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MINERAL RESOURCES DIVISION
Geological Survey Branch

GEOLOGICAL FIELDWORK 1994

A Summary of Field Activities and Current Research

Editors: B. Grant and J.M. Newell

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FOREWORD

The 1994 edition of Geological Fieldwork: A Summary of Field Activities and Current Research is the twentieth in this annual publication series. It contains reports on Geological Survey Branch activities and projects during the past year. The base budget of the Branch for the 1994/95 fiscal year was $5.54 million. This budget was supplemented by an additional $1.4 million, made up of $1 million from the Mineral Development Agreement, $337 000 from the inter-Ministry Corporate Resource Inventory Initiative and $60 000 from the Resource Inventory Commission.

The contents of this year's volume reflect the emphasis of Branch programs in 1994. Reports on two major integrated studies, the northern Vancouver Island and Interior Plateau projects are grouped together. Each section includes separate reports on bedrock mapping, surficial geology, applied geochemistry, drift exploration studies and aspects of metallogenesis. Both these projects focus on regions where major mines have either closed recently (Equity Silver), or will close in the near future (Island Copper), as a result of depletion of reserves. A similar, though slightly less ambitious approach has been taken with respect to regional mapping programs in the Gataga and Kootenay districts. In addition to reports on the progress of mapping, articles on aspects of applied geochemistry and mineral deposit studies are also presented. Of particular interest is a brief description of the Iron Range iron oxide breccia deposits in the Yahk area of the Kootenays, currently being explored as a possible analog of the Olympic Dam copper-uranium-gold deposits at Roxby Downs in South Australia. The Driftpile lead-zinc-barite deposits in the Gataga district, and three other deposits in the Kootenays, are covered by separate descriptive papers and advances in the understanding of the geology of the Goldstream orebody are outlined in a report on regional mapping in the northern Selkirk Mountains.

Other major contributions include 1:50 000 mapping projects in the Tulsequah area of northwestern British Columbia, where on-going exploration on the old Tulsequah Chief property continues to generate encouraging results, and in the Tatlayoko Lake area. A new metallogenic study has been initiated in the Tatogga Lake area, in the headwaters of the Iskut River, where the Red-Chris porphyry copper-gold deposit is being re-explored.

On other fronts, eight papers focus on the results and methodology of the province-wide mineral potential assessment project and the development of mineral deposit models specifically applicable in British Columbia. The Ministry's past efforts to promote development of the province's industrial minerals potential are reflected in increased private sector investment in this area; five papers focus on andalusite, sand and gravel, diatomite, perlite and dimension stone.

This volume also includes four papers from the Mineral Deposit Research Unit at The University of British Columbia, summarizing work completed in the Seneca, Tulsequah and Anyox volcanogenic massive sulphide camps.

For a second year, production of Geological Fieldwork to the camera-ready stage has been entirely by the authors. Under the general direction of the editors, authors have been responsible for the input, formatting and lay-out of their own papers. Although challenging and sometimes frustrating to the authors, in-house publication achieves substantial cost savings. Thanks to John Newell for thorough and timely edits and to Brian Grant for guiding the whole process to completion under tight deadlines.

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INTRODUCTION

Regional mapping (1:50000) this past summer on northern Vancouver Island covered the ground north of Quatsino Sound and west of Holberg Inlet. The map area extends through the western half of the Quatsino sheet (92L/12) to Cape Parkins (102I/8) at the entrance of Quatsino Sound, north to San Josef Bay (102I/9) at the southern boundary of Cape Scott Provincial Park, and east to adjoin mapping done north of Holberg in the 1993 field season. In all, some 750 square kilometres of hilly terrain were traversed along a system of largely well maintained logging roads, and over 200 kilometres of coastline was examined by boat.

Previous work in the map area includes studies of the surficial geology and till geochemistry (Kerr, 1992; Kerr and Sibbick, 1992; Kerr *et al.*, 1992), and regional geochemistry (Sibbick and Laurus, 1995, this volume). In addition, recent results of isotopic dating using the $^{40}Ar/^{39}Ar$ technique on igneous and hydrothermal minerals (Archibald and Nixon, 1995, this volume; Panteleyev *et al.*, 1995, this volume), in conjunction with new paleontological control (Haggart and Tipper, 1994), provide fresh insights into the most probable relationships between Jurassic volcanism and plutonism on northern Vancouver Island. In this brief interim report, we present the most notable results of the 1994 field season.

GENERAL GEOLOGY

Generalized aspects of the geology of northern Vancouver Island are shown in Figure 1. The region forms part of the Wrangellia tectonostratigraphic terrane of the Insular Belt. The oldest rocks encountered in the Quatsino Sound area belong to the Upper Triassic Vancouver Group and comprise tholeiitic flood basalts (Karmutsen Formation) at the base overlain by thinly bedded to massive limestone (Quatsino Formation) and intercalated marine shale, siltstone and impure limestone (Parson Bay Formation). The Lower to Middle Jurassic Bonanza Group (Archibald and Nixon, 1995, this volume) is composed of mafic to felsic volcanic and lesser intercalated sedimentary rocks laid down in both submarine and subaerial environments. The Bonanza group is unconformably overlain by marine to nonmarine Upper Jurassic(?) to Cretaceous clastic sequences and localized Tertiary volcanic rocks. The Mesozoic strata are intruded by Lower to Middle Jurassic granitoids of the Island Plutonic Suite, and mafic to felsic dikes and sills of Karmutsen, Bonanza and Tertiary age. Further descriptions of the geology of the Quatsino Sound region may be found in Jeletsky (1976), Muller *et al.* (1974) and Nixon *et al.* (1993a, 1994).

NEW STRATIGRAPHIC INSIGHTS

UPPER TRIASSIC PARSON BAY FORMATION

Sedimentary rocks of the Parson Bay Formation are restricted to the eastern margin of the map area south of Holberg Inlet. They are predominantly composed of well bedded, argillaceous lime mudstone and calcareous to noncalcareous siltstone and minor sandstone, and, as such, resemble the typically calcareous 'western facies' of the Parson Bay Formation (Nixon *et al.*, 1994; Hammack *et al.*, 1994)

UPPER TRIASSIC SUTTON LIMESTONE EQUIVALENT

A pale grey weathering, thin to medium-bedded, fairly pure limestone, believed to be equivalent to the Sutton Formation (uppermost Triassic), forms the tip of the southeastern peninsula of Drake Island (Figure 2). The base of this limestone unit, exposed on the eastern side of the peninsula, rests conformably on dark grey

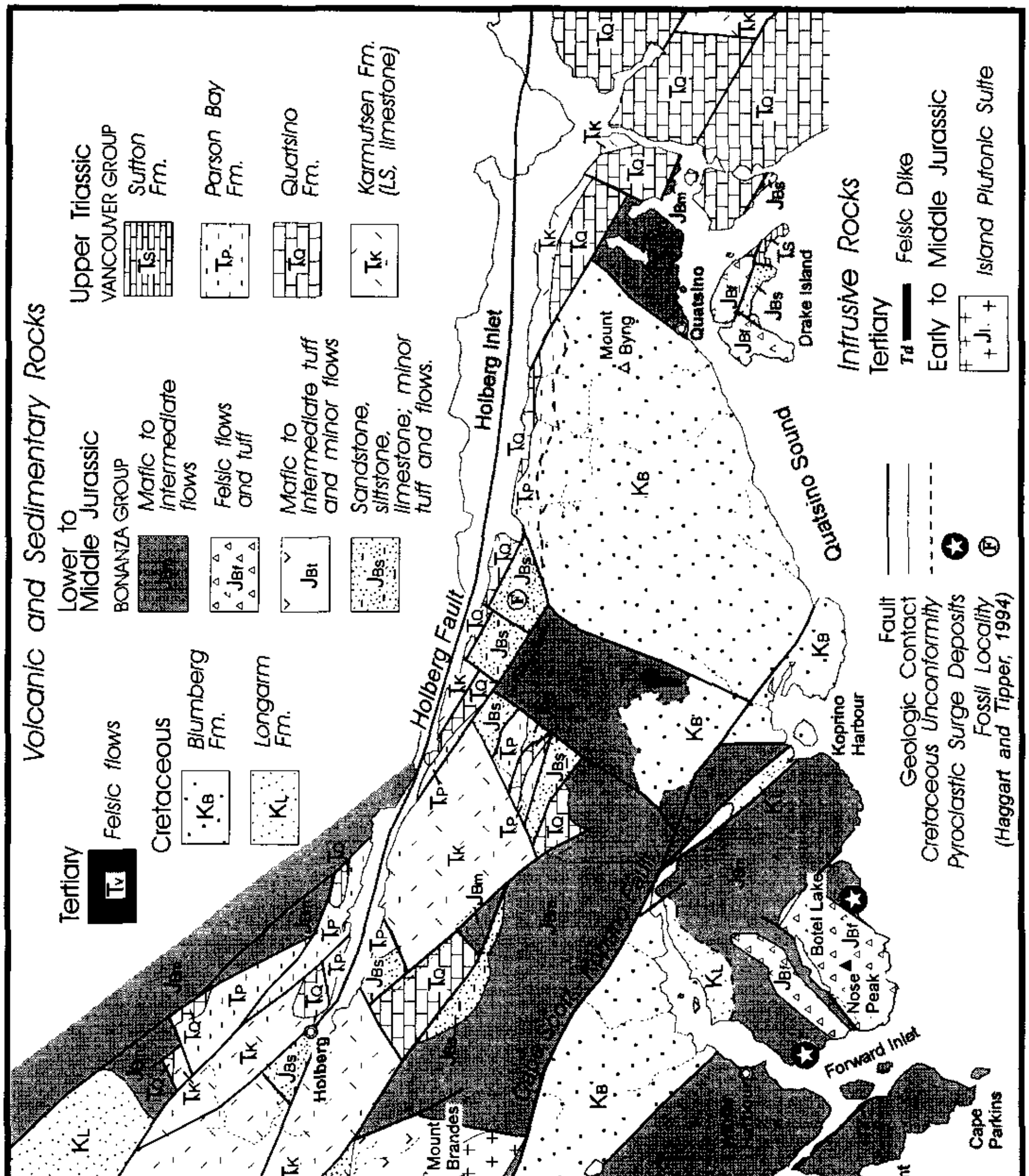

Figure 2. Generalized geology of the Quatsino - San Josef map area.

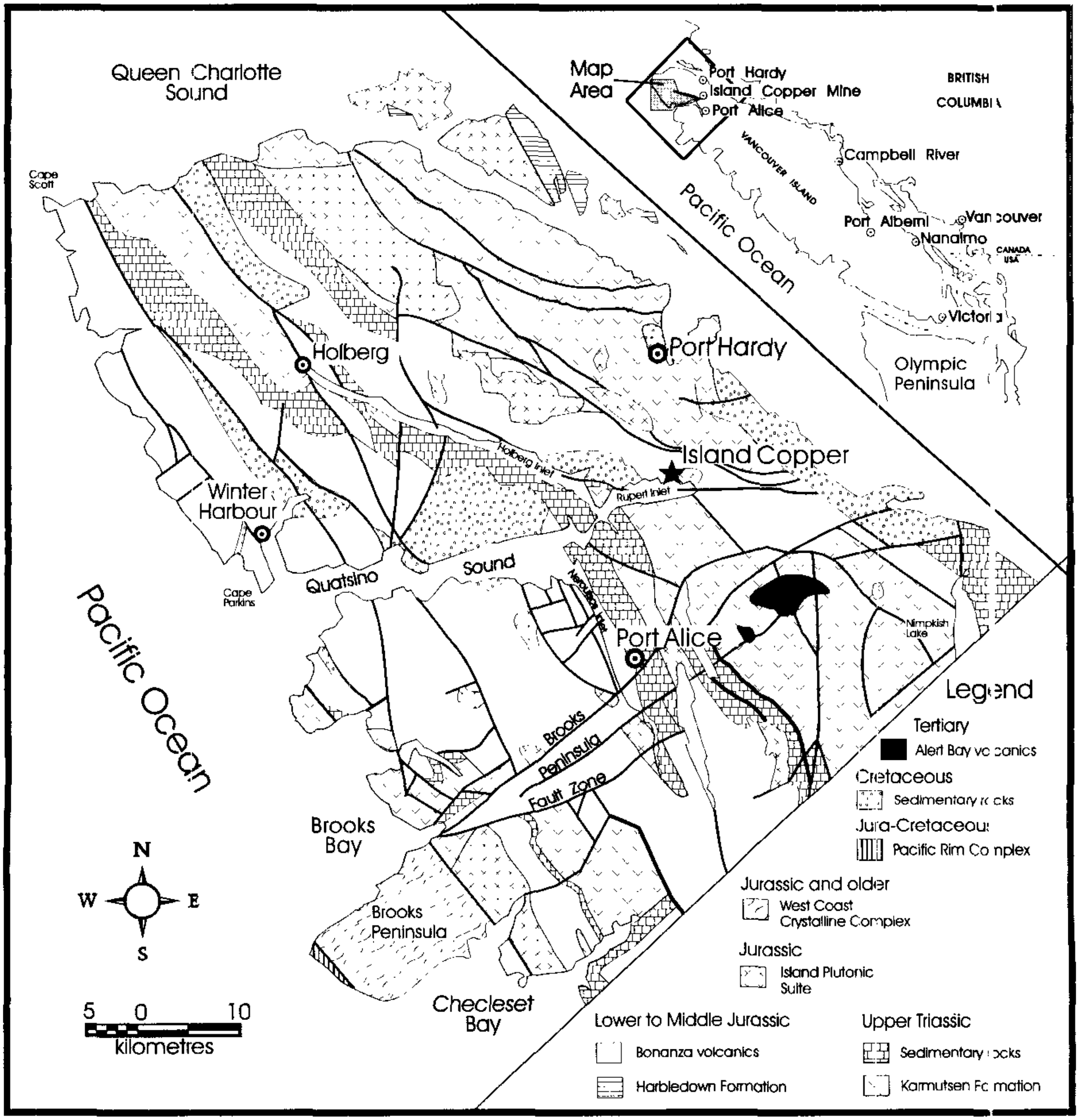

Figure 1. Regional geology of northern Vancouver Island (modified after Roddick and Muller, 1983). Shaded inset shows location of project area.

argillaceous limestone and limestone breccia which in turn passes down into laminated to thinly bedded, weakly calcareous shale, mudstone and interbedded impure limestone of the Parson Bay Formation. At one locality, bivalves (Halobia?) were recovered from the shales. This limestone was formerly included in the Quatsino Formation by Jeletzky (1976), but he also recognized Sutton limestone equivalents (up to about 80 m thick) on the south shore of Quatsino Sound opposite Drake Island (not shown in Figure 2).

LOWER JURASSIC SEDIMENTARY STRATA OF THE BONANZA GROUP

Sedimentary strata provisionally assigned to the Lower Jurassic are also exposed south of Holberg Inlet and on Drake Island where they form westerly dipping, westerly facing sequences locally disrupted by faulting and folding.

The top of the Sutton limestone equivalent on Drake Island is separated from a sequence of dark grey, thinly bedded argillaceous limestones, calcareous siltstones and mafic to intermediate lithic tuffs and lavas(?) by a feldspar porphyry dike and a bedding-plane-parallel fault, displacement across which may not be significant. The overlying strata comprise fine-grained clastics and impure to fairly pure limestones and limestone breccias (debris flows) interbedded with intermediate to mafic, waterlain crystal and lithic tuffs. All of these lithologies were placed in the Parson Bay Formation by Roddick and Muller (1983). This decision may well have been influenced by Jeletzky (1976), who noted an occurrence of what he considered to be Sutton limestone equivalent on the southwestern shore of Drake Island (*i.e.* at the top of the succession and underlying a felsic flow-dome complex described below). Although fossil control is currently lacking in these sedimentary strata, we have tentatively placed them in the lowermost part of the Bonanza Group, based on lithological considerations and the occurrence of Sutton limestone at the base of the succession.

A fossiliferous package of sedimentary rocks is found at the base of the Bonanza Group south and west of Holberg Inlet (unit J_{BS}, Figure 2). These rocks contain abundant marine fauna including ammonites, bivalves, corals, belemnites and gastropods. Fossil age determinations are pending. However, Haggart and Tipper (1994) have tentatively assigned a late Pliensbachian age to these strata, based on fossils collected approximately 20 kilometres southeast of the community of Holberg (Figure 2).

Lithologies include sandstone, limestone and debris-flow (laharic?) breccias with minor tuffs. The dominant rock type is a well bedded to massive, calcareous and noncalcareous arkosic to lithic wacke which is typically tuffaceous (Photo 1). The clastic rocks are locally interbedded with pure and impure lime mudstones which reach thicknesses greater than 6 metres. In structurally complex areas (*e.g* 4 km due south of Holberg and 5 km due west of Haggart and Tipper's (1994) fossil locality; Figure 2), fossil control is needed to confidently determine their stratigraphic identity.

Debris-flow breccias containing abundant clasts of impure and pure limestone are common locally, particularly near the base of the Lower Jurassic succession (Photo 2). These breccias were largely deposited in a marine basin and commonly display an erosive base with soft-sediment load structures. Typically these deposits are very poorly sorted with fragments ranging from pebble to cobble size supported in a mud matrix. The coarse material fines upward into fossiliferous sandstones. In areas of more abundant outcrop, multiple debris-flow breccia - sandstone cycles can be seen. Clasts within the breccia are composed of both volcanic and sedimentary rocks including sandstone, siltstone and limestone. The limestone clasts may have been derived from underlying Upper Triassic limestone (Quatsino or Sutton Formation) or consolidated Jurassic limestones observed to be intercalated with the breccias.

The basal contact of this sedimentary succession is typically faulted. However, sandstone of probable Early Jurassic age appears to conformably overlie calcareous and noncalcareous siltstone of the Parson Bay Formation along the southern shore of Holberg Inlet, approximately 3 kilometres southeast of Holberg. The upper contact of this package is well exposed near Haggart and Tipper's (1994) fossil locality (Figure 2) where tuffaceous sandstones grade upward into reworked waterlain tuffs (Photo 3) and minor plagioclase-phyric pillow lavas.

LOWER TO MIDDLE JURASSIC BONANZA GROUP VOLCANIC ROCKS

Volcanic rocks of the Bonanza Group in the Quatsino - San Josef area appear to form a largely bimodal rhyolite-basalt association similar to that documented previously south of Quatsino Sound in the Mahatta Creek map area (92L/5; Nixon *et al.*, 1993a, b). As with previous map areas, we have been able to subdivide the Bonanza Group into felsic and mafic to intermediate lithostratigraphic units, and marine and rare nonmarine sedimentary strata. Both submarine and subaerial volcanic environments are represented. The tectonic complexity of the map area and rapidly changing nature of volcanic facies prevent firm stratigraphic correlations at this time; age assignments await fossil identification and ongoing U-Pb zircon geochronometry. However, from ongoing work in the Quatsino - Port McNeill map area to the east, it is apparent that subaerial volcanism in the Bonanza Group extended into the Middle Jurassic (Archibald and Nixon, 1995, this volume).

PYROCLASTIC SURGE DEPOSITS

Previously unrecognized pyroclastic surge deposits, all of mafic composition, are preserved in coastal exposures on the south shore of Raft Cove near the mouth of the Mackjack River, on the north shore of

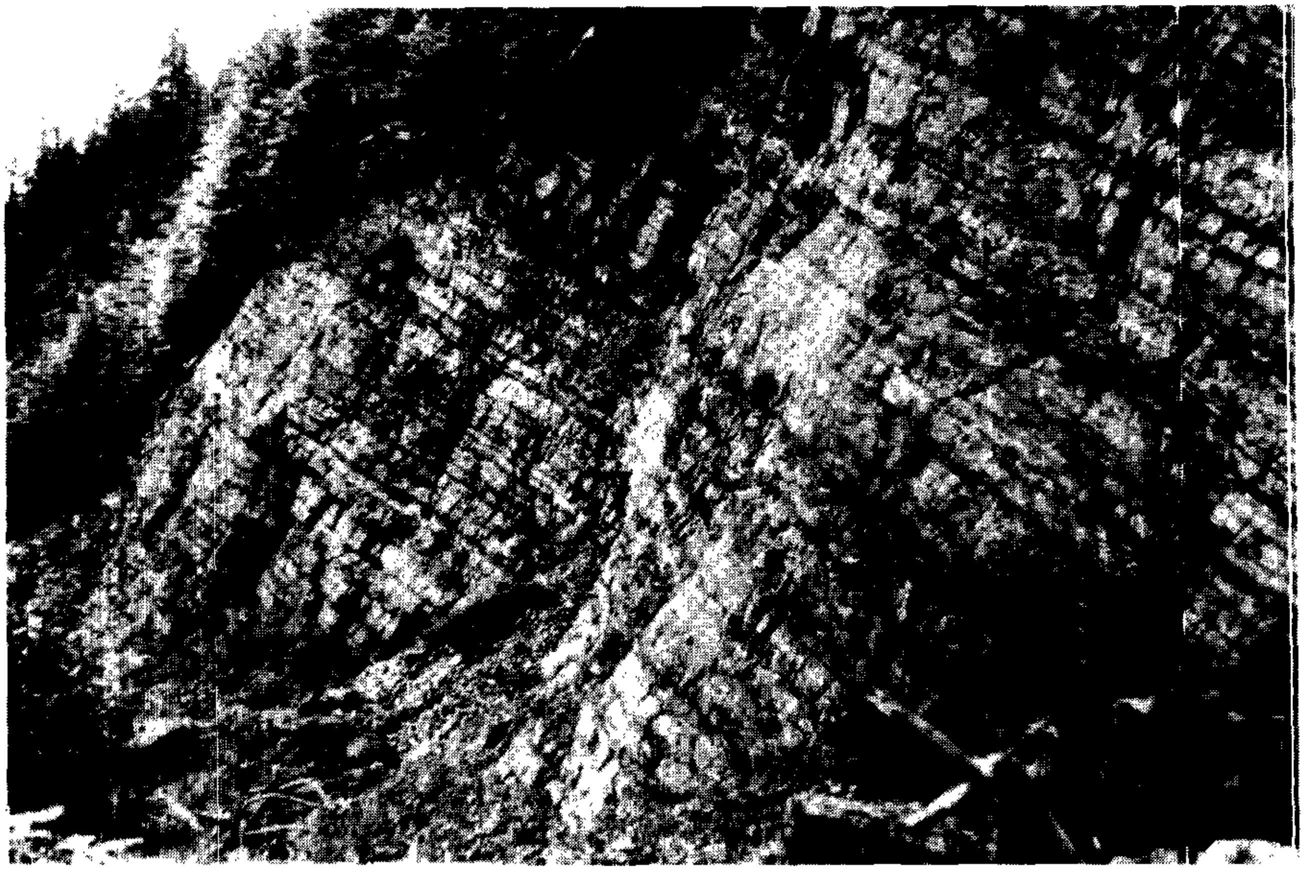

Photo 1. Well bedded Lower Jurassic sandstone and siltstone near fossil locality F in Figure 2.

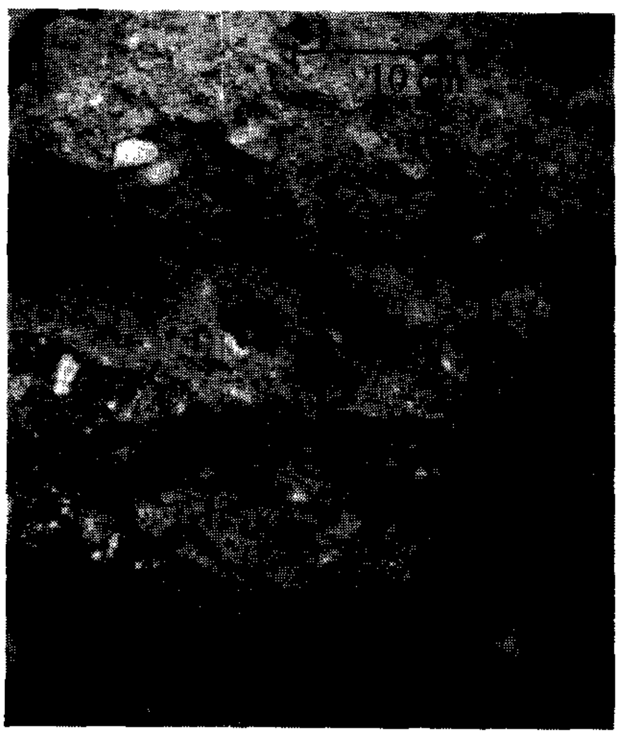

Photo 2. Debris-flow (laharic?) breccia containing volcanic and sedimentary clasts including angular limestone fragments (pale grey). Basal Jurassic strata involved in complex folding and thrusting approximately 13 kilometres southeast of Holberg.

Quatsino Sound due east of Nose Peak, and south of Winter Harbour in Foreward Inlet (Figure 2). The most extensive exposures are at the latter two localities.

