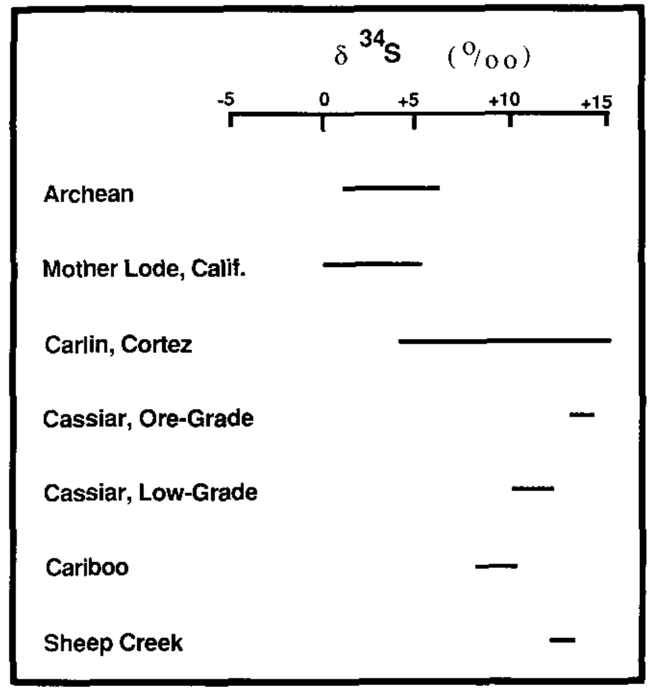

Figure 5-13-1. Results of $\delta^{34}S$ analyses from eastern Canadian Cordilleran gold deposits in comparison to results from Archean, Mother Lode and Carlin deposits (Kerrich, 1987; Taylor, 1986; Radtke *et al.*, 1980).

ACKNOWLEDGMENTS

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Data Systems

NEW MINFILE — A MAINFRAME AND PERSONAL COMPUTER BASED MINERAL INVENTORY DATABASE*

By A. F. Wilcox

KEYWORDS: Mineral Inventory MINFILE, MINFILE/pc, computer database, user's guide, mineral deposits.

INTRODUCTION

MINFILE is the Geological Survey Branch computerized mineral inventory database; it contains information concerning in excess of 9300 mineral occurrences in British Columbia. The Canada/British Columbia Mineral Development Agreement of 1985-1990 has funded the research and updating of the occurrence descriptions. It is expected that this widely available database on the province's mineral resources will be a valuable research tool for prospectors and geologists.

BACKGROUND

MINFILE is a relational database containing information on metallic and industrial mineral and coal occurrences within the Province of British Columbia. An occurrence is defined as bedrock or placer mineralization and does not include float showings, or geochemical or geophysical anomalies.

The mineral occurrence data were first stored in a manual card file started in 1967. From 1973 to 1976, The University of British Columbia Department of Geological Sciences, in cooperation with industry and the Ministry of Energy, Mines and Petroleum Resources developed a computerized mineral inventory file known as MINDEP. In 1976 MINDEP was transferred to the Geological Survey Branch and renamed MINFILE. From 1984 to the present, MINFILE has been redesigned to operate interactively on a VAX computer and on personal computers. Extensive updates, rewrites and additions improved the geological content of the file.

OVERVIEW OF THE NEW SYSTEM

The new system runs on a DEC-VAX 8650 mainframe computer and uses the VMS operating system. The relational database utilizes ULTRA/MANTIS for database management and software development, and SPECTRA for custom searches.

Major expansions of data fields allow more geological data to be entered. For example, the minerals fields now provide for separate listing of significant, associated and alteration minerals. Deposit Character and Deposit Classification fields are expanded with an increased number of terms included.

Data fields have been expanded to permit inclusion of separate reserve estimates for multiple ore zones on the same property and up to five reserve categories per year. Best assay information is now included in the database for occurrences where no reserves are reported.

Selected files in the database can be downloaded to personal computers for use with a new user-friendly program, MINFILE/pc, which has been developed in dBASE III+, allowing individual researchers to conduct their own searches.