Excellently preserved sequences of pyroclastic surge deposits are exposed at shoreline on the east coast of Forward Inlet. These deposits were formally included in the Waterlain Tuff Member of the Mathews Island Formation (about 250 to 400 m thick) by Jeletzky (1976). The strata strike nearly east-west, dip moderately (30 to 60°) to the north and are cut by northerly trending high-angle faults and northerly to northeasterly striking mafic aphanitic dikes. Several coarsening-upward stratigraphic sequences are exposed. The base of the lowest sequence is marked by laminated to thinly bedded, dark to medium grey, argillaceous micritic limestone intercalated, and eventually passing into, grey-green, very thinly bedded to thinly laminated, noncalcareous to calcareous tuffaceous siltstone and fine mafic tuff, most of which appears to be airfall in origin. Load and flame structures and convolute soft-sediment folds are locally prolific at this horizon. These fine-grained layers pass gradationally upward into well to moderately sorted fine lithic tuffs and lapilli tuffs with angular clasts generally less than a centimetre across. Although contacts between layers are usually planar, low-angle cross-stratification is not uncommon (Photo 4). Lapilli tuffs higher in the sequence are thin to thickly bedded more poorly sorted, and have a coarser average grain

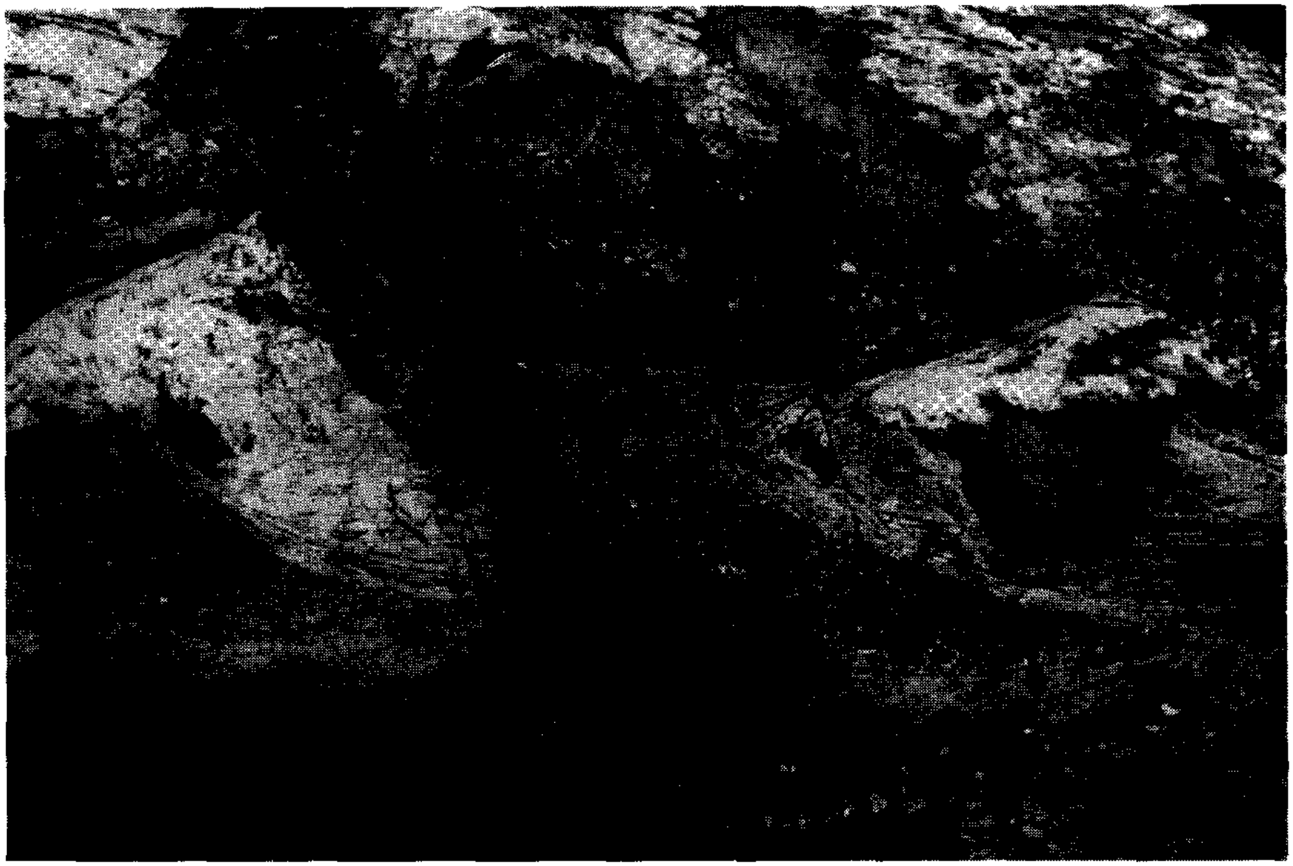

Photo 3. Trough cross-laminae in reworked tuffs near the top of the basal Bonanza sedimentary package near fossil locality F in Figure 2.

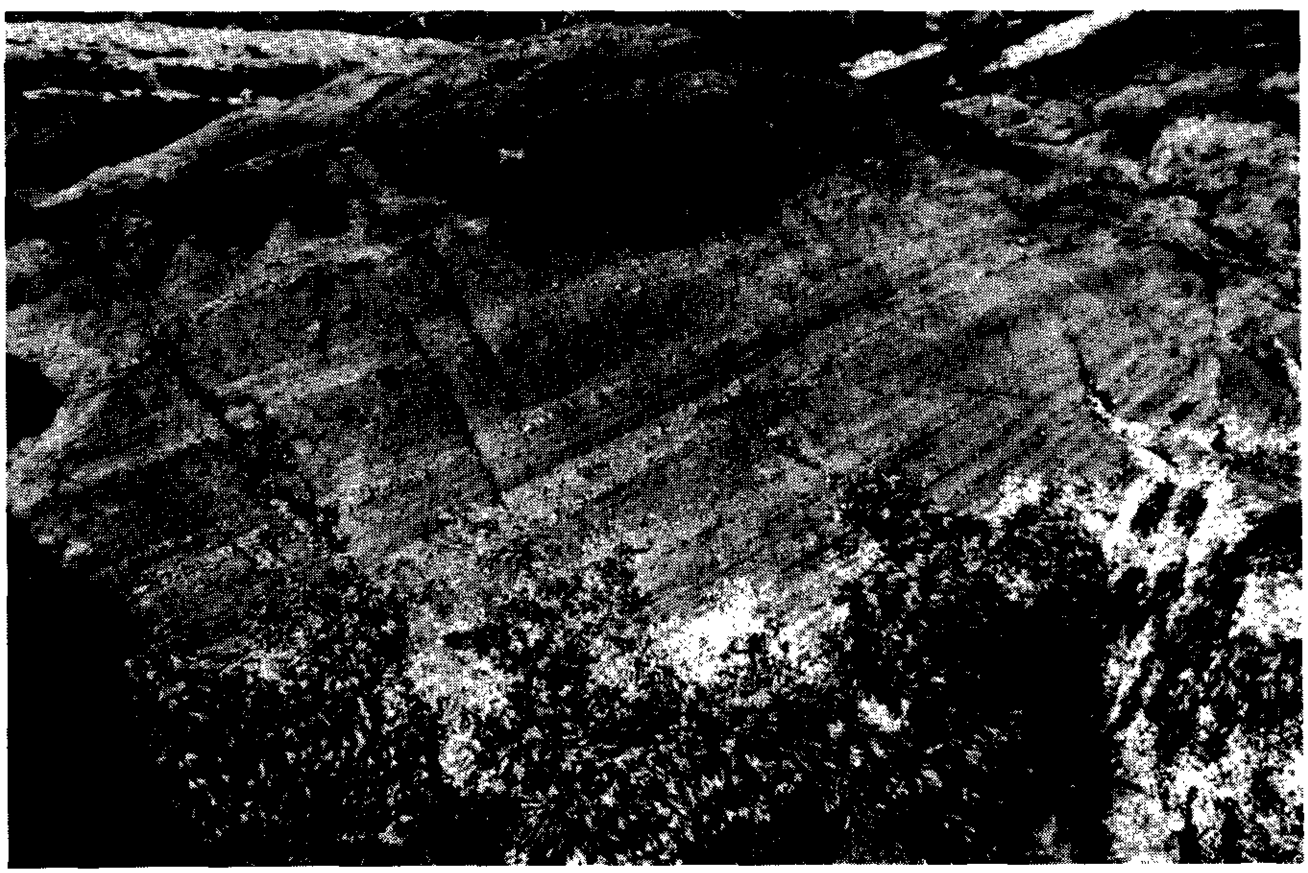

Photo 4. Thinly bedded, pyroclastic surge deposits studded with angular basaltic lapilli and showing low-angle cross-stratification. East shore of Foreward Inlet.

size (Photo 5). The thicker units may represent high-energy, high particle concentration, pyroclastic flow deposits, rather than low particle concentration, pyroclastic surge phenomena. Angular lapilli and blocks of mafic lava in these more thickly bedded layers reach 20 centimetres in diameter, and some have weakly vesiculated cores. They represent volcanic bombs either ballistically emplaced (Photo 6), or picked up and laid down (by saltation) in ground surge deposits. The pyroclastic sequence is capped by a mafic amygdaloidal aphanitic flow with a locally well developed basal breccia. Although there are structural complications, two more such cycles appear to stratigraphically overlie the lowest sequence.

Pyroclastic surge deposits east of Nose Peak do not appear to exhibit this coarsening-upward cycle. However, they too form part of a shallowing-upward sequence as they overlie a relatively thick succession of variably palagonitized pillow lavas, pillow breccias and bedded hyaloclastite deposits that stretches from this locality over a kilometre east to Nordstrom Cove (Photo 7). Inland, these deposits appear to interfinger with, and become replaced by, more massive lavas. The surge deposits are variably oxidized, medium to very thinly bedded, coarse lithic tuffs and lapilli tuffs containing dense to amygdaloidal, angular to subangular basaltic clasts up to 30 centimetres across. Contacts between surge layers are mostly planar. To the west, these deposits are overlain by a thin succession of massive to partly pillowed, strongly amygdaloidal basalt flows.

The recognition of volcanic sequences containing pyroclastic surge deposits in the Bonanza Group improves our understanding of the environment of explosive phreatomagmatic activity. The earliest strata in the sequence were clearly laid down in very shallow seas. Small volcanic edificies, probably of low relief (maars, tuff rings), eventually breached sea level as recorded by the pyroclastic surge deposits. Some of these deposits were wet (base surge) whereas others may have been essentially free of seawater (hot and dry); the latter may be represented in part by thin pyroclastic flow layers. Explosive activity culminated when subaerial lavas plugged the vent. The dormant centre(s) was eventually eroded, or subsided beneath sea level. Some time later, volcanic activity resumed to generate the next pyroclastic-effusive cycle.

RHYOLITES

New felsic (dacite-rhyolite) map units in the Bonanza Group are shown in Figure 2. By far the largest concentration of rhyolitic lavas is in the area of Nose Peak, overlooking the entrance to Quatsino Sound. The Nose Peak rhyolite is well exposed in steep sea cliffs at the entrance to Foreward Inlet, and it may extend farther south beneath the waters of Quatsino Sound to the Gillam Islands, which are almost entirely composed of rhyolite. The rhyolite unit overlies amygdaloidal basalt flows and pyroclastic surge deposits to the east (described above), and is intercalated with mafic to intermediate lavas and tuffs along strike to the northeast. A younger(?) rhyolitic unit to the northwest, on the other side of Botel Lake, extends northwards towards the Cretaceous unconformity (Figure 2).

The Nose Peak rhyolite is fairly typical of other Bonanza rhyolites. It constitutes a viscous flow-dome complex in which the amount of felsic pyroclastic material is relatively minor. This unit appears to reach a maximum thickness of about 2 kilometres in shoreline outcrops south of Nose Peak. Judging from the predominance of flow material and lack of pillows or hyaloclastite debris, the complex is believed to have been extruded subaerially. The lavas weather shades of grey, cream and pink and are strongly hematitic in places. The rock is generally aphanitic but may contain up to several percent euhedral feldspar phenocrysts (<2 mm). Millimetre-scale viscous flow laminations are usually strongly developed and intra-flow pumiceous layers up to 1 metre thick may also be preserved. Rare mafic to intermediate dikes are observed in coastal exposures.

Rhyolites north of Botel Lake appear to consist almost entirely of subaerial flows that are variably altered (discussed later). Minor flow breccias are best observed on weathered surfaces. The fresher rocks are grey aphanitic rhyolite or rhyodacite with distinctive platy jointing parallel to flow laminations; the latter locally delineate mesoscopic viscous flow folds. Rarely, euhedral plagioclase phenocrysts (up to 1 cm long by 2 mm wide) with hiatal textures form up to about 5 % of the rock.

A distinctive dacitic to rhyolitic flow-dome complex is well exposed on the northern and western parts of Drake Island where it is cut by a high-angle easterly trending fault (Figure 2). The complex overlies a westerly dipping succession of basalt(?) Jurassic sedimentary and volcanic strata (described previously). Thinly bedded to massive waterlain(?) tuffs at the base of the complex appear to rest conformably on impure limestones and fine-grained marine clastics. The tuffs are overlain by felsic flows and flow breccias, which form the main mass of the complex, and lesser volumes of volcanic breccias composed of accumulations of moderately sorted, lapilli to block-size angular clasts. The latter deposits appear to have irregular depositional contacts and may represent talus aprons of hyaloclastite debris formed during extrusion of felsic flows into shallow seawater; no pillows were observed. The uppermost parts of the complex exposed on the western shores of Drake Island contain laharic breccias and a densely welded ash-flow tuff that was deposited subaerially. The Drake Island flow-dome complex, therefore, appears to be an example of the emplacement of silicic lavas and pyroclastic deposits essentially at sea level in Early Jurassic time.

CRETACEOUS STRATA

LONGARM FORMATION EQUIVALENTS

Sandstones of the Longarm Formation are exposed at

Photo 5. Thinly bedded surge deposits overlain by high-energy, diffusely bedded, coarse pyroclastic flow deposits containing angular basaltic lapilli and bomb fragments. East shore of Foreward Inlet.

Photo 6. Bomb sag in basaltic pyroclastic (base) surge deposits exposed on the south shore of Raft Cove. Pencil magnet shows bomb trajectory.

Photo 7. Basaltic pillow breccia with palagonitized pillow rims and hyaloclastite matrix, north shore of Quatsino Sound.

Photo 8. Typical Blumberg Formation cobble conglomerate with well rounded plutonic clasts, approximately 10 kilome res north of Winter Harbour near Moore Lake.

five localities within the map area: north and east of Winter Harbour; northwest of Koprino Harbour; north of Holberg; and at Grant Bay and Raft Cove. At all of these localities, the rocks are arkosic to lithic wackes and arenites, and are typically fossiliferous. Coquinas within this unit commonly include the Early Cretaceous (late Valanginian) bivalve *Buchia crassicollis* (Jeletzky, 1976; Muller *et al.*, 1974; Haggart and Tipper, 1994). The distribution of this unit is largely confined to individual fault blocks, and deposition may have been partly controlled by grabens. East of Winter Harbour, this sandstone lies with angular unconformity on Bonanza Group volcanic rocks (Haggart and Tipper, 1994). Elsewhere, however, contacts between these lithologies are defined by high-angle faults, many of which were active after deposition of the youngest Cretaceous strata.

BLUMBERG FORMATION

Extensive outcrops of conglomerate and lesser sandstone and shale of the Blumberg Formation (Jeletzky, 1976) are found north and west of Quatsino, and north of Winter Harbour (Figure 2). The conglomerates contain abundant well rounded clasts of plutonic rocks believed to represent Coast Mountain intrusions (Jeletzky, *ibid.*; Photo 8).

Between Quatsino and Koprino Harbour, the Blumberg Formation has an estimated thickness of the order of 600 metres (Haggart and Tipper, 1994). Haggart and Tipper interpret these rocks as a prograding submarine fan-delta complex of post-Cenomanian age, rather than Albian as inferred by Jeletzky, and correlate these strata with the Honna Formation of the Queen Charlotte Group.

Blumberg Formation conglomerates and sandstones also occur in a fault-bounded block north of Winter Harbour (Figure 2). Previous work by Jeletzky (1976) placed Cretaceous sandstones exposed at shoreline and in creek beds in a 'coarse arenite unit' which he considered to be Aptian in age, and so underlie the Blumberg Formation. This package is dominated by northeasterly dipping arkosic to lithic wackes with minor tongues of conglomerate. In the vicinity of Moore Lake, however, these sandstones are observed to gradationally overlie a thick succession of Blumberg Formation conglomerates. This upward fining sequence is consistent with that described for the Honna Formation in the Queen Charlotte (Haggart, 1986). The sandstone unit is primarily massive at its basal contact with the conglomerates, and medium to thinly bedded in its upper part. The top of the sandstone unit was not observed, nor was the base of the conglomerate. These sandstones may in part represent a finer grained, distal equivalent to the conglomerates of the thick fan-delta complex west of Quatsino (Haggart and Tipper, 1994).

ISLAND PLUTONIC SUITE: MOUNT BRANDES PORPHYRY

A previously unmapped member of the Island Plutonic Suite, here named the Mount Brandes porphyry, forms some of the highest and most rugged terrain in the map area. The body underlies the area south of Mount Brandes and extends northwesterly beyond the radar facility (Radome), a distance of at least 6 kilometres (Figure 2). The maximum width of the body is about 1.5 kilometres, and it is flanked by mafic to intermediate flows and tuffaceous rocks of the Bonanza Group. Soils overlying this intrusion are a distinctive orange-brown.

The Mount Brandes porphyry contains euhedral phenocrysts of pinkish feldspar (plagioclase?) and lesser hornblende set in a greyish brown fine-grained groundmass. The bulk composition is probably monzonitic. The buff to orange-brown weathering rock is partially to extensively altered to clay minerals and locally propylitized. Feldspars are altered pink to pale green and amphibole is extensively chloritized. Trace amounts of pyrite are found locally.

TERTIARY LAVAS AND DIKES

Outcrops of Tertiary rhyolitic lavas were discovered approximately 5 kilometres north of Koprino Harbour (Figure 2). The lavas form pale grey to cream-weathering crags just south of the headwaters of the Koprino River. Although eroded by glaciers, the remnants of two small viscous flow lobes with steep lateral levees may be identified. The flows travelled south a maximum distance of about 1.3 kilometres from concealed vents at their northern margin. Outcrops of lateral flow levees locally reveal metre-scale interlayering of black, dense devitrified obsidian and buff rhyolite that dip inward away from the margin. The obsidian preserves flow laminations and small-scale flow folds; flow laminations in the rhyolite are generally inconspicuous. Some rhyolite joint surfaces exhibit well developed striae caused by differential movement of adjacent joint blocks during emplacement (Photo 9). The rhyolite contains several percent euhedral feldspar phenocrysts (<5 mm) and trace hornblende(?). A weak flow foliation is enhanced locally by limonite, clay and chlorite-filled vesicles. The presence of obsidian, albeit devitrified, distinguishes these Tertiary rhyolites from their Jurassic counterparts, which typically exhibit a strong flow lamination.

Tertiary dikes occur throughout the map area. They are observed to cut Triassic, Jurassic and Cretaceous lithologies. Practically all of these dikes are felsic, in sharp contrast to the Mahatta Creek map sheet further south where the majority of the dikes are mafic (Nixon *et al.*, 1993a). Locally, the dikes take advantage of pre-existing major fault zones. For example, a large anastomizing rhyolitic dike or dike swarm follows the shore of Browning Inlet for some 5 kilometres parallel to the submerged trace of the San-Josef - Browning fault

Photo 9. Joint surface in Tertiary rhyolite flow showing well developed striae generated by differential movement of lava blocks during flowage.

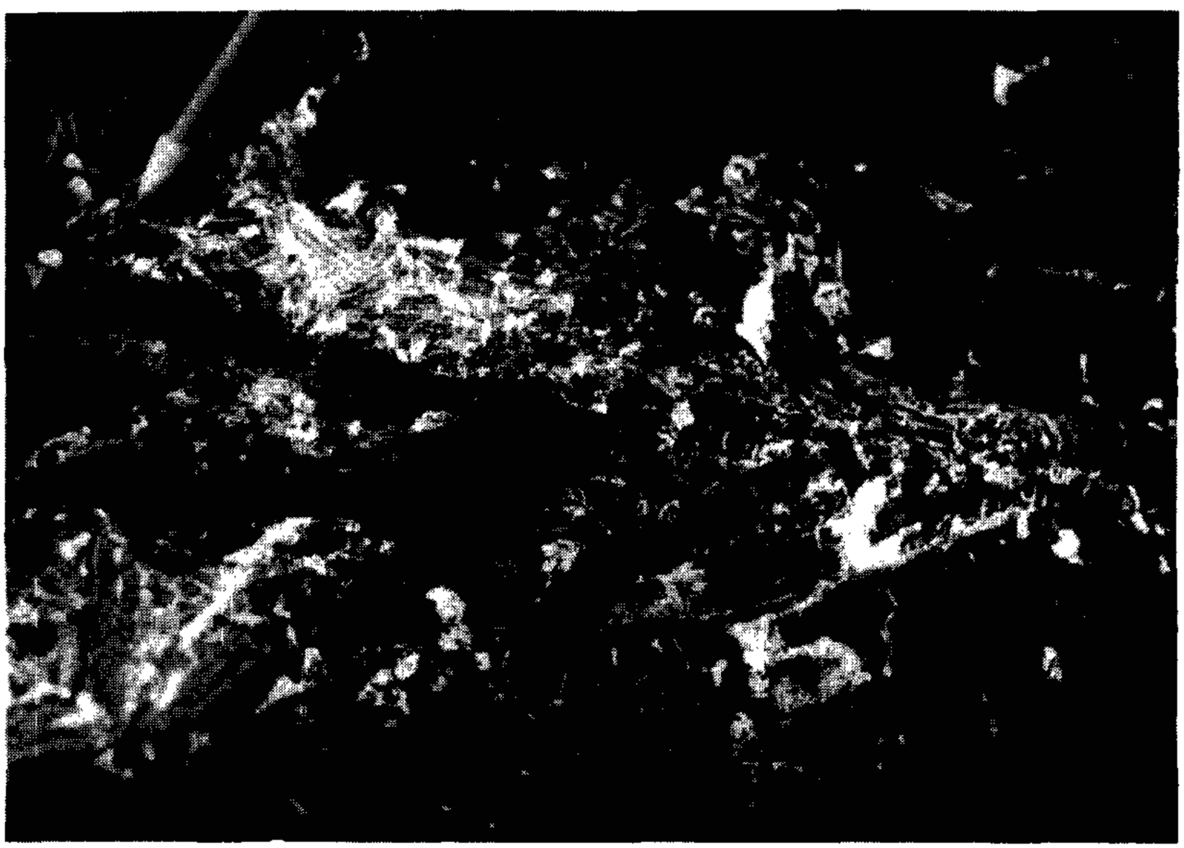

Photo 10. Mesoscopic isoclinal folds in intra-Bonanza calcareous shale approximately 3 kilometres west of Koprino Harbour.

(Figure 2). Jeletsky (1976) previously included this dike with the Island Plutonic Suite (formerly "Coast Intrusions"). Farther north, another Tertiary felsic dike exposed in roadcuts over a distance of some 3 kilometres trends due south away from the same fault zone. Like the lavas described above, felsic dikes are typically aphanitic to weakly porphyritic with euhedral plagioclase phenocrysts (<6 mm) set in a finely crystalline, variably clay-altered groundmass. Angular to subrounded xenoliths of devitrified black obsidian are locally concentrated in the southernmost outcrops of the Browning Inlet dike on the shoreline southwest of Mathews Island.

STRUCTURE

Three phases of deformation have been identified in the rocks of the Quatsino Sound area: a pre-Cretaceous deformation, supported by the presence of an angular unconformity below the base of the Cretaceous clastic succession; Late Cretaceous to Tertiary transpression; and Tertiary extension. Faulting appears to have been an important strain-release mechanism throughout all of these deformational episodes. A more detailed discussion of the structural history may be found in Nixon *et al.* (1993a).

PRE-CRETACEOUS UNCONFORMITY

An angular unconformity is apparent from map relations between the Triassic-Jurassic (Bonanza Group and older) and Cretaceous strata (Longarm Formation equivalents and younger). This unconformity is exposed in Michelson Creek approximately 3 kilometres northwest of Mount Byng. Here, gently dipping Blumberg conglomerates rest with marked angular discordance on moderately dipping thinly bedded sediments of the Parson Bay Formation. At present, it is not clear whether this deformation was the result of rotation of strata during block-faulting or a compressional event.

LATE CRETACEOUS TO EARLY TERTIARY TRANSPRESSION

Pre-Cretaceous deformation was followed by northerly to northeasterly directed transpression which postdates deposition of the Late Cretaceous Blumberg Formation, but certainly predates Tertiary intrusive and extrusive activity. During this deformational episode, strain was largely accommodated along prominent northwesterly trending faults, at least some of which have oblique right-lateral motion (Nixon *et al.*, 1993a). A significant amount of movement may have occurred on the Holberg fault during this phase of deformation (Nixon *et al.*, 1994). Northeasterly trending antithetic faults are also common and tend to exhibit a left-lateral, northwest-up sense of displacement. Minor northwesterly trending thrust faults with a south-up sense of motion have been recognized locally (due west of fossil locality F in Figure 2). Substantial strain has been accommodated by flexural slip folding and bedding parallel shear of well bedded sedimentary strata of the Parson Bay Formation and Bonanza Group, resulting in local tectonic thickening of these units (Photo 10). Folding is particularly evident near the major faults.

TERTIARY EXTENSION

Many northeasterly to east-northeasterly trending normal faults in the area were formed in the Tertiary during extension of the Queen Charlotte Basin (Riddihough and Hyndman, 1991). The southern limit of this extensional province appears to be marked by the northeasterly trending Brooks Peninsula fault zone (Figure 1) which is coincident with felsic to mafic Tertiary dike swarms (Nixon *et al.*, 1993a). Tertiary extension is less obvious in the Quatsino - San Josef map area than further south. Tertiary dikes that intrude fault zones are mainly felsic, and some of the longest dikes were emplaced along northerly or northwesterly striking faults.

MINERAL POTENTIAL

The recently released mineral potential assessment of Vancouver Island rated the Quatsino - San Josef area highly in terms of its peceived potential for undiscovered mineral deposits (Massey, 1995, this volume). However, the extent of alteration and mineralization found in outcrop renders the map area less appealing than ground east of Holberg Inlet. The apparent paucity of intrusions of the Island Plutonic Suite may be a key factor.

The most widespread alteration is associated with rhyolitic and basaltic lavas and dikes exposed on ridges north of Botel Lake. The alteration appears to be centred on a north-northeasterly striking rhyolitic flow unit. The rocks are pastel shades of red, yellow and green and have a weakly developed clay and iron oxide dominated alteration assemblage containing minor pyrite, hematite, epidote, quartz, pale blue-green ?celadonite, and rare native sulphur. Irregular vuggy quartz-rich zones and stringers, textures suggestive of acid leaching, are found locally. However, neither the mineral assemblage nor the textures are as diagnostic of acid sulphate alteration as those associated with rhyolitic stratigraphy north of Holberg Inlet at Mount McIntosh and in the Pemberton Hills (Panteleyev and Koyanagi, 1994; Nixon *et al.*, 1994). Instead, this weak argillic-oxide overprint may reflect low-temperature solfataric activity. Whatever its origin, it does appear to be spatially related to its rhyolitic host.

The west coast of Vancouver Island north of the Brooks Peninsula contains some of the most pronounced mercury anomalies in the province. The highest reported mercury concentrations occur in stream sediments, sampled as part of the Regional Geochemical Survey, that come from tributaries of the Macjack River which flows into Raft Cove (Figure 2). Sibbick and Laurus (1995) conducted further sampling and were able to reproduce these anomalies. Although there appears to be an overall relationship between the trend of the general belt of mercury anomalies and major northwesterly striking faults, the source of the mercury at the Macjack occurrences remains to be satisfactorily explained.

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NOTES

INTEGRATED DRIFT EXPLORATION STUDIES ON NORTHERN VANCOUVER ISLAND (92L)

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KEYWORDS: Biogeochemistry, borehole logging, density, drift exploration, electromagnetics, gravity, magnetics, till geochemistry, Quaternary, surficial geology

INTRODUCTION

Recent geoscience research by the British Columbia Geological Survey Branch (BCGS) on northern Vancouver Island has examined parts or all of map sheets 92L/5, 6(W), 11(W), 12 and 102I/9 (Figure 1). The objectives and results of these integrated have been well summarized (Panteleyev *et al.*, 1994) and detailed in a series of discipline specific publications (*e.g.* Nixon *et al.*, 1994; Sibbick and Laurus, 1995, this volume). With respect to the drift exploration program, studies to date have concentrated on the collection of till geochemistry data and generation of newsurficial geology maps at a scale of 1:50 000 (Huntley and Bobrowsky, 1995, this volume). In addition, cooperative drift exploration studies were begun in 1994, involving federal and university scientists. This paper provides an outline of the activities and preliminary results of the geophysical and drilling surveys completed this year at several locations in the larger study area (Figure 2).

The broader intent of the cooperative research centres on developing and testing techniques which will assist mineral explorationists in dealing with a complex overburden cover. A number of widely used methods were focused on three target areas to address the following objectives:

- Develop, contrast and evaluate techniques for determining overburden thickness.
- Establish and refine methodologies for interpreting the stratigraphy and sedimentology of buried unconsolidated sediments.
- Explore and assess the potential for utilizing geophysical and geochemical techniques in the recognition and identification of buried bedrock.

The methods of subsurface evaluation used for this cooperative study include mud rotary drilling, flight auger drilling, gravity surveying, magnetometer surveying, electromagnetic (EM) surveying, seismic profiling, till geochemistry and biogeochemistry.

Several criteria support the selection of the three study sites chosen. Site 1 (Rupert Main) is an area known to be covered by a thick blanket of unconsolidated sediment (Figures 2 and 3). This site was viewed as the best to establish methods for evaluating drift thickness. The subdued, low-relief topography and recently logged surface were important factors in the application of geophysical techniques such as EM. Existing diamond-drillhole data ensured selection of a thick section for our drilling. The potential for encountering exceptionally thick overburden (215 m; Bobrowsky and Meldrum, 1994) would result in the longest stratigraphic record ever recovered in the region. The area is of potential economic interest, although little is known of the bedrock geology because of the thick and extensive surficial cover. Finally, the eastward extension of the Holberg fault runs through this area. Given the above, four transect legs were laid out in site 1 (Figure 3). Site 2 (View Point road) is a well mapped region (1:2400-scale bedrock data), where diamond drilling data are extensive and overburden is relatively thin and of constant thickness (Figures 4 and 5). The site was chosen for the purpose of developing interpretive methods for recognizing changes in bedrock. Orientation of bedrock units oblique to paleo-iceflow is important in our study of glacial dispersion models. A single long transect paralleling paleo-iceflow was surveyed. Site 3 (Red Dog) is an area of high mineral exploration interest (Figure 6). Little is known of the unconsolidated cover or the underlying bedrock geology. This area provides a test case for the techniques refined at the other two sites. A

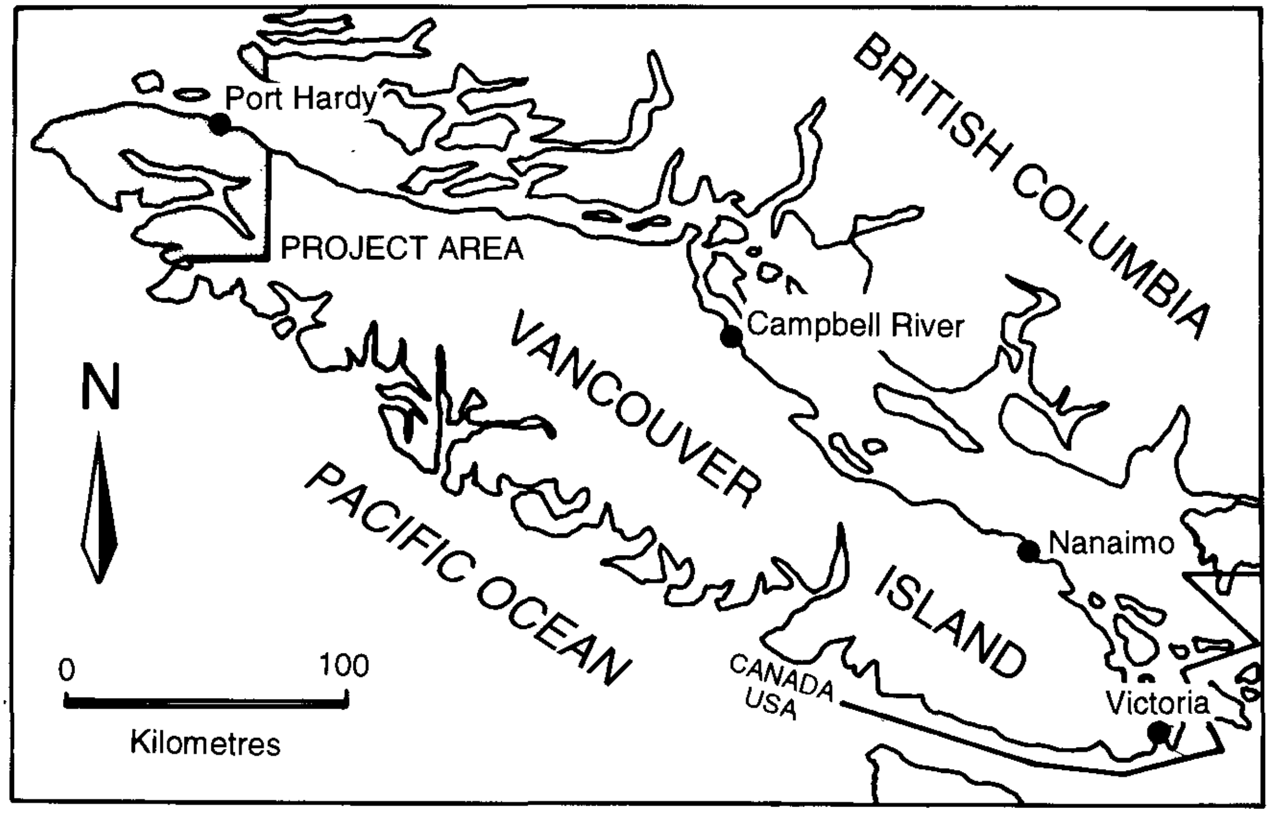

Figure 1. Integrated base metal exploration study area on northern Vancouver Island.

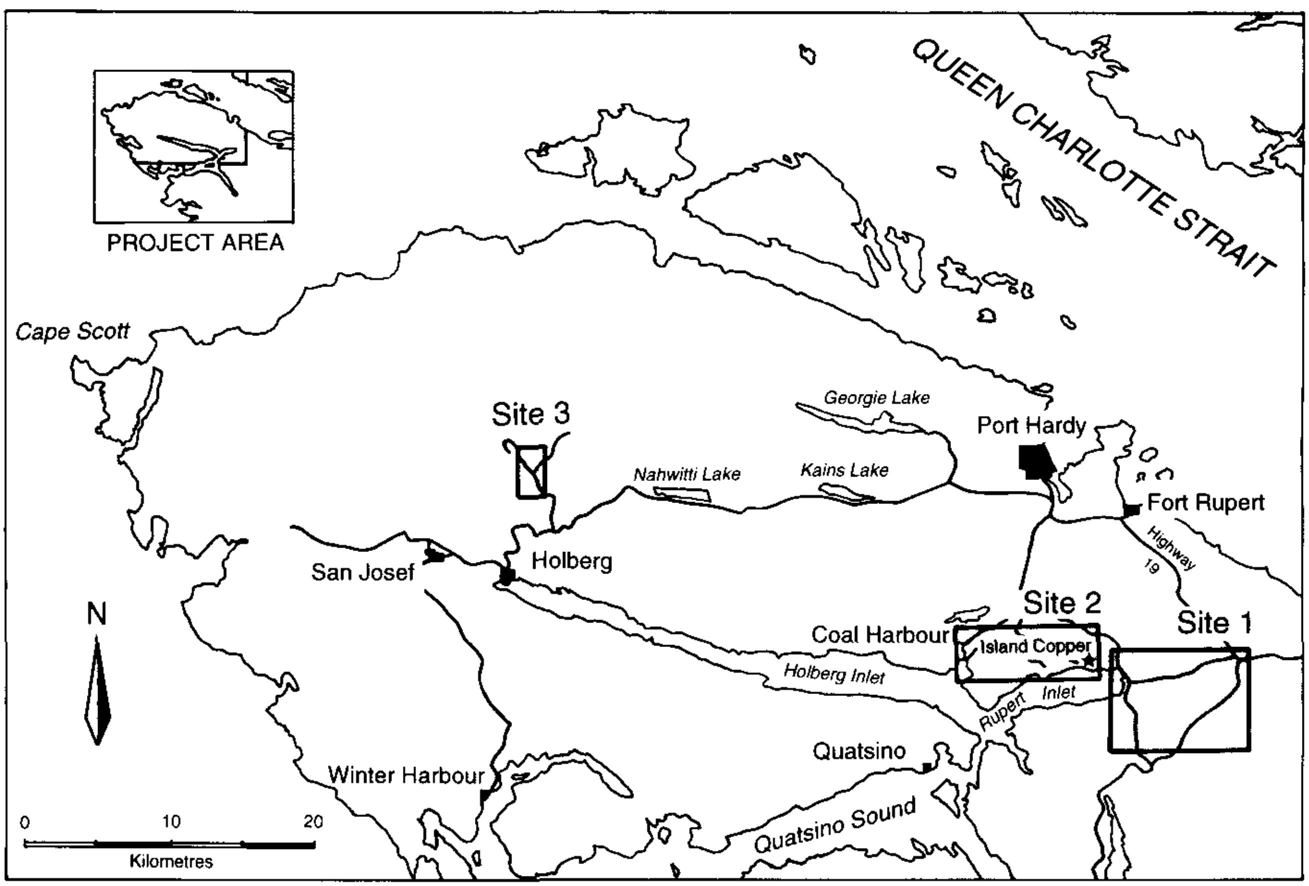

Figure 2 Cooperative BCGS-GSC drift exploration program study sites on northern Vancouver Island.

single transect was established in the area because of limited access. This example potentially allows us to evaluate methods of determining sediment thickness, composition and bedrock lithology.

SUBSURFACE PROGRAM

DRILLING RESEARCH

Drilling was carried out using a Mobile B-53 drill rig mounted on an International truck, owned and operated by Simon Fraser University (Photo 1). Mud rotary drilling was used to establish depth to bedrock and subsurface stratigraphy at Rupert Main (site 1, leg 1), whereas hollow-stem flight augering was used along View Point road (site 2) to obtain subsurface till samples for geochemical analysis (Table 1).

Mud rotary drilling was completed at a single location (NVI94-DH01) at site 1, leg 1 (Figure 3). The rig was positioned on a forestry spur road abutting a small lake to ensure a continuous water supply. A commercially available bentonite mud (Quick Gel™) in the ratio of about 10 kilograms per 400 litres of water was used as the drilling mud after propellor mixing to obtain the appropriate mud-water emulsion The drill hole

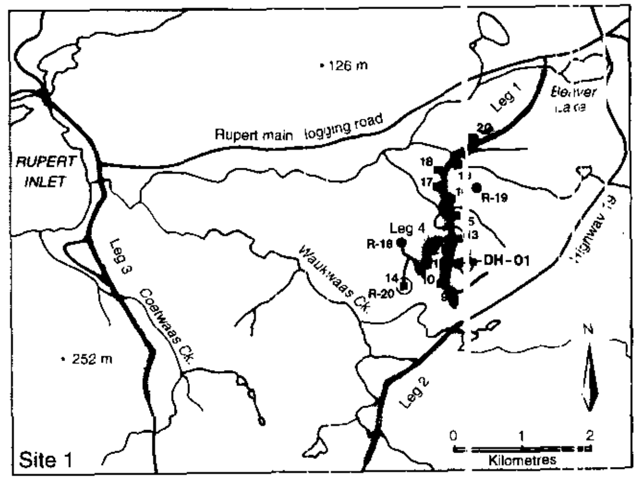

Figure 3. Detail of site 1 (Rupert Main) study area. Four transects numbered as legs 1 to 4; EM locations shown as numbered squares (*e.g.* ■ 5); BHP diamond-drill hole locations shown as numbered circles (*e.g.* • R-19); rotary and flight auger boreholes shown as numbered circles (*e.g.* • DH-01; • 4); spot elevations given as small dots (*e.g.* • 560 m). This key is consistent for figures 4, 5 and 6).

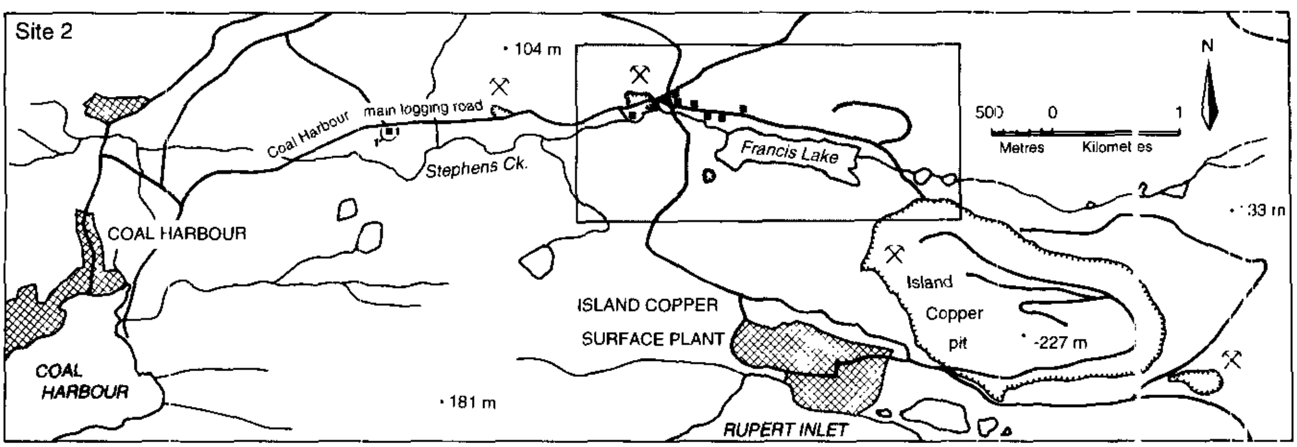

Figure 4. Location map of site 2 study area (View Point road). See Figure 2 for location. See Figure 3 for legend.

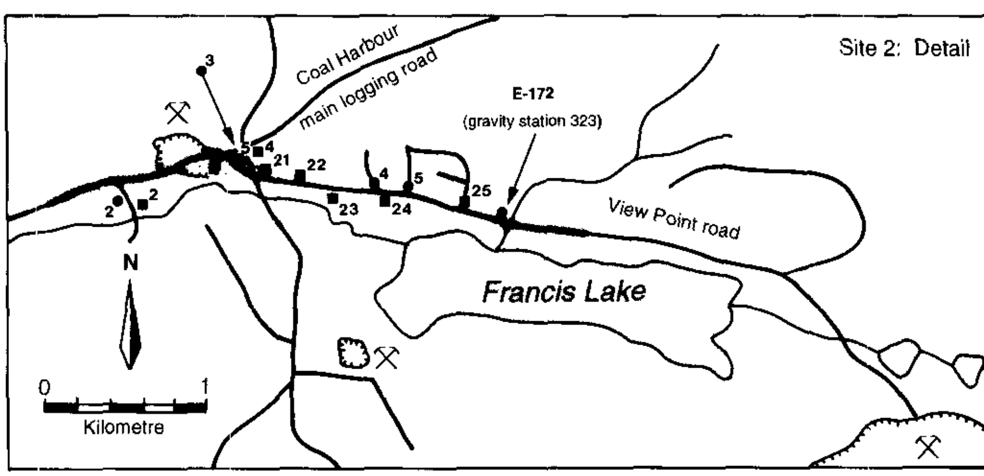

Figure 5. Detail of site 2 (View Point road). See Figure 4 for location. See Figure3 for legend.

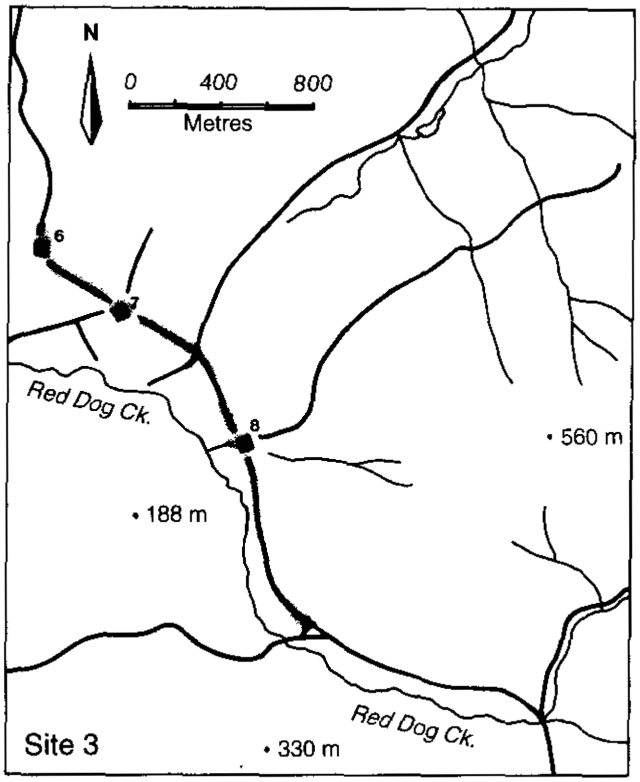

Figure 6. Detail of site 3 (Red Dog). See Figure 2 for location. See Figure 3 for legend.

was cased for 3 metres through the constructed road bed and partly into till after which a 10 centimetre tricone bit was advanced on a BW drill string. Core cuttings were constantly monitored and Shelby tube samples were occasionally obtained using a 70 kilogram drill mounted hammer. The drilling rate was routinely documented every 1.5 metres to provide indirect information on the various subsurface deposits.

An Acker 19-centimetre hollow-stem flight auger was used for drilling where rapid stratigraphic evaluation of the Quaternary surficial deposits and subsurface till geochemistry samples were needed. The flight auger apparatus proved ideal for quick geochemical sampling because the sediment attached to the auger corresponds to its original subsurface position. Contamination of the samples is minimized using this technique by removing the outer sediment surface when the auger is pulled. This method also avoids the use of drilling mud needed in conventional rotary drilling. Operational problems with the auger included large rock fragments in the upper road-fill which slowed initial drilling rates.

BOREHOLE LOGGING

Subsurface geophysical logging of boreholes was accomplished using a portable Mount Sopris 1000-C 300 logger (Photo 1). The 1000-C logger is equipped with metres of 2.5 millimetre steel-armoured cable with a tensile strength of 1000 pound (4.45 kilonewtons); such a strength is critical when a logging tool is trapped by lateral sediment squeezing which is common in Quaternary deposits The logging tool used for this project was a 41 millimetre (outer diameter) combination probe (HLP-2375/S) capable of recording the following properties: natural gamma radiation, spontaneous potential (SP) and resistance (R). All three characteristics were measured in uncased holes, whereas only natural gamma data were acquired for cased holes (whether steel or plastic).

Borehole geophysical logging was run in flight auger holes drilled at site 2 (Figure 4), and in the existing holes drilled by BHP Minerals Canada Limited as part of its exploration program at sites 1 and 2. Logging was extended into bedrock at BHP hole E-172 (Figure 5) to provide a background signature of the gamma signal in Bonanza volcanics which will provide a baseline for the interpretation of the Quaternary sediment signatures (*cf.* Asquith, 1982; Dewan, 1983; Serra, 1985).

SUBSURFACE RESULTS

Mud rotary hole NVI94-DH01 at site 1 (Figure 3) was drilled to a depth of 72 metres. Drilling terminated at this depth when the drill bit sheared from the rod as it penetrated compact sediments. Nonetheless, a variety of glacial sediments were described and sampled to this depth. A total of five auger holes were drilled along an east-west transect at site 2 (Figure 5). Average depth of drilling for the five holes was 3.7 metres and thirteen till samples were retrieved. Augering was restricted to locations with basal till to further the local till geochemistry survey (see below).

Exceptional results were obtained from the borehole geophysical logging. Figure 7 shows the gamma log for BHP hole R-19. This figure shows a stable signature for the lowermost 5 metres which represents compact, massive matrix-supported diamicton (lodgment till) overlying bedrock at 7.5 metres. At approximately 2.5 metres below ground surface the gamma signal weakens as it passes through loose, matrix-supported diamicton (ablation till) and weakens further from 1.5 to 1 metre when the upper soil horizon is measured. The strong signal for the topmost metre represents the artifical road fill consisting of crushed volcanic rock. This interpretation is verified from nearby surface exposures. BHP hole E-172 (corresponding to gravity station 323) displays a comparable record. From 14 to 6 metres below surface, the deposit most likely consists of stratified interbeds of sand and gravel (advance outwash). The upper 6 metres consists of upper soil horizons, lodgment till, ablation till and bedrock (Figure 8). The weaker road-bed signature at the top of the log reflects differences in road-fill at the two localities.

GRAVITY SURVEY

A total of 323 gravity measurements, at station intervals of 10 to 100 metres, were acquired at the three sites (Figure 2; Table 2). All stations were flagged to

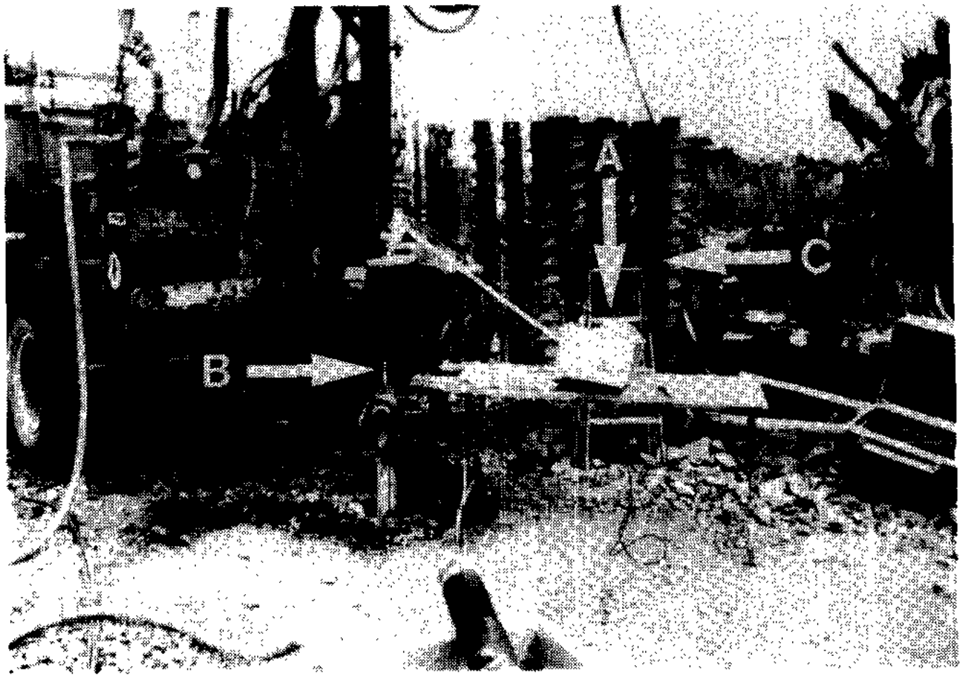

Photo 1. View of Mobile B-53 drill rig at site NVI94-DH01. Arrow A points to portable Mount Sopris 1000-C borehole logger. Arrow B points to 41-millimetre (outer diameter) combination probe at top of steel casing. Arrow C points to collection of 19-centimetre hollow-stem flight auger sections.