REVIEW OF PROGRESS

Over 3500 occurrences have been recoded to date. This represents more than 40 per cent of the previously recorded data in MINFILE. Many previously unreported occurrences are now being coded and entered into the database. Data entry of the 3500 recoded occurrences is about 80 per cent complete. New report formats have been designed to make them easier to read; in previous versions of hard-copy reports it was neccessary to have a separate manual to translate the codes used in the printouts. Codes have now expanded (*see* Figure 6-1-1).

New mineral inventory maps have also been designed. The old mineral inventory maps classified occurrences by accuracy of location; the new maps show the status of the property (producer, past producer, developed prospect, prospect, showing).

The data are also available on floppy diskettes. The first release of data was for the Seymour Arm (82M) and Whitesail Lake (93E) (Figure 6-1-2). Other map areas will follow after the data have been reviewed by staff geologists.

The Seymour Arm map area contains 244 recorded mineral occurrences. It covers parts of the Shuswap Highlands to the east and the Columbia Mountains to the west. The Goldstream mine is located in the northeastern quadrant of the map area. The western half of the map sheet covers the Adams Plateau and Barriere Lakes areas where a variety of occurrences are being actively explored, including the polymetallic massive sulphide deposits of Rea Gold.

The Whitesail Lake map area contains 114 known mineral occurrences. It covers the contact of the Coast and Intermontane tectonic belts. At this latitude the Coast plutonic belt is mainly comprised of metamorphosed and deformed rocks of probable Paleozoic age, intruded by Cretaceous and Tertiary plutonic rocks. Immediately to the east, the Intermontane Belt is underlain by mildly deformed Lower Jurassic to Tertiary volcanic and sedimentary rocks.

A coding manual, version 2.2, which is a guide to the codes used by the Geological Survey Branch, has also been produced and released. All other outstanding coding manuals, with or without a version number, are obsolete and

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

MINFILE NO.: 082M 065

NAME(S): ENERGITE,ENARGITE,NORTH STAR(SOUTH SHOWING)

STATUS: Past Producer - Underground
MINING DIVISION: Kamloops
N.T.S.: 082M05W
LATITUDE: 51 21 00
LONGITUDE: 119 59 30
ELEVATION 1540 Metres
UTM ZONE: 11
UTM NORTHING: 5692778
UTM EASTING: 291673
COMMENTS: Symbol (Map 53).
LOCATION ACCURACY: Within 500 M

COMMODITIES:	Lead	Silver	Zinc	Copper	Gold
SIGNIFICANT MINERALS:	Galena	Sphalerite	Pyrite	Chalcopyrite	
ASSOCIATED MINERALS:	Quartz				
ALTERATION MINERALS:	Ankerite				
ALTERATION TYPE(S):	Silicific'n				
AGE OF MINERALIZATION:	Unknown				
DEPOSIT CHARACTER:	Vein	Concordant			
DEPOSIT CLASS.:	Epigenetic	Hydrothermal			
SHAPE:	Irregular				
MODIFIER:	Sheared				

DIMENSIONS: 180 120 (METRES) STRIKE/DIP: 165 50W
COMMENTS: Area of mineralized quartz veins; attitude of host rocks.

DOMINANT HOST ROCK: Metasedimentary
LITHOLOGY: Phyllite
Chert
Siltstone
Slate
Sandstone
Limestone

	STRATIGRAPHIC NAME	STRATIGRAPHIC AGE	ISOTOPIC AGE	DATING METHOD	MATERIAL DATED
FORMATION:	Eagle Bay	Mississippian	360	Fossil(Conodont)	CONODONT IN LIMESTONE
	Fennell	Paleozoic	360 Ma		

COMMENTS: Dating by Preto, et. al.,1980
Fennell Fm rocks also occur in the area

TECTONIC BELT: Omineca
TERRANE: Kootenay
PHYSIOGRAPHIC REGION: Shuswap Highland
METAMORPHIC TYPE: Regional
GRADE: Greenschist

PRODUCTION: ** ALL METRIC VALUES ARE IN KILOGRAMS EXCEPT PRECIOUS METALS WHICH ARE IN GRAMS **
** ALL IMPERIAL VALUES ARE IN POUNDS EXCEPT PRECIOUS METALS WHICH ARE IN OUNCES **

MINFILE NO.: 082M 065
CONTINUED...

B C SYSTEMS

RUN DATE: 87/09/15
RUN TIME: 00:00:19

MINISTRY OF ENERGY, MINES AND PETROLEUM RESOURCES
MINERAL RESOURCES DIVISION - GEOLOGICAL SURVEY BRANCH
MINFILE - REPORT

PAGE: 128

YEAR	Tonnes Mined	Tonnes Milled	Silver	Lead	Zinc	Copper
1972	5	0	3,452	1,341	651	
1954	31	0	280			1,581
METRIC TOTAL:	36	0	3,732	1,341	651	1,581
IMPERIAL TOTAL:	Tons 39	Tons 0	119	2,956	1,435	3,485

GEOLOGY:

The property is underlain by Devonian to Permian age Fennell Formation rocks consisting of cherts and phyllites in the west and Mississippian age Eagle Bay Formation rocks consisting of phyllites, siltstones and sandstones in the east. A fault striking 150 degrees and dipping steeply fault, separating the two formations, has sheared and silicified the metasediments. The rocks generally strike 160 to 170 degrees and dip 50 to 90 degrees to the west, and in places, display rusty carbonate alteration. To the east is a Mississippian limestone unit.

Mineralization consisting of galena and pyrite and lesser sphalerite and chalcopyrite, occurs within several quartz veins within a northerly trending zone measuring about 200 by 120 metres. Individual veins and lenses vary from a few centimetres to several metres wide and vary in orientation, although northerly strikes and moderate (40 to 50 degrees) easterly dips predominate.

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EMPR AR 1927-188,190,191; *1935-D7-8; *1936-D36-39; 1939-93; 1954-A48
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EMPR EXPL 1975-57; 1976-63; 1978-E108; 1980-140; 1985-C105
GCNL #2, 1983; #191, 1984
GSC OF 637
EMPR FIELDWORK 1978, pp. 31-37; 1979, pp. 28-36; 1984, pp. 67-76
*Dickie, G.J., Preto, V.A. and Schiarizza, P. (in preparation 1986): Mineral Deposits of the Adams Plateau-Clearwater Area
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EMPR MAP *53, 56

DATE CODED: 850724 CODED BY: AFW FIELD CHECK: NO
DATE REVISED: 870730 REVISED BY: LDJ FIELD CHECK: NO

MINFILE NO.: 082M 065

B C SYSTEMS

Figure 6.1.1. Sample print out.