TABLE 1: DRILLING SUMMARY FOR NORTHERN VANCOUVER ISLAND

Drill hole number	Northing	Easting	Depth logged (m)	Casing	Gamma	SP	Resistivity
NVI94-FA01	5607450	603159	4.0	OPEN	-	-	-
NVI94-FA02	5607728	604753	2.7	OPEN	-	-	-
NVI94-FA03	5607852	605813	4.2	OPEN	-	-	-
NVI94-FA04	5607761	605426	2.7	OPEN	-	-	-
NVI94-FA05	5607743	605564	5.0	OPEN	-	-	-
NVI94-DH01[b]	5603791	617409	21.0	TOP 3 m	X	X	X
R-18[c]	5604240	616690	92.4	PVC	X	-	-
R-19	5605290	617850	7.5	OPEN	X	X	X
R-20	5603550	616500	38.8	OPEN	X	X	X
E-171[d]	5607939	605705	1.3	OPEN	X	-	-
E-172	5607689	605955	60.0	STEEL	X	-	-
E-175	5607875	605521	4.4	OPEN	X	-	-
E-176	5607763	607095	20.0	STEEL	X	-	-
E-178	5607674	606944	2.5	OPEN	X	-	-

a - flight auger holes by SFU
b - mud rotary drill hole by SFU
c - BHP diamond-drill hole
d - BHP diamond-drill hole

TABLE 2: GRAVITY AND MAGNETIC MEASUREMENTS FOR NORTHERN VANCOUVER ISLAND*

Site number	Leg number	Number of gravity stations	Number of magnetic stations	Station interval (m)	Profile length (km)
One	1	105	105	40	4.160
	2	31	-	100	3.000
	3	48	-	50	4.700
	4	15	15	50	0.700
Two	1	69	69	10-30	1.505
Three	1	55	-	40	2.160

* new gravity and magnetic measurements for 1994, see text for explanation.

using a LaCoste and Romber (model G) gravimeter. Daily surveying started and ended at a national gravity control station located in Port Hardy airport (station number 9275-67) near the study area. The maximum gravity closure error during the survey period was 0.074 milligal. Accuracy checks were performed by repeating gravity measurements at three stations. The mean gravity difference for repeat measurements was 0.15 milligal.

COORDINATE DATA

Two portable Trimble Pathfinder CA code global positioning data logging systems (GPS) were used to establish the latitude and longitude for 195 of the 323 gravity stations. Although this system is capable of providing station elevations, it is not sufficiently accurate for high-resolution gravity surveying. Station elevations were consequently determined using a Model D GDD electronic chain and level and altimetry. The coordinates of the remaining stations were determined by interpolation. To obtain the highest possible coordinate accuracy, the GPS receivers were operated in differential mode, that is, data were recorded simultaneously at the gravity station and at a temporary base station deployed in the area. All GPS data were then processed using the Pathfinder software package (P-Finder) supplied with the GPS system. Station latitudes and longitudes were typically located to within 5 metres.

Both electronic chain and level and a Paroscientific digital altimeter were used to provide greater control on station elevations. The chain and level apparatus provided very accurate relative height differences between stations along all traverses (vertical variation was typically less than a few centimetres). Absolute heights were subsequently calculated by running ties between the start of each traverse and the nearest geodetic bench mark.

GRAVITY RESULTS

Processing of the gravity data is in progress. Most of the measurements have been reduced to the International Gravity Standardization Net 1971 (Morelli, 1974) and theoretical gravity values calculated using the Geodetic Reference System 1967 gravity formula. Simple Bouguer anomalies have been calculated using standard density of 2670 kilograms per cubic metre, but terrain corrections have yet to be applied. Because the study sites are in low-relief terrain, it is anticipated that corrections will not be significant. Density determinations on both bedrock and drift samples will be undertaken in the near future and used to constrain quantitative gravity models.

Figure 9 shows the simple Bouguer anomaly along one traverse (leg 1) of the Rupert Main area (site 1). The anomaly reflects lateral density variations at all depths beneath the traverse including those related to topography on the bedrock surface. However, by ignoring the contribution of deep lateral density variations and assuming uniform composition of the unconsolidated sediments, this anomaly can be interpreted in terms of variations in overburden thickness. Briefly, for a north-south transect, the data suggest that drift thickness increases uniformly at distances between 0 and 1.8 kilometres, thins slightly over the distance 1.8 and 3.1 kilometres and then thickens significantly between 3.1 and 3.5 kilometres to the south. From this point onward, the overburden appears to thin appreciably.

MAGNETIC SURVEY

Total intensity field measurements were obtained at 189 stations along two traverses (legs 1 and 4) at Rupert Main (site 1) and the View Point road (site 2) using a portable Scintrex (model MP2) proton precession magnetometer (Table 2). The measurements

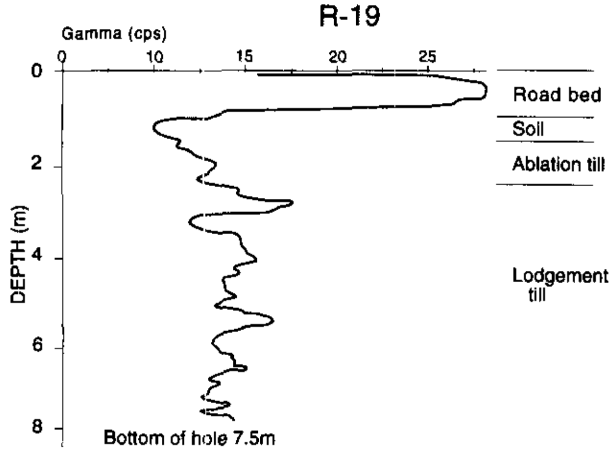

Figure 7. Gamma log through 7.5 metre BHP diamond-drill hole R-19 at site 1. See Figure 3 for location. See text for explanation

were made in the early fall during a period when predicted geomagnetic activity was very quiet (Figure 10). During magnetic storms, the magnetic field may vary by hundreds of nanoteslas over short time periods, thereby impeding magnetic surveying.

Representative samples of the bedrock and unconsolidated sediment were collected in the study sites. Samples will be analyzed to determine their magnetic susceptibility and the results will be used to constrain quantitative models of depth to basement.

MAGNETIC RESULTS

The raw data for leg 1 at site 1 (Rupert Main) show variations of several hundred nanoteslas (Figure 9). Assuming a simple two-layer model of non magnetic cover overlying magnetic basement, the data can be interpreted as suggesting: uniform drift thickness over the distance 0 to 1.7 kilometres, followed by an abrupt but short distance of sediment thinning (marked by gradients of more than 6 nanoteslas per metre), and a progressive thickening to the south with the exception of a 0.5 kilometre zone (2.8 to 3.3 kilometres) where overburden gradually thins. Magnetic measurements adjacent to the 1.7-kilometre magnetic anomaly spike, but off the traverse line suggest that the high values may be caused by a south-southeast-plunging body (fault or dike?) striking at around 340°. If this interpretation is correct and the shallowing of bedrock is in error, the interpretive models developed to determine overburden thickness are too simplistic in their starting assumptions and will be reevaluated.

ELECTROMAGNETIC SURVEY

The electromagnetic (EM) survey used a Geonics EM-47 (Protem) time-domain EM system in a central sounding mode; using a receiver at the centre of a square transmitter loop. The transmitter consisted of a

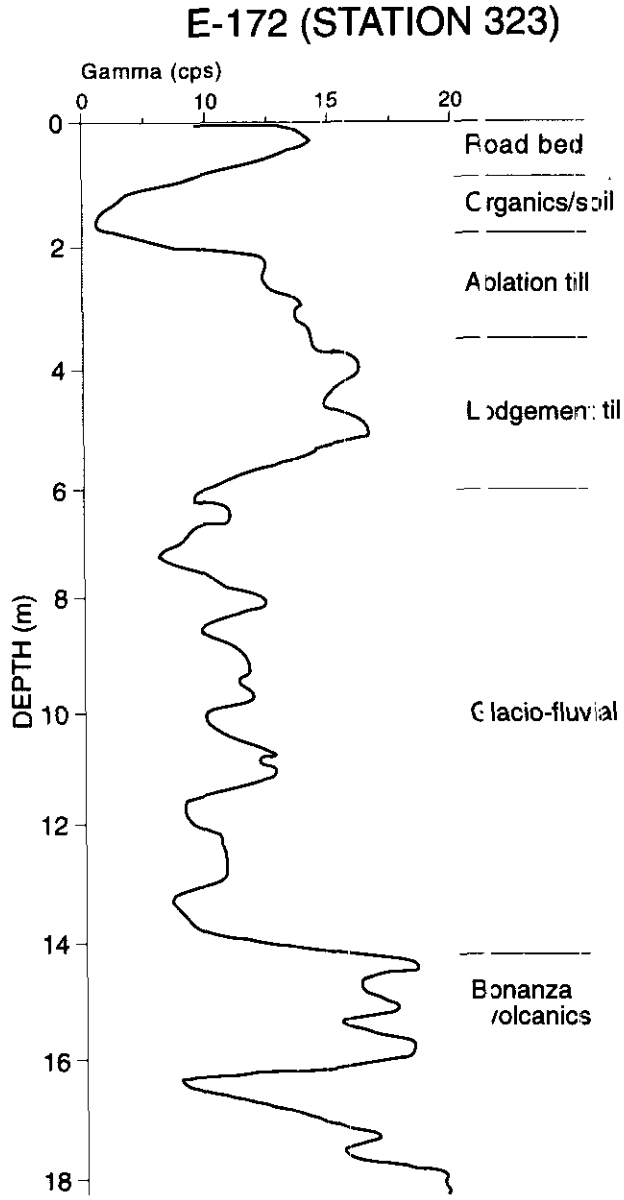

Figure 8. Gamma log showing upper 18 metres at BHP diamond-drill hole E-172 (gravity station 323 at site 2. See Figure 5 for location. See text for explanation.

arranged in the shape of a square loop with sides measuring 40 or 80 metres. The receiver coil was a multi-turn coil with a diameter of approximately 1 metre (coil area times the number of turns equal to 31.4 square metres). A reference cable was connected between the transmitter and receiver to control the timing of waveform transmission and voltage receipt

The transmitter current is an almost square wave with a sine-wave rise time and a linear ramp at the end of the square wave to turn off the current. The frequency of the square wave is defined as 1/T, where T is the period. The period consists of a positive square wave of duration T/4, followed by an off-time duration T/4. These are then reversed to give a total period of T.

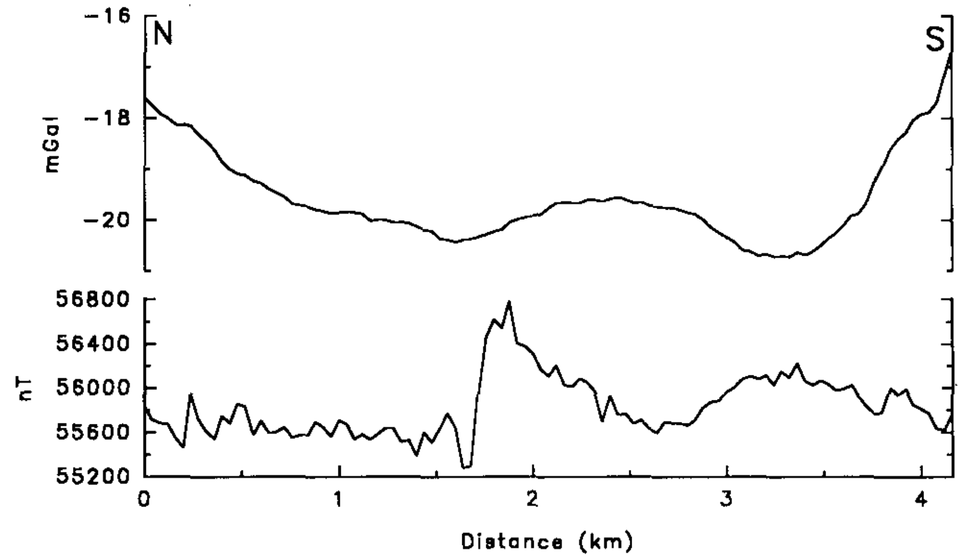

Figure 9. Rupert Main (site 1) leg 1 gravity and magnetic surveys. Upper diagram shows the Bouguer anomoly in milligal (mGal) and the lower diagram shows the magnetic anomaly in nanoteslas (nT). See text for details.

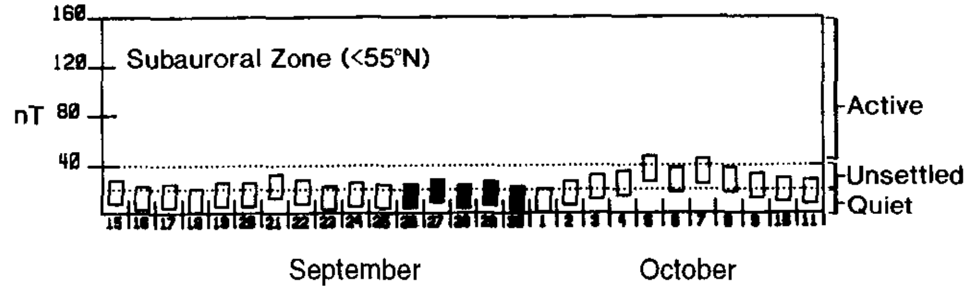

Figure 10. Predicted mean of geomagnetic activity levels for September 15 to October 11, 1994. As activity was forecast to be less than 20 nanoteslas (nT) for most of this period, it proved an ideal time for magnetic surveying.

The three frequencies associated with the EM-47 system are UH = ultra high frequency (285 Hz), VH = very high frequency (75 Hz) and H = high frequency (30 Hz).

The voltage measured by the EM-47 unit is measured in millivolts but is displayed as nanovolts per amp-metre squared (dipole moment) when plotted as a log-log function of time using TEMIXGL software from Interpex Limited, Golden, Colorado. The receiver voltage is measured in twenty time windows for each of the three frequencies. Times range from 6 microseconds to 7 milliseconds, with UH times from 6.85 microseconds to 701 microseconds, VH times from 48.3 microseconds to 2.825 milliseconds and H time from 100 microseconds to 704 milliseconds. The receiver voltage is sampled logarithmically in time. Each measurement is averaged over a time window and the time at the centre of the averaging window is defined to be the time for that window. The windows increase at longer times because the voltages are usually smaller.

The voltages are converted to apparent resistivity values using late-time normalized voltages (Fitterman and Stewart, 1986). The apparent resistivity is defined to be the ratio of the measured voltage to the voltage that would be measured over a half-space of constant resistivity. Once the apparent resistivity versus time curves are computed, the data can be interpreted in terms of multi-layered earth models using standard forward and inverse mathematical modelling programs. A number of assumptions are required to ensure the data can be meaningfully represented by a layered earth model. We used the TEMIXGL software package for modelling the data from the study area.

EM RESULTS

Edited log-log resistivity plots for two soundings obtained from site 1 (gravity stations 90 and 50) are shown in Figures 11 and 12. Solid lines reflect the apparent resistivity curves computed for the layered earth models shown in the figures. The squares, triangles and plus signs are the measured values of apparent resistivity. Note that sounding depths for overburden vary from approximately 23 metres at station 50 to 226 metres at station 90. Both models were obtained using the interactive graphics and inversion modes of the TEMIXGL software. Three iterations were required for the inversions to provide fitting errors of 7.7% and 13.4% for soundings 90 and 50, respectively.

The simple one-layer overburden interpretation for station 50 confirms airphoto interpretation and ground truthing observation for a shallow sediment cover in this area. Overburden at this location, 2 kilometres south along leg 1, consists of stratified sand, gravel and ablation till. In contrast, the data from station 90 suggest

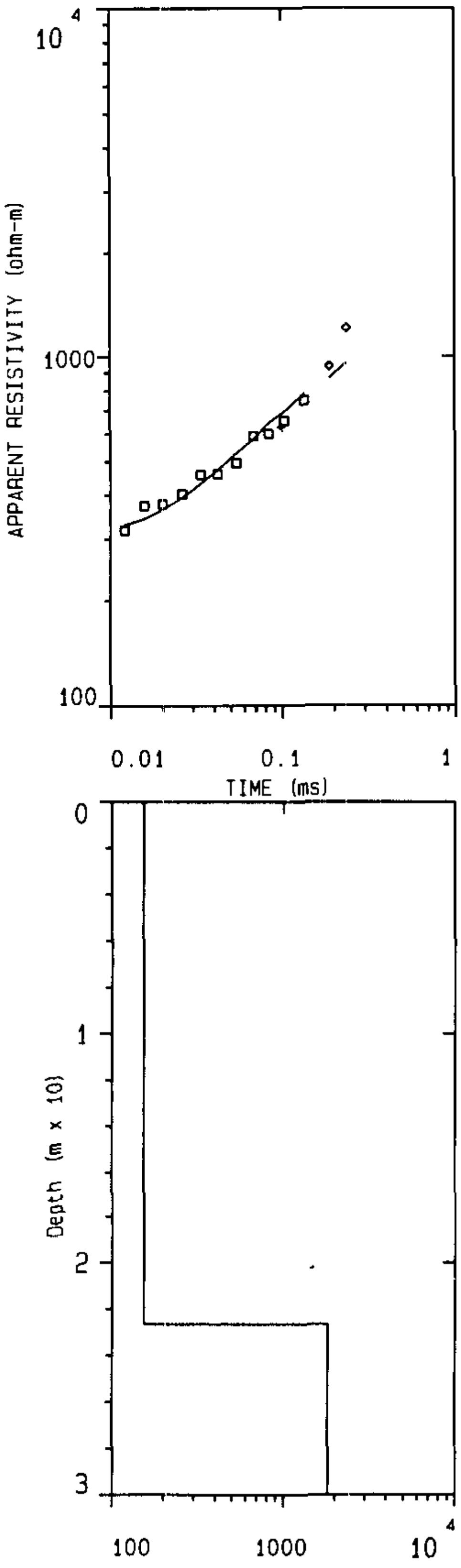

Figure 11. Electromagnetic survey at gravity station 50 (site 1). See Figure 3 for location. Top illustration shows apparent resistivity results in ohm-metres (ohm-m), whereas lower illustration shows stratigraphic interpretation. See text for details.

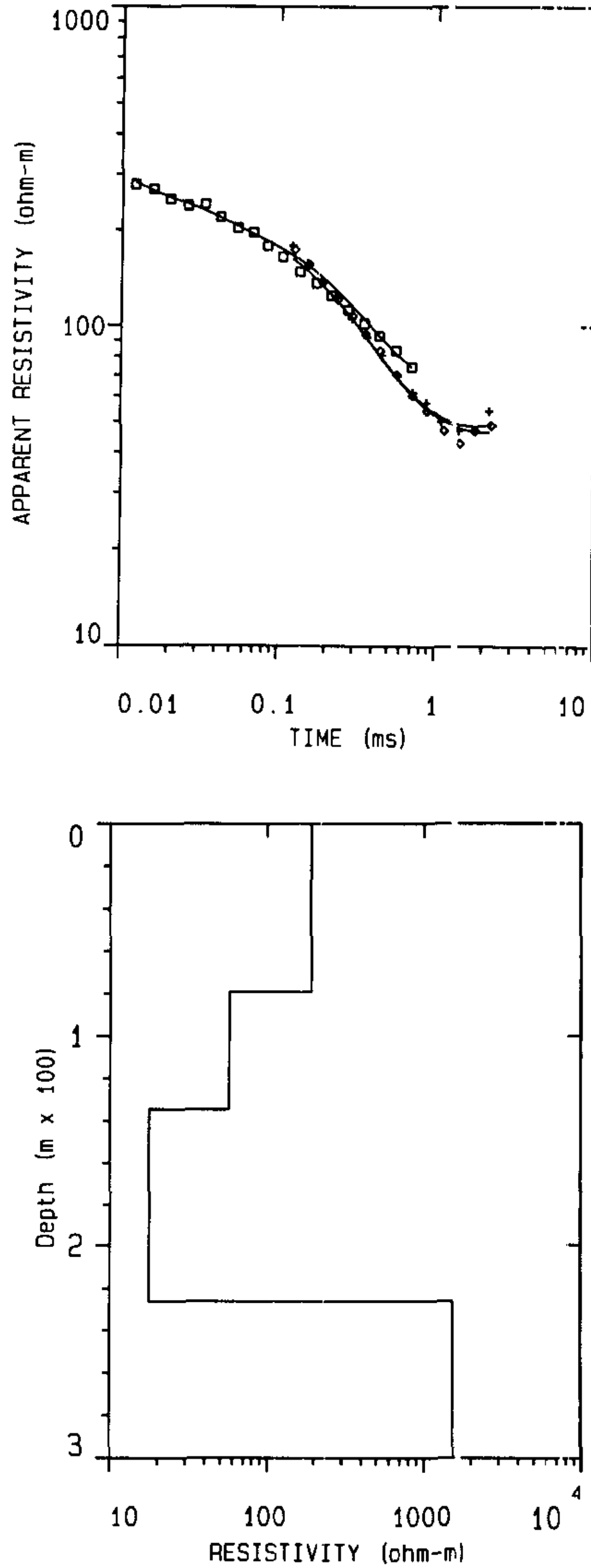

Figure 12. Electromagnetic survey at gravity station 90 (site 1). See Figure 3 for location. Top illustration shows apparent resistivity results in ohm-metres (ohm-m) whereas lower illustration shows stratigraphic interpretation. See text for details.

a sediment cover consisting of at least three distinct types of deposit. The resistivity of the upper 75 metres compares favourably with the sediment suite (drift) observed at station 50 and may also consist of sand/gravel and ablation till. At station 90, the resistivity interpretation indicates two other sediment complexes underlie the deglacial deposits. Bedrock was easily recognized by the EM-47 system at this significant depth (226 metres) only because of the large conductivity contrast of the conductive layer 80 metres thick (17 ohm-metre), directly overlying bedrock. Interpretation of the 150 metres of unconsolidated sediment over bedrock requires additional data analysis, including drill-hole logs and down-hole geophysical logs.

TILL GEOCHEMISTRY SURVEY

A detailed till geochemistry survey was undertaken at site 2 to complement the modelling and technique development component of the drift exploration program (Photo 2). The area was selected on the basis of detailed 1:2400-scale bedrock geology map data verified by diamond drilling. There is lithologically and mineralogically distinct bedrock striking around 180°; documented local and regional glacial paleo-iceflow perpendicular to the bedrock strike; good subsurface exposure of till along new road-cuts and at flight auger drilling stations; and proximity to a defined mineralized zone.

Bulk sediment samples (1 to 5 kilograms) of both oxidized and unoxidized basal till were collected along vertical profiles (Photo 2) and from five flight auger holes (Figures 4 and 5). Sample locations represent a fan-shaped transect which parallels documented paleo-ice-flow with sites up-ice and down-ice from mineralization. This study will be used to define glacial dispersal from the mineralized zone and the subsequent effect of soil formation on the geochemistry of the sediments. Representative splits of the +63-micron fraction samples will be submitted for aqua regia-extraction and inductively coupled plasma emission spectroscopy (ICP-ES) and instrumental neutron activation (INA) analysis.

BIOGEOCHEMISTRY SURVEY

Sampling undertaken will evaluate the effectiveness of biogeochemistry as an exploration tool in the northern Vancouver Island region. Studies in other regions have demonstrated that trees absorb and accumulate metals in their tissues, and by analyzing appropriate parts of trees it is possible to define areas of relative metal enrichment that may assist in locating zones of concealed mineralization.

A total of 248 samples were collected from 176 sites within a 10 by 50 kilometre east-west corridor on the north shore of Rupert Inlet, extending from Red Dog

Photo 2. View of till geochemistry survey station PTB94-105 near site 2. Eight till samples were taken down a 3.7 metre trenched face

(Figures 2 and 6), to east of the Island Copper mine (Figure 2). Detailed sampling was also conducted in the site 2 and site 3 areas to complement other geoscience studies. Western hemlock was chosen as the prime sample medium because it was present at all but a few of the desired sample sites. At each sample station, seven twigs were collected, that samped the last 10 years of growth. In reforested areas, only 3 to 5 years of growth could be evaluated. Tests are being conducted to determine if the composition of the younger growth is similar to that of the more common 10-year old sample. Samples of several different plant species were also collected to determine their relative sensitivities to the presence of a wide range of metals and pathfinder elements. The potential usefulness of each species for prospecting will be assessed from this information.

All samples were left to air dry (in paper bags) for one month before the foliage was separated from the twigs. Subsequently, all western hemlock twig samples were reduced to ash by ignition in a kiln at 470°C. A 0.5-gram portion was submitted for multi-element instrumental neutron activation analysis, and a 0.25-gram split was submitted for multi-element ICP-ES analysis. Preliminary results show a large area surrounding the Island Copper orebody that has unusually high concentrations of several metals, notably we found maxima of 240 ppb Au, 1241 ppm Mo and 4784 ppm Cu in ash.