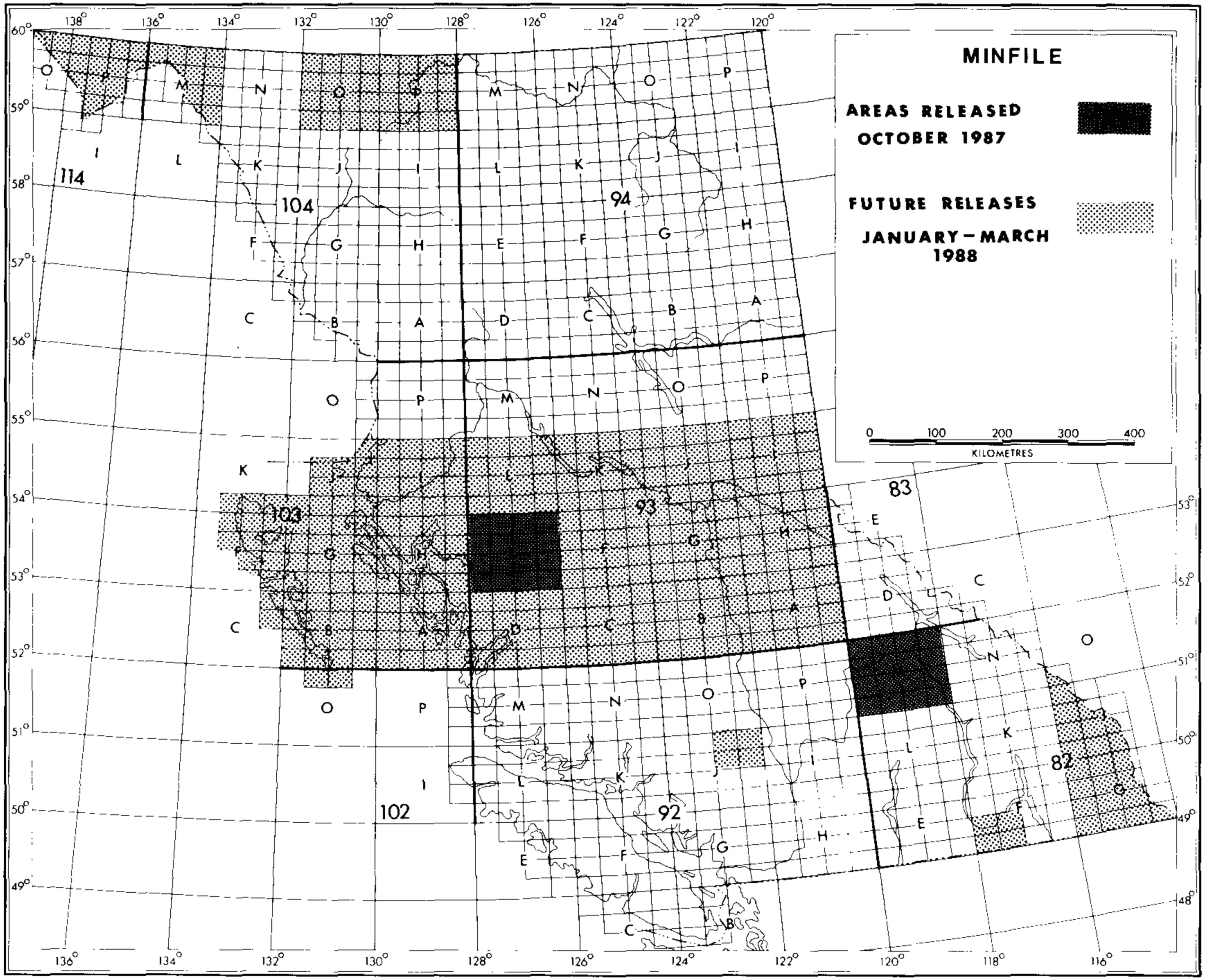

Figure 6-1-2. Map showing present and future releases of MINFILE.

should be discarded. This manual is used by all Geological Survey Branch staff in the write-up and coding for all properties. It explains the codes and sources of information used and the rationale applied to the description of mineral occurrences.

MINFILE/pc[1] *is written in dBASE III + and compiled in* FOXBASE Plus. MINFILE/pc requires a 10-megabyte hard-disk drive to work effectively, a minimum of 612 kilobytes RAM (preferably 640 kilobytes and DOS 3.1 or higher) and can be used in conjunction with our data diskettes.

MINFILE/pc

The strength of the MINFILE system is its ability to search, sort and manipulate data entered in various information fields.

MINFILE/pc was designed specifically for searching aspects of the database which were considered of prime importance. The program utilizes 20 relationships used in the main database.

SEARCH DATABASE (MENU1000)

When users search the database, they are presented with twelve search options as follows:

1. Location.	7. Deposit character.
2. *Commodity.*	8. *Deposit classification.*
3. Status.	9. Lithology.
4. Deposit name.	10. Formal/informal host.
5. Mineralogy.	11. Deposits with production.
6. Host rock, mineral age.	12. Deposits with reserves.

Each of these will now be discussed in more detail.

Location (SRCH1010)

It is recommended that location searches be carried out initially to reduce the number of deposits to a more manageable level. The location search is divided into three sections and you may search any one of them at one time. The first part of the location search that you may choose is by latitude/longitude. Valid latitudes and longitudes for British Columbia are from 48 to 60 degrees north latitude, and 114 to 140 degrees west longitude. The second option is to search the database using UTM coordinates. The valid coordinates for British Columbia are: UTM Zones 07 to 11; Northings from 5370000 to 6652000; and Eastings from 290000 to 710000. The third section of the screen that can be searched contains the NTS map sheet (you may enter any valid British Columbia designations ranging in scale from 1:1 000 000 to 1:250 000, that is, you may enter any or all of the following **082 M 05 E**. You may enter up to four map sheets for any given search. You may also search on two mining divisions, tectonic belts, physiographic regions or terranes.