CONCLUSIONS

The initial interpretations of the coincident drilling, gravity, magnetic and EM data are promising, although in some cases, inconsistent. Preliminary evaluation of the data sets indicates all methods have a high potential for providing useful information.

Although labour-intensive, we conclude that mud rotary drilling can be successfully used in complex surficial terrains consisting of dense till, coarse glaciofluvial sediment and cohesive marine deposits. In areas where borehole data are lacking, the effort expended by drilling is necessary to provide a means for examining the subsurface using borehole geophysics. Similarly, flight augering proved to be a quick and invaluable method for shallow subsurface testing and sampling.

Once drill holes are available, exceptional data return are provided by borehole geophysical methods. Although not discussed at length in this paper, gamma, SP and resistivity measurements all provide good detail about the composition of buried, unconsolidated sediments. Down-hole logging is quick, inexpensive and reliable and recommended for the evaluation of overburden cover where diamond drilling is undertaken.

Gravity, magnetometer and electromagnetic surveys all generated useful data. Both gravity and magnetometer measurements were easy to collect along the linear transects, whereas the EM surveying proved somewhat slower in the rough terrain. Results evaluated thus far are informative, although minor discrepancies exist. To date, our effort has primarily focused on the ability to establish overburden thickness. All three techniques were successful in dealing with sediment cover in excess of 200 metres in thickness. For example, for leg 1 at site 1, results for the three techniques are in rough agreement, indicating a general thickening of sediment from north to south. However, the magnetometer survey recognized a prominent anomaly mid-way along the section, not recognized by the gravity measurements. One noteworthy comparable interpretation is the identification of a substantial change in sediment character near drill hole NVI94-DH01. Both gravity and magnetometer data suggest there is a thick deposit of unconsolidated sediment in this area. The actual depth of bedrock was estimated to be 226 metres from the EM record, which also suggests a stratigraphic break at a depth of 72 metres. The latter break is confirmed by the mud rotary drilling at hole NVI94-DH01. The total depth to bedrock (226 m) is consistent with diamond drilling results within the general area.

In efforts to establish overburden thickness, the composition and character of the unconsolidated sediment cannot be overlooked. Similarly, the nature of the underlying bedrock plays an important rôle in the character of the data. Preliminary results indicate that the assumptions used thus far in the evaluation of our data are too simple. These data sets offer an opportunity to integrate methods and improve the interpretive models and algorithms. Further interpretation of the data from these sites will provide a better understanding of the limitations and capabilities of drilling, borehole geophysics, gravity, magnetometer and EM surveying for mapping drift thickness, composition and buried bedrock.

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NOTES

SURFICIAL GEOLOGY AND DRIFT EXPLORATION:

MAHATTA CREEK MAP AREA (92L/5)

By David H. Huntley and Peter T. Bobrowsky

KEYWORDS: Vancouver Island, surficial geology, drift exploration, till geochemistry, paleo-iceflow, Quaternary, Holocene.

INTRODUCTION

In 1993, detailed drift exploration and surficial mapping was undertaken in NTS sheets 92L/6 (Alice Lake) and 92L/11 (Port McNeill) as part of an integrated resource assessment program defining the mineral potential of northern Vancouver Island (Panteleyev *et al.*, 1994; Bobrowsky and Meldrum, 1994). A similar, but independent study covering NTS sheet 92L/12 (Quatsino), was completed in 1991 (Kerr 1992; Kerr and Sibbick, 1992). This year, surficial mapping and till geochemistry sampling was extended into NTS 92L/5 (Mahatta Creek; Figure 1); an area supporting a number of mineral occurrences (Figure 2) and recent detailed bedrock mapping information (Nixon *et al.*, 1993a, 1993b).

- Surficial geology fieldwork in the Mahatta Creek map area represents the final stage of a drift program on the northern part of Vancouver Island. The objectives in this area are the same as those established in the surrounding sheets and include:
- Mapping surficial sediments and documenting the Quaternary geologic history.
- Completing a regional drift-exploration project focused on till geochemistry.
- Developing interpretive drift exploration models and products.

This paper reviews the mapping and till sampling procedures used in 92L/5, provides summary statistics regarding the drift sampling program and offers an interpretation of the Quaternary geologic history of the area based on airphoto analysis and ground truthing observations. Results of the till geochemistry sampling program will appear in a publication covering all four map sheets examined on northern Vancouver Island.

PHYSICAL SETTING

The study area lies on the west side of Vancouver Island and is surrounded on three sides by ocean waters: Brooks Bay to the southwest, Quatsino Sound to the northwest and Neroutsos Inlet to the northeast. Coastal lowlands are dominated by glacially smoothed, joint and fault-faceted bedrock hillocks, ranging in height from 10 to 100 metres. Inland from coastal margins, much of the central and southeastern land area is a glaciated montane landscape with highly variable relief: the highest peak in the map area, Mount Wolfenden (1273 metres above sea level), lies only 3 kilometres from the shore of Neroutsos Inlet (Figure 2). Montane and lowland areas are incised by U-shaped valleys that drain to fjords such as Quatsino Sound, Neroutsos, Klaskino and Klaskish inlets. Valleys and fjords exploit regional northwest and northeast-striking faults.

Subaerial tuffs, basaltic to rhyolitic lavas and clastic sediments and limestones of the Lower Jurassic Bonanza Group cover much of the study area. These rocks are the principal host for local copper, molybdenum, lead, zinc and gold mineralization (Nixon *et al.*, 1993b). Up to three-quarters of the map area is presently mantled by a Quaternary drift of variable thickness.

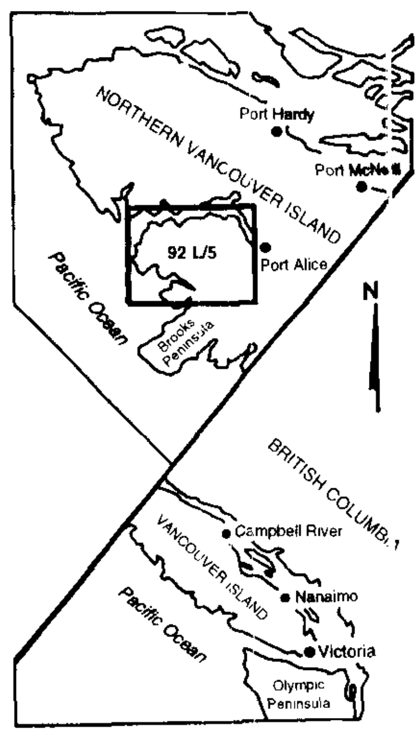


Figure 1. Location of the Mahatta Creek map area.

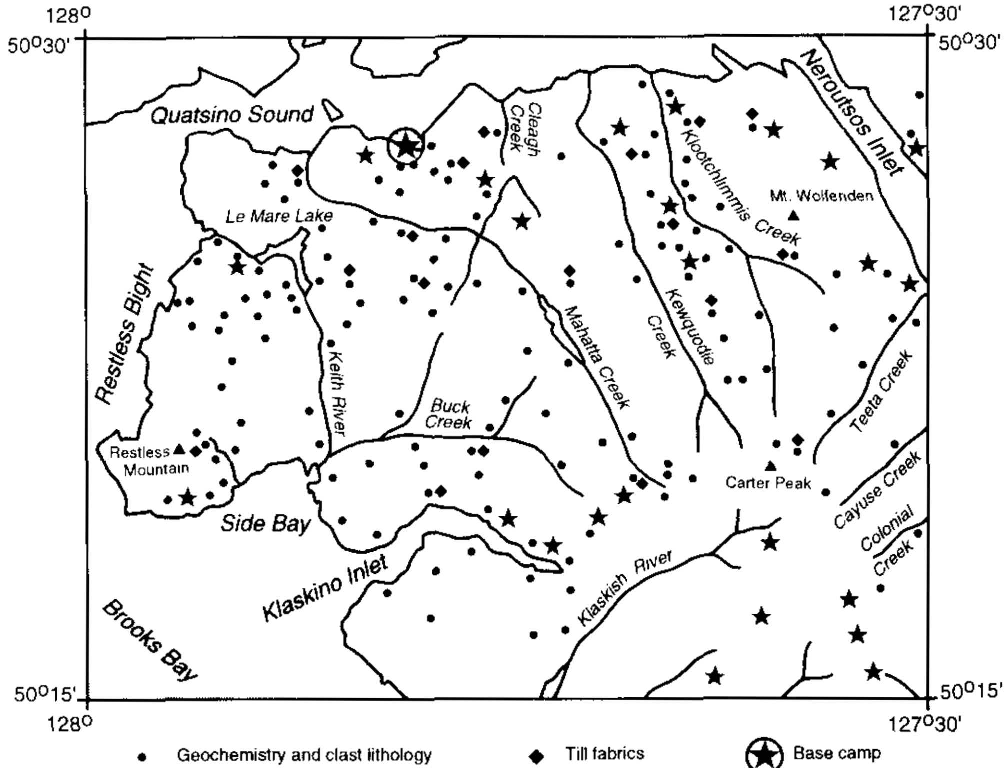


Figure 2. Sample design

METHODS

Fieldwork was based out of a camp established at the Mahatta River log sort, 65 kilometres west of Port Alice on the south shore of Quatsino Sound (Figure 2). Much of the map area was reached by logging roads using a four wheel-drive vehicle. Off-road access was gained by mountain bikes or on foot. Natural and culturally derived exposures such as road cuts provided the primary sampling source for surface and subsurface sediments. Where exposure was poor or lacking, shovel excavations were used to create new exposures.

Preliminary 1:50 000-scale surficial geological mapping and airphoto interpretation of the landforms was completed in the office before fieldwork commenced, using photo suites BC7711 and BC7714. Terrain units were classified as polygons according to the type of surficial material and surface expression. These criteria were coded using mapping standards detailed in Howes and Kenk (1988).

Verification of airphoto interpretation consisted of ground truthing observations at 143 field stations (Figure 2), which were located (UTM coordinates) with the aid a Trimble Navigation global positioning system (accuracy as good as ±30 metres). Elevations were determined using a Thommen altimeter, benchmarked to daily mean sea level at base camp (accuracy ±5 metres).

At each station, exposures were logged in detail using traditional Quaternary geology mapping techniques to document the nature, type and extent of the overburden cover (Figure 3). Observations included general exposure attributes such as depth to bedrock, depth of oxidation, surface expression, section height, length and number and type of facies. Specific characteristics of the various facies was also recorded and included information on the type of basal contact, texture, percentage of clasts and fines, clast shape, roundness and size, presence of striae, faceting and fabric, and presence of sedimentary and deformational structures (Table 1). Paleocurrent directions were determined in waterborne sediments from orientations of relict channels, cross-bedding and clast imbrication.

Undisturbed basal (lodgement) till matrix samples (1 to 5 kilograms per sample) were collected at 86 sites for geochemical analysis. Additional samples of ablation till, colluvium and glaciofluvial sediments were taken from 34 locations (Table 2). Sampling was restricted to the unweathered C-horizon which ranged from 0.5 to 9 metres below surface. Sediment samples were stored in heavy-mil plastic bags. In the laboratory, sediment samples were air-dried at 25-30°C for a minimum of 48 hours, then crushed and sieved to obtain a -230-mesh fraction. Seven duplicate field and ten laboratory split samples were integrated into the sample suite. Representative splits have been submitted for aqua regia inductively coupled plasma emission spectroscopy (ICP-ES) and instrumental neutron activation (INA) analysis.

Former ice-accumulation areas and limits of glaciation were identified from the distribution of cirques, glacial troughs and landforms such as moraines, and glaciofluvial deposits. Regional and local paleo-iceflow patterns were established by plotting the distribution of glacial troughs, roches moutonées and striae on the preliminary 1:50 000-scale surficial geology map. Additional paleo-iceflow data were derived from pebble fabrics measured in exposures of lodgement till.

At 18 locations, the trend and plunge of 50 prolate shaped clasts (at least 2 centimetres in length) was recorded. Two and three-dimensional statistics were generated from the measurements using Rosy™ and Stereo™ stereographic projection programs. Glacial transport paths will be further defined by the examination of clast provenance for 59 locations. Approximately 100 clasts were obtained from lodgement till exposures at these locations. Variations in pebble lithology frequency will then be integrated with facies analyses and inferred ice-flow directions to generate ice-transport and depositional models.

LITHOFACIES DESCRIPTIONS

The Quaternary cover ranges in thickness from less than a metre in upland areas and montane valleys to greater than ten metres in lowlands (Figure 3). Within this cover, eight lithofacies are distinguished, including four diamictons, and subordinate glaciofluvial, glaciolacustrine, fluvial and marine facies. Certain diamictons are primary indicator facies as they represent first derivatives of erosion and deposition (Shilts, 1993). 1994). As such, they can be confidently used in exploration for buried mineral occurrences (Bobrowsky and Meldrum, 1994). Other lithofacies have undergone secondary or tertiary resedimentation and are less reliable indicators (Shilts, 1993). Quantitative data were collected mainly for diamicton and glaciofluvial facies and are summarized in Tables 1 and 2. Other subordinate facies descriptions are supplemented with qualitative observations.

FACIES A

Facies A comprises grey to olive-brown massive diamictons veneering or blanketing lowlands and montane valley sides between 600 to 880 metres above sea level. In these areas, facies A usually overlies striated or glacially streamlined bedrock (Figure 3, logs 2, 4, 5 and 6; Photo 1). Observed thickness for this facies ranges from 0.5 to 6.0 metres, with a mean of 2.4 metres based on 86 observations (Table 2). The facies is matrix supported, composed mainly of homogeneous, compact silt and clay (70% based on 86 samples); bedding-parallel fissility is found in 30% of samples. Clast content varies from 10 to 30%, and consists of subrounded, locally derived lithologies with occasional rounded exotic clasts (Table 1). Mean clast size generally ranges from 3 to 20 centimetres, but boulders up to 3 metres are found. Clast shapes range from prolate to equant, with a mean shape being bladed (Table 1). Approximately 95% of facies A deposits contain striated

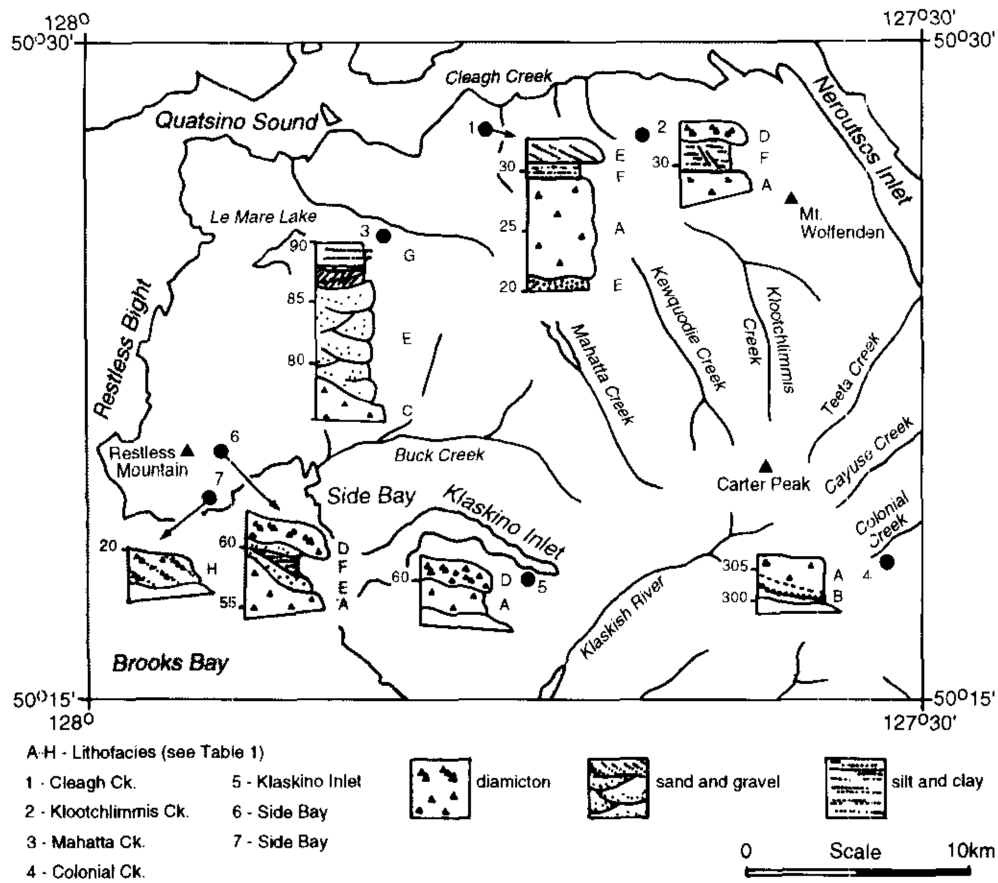


Figure 3. Simplified and selected stratigraphy (section elevations in metres above sea level)

TABLE 1: DRIFT SEDIMENTOLOGY AND GENETIC INTERPRETATION

Facies	Matrix Texture[a]	Matrix Structure[b]	Clast Content[c]	Clast Size[d]	Clast Roundness[e]	Clast Shape[f]	Genesis[g]
FACIES A	Matrix-supported	Massive	17	3	Subround	Blade	Lodgement till
FACIES B	Matrix-supported	Stratified	≈ 20	≈3	Subround	Blade	Basal melt-out till
FACIES C	Matrix-supported	Stratified	38	4	Subangular	Oblate	Supraglacial, or ablation till
FACIES D	Clast-supported	Massive	61	3	Subangular	Blade	Colluvium
FACIES E	Gravel and sand	Stratified	22	3	Round	Oblate	Glaciofluvial sediments
FACIES F	Silt and clay	Laminated	<1	<1	-	-	Glaciolacustrine sediments
FACIES G	Gravel and sand	Stratified	≈ 30	≈3	Round	Oblate	Fluvial sediments
FACIES H	Matrix-supported	Massive	≈ 40	≈3	Subangular	Blade	Marine sediments

a Mean observed grain sizes and arrangement of clasts
b Mean observed three-dimensional arrangement of contacts or internal discontinuities
c Mean percentage clast content
d Mean clast size in centimetres
e Mean sharpness or degree of rounding of edge of clasts
f Mean shape of clasts
g Interpreted origin of facies

TABLE 2: DRIFT SAMPLE MEDIA AND STATISTICS

Facies Type	Bulk Sample[a]	Pebble Sample[b]	Drift Depth[c]	Oxidation Depth[d]	Sample Depth[e]
FACIES A	86	59	2.45	0.80	2.01
FACIES C	11	10	3.11	0.76	2.53
FACIES D	13	12	2.38	0.80	2.13
FACIES E	10	0	5.03	1.29	2.30
	Total = 120	Total = 81	Mean = 3.24	Mean = 0.91	Mean = 2.74

a Number of geochemical samples collected
b Number of pebble samples collected
c Mean depth of sampled drift medium in metres
d Mean depth of oxidation in metres
e Mean depth of collection for geochemical sample

and/or faceted clasts. Prolate clasts display a moderate to strong preferred fabric in the direction of local paleoice-flow (see section on paleo-iceflow, below). Basal contacts are gradational where they overlie facies B, and erosional and sharp over all other deposits. Facies A deposits are interpreted to represent lodgement tills deposited at the base of active glacier ice (*cf.* Muller, 1983; Dreimanis, 1976; 1988).

FACIES B

Facies B are grey to olive-brown diamictons, locally preserved as veneers in leeside bedrock cavities found along montane valleys between 600 and 880 metres above sea level (Figure 3, log 4). This facies is found at three sites and is consistently overlain sharply by facies A (Photo 1). Observed thickness does not exceed 0.5 metre. Facies B diamictons are stratified and matrix supported. Matrices are composed predominantly of silt and clay (Table 1). Quantitative assessment of clast content and shape is lacking, as this facies was not included in the geochemical drift sampling program. However, general field observations suggest roundness and shape values similar to those observed in facies A, and clast provenance appears to be primarily of local origin. Diamictons comprising facies B are interpreted to represent basal melt-out tills (*cf.* Shaw, 1985), deposited through basal melting of stationary or stagnant glacier ice.

FACIES C

Grey to reddish brown, partly weathered diamictons, blanketing valley floors and overlying facies A or bedrock, characterize facies C (Figure 3, log 3; Photo 2). Basal contacts range from erosional (11 of 19 observations) to gradational (43%). Facies thickness averages 3.1 metres and ranges from 0.7 to 10.0 metres. Matrices are deficient in silt and clay, and display a wide textural and structural range, including massive matrix supported (42%) and stratified matrix supported (58%). Clast content varies from 35 to 65%, and consists predominantly of distally derived subangular to subrounded pebbles. Observed clasts range from 1 to 10 centimetres, with an average size of 4 centimetres (based on 11 samples; Table 1). Approximately 40% of the deposits observed contain striated or faceted clasts. Facies C diamictons are interpreted as supraglacial or ablation tills (*cf.* Dreimanis, 1988) accumulated by surface melting of ice in areas dominated by downwasting of stagnant ice (*cf.* Boulton and Eyles, 1979).

FACIES D

Facies D consists of weathered, olive to reddish brown diamictons found along steep valley margins, where they form blanket or fan-shaped deposits overlying bedrock and other sediments (Figure 3, logs 2, 5 and 6; Photo 3). Basal contacts are primarily erosional (8 of 13

Photo 1. Stratified matrix supported diamictons typical of facies B (basal melt-out till) overlain by massive matrix supported diamicton characterizing facies A

observations), although gradational contacts are observed. Deposit thickness averages 2.4 metres for 13 samples, and ranges from 2.0 to 3.5 metres (Table 2). Diamicton matrices are deficient in fines, and have textures and structures ranging from stratified clast supported (14 %) to massive clast supported (86%). Relict structures (fissility, fabric, bedding) are locally preserved. Clast contents vary from 50% (stratified clast supported) to 80% (massive clast supported), with a mean content of 61% (Table 1). Mean clast size ranges from 2 to 5 centimetres, with a maximum of 80 centimetres. Facies D diamictons are interpreted as mass movement deposits derived from mechanically weathered bedrock, solifluction (*cf.* Eyles and Paul, 1983), and tills that have undergone direct, gravity-induced mass movement (*cf.* Lawson, 1988).

FACIES E

Facies E consists of gently undulating blankets of yellow to red-stained sand and gravel, confined to anomalous settings above or adjacent to contemporary valley floors (Photo 4). Deposit thickness exceed 10 metres (Figure 3, log 3). This facies may onlap or incise diamicton facies A, C or D (Figure 3, logs 1, 2 and 3). Where evident, basal contacts are predominantly erosional (8 of 10 observations) and channelized. Gravels are polymictic, with rounded clasts ranging from 1 to 6 centimetres in diameter. Sands are well sorted and often normally graded. Foreset, trough-cross, ripple-drift and laminar bedding are preserved in this facies and often indicate paleoflows counter to the present drainage direction. Normal faults are common along exposed flanks of deposits. Gravel and sand deposits of facies E are interpreted as ice-proximal glaciofluvial sediment (*cf.* Miall, 1977; Rust and Koster, 1984).

Photo 2. Massive matrix supported diamicton typical of facies C (ablation till).

Photo 3. Couplets of stratified and massive diamictons characterizing facies D (colluvium).

Photo 4. Exposed section of normally graded gravel and sand typical of facies E (glaciofluvial sediments). Sequence forms a terrace graded to 30 m above sea level along Mahatta Creek.

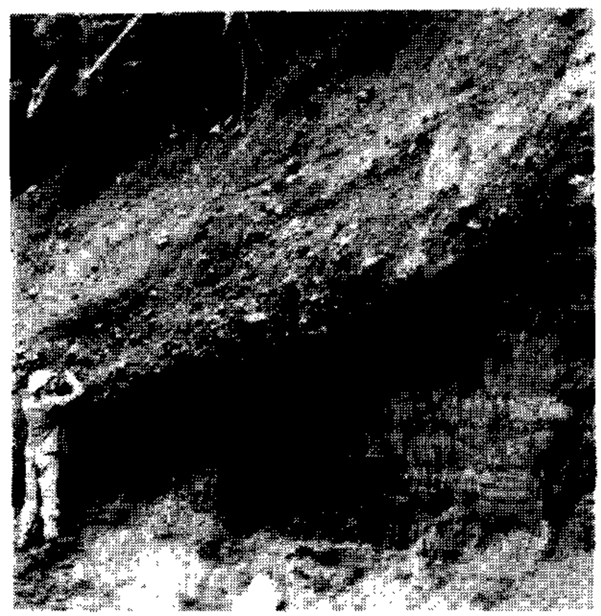


Photo 5. Rhythmically interbedded fine sand, silt and clay characterizing facies F (glaciolacustrine sediments). Facies F is truncated by late or postglacial debris-flow diamictons (facies D).

FACIES F

Facies F consists of grey to olive-green, rhythmically interbedded fine sand, silt and clay with dispersed clasts which are occasionally faceted and/or striated (Photo 5). Facies F deposits are confined to lower reaches of valleys where they disconformably overlie facies A. Upper contacts may be erosional or gradational, whereas lower contacts are always gradational At Klootchlimmis Creek (Figure 3, log 2), facies F is cross-cut by normal faults with displacements that rarelyexceed 10 centimetres. Fault planes are oriented parallel to valley sides, and indicate extension into valleys. Facies F sediments are unconformably overlain by ice-contact sediment gravity-flow deposits (facies D; Photo 5). At Cleagh Creek (Figure 3, log 1) and Side Bay (Figure 3, log 6) profiles coarsen upwards through facies E into facies F. Maximum thickness does not exceed 3 metres. Dispersed clasts with penetrative structures are interpreted to represent dropstones in an ice-proximal setting (Brodzikowski and van Loon, 1991). Rhythmic bedding and other characteristics of facies F lend support to the interpretation that it was deposited in a glaciolacustrine environment (*cf.* Shaw, 1975; Catto, 1987).

FACIES G

Facies G comprises undulating blanket deposits of yellow-stained clast and matrix-supported sand and gravel, confined primarily to contemporary valley floors (Figure 3, log 3). The intercalated beds of sand and gravel occur in channel features incised into other types of deposits (such as facies E) or bedrock and do not exceed 5 metres in thickness. Interbed contacts range from sharp, erosional to gradational, whereas the basal contact of the facies is erosive. Clasts in the gravel component are rounded to well rounded with a mean diameter of approximately 3 centimetres; provenance is highly variable, which indicates derivation from a number of sources. The gravels are moderately to well sorted. The sand component is well sorted and normally graded. Foreset, trough-cross, ripple-drift and laminar bedding indicate flow direction similar to the present-day drainage (contrast with facies E). Facies G is interpreted as fluvial sediments deposited by braided or anastomosing streams (*cf.* Miall, 1977; Collinson, 1978).

FACIES H

Facies H consists of veneers or blankets of reddish stained, poorly sorted, matrix supported sand and gravel overlying bedrock platforms below 20 metres above sea level (Figure 3, log 7). The sediments are typically massive, but occasionally display crude coastward-dipping stratification. Clast content averages 40% and pebble lithologies are highly variable (Table 1). Facies H is interpreted as wave-reworked deposits (*cf.* Elliot, 1978).

GEOMORPHIC DESCRIPTIONS

LIMITS TO GLACIATION

Evidence of glaciation is absent or not preserved above 600 to 880 metres above sea level along interfluves in several parts of the study area (Figure 4). Characteristically, exposed bedrock appears to have undergone frost shattering rather than glacial streamlining or deposition. Features resembling gendarmes and tors are preserved along some ridges, for example between Carter Peak and Mount Wolfenden. On gentle slopes, bedrock is frequently draped by sediment gravity-flow deposits, resembling solifluction deposits or thin soils; glacial sediments are absent.

These observations suggest a stable surface elevation for ice cap development over the study area prior to deglaciation, and a minimum limit to glaciation (*cf.* Huntley and Broster, 1994). This limit probably varied from about 880 metres above sea level in the east and southeast to 600 metres elevation along the western seaboard (Figure 4), resulting in an ice surface gradient of approximately 2.3° (between Restless Mountain and Carter Peak). Ice thicknesses greater than 900 metres were attained by major ice streams occupying Neroutsos Inlet and Quatsino Sound. Elsewhere, ice thickness
Inlet and Quatsino Sound. Elsewhere, ice thickness
averaged in the order of 670 metres in the eastern montane valleys to 520 metres in western coastal areas. During full glacial times, approximately 22 square kilometres (2% of the map area) may have been ice-free, 32% of which was the land area surrounding Mount Wolfenden.

GLACIAL LANDFORMS AND PALEO-ICEFLOW PATTERNS

Below 660 to 880 metres above sea level, all drainage basins show significant derangement through glacial erosion. Ice accumulation and erosion focused in the headwaters of all major valleys resulted in the formation of cirques, horns and arêtes. Cirque floors range from 300 metres above sea level near Restless Bight to 610 metres above sea level in the southeast part of the map area. This suggests that interior areas were primary ice-accumulation zones and coastal areas functioned as low-elevation tributary ice sources at later stages of glaciation. Most cirques are oriented north to northwest, although southeast of Klaskish and Teeta rivers, cirques face southwest or northeast (Figure 4).

All major valleys have a prominent U-shaped morphology, suggesting they accommodated glaciers at sometime in their past. Although pre-late Wisconsinan sediments were not observed, the well developed nature of the valleys argues for repeated glacial erosion focused along structural features such as faults. Regional paleo-iceflow was directed along northwest and northeast-oriented fault-controlled valleys (Figure 4). South of latitude 50°21' N, ice generally flowed to the southwest toward Brooks Bay, whereas north of this latitude, ice flowed into Quatsino Sound. Roches moutoneés and striae are ubiquitous and consistently indicate down-valley ice flow along montane reaches of valleys. Paleo-iceflow along Klaskino Inlet and Klaskish River was west and southwest, respectively. In contrast, ice flowed northeast along Teeta, Cayuse and Colonial creeks. Northwesterly ice flow was restricted to Mahatta, Kewquodie and Klootchlimmis creeks. An exception to this pattern occurs near Le Mare Lake, where paleo-iceflow was directed southward along Keith River into Side Bay. In summary, directional landforms indicate that early ice-flow was controlled by valley orientation, but as ice thickened, glaciers were no longer confined and spilled out over coastal lowlands and valley divides

Clast fabric and striae orientation data (Table 3) provide other paleo-iceflow information. Mean vectors for two-dimensional and three-dimensional fabric data predominantly cluster in an up-ice direction (Table 3). This is consistent with expected fabrics in lodgement tills as clasts become aligned parallel to upward-directed ice-flow lines below the equilibrium line altitude (*cf.* Dowdeswell and Sharp, 1986). Exceptions to this rule occur in tills deposited in cirque basins (field stations 9 and 43; Table 3). Here, clast fabrics cluster subparallel to

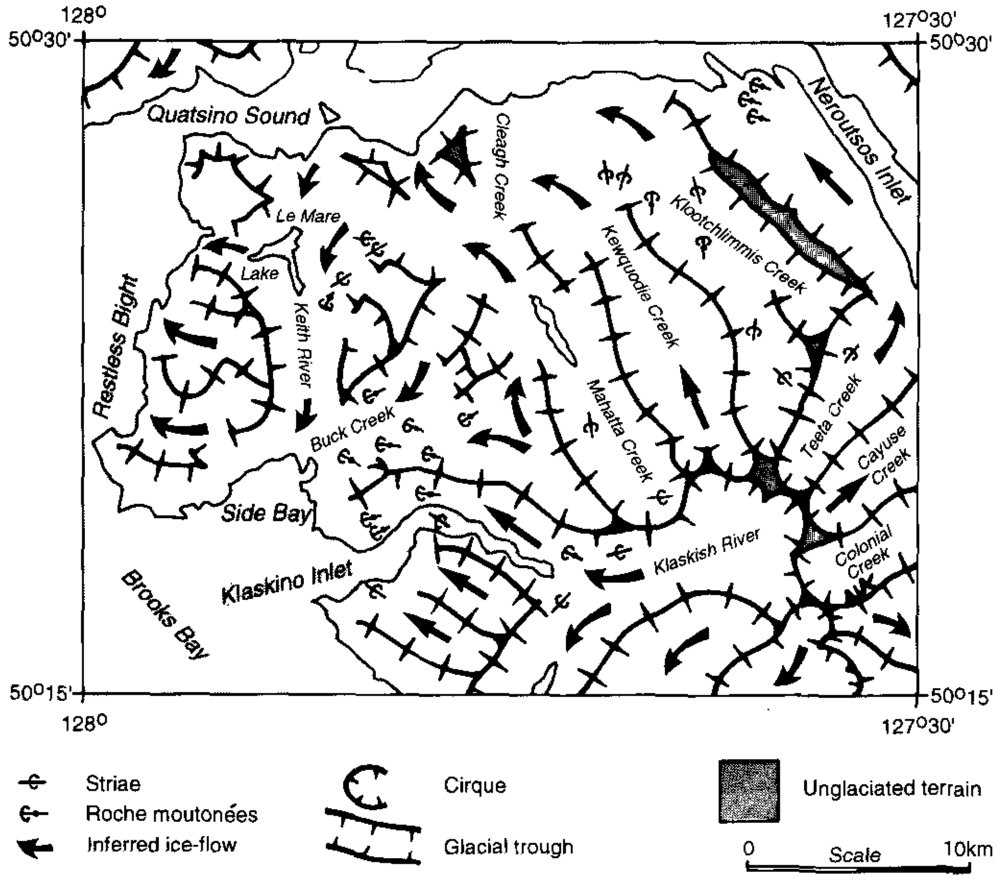


Figure 4. Paleo-iceflow patterns

the direction of ice flow and presumably reflect clast alignment with respect to downward-directed ice-flow lines. In areas of expected divergent flow (field stations 49, 53, 65 and 76; Table 3), fabrics tend toward a girdle distribution.

MORAINES

Gently undulating ground moraine was deposited ubiquitously over lowland areas and valley sides. The morainal sediments consist of lodgement (facies A) and melt-out till (facies B). In areas of high to moderate relief, and on steep slopes, morainal blankets are rare or extensively reworked by deglacial and postglacial mass-movement processes (facies D). Along valley floors, ablation till (facies C) and ice-contact sediments (facies E) form isolated patches of hummocky ground moraine and glaciofluvial deposits. These landform assemblages are indicative of an ice-retreat history characterized by stagnant ice conditions, with dead ice confined to valley floors (*cf.* Fulton, 1991).

Approximately 1 kilometre upstream from the mouth of Klootchlimmis Creek, a ridge 30 metres high forms a barrier between the coastal lowland along Quatsino Sound and higher ground to the south. Postglacial fluvial incision has revealed a complex interior, composed of lodgement till and ablation till that moraine for a glacier lobe that occupied Klootchlimmis is partly draped down-valley by colluvium and glaciofluvial sediments. Ridge morphology, position and facies association suggest that it may represent a terminal valley, or an interlobate moraine formed between ice in Quatsino Sound and Klootchlimmis Creek.

GLACIOFLUVIAL AND GLACIOLACUSTRINE LANDFORMS

Relict glaciofluvial landforms are graded to local paleo-baselevels at 210, 152, 90, 60 and 30 metres above sea level. In upland reaches of valleys, deglacial kame terraces, till and bedrock-walled meltwater channels have profiles graded to 210 and 152 metres above sea level (Figure 5A). Kames and channels locally form landform assemblages with eskers and hummocky ground moraine and are implicitly deglacial ice-contact forms. The above observations suggest two early stages of stable ice margins in upland areas during deglaciation.

Incised remnants of broad, gently undulating plains form paired terraces in lower valley reaches. Terraces have steep, long profiles ranging from 0.6° (Mahatta Creek) to 3.2° (Teeta Creek), and are interpreted as portions of a relict network of glacial spillways graded to a relative base level 90 metres above sea level. Foresets, ripples and clast imbrication in glaciofluvial sediments indicate paleoflows directed to outlets at Side Bay, Klaskino Inlet, Klootchlimmis and Cleagh creeks. Terraces are absent along Quatsino Sound and Side Bay, suggesting that meltwater drainage was facilitated by supraglacial channels formed on remnant glacier lobes in these areas. The 90-metre base level was

TABLE 3: PALEO-ICEFLOW DATA

Field Station	Easting	Northing	Facies[a]	Data Type[b]	Mean Vector[c]	E1[d]	E2[d]	E3[d]	Inferred Paleoflow[e]
2	595400	5585600	A	3D	160 / 12	0.70	0.22	0.08	NW
9	602500	5580250	A	3D	278 / 01	0.61	0.31	0.08	NW
18	593250	5590630	A	3D	161 / 04	0.55	0.32	0.12	NNW
29	595570	5575730	A	3D	065 / 09	0.56	0.30	0.14	WNW
39	586190	5575520	A	3D	097 / 08	0.65	0.30	0.04	WNW
43	601370	5579220	A	3D	100 / 08	0.56	0.34	0.09	NE
49	584790	5583560	A	3D	020 / 12	0.48	0.42	0.10	SW
53	583670	5588390	A	3D	030 / 06	0.50	0.41	0.08	W / NW
65	589300	5589090	A	3D	154 / 06	0.50	0.43	0.06	W / SE
76	579930	5583540	A	3D	104 / 00	0.52	0.41	0.07	S
98	580350	5588640	A	3D	002 / 09	0.55	0.36	0.09	SW
114	576450	5577390	A	3D	055 / 18	0.63	0.31	0.06	S
126	588710	5577600	A	3D	047 / 13	0.62	0.27	0.11	WSW
131	581220	5584800	A	3D	058 / 16	0.76	0.17	0.07	SSW
137	593520	5587710	A	3D	142 / 03	0.69	0.23	0.08	NW
141	585510	5589110	A	3D	146 / 14	0.68	0.26	0.05	NNW
15	596550	5591540	A	2D	090	-	-	-	NW
33	589110	5586650	A	2D	114	-	-	-	NW
3	593770	5586560	R	Striae	232	-	-	-	SW
23	596730	5586520	R	Striae	314	-	-	-	NW
76	579930	5583540	R	Striae	126	-	-	-	SE
131	581220	5584800	R	Striae	202	-	-	-	SSW
137	593520	5587710	R	Striae	320	-	-	-	NW

a Facies sampled: A - lodgement till; R - bedrock

b Type of data collected at site: 3D - equal-area lower-hemisphere plot of dip direction and plunge of prolate clast long axes (n = 50); 2D - directional circular-frequency plot of prolate clast long axis (n = 50); Striae - glacially striated bedrock surface

c Mean trend and plunge of data set (n = 50)

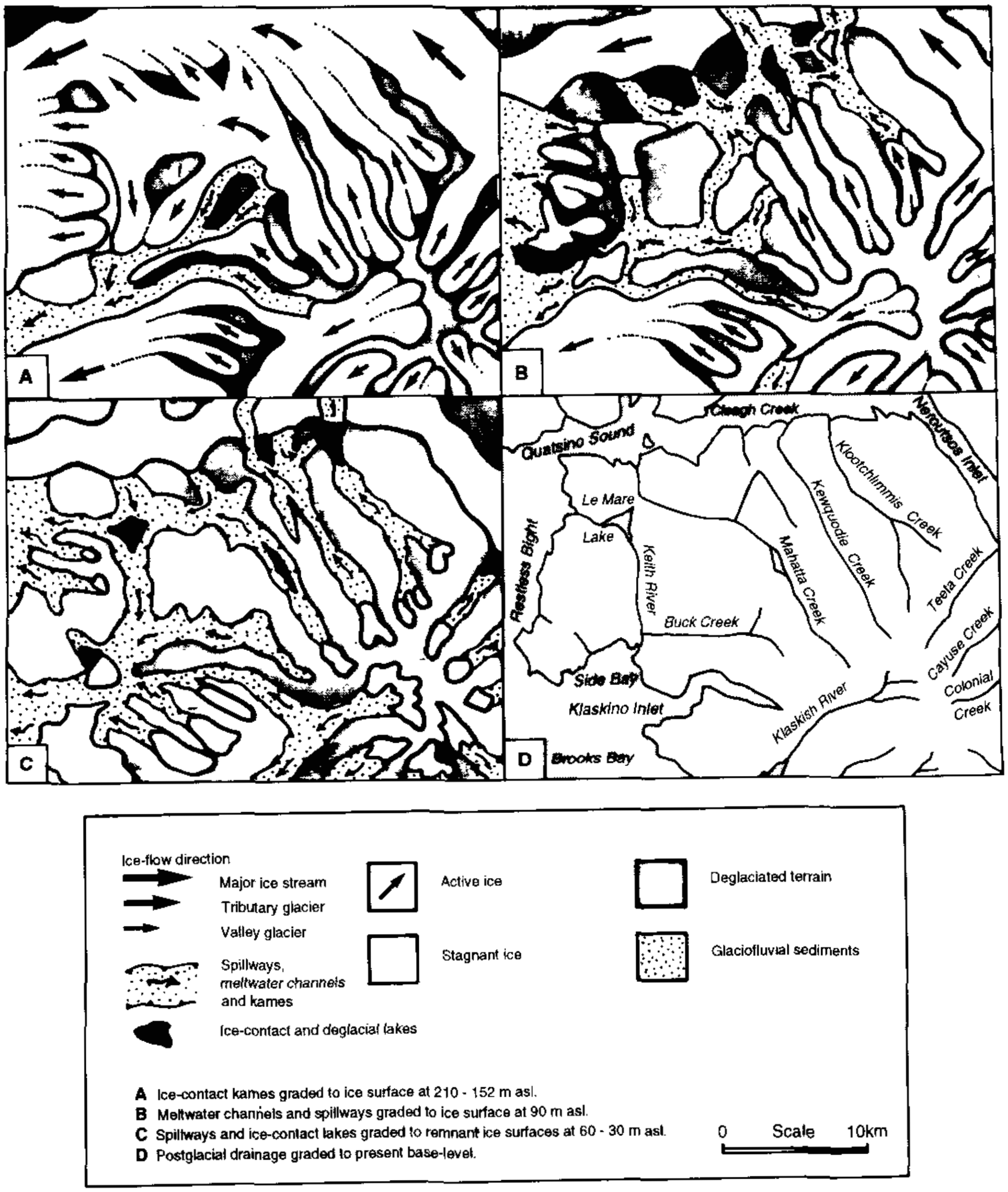
d Eigenvectors E1 - E3: E1 > E2 > E3 - single area of point concentration on the sphere; E1=E2>E3 - girdle distribution where points lie on a great circle trace; E1=E2=E3 - uniform distribution.

e Paleoice-flow determined from directional glacial landform (U-shaped trough, roche moutonée)

possibly controlled by ice confined to Quatsino Sound and Side Bay, as well as the lowest reaches of Mahatta, Koskimo and Cleagh creeks, and suggests a third stable elevation for the ice surface during deglaciation (Figure 5B). Below 90 metres elevation, glaciofluvial sediments and colluvium prograde over, or truncate locally deformed glaciolacustrine sequences (Photo 5). In the southeast, incised glaciofluvial and lake deposits are graded to 60 metres elevation, whereas in the northeast, including Cleagh and Klootchlimmis valleys, sequences are graded to 30 metres above sea level. Sediments are interpreted as being deposited in lakes dammed by remnant ice and morainal deposits at valley confluences (Figure 5C). Deformation is implicitly related to postglacial incision of deglacial sediments and slumping into contemporary valley axes. The 60 and 30-metre base levels represent two final stable ice-retreat surfaces prior to full deglaciation (Figure 5D).

POSTGLACIAL LANDFORMS

At Restless Bight, Side Bay and Quatsino Inlet, distinctive plains are formed at about 20 metres above sea level. Here, glacial sediments have been extensively reworked and locally display crude coastward-dipping stratification. The plains are interpreted as wave-cut platforms and indicate a maximum postglacial incursion to 20 metres above sea level in this area. Inland, glacial deposits have been extensively remobilized, and postglacial fan aprons and debris flows are ubiquitous. Although some remobilization implicitly occurred during the paraglacial stage of deglaciation (*cf.* Church and



Model of deglaciation for the Mahatta Creek map area.

Ryder, 1972), recent slides are attributed to local farming practices

REGIONAL GLACIAL HISTORY

Howes (1983) recognized two tills separated by glaciomarine silt, ^{14}C dated at 20 600±330 years BP (GSC-2505) on northern Vancouver Island. The tills indicate two glaciations probably correlative to the early Wisconsinan Muchalat River drift (Howes 1981) or Dashwood drift (Alley, 1979) and a later advance (Port McNeill till) correlated with the Fraser Glaciation. Olympia nonglacial interval sediments are not found in the area, suggesting that materials were deposited in transient sedimentary environments (Howes, 1983).

With the onset of climatic deterioration at the end of the Olympia nonglacial interval, ice accumulated in the Coast Mountains and montane areas of northern Vancouver Island. Westward-flowing glaciers from the Coast Mountains entered the Strait of Georgia and Queen Charlotte Strait, reaching a maximum thickness of about 2000 metres (Clague, 1983). Over northern Vancouver Island, mountain ice caps fed a system of glaciers confined to major valleys (*cf.* Davis and Mathews, 1944) and ice thickness probably did not exceed 750 metres (Howes, 1983). Glacier advance was also marked by glacio-eustatic lowering of sea level up to 100 metres near Port Hardy (Clague *et al.*, 1982; Howes, 1983) and glacio-isostatic depression of land surfaces of up to 100 metres north of Cape Scott (Luternauer *et al.*, 1989). By

20 600±330 years BP, glaciomarine silts were deposited in front of advancing ice margins. These sediments are probably contemporaneous with the ubiquitous Quadra sand exposed throughout much of the Strait of Georgia. At about 15 000 years BP, Vancouver Island glaciers coalesced with Coast Mountain ice; an event marked by the widespread truncation of glacier advance sequences and deposition of Port McNeill till.

Climate warming began around 13 630±310 years BP (WAT-721), and resulted in ice stagnation as glaciers were cut off from source areas (*cf.* Fulton, 1991). Thus, the Fraser Glaciation maximum lasted for approximately 7000 years. Supraglacial (ablation) till and glaciofluvial sediments were deposited during ice retreat. At this time, terrestrial deglacial sediments were deposited as much as 95 metres below present sea level (Luternauer *et al.*, 1989). Raised deltas, beach deposits and strand lines at 90 and 20 metres above sea level suggest a marine transgression as part of the postglacial cycle (Howes, 1983). The latter deposits were eventually exposed through rapid crustal rebound during the early Holocene (Luternauer *et al.*, 1989).

LOCAL GLACIAL HISTORY

Geomorphic and lithostratigraphic evidence accumulated in this study suggests that sediments and landforms in the Mahatta Creek map area are products of the late Wisconsinan Fraser Glaciation. This does not preclude the existence of older deposits; rather, pre-Fraser Glaciation landforms and sediments were probably modified or eroded during the final glaciation.

The advance stage of the Fraser Glaciation was marked by ice accumulation in cirques and the formation of isolated mountain ice caps on major peaks in the east-central part of the map area. South of latitude 50°21' N, glaciers flowed west to southwest, whereas north of this latitude, paleo-iceflow was north to northwest (Figure 4, Figure 5). Exceptions to the regional flow directions occurred along Teeta, Cayuse and Colonial creeks where northeast flow occurred, and around Le Mare Lake where ice flow was to the south (Figure 4). Divergent flow occurred as montane valley glaciers entered lowland and coastal regions. By the glacial maximum (*circa* 15 000 years BP), valley glaciers were confluent with large west-flowing ice streams occupying Quatsino Sound and Klaskino Inlet. These glaciers probably formed a large piedmont apron as they flowed over Brooks Bay (*cf.* Luternauer *et al.*, 1989). At this time, a stable surface elevation for ice cap development varied from 880 metres above sea level in the east to 600 metres above sea level along the western seaboard. Ice thickness greater than 900 metres was attained by major glaciers occupying Neroutsos Inlet and Quatsino Sound. Elsewhere, ice thickness ranged from 670 metres in eastern montane valleys to 520 metres in western coastal areas. During full glacial conditions, approximately 2% of the map area was ice-free.

In front of advancing ice margins, glaciofluvial sediments were deposited along valley floors. Much of the evidence for these deposits has been removed by subsequent glaciation. However, observed deposits at Cleagh Creek, for example, are presumed to be correlative with Port McNeill advance sediments (*cf* Howes, 1983). In most areas, glacially streamlined bedrock is directly overlain by Fraser Glaciation lodgment or basal melt-out till. The tills form extensive ground moraine cover over much of the study area. Above the glacial limit, bedrock was subject to frost shatter, producing localized solifluction deposits and talus.

At the start of deglaciation, the altitude of the local equilibrium line rose above the maximum elevation of the area (*cf.* Fulton, 1991). In coastal areas and lower valley reaches, glaciers were isolated from source areas and downwasted *in situ*. This resulted in deposition of hummocky ground moraine comprising ablation till. Kames, eskers, terraced spillways and meltwater channels formed near to these moraines and indicate a complex pattern of ice retreat. Meltwater drained first to outlets at Side Bay, Klaskino Inlet, Klootchlimmis and Cleagh creeks, and then by supraglacial channels formed on remnant glacier lobes in Quatsino Sound and Side Bay to ice-free areas of the continental shelf. Glaciofluvial and glaciolacustrine deposits were graded to local base levels at 210, 152, 90, 60 and 30 metres elevation. Base levels relate to five progressively lower, stable ice-surface elevations during retreat (Figure 5A-D), and not marine incursion limits attributed to glacio-isostatic depression (*cf.* Howes, 1983; Luternauer *et al.*, 1989).

In coastal regions, glacio-isostatically depressed areas were inundated to a maximum depth of 20 metres above sea level. In these areas, glacial and deglacial units were locally reworked and subsequently exposed by rebound during the Holocene. Terrestrial glacial sediments on slopes were extensively remobilized and redeposited. Elsewhere, glacial deposits were modified *in situ* through pedogenesis. Where underlying geology is dominated by acidic Bonanza Group volcanics, podzols with distinctive aluminum and iron-rich B-horizon hardpans developed (Bobrowsky and Meldrum, 1994). Fluvial deposits of variable thickness were deposited along most valley floors, and overlie most older units. Organic deposits are rare and restricted to poorly drained depressions along valley floors.

CONCLUDING REMARKS

Fieldwork and findings in this paper present the final field component of a drift exploration program on northern Vancouver Island. Although detailed geochemical and lithological sampling was undertaken, data interpretation remains outstanding. Combining information from detailed logging, mapping of sediments, and paleoice-flow patterns will provide a powerful interpretative tool for these data.