Commodity (SRCH1020)

The commodity search screen is divided into two parts. *The first part deals with "primary commodities" or com*modities that are listed first in MINFILE printouts or on MINFILE maps. You may choose up to five primary commodities per search. The second part deals with the AND, OR, NOT conditions; you may also enter five commodities in each part of the search.

Status (SRCH1030)

The five valid STATUS types used in the MINFILE database are used for searching: showing, prospect, developed prospect, producer and past producer. You may choose up to three status types.

Deposit Name (SRCH1040)

You may enter from one to thirty characters of a deposit name at the prompt. For example, if you entered **blu** you would receive a listing of all deposits in the database that started with the first three letters "BLU" such as BLUEBIRD, BLUEBELL, etc.

Mineralogy (SRCH1050)

The mineralogy search gives you the option of seaching significant, associated or alteration minerals. As in the commodity search, the Boolean algebra expression has been expanded into sentence structure to better explain the AND, OR, NOT logic. Up to five minerals may be entered in any section of the Boolean expression.

Age Search (SRCH1060)

The age search allows the user to search on either the age of the host rocks or the age of mineralization. A range of ages or a specific age may be entered.

Deposit Character (SRCH1070)

The deposit character search menu allows the user to enter up to five deposit character codes in either the AND or OR Boolean expression. The new valid deposit characters are:

1. Vein.	8. Stratabound.
2. Stockwork.	9. Stratiform.
3. Breccia.	10. Concordant.
4. Pipe.	11. Discordant.
5. Unconsolidated.	12. Massive.
6. Podiform.	13. Disseminated.
7. Layered.	**Unknown

Deposit Classification (SRCH1080)

The valid new deposit classification codes are listed below. Five valid codes in either section of the Boolean algebra expression may be choosen.

1. Replacement.	11. Skarn.
2. Magmatic.	12. Pegmatite.
3. Volcanogenic.	13. Placer.
4. *Sedimentary.*	14. Precipitate.
5. Syngenetic.	15. Exhalative.
6. Epigenetic.	16. Diatreme.
7. Hydrothermal.	17. Epithermal.
8. Residual.	18. Mesothermal.
9. Porphyry.	19. Fossil fuel.
10. Igneous contact.	**Unknown.

[1] This software is not supported by the Geological Survey Branch. Source code may be obtained by writing the Chief Geologist.

Lithology (SRCH1090)

The user may enter up to five rock types. The rock modifiers are optional. If for example you wished to search "biotite granites" you would enter the appropriate code for granite in rock type and the appropriate code for biotite as a modifier. If you wished to search all granites you would just enter the code for granite in the rock type field.

Host Rock (SRCH1100)

The user may enter either two groups, formations or igneous metamorphic/other host rock names. For a complete list of host rocks included in the system the reader is referred to the coding manual.

Production (SRCH1110)

The production search is different from the previous ten in that the entry of a year is required to activate this search. The year can be either a specific year or a range of years during which production occurred. This range of years can then be combined with a range of ore mined or ore milled. When using the production search, a commodity must be present in the Boolean algebra expression.

Reserves (SRCH1120)

The ore reserve search, like the production search, requires that a specific year or a range of years be entered in order to begin searching the database. Once the range of years has been selected the user may then specify a tonnage range. The default is the whole database. This criterion is then combined with the reserve categories. At least one reserve category must be chosen. The final section of this screen allows the user to choose an appropriate commodity and grade or range of grades. At least one commodity and grade must be selected. Three commodities and grades per search may be chosen. An example of the type of question that can be answered is as follows: list all the deposits that have gold reserves in excess of 10 000 tonnes grading greater than 5 grams per tonne, calculated no earlier than 1985.

ACKNOWLEDGMENTS

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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 explorationists, who otherwise may be unaware of them.

Earth Science Departments are encouraged to send a current listing to the Editor, Geological Fieldwork and Current Research, no later than October 31 of each year.

THE UNIVERSITY OF BRITISH COLUMBIA, 1985

McKenzie, K.J., Sedimentology and Stratigraphy of the Southern Sustut Basin, North Central British Columbia. (M.Sc.)

McPhail, D.C., The Stability of Mg-chlorite. (M.Sc.)

Sun, M., Sr Isotopic Study of Ultramafic Nodules from Neogene Alkaline Lavas of British Columbia, Canada and Josephine Peridotite, Southwest Oregon, U.S.A. (M.Sc.)

THE UNIVERSITY OF BRITISH COLUMBIA, 1986

Cassidy, J.F., The 1918 and 1957 Vancouver Island Earthquakes. (M.Sc.)

Denton, Alexander, W.S., Tectonics and Sediment Geochemistry of Tuzo Wilson Seamounts, Northeast Pacific Ocean. (M.Sc.)

England, L.A., Long-term Transient Regional Groundwater Flow in a Heterogenous Mature Basin with Large Hydraulic Conductivity Contrasts. (M.Sc.)

Gannon, M.P., A Comparison of the L1 Norm and L2 Norm (Least Squares) Methods of Analysing Strain Relief Data. (B.A.Sc.)

Goutier, F.M., Galena Lead Isotope Study of Mineral Deposits in the Eagle Bay Formation, Southeastern British Columbia. (M.Sc.)

Hickson, C.J., Quaternary Volcanism in the Wells Gray–Clearwater Area, East Central British Columbia. (Ph.D.)

Kavanagh, R.E., Development of an Algorithm to Determine the Three-dimensional Hydraulic Conductivity Tensor of Anisotropic Media Based on the Cross-hole Test Methodology. (B.A.Sc.)

Klatt, H.K., Geology and Petrology of the Dary Tungsten Prospect in the Horsethief Creek Group, Duncan Lake Area, Southeast British Columbia. (B.Sc.)

Mäder, U.K., The Aley Carbonatite Complex. (M.Sc.)

Mase, C.W., The Effects of Frictional Heating on the Thermal, Hydrologic and Mechanical Response of a Fault. (Ph.D.)

Nauss, A.L., Lithiotis Bioherms in the Pliensbachian (Lower Jurassic) of North America. (M.Sc.)

Perkins, E.H., The Theoretical Basis for the Modelling of Chemical Reactions in Rock-water Systems with Specific Reference to the Heat Flow, Fluid Flow and Solute Transport Laws. (Ph.D.)

Richardson, J.T., The Use of Surface Measurements to Characterize Subsurface Hydraulic Fractures. (B.A.Sc.)

Uyeda, E.Y., Quantitative Analysis of Debris Torrent Magnitudes for Alberta, Newman and Sclufield Creeks, Highway 99, Howe Sound, B.C. (B.A.Sc.)

Wang, X., A Study on the Equilibrium Grossular – Clinochlore = 3 Diopside + 2 Spinel + $4H_2O$. (M.Sc.)

THE UNIVERSITY OF BRITISH COLUMBIA, 1987

Andrew, A., Lead and Strontium Isotope Study of Five Volcanic and Intrusive Rock Suites and Related Mineral Deposits, Vancouver Island, British Columbia. (Ph D.)

Bloodgood, M.A., Deformational History, Stratigraphic Correlations and Geochemistry of Eastern Quesnel Terrane Rocks in the Crooked Lake Area, East Central British Columbia. (M.Sc.)

Brown, D.A., Geological Setting of the Volcanic-hosted Silbak Premier Mine, Northwestern British Columbia (104A/4, B/1). (M.Sc.)

Cahn, L.S., Development of Guidelines for Design of Sampling Programs to Predict Groundwater Discharge. (M.Sc.)

Desloges, J.R., Paleohydrology of the Bella Coola River Basin: An Assessment of Environmental Reconstruction. (Ph.D.)

Devlin, B.D., Geology and Genesis of the Dolly Varden Silver Camp, Alice Arm Area, Northwestern British Columbia. (M.Sc.)

Jakobs, G.K., Middle Jurassic Biostratigraphy of the Bowser Lake Group, Smithers Area, Northeastern British Columbia. (B.Sc.)

Juras, S.J., Geology of the Polymetallic Volcanogenic Buttle Lake Camp, with Emphasis on the Price Hillside, Central Vancouver Island, British Columbia, Canada. (Ph.D.)

Maddison, L., Biostratigraphy of the Mount Head Formation Near Overfold Mountain, 55km Southeast of Fernie, British Columbia. (B.Sc.)

McColl, K.M., Geology of Britannia Ridge, East Section, Southwest British Columbia. (M.Sc.)