To facilitate future drift exploration, we have ranked Quaternary deposits described in this paper according to their potential utility for geochemical and lithological sampling (*cf.* Bobrowsky *et al.*, 1994; Proudfoot *et al.*, 1994; Table 4). Lodgement till (facies A), basal melt-out till (facies B) and some colluvium

TABLE 4: DRIFT SAMPLING MATRIX

Drift Sampling Category[a]	I	II	III	IV	V
Terrain Unit[b]	R Mv Cv	Mb Cb Cv/M	Mx Cx Mh/M	FG F	LG W
Facies Unit	A B D	A B D	A B D C/A	E G	F H
Drift Thickness	< 1 m	> 1 m	< 10 m	< 10 m	< 10 m
Transport Distance	10s of metres	10s to 100s of metres	10s to 100s of metres	10s to 1000s of metres	10s to 1000s of metres
Derivative Phase	1st	1st	1st 2nd	2nd 3rd	3rd 4th
Genetic Interpretation	Very Easy	Easy	Moderate	Difficult	Very Difiicult
Geochemical and Pebble Sampling Interpretation	Very Easy	Easy	Moderate	Difficult	Very Difficult

a Drift Sampling Category. I - very high; II - high; III - moderate; IV - low ; V - very low. Categories refer to their potential utility, or favourablity for drift sampling based on: the type of facies and terrain unit; drift thickness and proximity of units to parent material or bedrock; transport distance and transport direction; derivative phase (*cf.* Shilts, 1993); and ease of interpretation of data (*cf.* Bobrowsky *et al.*, 1994; Proudfoot *et al.*, 1994).

b Terrain units (after Howes and Kenk, 1988). C - colluvium; M - till; FG - glaciofluvial sediment; LG - glaciolacustrine sediments; F - fluvial sediment; W - marine sediment. v - veneer (< 1 m); b - blanket (> 1 m); x - complex or combined units; h - hummocky. Mh/M - upper unit (Mh) stratigraphically overlies lower unit (M) ; C/A - upper facies (C) stratigraphically overlies lower facies (A)

(facies D) represent first derivative products of erosion and deposition with relatively simple and short transport histories (*cf.* Shilts, 1993). Where these deposits form thin veneers over bedrock (Mv, Cv), they rank as highly favourable deposits for drift sampling (category I; Table 4). The second category of favourable deposits (category II; Table 4) includes blanket deposits of lodgement and melt-out till (Mb), colluvium (Cb), and colluvial veneers overlying till (Cv/M). Moderately favourable deposits for sampling (category III) include complex sedimentary units (e.g. Mx, Cx, Mh/M), comprising basal tills, colluvium and ablation till (facies C). Less favourable deposits (category IV; Table 4) include glaciofluvial (facies E) and fluvial sediments (facies G). These deposits form thick sedimentary units (FGb, Fb) with transport distances ranging from tens to thousands of metres (Table 4). Third and fourth derivative products are represented by glaciolacustrine (facies F) and marine sediments (facies H). They form simple sedimentary units (LGb, Wb), but because of complex histories and potentially long transport distances, they are the least favourable sampling media (category V; Table 4). We recommend that future exploration in the map area focus on drift sample categories I and II.

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$^{40}Ar/^{39}Ar$ GEOCHRONOMETRY OF IGNEOUS ROCKS IN THE QUATSINO - PORT McNEILL MAP AREA, NORTHERN VANCOUVER ISLAND (92L/12, 11)

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Keywords: geochronometry, $^{40}Ar/^{39}Ar$ dating, Island Plutonic Suite, Vancouver Island, Rupert Stock, Nahwitti Batholith, Glenlion Stock, Jurassic magmatism, Bonanza Group

INTRODUCTION

Previous geochronological studies of early Mesozoic igneous rocks on Vancouver Island have primarily used conventional K-Ar dating techniques to broadly establish an Early to Middle Jurassic age for volcanic lithologies of the Bonanza Group and intrusions of the Island Plutonic Suite. In the Cape Scott (102I) - Alert Bay (92L) area, for example, some 24 K-Ar age determinations have been made on mineral separates and whole-rocks (University of British Columbia Geochronological Database) that span a range from 184 Ma to 105 Ma or latest Early Jurassic to latest Early Cretaceous [according to the time scale of Harland *et al.* (1990) and using dates recalculated with the new decay constants recommended by Steiger and Jäger (1977)]. Even though a considerable number of samples have been dated, it is presently unclear if this spread in K-Ar dates primarily reflects substantially different ages of emplacement, partial thermal resetting of the K-Ar system or slow cooling following emplacement. Compounding these uncertainties are systematic differences between the materials that were used to date the volcanic and plutonic assemblages. All Bonanza age determinations rely exclusively on poorly characterized whole-rock samples whereas variably altered hornblende and biotite separates (commonly with impurities) have provided dates for the Island Plutonic Suite. Although there is some overlap of dates between the volcanic (105-163 Ma) and plutonic (184-148 Ma) rocks, the predominantly younger K-Ar dates obtained from the Bonanza are all considered to be minimum (cooling) ages only. This interpretation is necessary in order to reconcile fossil data which, in all but a single case (discussed later), have established an early Sinemurian to late Pliensbachian (middle Early Jurassic) age for the Bonanza Group on Vancouver Island (*c.f.* Muller *et al.*, 1974). The widely embraced concept that Jurassic volcanism is contemporaneous with plutonism on northern Vancouver Island is thus not supported by existing data.

In order to better resolve some of these uncertainties, we have begun to apply $^{40}Ar/^{39}Ar$ geochronometry to selected rock suites to try to obtain more precise data concerning the age of pluton emplacement and the late thermal history of the region. In this preliminary report,

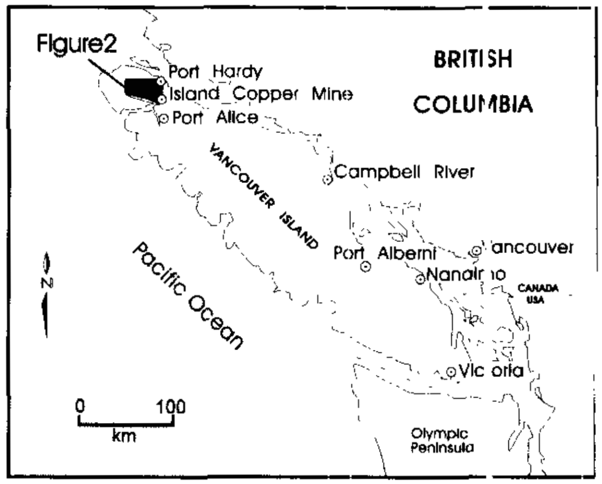

Figure 1. Location of Quatsino-Port McNeill map area.

we present $^{40}Ar/^{39}Ar$ age spectra for intrusions of the Island Plutonic Suite in the Quatsino - Port McNeill map area. The samples were collected as part of the regional mapping component of the Northern Vancouver Island integrated project (Nixon *et al.*, 1994). They represent hornblende and biotite-bearing granitoids from the Nahwitti batholith, and the Glenlion and Rupert stocks, as well as a high-level hornblende-phyric dike intruding the Bonanza Group. The $^{40}Ar/^{39}Ar$ age data reported below are combined with existing K-Ar and Rb-Sr dates, recently documented fossil occurrences and other new $^{40}Ar/^{39}Ar$ age spectra for hydrothermal minerals in acid sulphate-altered volcanic rocks of the Bonanza Group (Panteleyev *et al.*, this volume) in order to re-examine temporal relationships between Jurassic plutonism and volcanism in northern Vancouver Island.

GEOLOGICAL SETTING

The tectonic setting and regional geology of northern Vancouver Island were recently summarized by Nixon *et al.* (1994). Briefly, the oldest stratigraphic components in the Quatsino - Port McNeill area are the Upper Triassic Vancouver Group, which consists of a submarine to subaerial sequence of tholeiitic flood basalts (Karmutsen Formation) capped by thinly bedded to massive lime mudstone (Quatsino Formation) and overlain by thinly bedded and intercalated calcareous to noncalcareous siliciclastics and micritic limestone. The Upper Triassic lithologies are succeeded upwards by a thick Lower Jurassic sequence of submarine to subaerial, mafic to

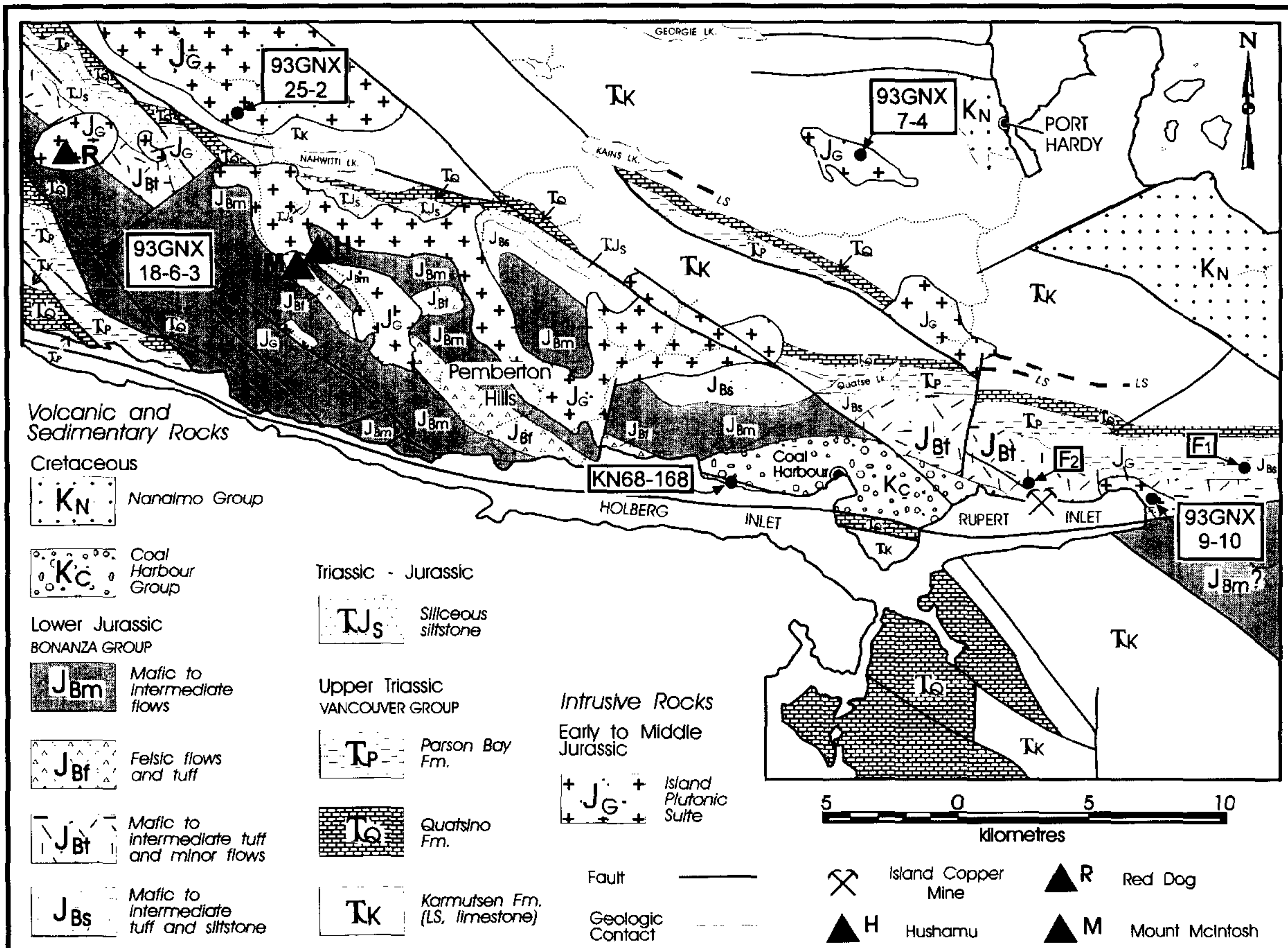

Figure 2: Generalized geology of Quatsino - Port McNeill area showing $^{40}Ar/^{39}Ar$ sample sites and other conventional K-Ar (KN68-168) and fossil (F_1, F_2) localities discussed in the text.

felsic arc volcanic and sedimentary rocks of the Bonanza Group. These older strata are unconformably overlain by an uppermost Jurassic(?) to Cretaceous marine and nonmarine succession of fine to coarse arc-derived clastic rocks. Intrusive rocks comprise stocks and batholiths of the Island Plutonic Suite and their associated porphyritic phases, and mafic to felsic dikes and sills of Karmutsen, Bonanza and Tertiary age. The geologic elements of Vancouver Island form the southern tip of the Wrangellia tectonostratigraphic terrane which extends northwards through the Queen Charlottes into southeastern Alaska.

SAMPLE DESCRIPTIONS

Granitoids of the Island Plutonic Suite are the focus of this dating study. Descriptions of these intrusions are provided by Carson (1973), Muller *et al.* (1974), Cargill *et al.* (1976), and Nixon *et al.* (1994). The rocks are generally medium-grained, equigranular hornblende-bearing diorite and quartz diorite, monzodiorite to quartz monzodiorite and granodiorite (nomenclature after Le Maitre, 1989). Propylitic and argillic alteration assemblages and skarn mineralization are locally well developed. Important porphyry copper-gold mineralization occurs at the Island Copper mine on Rupert Inlet and at Red Dog and Hushamu farther west (Figure 2).

Sample 93GNX25-2 comes from the southern margin of the Nahwitti batholith. This body is exposed north of Nahwitti Lake and extends to the north coast of the Island (Figure 2). It is a coarse to medium-grained (2-6 mm) equigranular hornblende-biotite quartz diorite to quartz monzodiorite containing 5% or more modal quartz and about 10 to 20% hornblende. A marginal zone up to a kilometre wide contains subequal proportions of biotite and hornblende and sparse xenoliths of feldspathic amphibolite. The plagioclase in this sample is moderately saussuritized; hornblende is weakly chloritized, unzoned and free of inclusions; and biotite is typically well chloritized with oxides accompanying chlorite along cleavages.

The Glenlion stock is exposed in roadcuts along the Holberg - Port Hardy road and in the headwaters of Glenlion Creek. It is a medium to coarse-grained, equigranular to weakly porphyritic (<7 mm) hornblende diorite with intrusion breccias (agmatites) containing xenoliths of variably pyritized and silicified Karmutsen lavas at its margins. Rare centimetre-scale modal layering of hornblende and feldspar is developed locally within the stock in zones up to several metres wide. Sample 93GNX7-4 has weakly sericitized feldspars, fresh poikilitic hornblende that includes all the other minerals, .and somewhat chloritized biotite.

The Rupert stock is a medium to coarse-grained, equigranular to porphyritic granodiorite containing up to 30% modal quartz, 60% feldspar, about 10% chloritized biotite and trace amounts of hornblende. Outcrops in the eastern part of the intrusion locally exhibit intense argillic alteration. The westnorthwest-trending quartz-feldspar porphyry dike (100-150 m wide) that hosts porphyry copper-gold mineralization at Island Copper is considered to be an offshoot of the Rupert stock. Coarsely porphyritic dikes of quartz (<1.5 cm) and plagioclase (<1 cm), rarely accompanied by hornblende (<1.5 cm) with hiatal to seriate textures are also found southwest of Quatse Lake and on Rupert Main logging road southeast of Rupert stock. Sample 93GNX9-10 contains severely altered feldspars, biotite is extensively chloritized (> 50 vol. %) and minor hornblende is altered to chlorite and carbonate.

Hornblende-bearing porphyritic dikes and sills, apophyses of Island Plutonic Suite granitoids, are widespread in the Bonanza Group and Upper Triassic sedimentary succession. Sample 93GNX18-6-[illegible] was collected from a coarsely porphyritic dike-sill complex containing large (≤2 cm) euhedral hornblende crystals set in a fine-grained quartzofeldspathic groundmass. Except for a weakly chloritized rim, the amphibole crystals are unaltered, and unzoned and free of inclusions. Soft-sediment deformation structures and, locally, a flow breccia occur at the margin of this dike-sill complex, which intrudes thinly bedded intra-Bonanza sedimentary rocks.

$^{40}Ar/^{39}Ar$ ANALYTICAL METHODS

Mineral separates were prepared using a Frantz magnetic separator, heavy organic liquids and, where appropriate, hand-picking. Samples and 15 flux monitors (standards) were irradiated with fast neutrons in position 5C of the McMaster nuclear reactor (Hamilton, Ontario) for 29 hours. The monitors were distributed throughout the irradiation container, and J-values for individual samples were determined by interpolation.

Step-heating experiments and analysis of the monitors were done in a high-purity silica tube, heated using a Lindberg tube furnace. The bakeable, ultra-high vacuum, stainless-steel argon extraction system is operated on-line to a substantially modified, A.E.I MS-10 mass-spectrometer run in the static mode. Measured mass-spectrometric ratios were extrapolated to zero time, corrected to an $^{40}Ar/^{36}Ar$ atmospheric ratio of 295.[illegible], and corrected for neutron induced ^{40}Ar from potassium, and ^{39}Ar and ^{36}Ar from calcium. Dates and errors were calculated using formulae given by Dalrymple *et al.* (1981), and the decay constants recommended by Steiger and Jäger (1977). Inverse isochrons were calculated using the procedures of Hall (1981). The errors given in Table 1 were used to plot the age spectra shown in Figures 3 and 4. Errors represent analytical precision at the 2σ level of confidence, assuming no error in the J-value.

RESULTS

Analytical data for seven mineral separates including three hornblendes, three biotites and a plagioclase, are listed in Table 1 and shown as age spectra in Figures 3 and 4. Inverse isochrons for selected experiments are also

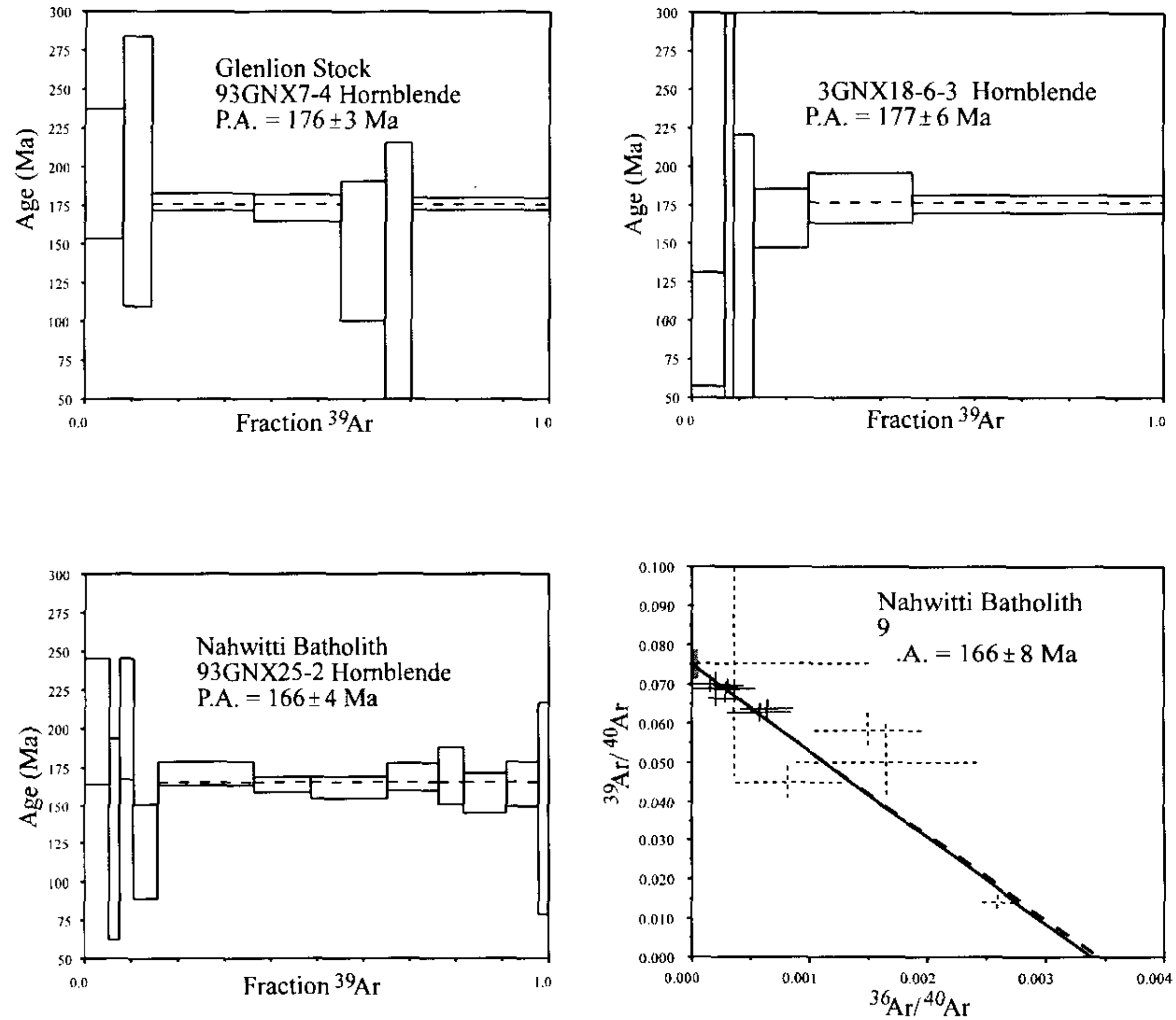

Figure 3: $^{40}Ar/^{39}Ar$ results of step heating experiments for hornblende. The horizontal, dashed line on the age spectra is the plateau segment date (see Table 1) and indicates which steps were included in the age calculation. The heavy dashed line on the $^{40}Ar/^{39}Ar$ inverse isochron plot for 93GNX25-2 hornblende is the best-fit line through the solid crosses; the size of the crosses is an indication of the 2σ error associated with the ratios for each step. Crosses with dotted lines were not included in the age calculation. The solid line connects the best-fit, inverse $^{40}Ar/^{39}Ar$ ratio to the inverse atmospheric $^{40}Ar/^{36}Ar$ ratio. The near-correspondence of the two lines indicates that this hornblende does not contain excess argon. All quoted errors are at the 2σ level of confidence.

plotted. All data are shown with 2σ error bars. Table 1 also contains the ratios used to calculate $^{40}Ar/^{39}Ar$ inverse isochron (correlation) ages.

HORNBLENDE

The three hornblende separates yield well defined plateaus or plateau segments for more than 70% of the ^{39}Ar released, in spite of their low estimated potassium abundances (<0.4% K).

Hornblende from the Glenlion stock (93GNX7-4) has an integrated date of 170±11(2σ) Ma. The three largest steps, accounting for 70% of the ^{39}Ar released, yield a plateau date of 176±3(2σ) Ma. An inverse isochron for this sample yields an identical date and reveals no anomalous initial argon. The best estimate of the cooling age for hornblende in this rock is considered to be the plateau date of 176±3(2σ) Ma.

Hornblende from the southern part of the Nahwitti batholith (93GNX25-2) has an integrated date of 165±5 Ma and a well defined, seven-step plateau for 82% of the ^{39}Ar released. The plateau date (166±4 Ma) and the inverse isochron date (166±8 Ma) agree and there is no indication of excess argon despite the low estimated potassium content (*ca.* 0.2% K). The plateau date is

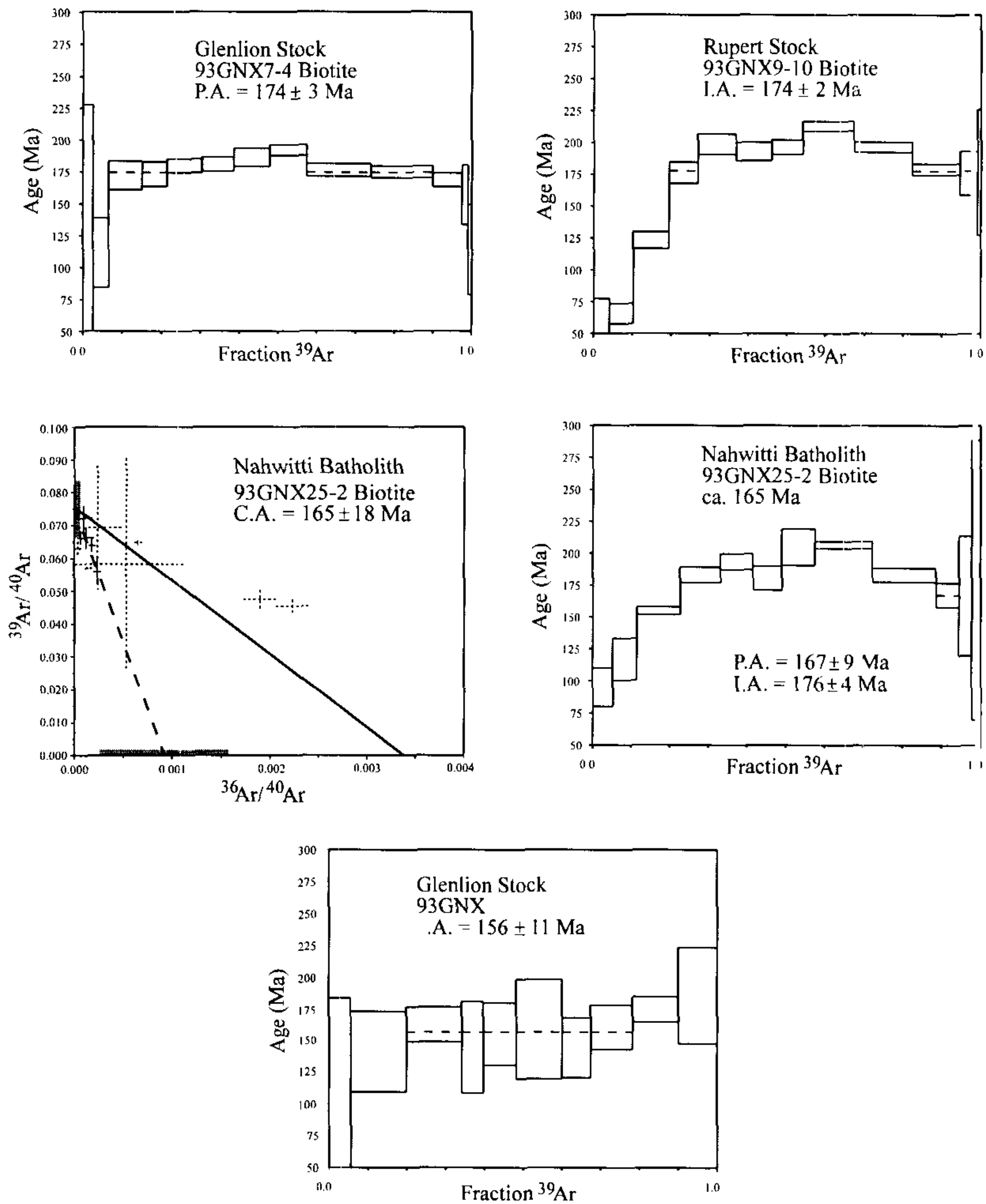

Figure 4: $^{40}Ar/^{39}Ar$ results of step heating experiments for biotite and plagioclase. The $^{40}Ar/^{39}Ar$ inverse isochron for 93GNX25-2 biotite indicates that this sample contains excess argon with an initial $^{40}Ar/^{36}Ar$ ratio much greater than atmospheric argon. Quoted errors are at the 2σ level of confidence.