McKenna, G.T., Evidence of a Large Scale Mass Wasting on the Fraser River Delta Front at Sands Head, British Columbia. (B.A.Sc.)

Nicol, D.R., The Feasibility and Technical Design of a Proposed Squamish Highway Tunnel. (B.A.Sc.)

Rapp, P.A., Rock Toppling and Massive Slope Instability in the Beaver Valley, British Columbia. (B.A.Sc.)

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Stewart, T.W.G., A Geotechnical Investigation for the Design of a Four Lane Highway Tunnel, Porteau Cove, British Columbia. (B.A.Sc.)

Vanbuskirk, C.D., Reassessment of the Griffith Landslide, Rogers Pass, British Columbia. (B.A.Sc.)

Wade, L., Gold and Its Relationship to the Mineralogy in the Eileen Vein at Erickson Gold Mine, Cassiar, North-central British Columbia. (B.Sc.)

Walters, L.K., A Geological Interpretation of Lithoprobe Seismic Reflection Profile 3, Southern Vancouver Island, British Columbia. (B.Sc.)

Wetherill, J.F., Report on the Ark Property, Port Alberni Mining Division, Vancouver Island, British Columbia. (B.A.Sc.)

Wong, G.Y., A Statistical Analysis of Point Counting Precision as Applied to Coal Petrography. (B.A.Sc.)

UNIVERSITY OF ALBERTA

Zhang, X., Fluid Inclusion and Stable Isotope Studies of the Gold Deposits in Okanagan Valley, British Columbia. (1986, M.Sc.)

UNIVERSITY OF CALGARY

Freeman, K.J., Hydrothermal Metamorphism of Telkwa Formation Volcanics near Terrace, British Columbia. (1986, M.Sc.)

Mihalynuk, M.G., Metamorphic, Structural and Stratigraphic Evolution of the Telkwa Formation, Zymoetz River Area (NTS 103I/8 and 93L/5), Near Terrace, British Columbia. (1987, M.Sc.)

CARLETON UNIVERSITY

Coleman, V., A Metamorphic and Kinematic Study of the Monashee Décollement, Southeastern British Columbia. (1987, B.Sc.)

MacKinnon, H., Examination of Concentrates from Atlin, British Columbia Placers: Economic Implications. (1986, B.Sc.)

Rees, C.J., The Intermontane–Omineca Belt Boundary in the Quesnel Lake Area, East-central British Columbia: Tectonic Implications Based on Geology, Structure and Paleomagnetism. (1987, Ph.D.)

Scammell, R.J., Stratigraphy, Structure and Metamorphism of the North Flank of the Monashee Complex, Southeastern British Columbia: A Record of Proterozoic Extension and Phanerozoic Crustal Thickening. (1987, M.Sc.)

Zwicker, E., Epidote-altered Volcaniclastic Rocks Associated with the Quesnel River Gold Deposit, British Columbia. (1987, B.Sc.)

NORTHERN ILLINOIS UNIVERSITY

Fox, K.J., Sedimentology of Late Pleistocene Ice-contact Glaciomarine Delta and Submarine Outwash Fan Lithofacies, Fraser Lowland, British Columbia, Canada. (1986, M.Sc.)

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Journeay, J.M., Stratigraphy, Internal Strain and Thermotectonic Evolution of Northern Frenchman Cap Dome: An Exhumed Duplex Structure, Omineca Hinterland, Southeast Canadian Corillera. (1986, Ph.D.)

SIMON FRASER UNIVERSITY

Morningstar, O.R., Floodplain Construction and Overbank Deposition in a Wandering Reach of the Fraser River, Chilliwack, British Columbia. (1987, M.Sc.)

UNIVERSITY OF TORONTO

Yagishita, K., Mid- to Late Cretaceous Sedimentation in the Queen Charlotte Islands, British Columbia; Lithofacies, Paleocurrent and Petrographic Analyses of Sediments. (1985, Ph.D.)

WESTERN WASHINGTON UNIVERSITY

Bream, S.E., Depositional Evironment, Provenance and Tectonic Setting of the Upper Oligocene Sooke Formation, Vancouver Island, British Columbia. (1987, M.Sc.)

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