TABLE 1 - ANALYTICAL DATA FOR HORNBLENDE, BIOTITE AND PLAGIOCLASE MINERAL SEPARATES.

93GNX18-6-3 Hornblende 60/80

J Value: 0.007165 ± 0.000044 Volume ^{39}Ar: 18.98 x 10^{-9} cm^3 NTP Mass: 203.0 mg Approximately 0.18% K; 3.85% Ca
Integrated Age: 166.6 ± 12.6 Ma Initial $^{40}Ar/^{36}Ar$: 301.4 ± 176.9 (MSWD = 1.16, isochron between -0.41 and 3.83)
Correlation Age: 175.5 ± 6.8 Ma (86.8% of ^{39}Ar, steps marked by >) Plateau Age: 177.0 ± 6.4 Ma (75.2% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	$^{36}Ar/^{40}Ar$	$^{39}Ar/^{40}Ar$	r	Ca/K	% $^{40}Ar^*$	% ^{39}Ar	$^{40}Ar^*/^{39}K$	Age ± 2σ
800	25.364 ± 0.852	1.335 ± 0.013	0.047 ± 0.389	20.623 ± 0.299	0.057 ± 0.013	4.317 ± 0.863	0.00178785 ± 0.00063146	0.062929 ± 0.003687	0.007	28.26	32.97	7.04	7.496 ± 3.001	94.4 ± 36.8
875	41.685 12.225	0.353 0.042	0.104 0.139	7.371 2.261	0.130 0.036	4.545 0.909	0.00302950 0.00000000	0.009382 0.000000	0.675	38.19	8.01	1.86	11.168 46.388	138.9 555.2
950	24.038 3.331	0.815 0.038	0.251 0.056	8.404 0.906	0.059 0.022	4.934 0.987	0.00212325 0.00000000	0.042444 0.000000	0.266	18.86	26.95	4.29	8.778 9.125	110.0 110.9
1000>	40.963 2.004	2.196 0.037	0.847 0.047	23.518 0.704	0.045 0.010	5.339 1.068	0.00058323 0.00014566	0.061322 0.002026	-0.035	19.60	67.54	11.57	13.497 1.637	166.5 19.3
<1050>	75.232 4.792	4.191 0.044	1.660 0.059	44.977 0.496	0.060 0.011	5.920 1.184	0.00041103 0.00000000	0.060149 0.000000	0.091	19.64	76.31	22.08	14.606 1.397	179.6 16.4
<1200>	154.902 2.355	10.092 0.053	4.562 0.051	112.285 0.594	0.067 0.015	9.653 1.931	0.00003911 0.00000003	0.069111 0.000000	-0.245	20.36	87.06	53.16	14.302 0.496	176.0 5.8

93GNX7-4 Hornblende 60/80

J Value: 0.007191 ± 0.000036 Volume ^{39}Ar: 33.27 x 10^{-9} cm^3 NTP Mass: 201.0 mg Approximately 0.32%K; 4.92% Ca
Integrated Age: 170.1 ± 11.5 Ma Initial $^{40}Ar/^{36}Ar$: 317.6. ± 321.6 (MSWD = 0.25, isochron between 0.18 and 2.63)
Correlation Age: 175.3 ± 16.2 Ma (84.7% of ^{39}Ar, steps marked by >) Plateau Age: 176.0 ± 3.4 Ma (70.5% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	$^{36}Ar/^{40}Ar$	$^{39}Ar/^{40}Ar$	r	Ca/K	% $^{40}Ar^*$	% ^{39}Ar	$^{40}Ar^*/^{39}K$	Age ± 2σ
800>	85.963 ± 7.551	2.741 ± 0.218	1.160 ± 0.117	5.455 ± 0.635	0.145 ± 0.018	4.317 ± 0.863	0.00157919 ± 0.00026307	0.033565 ± 0.004115	0.414	3.64	50.13	8.24	15.890 ± 3.591	195.2 ± 41.8
875>	52.569 11.772	1.987 0.441	1.461 0.329	7.054 1.640	0.072 0.019	4.545 0.909	0.00114291 0.00000000	0.041323 0.000000	0.419	6.50	59.42	5.97	16.027 7.494	196.8 87.2
<950>	124.463 1.405	7.317 0.081	12.006 0.135	50.472 0.603	0.079 0.010	4.934 0.987	0.00041273 0.00000000	0.061048 0.000000	-0.094	12.62	81.13	21.99	14.383 0.469	177.6 5.5
<1000>	102.894 0.740	6.238 0.044	13.157 0.094	53.161 0.407	0.066 0.015	5.339 1.068	0.00035559 0.00007892	0.063702 0.000481	-0.144	15.60	80.81	18.75	14.049 0.733	173.6 8.6
1030	53.070 10.445	3.225 0.412	5.967 0.762	30.468 5.740	0.060 0.013	5.662 1.132	0.00070343 0.00000000	0.067736 0.000000	0.399	17.29	66.31	9.69	11.695 3.782	145.7 45.3
1060	23.668 19.583	1.873 0.587	2.782 0.872	12.869 7.333	0.048 0.030	6.063 1.213	0.00140162 0.00000058	0.106221 0.000031	0.646	12.58	39.36	5.63	5.515 11.651	70.2 45.4
<1200>	158.254 0.670	9.887 0.041	19.420 0.083	116.230 0.725	0.090 0.011	9.653 1.931	0.00018717 0.00000000	0.066152 0.000000	-0.451	21.51	83.02	29.72	14.281 0.333	176.4 3.9

93GNX7-4 Plagioclase 40/60

J Value: 0.007179± 0.000040 Volume ^{39}Ar: 32.41 x 10^{-9} cm^3 NTP Mass: 203.0 mg Approximately 0.31% K; 2.55% Ca
Integrated Age: 156.4 ± 10.1 Ma Initial $^{40}Ar/^{36}Ar$: 578.7 ± 544.2 (MSWD = 0.70, isochron between 0.29 and 2.41)
Correlation Age: 140.8 ± 36.5 Ma (67.1% of ^{39}Ar, steps marked by >) Plateau Age: 156.5 ± 11.1 Ma (58.3% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	$^{36}Ar/^{40}Ar$	$^{39}Ar/^{40}Ar$	r	Ca/K	% $^{40}Ar^*$	% ^{39}Ar	$^{40}Ar^*/^{39}K$	Age ± 2σ
500	58.441 ± 9.993	1.807 ± 0.157	0.540 ± 0.095	4.431 ± 1.236	0.150 ± 0.025	4.037 ± 0.807	0.00249638 ± 0.00064624	0.033191 ± 0.006769	0.639	4.49	23.83	5.58	7.903 ± 6.896	99.6 ± 84.5
600	94.933 9.741	4.649 0.469	0.812 0.140	27.287 2.897	0.149 0.019	4.075 0.815	0.00141703 0.00000000	0.051048 0.000000	0.419	10.74	53.39	14.35	11.387 2.696	141.8 32.3
<700>	71.482 3.411	4.638 0.216	0.170 0.727	28.288 1.410	0.043 0.012	4.154 0.831	0.00031882 0.00000000	0.068747 0.000000	0.028	11.16	82.18	14.31	13.176 1.219	163.1 14.4
<750	32.826 3.494	1.808 0.177	0.066 0.569	9.236 1.008	0.042 0.013	4.221 0.844	0.00089159 0.00023017	0.063126 0.005040	0.152	9.35	61.95	5.58	11.668 3.056	145.1 36.5
<800>	48.879 3.282	2.727 0.181	0.079 0.744	10.690 0.750	0.053 0.014	4.317 0.863	0.00079729 0.00000000	0.061147 0.000000	0.100	7.17	67.92	8.42	12.501 2.144	155.1 25.5
<875>	48.879 3.282	2.727 0.181	0.079 0.744	10.690 0.750	0.053 0.014	4.317 0.863	0.00047717 0.00000007	0.067003 0.000004	0.203	5.29	78.08	11.83	12.820 3.340	158.8 39.6
<950	42.237 2.306	2.404 0.125	0.395 0.094	6.461 0.349	0.050 0.014	4.934 0.987	0.00085112 0.00000000	0.064456 0.000000	0.046	4.92	64.83	7.42	11.613 2.046	140.5 24.5
<1025>	57.689 3.946	3.490 0.198	0.457 0.156	9.339 0.556	0.044 0.009	5.604 1.121	0.00044257 0.00000000	0.067009 0.000000	0.067	4.90	77.11	10.77	12.972 1.540	160.6 18.3
1100>	72.104 1.230	3.825 0.059	0.509 0.173	12.320 0.206	0.063 0.010	6.752 1.350	0.00056954 0.00000000	0.058505 0.000000	-0.195	5.89	73.97	11.80	14.216 0.851	175.3 10.0
1200>	68.046 7.762	3.224 0.357	0.969 0.132	25.130 2.949	0.073 0.016	9.653 1.931	0.00058054 0.00183206	0.055020 0.060106	0.138	14.26	68.21	9.95	15.057 3.286	185.2 38.4

All volumes are x 10^{-9} cm^3 NTP. All errors are 2 x standard error.

93GNX7-4 Biotite 40/60

J Value: 0.007198 ± 0.000032 Volume ^{39}Ar: 105.13 x 10^{-9} cm^3 NTP Mass: 123.0 mg Approximately 1.67% K; 2.96% Ca

Integrated Age: 172.6 ± 3.9 Ma Initial ^{40}Ar/^{36}Ar: 412.8 ± 223.9 (MSWD = 1.48, isochron between 0.37 and 2.26)

Correlation Age: 172.7 ± 9.3 Ma (73.7% of ^{39}Ar, steps marked by >) Plateau Age: 174.3 ± 3.4 Ma (47.5% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar*	% ^{39}Ar	^{40}Ar*/^{39}K	Age ± 2σ
500	83.769 ± 17.288	2.727 ± 0.482	0.859 ± 0.166	2.570 ± 0.519	0.205 ± 0.067	4.037 ± 0.807	0.00239434 ± 0.00098992	0.034215 ± 0.009589	0.406	1.72	27.58	2.59	8.548 ± 9.772	107.7 ± 119.5
575	106.521 1.898	4.192 0.073	1.011 0.095	1.722 0.792	0.235 0.031	4.063 0.813	0.00215746 0.00000000	0.040947 0.000000	0.083	0.75	34.70	3.99	8.852 2.209	111.4 27.0
<650>	142.524 1.451	8.961 0.081	2.060 0.099	2.208 0.647	0.061 0.028	4.108 0.822	0.00033608 0.00000000	0.064850 0.000000	-0.023	0.45	87.19	8.52	13.889 0.939	171.9 11.1
<700>	109.969 1.496	6.677 0.063	1.493 0.186	0.878 0.261	0.056 0.017	4.154 0.831	0.00039347 0.00008368	0.063206 0.000593	-0.034	0.24	84.82	6.35	13.982 0.817	173.0 9.6
750>	150.154 0.558	9.455 0.034	2.202 0.124	1.567 0.128	0.043 0.015	4.221 0.844	0.00019274 0.00000000	0.064902 0.000000	-0.131	0.30	91.40	8.99	14.530 0.463	179.5 5.4
800>	144.400 1.720	8.513 0.084	1.978 0.103	1.523 0.330	0.067 0.012	4.317 0.863	0.00037035 0.00000002	0.060869 0.000000	-0.040	0.33	86.16	8.10	14.631 0.484	180.6 5.7
850>	156.529 1.094	9.591 0.066	2.398 0.123	2.838 0.180	0.040 0.019	4.455 0.891	0.00015854 0.00000000	0.063167 0.000000	-0.069	0.54	92.30	9.12	15.089 0.620	186.0 7.3
900	169.982 1.037	10.112 0.048	2.771 0.089	2.805 0.249	0.042 0.012	4.652 0.930	0.00015317 0.00000000	0.061256 0.000000	-0.138	0.51	92.57	9.62	15.586 0.361	191.8 4.2
<950>	272.578 0.687	17.512 0.066	7.653 0.031	18.192 0.288	0.083 0.025	4.934 0.987	0.00022912 0.00000000	0.065509 0.000000	-0.076	1.90	90.87	16.66	14.232 0.422	175.9 5.0
<1000>	251.666 0.684	16.750 0.078	13.417 0.051	39.651 0.983	0.062 0.021	5.339 1.068	0.00013588 0.00144843	0.068028 0.007942	-0.100	4.33	92.58	15.93	14.110 0.378	174.5 4.5
1050	120.731 2.356	7.994 0.121	4.298 0.090	15.171 0.467	0.045 0.008	5.920 1.184	0.00018044 0.00056195	0.069681 0.014689	-0.131	3.47	88.90	7.60	13.586 0.456	168.3 5.4
1100	30.554 0.028	1.708 0.160	1.345 0.020	6.356 0.885	0.032 0.009	6.752 1.350	0.00032231 0.00287023	0.071721 0.054759	-0.217	6.81	68.78	1.62	12.615 1.950	156.8 23.2
1200	20.812 1.197	0.938 0.037	0.964 0.051	6.133 0.584	0.043 0.008	9.653 1.931	0.00080802 0.00376582	0.083946 0.076281	-0.381	11.96	38.50	0.89	9.068 2.897	114.1 35.3

93GNX9-10 Biotite 40/60

J Value: 0.007216 ± 0.000026 Volume ^{39}Ar: 135.02 x 10^{-9} cm^3 NTP Mass: 102.0 mg Approximately 2.59% K; 1.12% Ca

Integrated Age: 173.9 ± 2.2 Ma Initial ^{40}Ar/^{36}Ar: 239.5 ± 722.9 (MSWD = 0.06, isochron between -0.41 and 3.83)

Correlation Age: 179.3 ± 23.1 Ma (24.3% of ^{39}Ar, steps marked by >) Plateau Age: 177.4 ± 4.7 Ma (24.3% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar*	% ^{39}Ar	^{40}Ar*/^{39}K	Age ± 2σ
500	112.008 ± 3.630	5.479 ± 0.175	2.243 ± 0.087	1.372 ± 0.638	0.289 ± 0.019	4.037 ± 0.807	0.00254705 ± 0.00019369	0.050812 ± 0.002388	0.312	0.46	23.72	4.06	4.868 ± 1.219	62.3 ± 15.3
575	160.158 3.564	8.313 0.185	2.766 0.095	2.069 0.257	0.397 0.013	4.063 0.813	0.00245656 0.00000000	0.053327 0.000000	0.397	0.46	26.58	6.16	5.140 0.632	65.7 7.9
650	213.459 3.537	12.517 0.206	3.685 0.098	1.131 0.153	0.307 0.018	4.108 0.822	0.00139939 0.00000000	0.059886 0.000000	0.175	0.17	57.38	9.27	9.793 0.531	123.2 6.5
<700>	163.377 3.113	10.075 0.183	3.395 0.104	0.898 0.353	0.068 0.020	4.154 0.831	0.00033792 0.00006272	0.063386 0.000863	0.014	0.16	87.52	7.46	14.201 0.706	176.0 8.3
750	227.869 5.746	13.345 0.332	4.399 0.133	0.827 0.140	0.041 0.016	4.221 0.844	0.00012075 0.00000000	0.059768 0.000000	0.012	0.11	94.46	9.88	16.134 0.693	198.7 8.9
800	206.914 4.996	12.405 0.299	3.693 0.142	0.709 0.301	0.042 0.011	4.317 0.863	0.00013663 0.00000001	0.061337 0.000001	0.012	0.10	93.77	9.19	15.645 0.614	193.0 7.2
850	189.092 3.265	11.036 0.190	3.724 0.095	2.561 0.158	0.044 0.010	4.455 0.891	0.00015499 0.00000000	0.059864 0.000000	-0.019	0.42	92.91	8.17	15.940 0.483	196.4 5.6
900	324.603 4.050	17.887 0.223	6.642 0.108	1.734 0.457	0.047 0.006	4.652 0.930	0.00009530 0.00000000	0.055992 0.000000	-0.033	0.18	95.60	13.25	17.357 0.329	212.9 3.8
950	333.415 4.780	20.054 0.286	6.119 0.122	2.610 0.044	0.045 0.008	4.934 0.987	0.00008530 0.00000000	0.061153 0.000000	-0.022	0.24	95.81	14.85	15.940 0.350	196.4 4.1
<1000>	249.711 4.721	16.565 0.228	4.446 0.112	3.825 0.676	0.035 0.006	5.339 1.068	0.00006702 0.00014064	0.067908 0.007679	-0.053	0.42	95.62	12.27	14.434 0.366	178.8 4.3
<1050>	97.963 2.024	6.116 0.119	1.681 0.112	4.248 0.579	0.039 0.029	5.920 1.184	0.00018928 0.00099360	0.066548 0.006717	-0.043	1.27	88.21	4.53	14.186 1.459	175.8 17.2
1200	25.344 3.217	1.227 0.110	0.922 0.095	10.081 1.275	0.029 0.012	9.653 1.931	-0.00037931 0.00408134	0.077942 0.088540	-0.310	15.04	65.71	0.91	14.268 4.199	176.8 49.6

All volumes are x 10^{-9} cm^3 NTP. All errors are 2 x standard error.

93GNX25-2 Hornblende 40/60

J Value: 0.007206 ± 0.000012 Volume ^{39}Ar: 35.47 x 10^{-9} cm^3 NTP Mass: 296.0 mg Approximately 0.23% K; 3.91% Ca
Integrated Age: 165.4 ± 4.7 Ma Initial ^{40}Ar/^{36}Ar: 286.3 ± 151.7 (MSWD = 1.08, isochron between 0.37 and 2.26)
Correlation Age: 165.6 ± 8.1 Ma (82.2% of ^{39}Ar, steps marked by >) Plateau Age: 165.6 ± 3.6 Ma (82.2% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar*	% ^{39}Ar	^{40}Ar*/^{39}K	Age ± 2σ
700	136.964 ± 4.374	1.865 ± 0.055	0.693 ± 0.084	2.395 ± 0.089	0.359 ± 0.016	4.154 ± 0 831	0.00259184 ± 0.00014786	0.014035 ± 0.000625	0.423	2.35	22.56	5.26	16.680 ± 3 499	204 8 ± 40.6
800	20.657 2.776	0.820 0.054	0.274 0.112	2.320 0.518	0.042 0.012	4 317 0 863	0 00165362 0.00000000	0.050163 0.000000	0.294	5.18	39.55	2 31	10.194 5 424	127.9 65.7
875	27.661 1.447	1.047 0.054	0.963 0.059	7.705 0.512	0.036 0.010	4.545 0.909	0 00081600 0.00000000	0 045116 0 000000	-0 019	13.47	61.25	2 95	16.820 3 346	206.4 38.8
975	35.963 2.055	1.824 0.047	2.888 0.080	16.066 0.714	0.067 0.014	4.781 0.956	0 00149954 0.00022899	0 058242 0 002250	0.134	16.12	44.85	5.14	9.562 2.532	120 2 30.8
<976>	114 591 1.144	7.300 0.069	13.629 0.133	70.019 0.713	0.066 0.015	5.119 1.024	0.00028507 0.00000000	0.066394 0 000000	-0 100	17 55	82.73	20.58	13 793 0.650	170.9 7.7
<1000>	68.459 0.659	4.385 0.040	8 234 0.083	41 835 0.387	0 047 0.005	5.339 1.068	0.00029529 0.00000003	0.069170 0.000000	-0.388	17.46	79.40	12.36	13 196 0.414	163.9 4.9
<1020>	89.152 1.316	5 855 0.086	10 843 0.164	56 907 0.905	0 059 0.010	5.547 1 109	0.00030992 0.00000000	0.069730 0.000000	-0.141	17.79	80.23	16.51	13.028 0.602	161.9 7.1
<1040>	61.499 1.082	3.918 0.067	7 081 0.124	38.568 0.670	0 038 0.009	5.786 1 157	0 00016125 0.00000000	0.070007 0.000000	-0.238	18.02	81 39	11 04	13.604 0 747	168.7 8.9
<1060>	34.472 1.272	1 965 0.040	3.550 0.075	18.774 0.616	0.031 0.009	6.063 1 213	0 00020016 0.00000000	0 068862 0.000000	-0.239	17.49	73 30	5 54	13.663 1 546	169.4 18.3
<1080>	57.504 1.327	3.272 0.051	6.438 0.103	33.297 0.754	0.063 0.011	6 383 1.277	0 00064308 0.00090425	0 063707 0 010044	-0.144	18.62	67 53	9 23	12.714 1.095	158.2 13.0
<1120>	46.274 0.347	2.468 0.018	5.632 0.046	28.385 0.220	0.054 0.010	7.178 1.436	0.00057973 0.00079419	0 062769 0 007008	-0.354	21.05	65 28	6 96	13.202 1.210	163.9 14 4
1200	19.607 3.148	0.752 0.055	1.562 0.119	7.010 1.194	0.038 0.010	9 653 1.931	0.00036365 0.00292756	0.075274 0.073336	-0.180	17.05	42.53	2 12	11.857 5.742	147.9 68.8

93GNX25-2 Biotite 40/60

J Value: 0.007214 ± 0.000028 Volume ^{39}Ar: 125.77 x 10^{-9} cm^3 NTP Mass: 93.0 mg Approximately 2.64% K; 2.25% Ca
Integrated Age: 175.9 ± 3.8 Ma Initial ^{40}Ar/^{36}Ar: 1083.2 ± 775.0 (MSWD = 2.84, isochron between 0.18 and 2.63)
Correlation Age: 164.6 ± 18.2 Ma (48.6% of ^{39}Ar, steps marked by >) Plateau Age: 167.4 ± 9.4 Ma (5.9% of ^{39}Ar, steps marked by <)

	Volumes						Correlation Ratios							
Temp (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar*	% ^{39}Ar	^{40}Ar*/^{39}K	Age ± 2σ
500	149.241 ± 4.588	6 596 ± 0.197	2 444 ± 0.113	5 541 ± 0.711	0.338 ± 0.022	4.037 ± 0.807	0 00222962 ± 0.00016534	0 045461 ± 0.001997	0.303	1 54	32 87	5 24	7.504 ± 1.217	95.1 ± 15 0
575	167 900 7.075	7.778 0.327	2.333 0.127	4.051 0.286	0 325 0.024	4.063 0 813	0.00189311 0.00000000	0 047523 0.000000	0.349	0 95	42.75	6.18	9.271 1.337	116 8 16 3
650	222.830 1.876	14.168 0.119	3.832 0.092	3.380 0.600	0 157 0 009	4.108 0 822	0.00065139 0.00000000	0.064886 0 000000	0.018	0 44	79.00	11.27	12.445 0.248	155 1 3.0
700>	210.259 5.420	13.155 0.217	3 907 0.103	2.092 0.392	0 052 0.007	4.154 0.831	0.00018128 0.00001847	0.063939 0.001003	0.064	0 29	92.53	10.46	14.802 0.505	183 0 5 9
750	171.871 4.083	10 550 0.250	3 049 0.131	0 967 0.235	0.021 0.004	4.221 0.844	0 00003988 0.00000000	0.063040 0 000000	-0.058	0.17	96 18	8.39	15.676 0.551	193 3 6 4
800>	144.689 5.075	9 267 0.295	2 602 0.122	1 598 0.449	0.032 0.011	4.317 0.863	0 00012012 0.00000002	0.066133 0.000001	0.009	0.32	93 31	7.37	14.584 0.799	180.5 9.4
850>	198.453 9.887	10 822 0 523	3 556 0.224	2 015 0 327	0.061 0.007	4.455 0.891	0 00023391 0.00000000	0.055866 0.000000	0.194	0 34	90 78	8.60	16.663 1.233	204.8 14.3
900	331 247 1.289	18.563 0 065	5 978 0 082	4 311 0.040	0.063 0.014	4.652 0.930	0 00014223 0.00000000	0.056924 0.000000	-0.092	0.42	94 20	14.76	16.829 0.240	206 7 2.8
950>	314.897 6.380	20.508 0 415	6.339 0.145	8.356 0.438	0.039 0.011	4.934 0.987	0 00006663 0 00000000	0.066271 0.000000	-0.005	0.75	96.11	16.31	14.792 0.462	182.9 5.4
<1000>	108.208 4.564	7.412 0 195	2.828 0.095	8.470 0.529	0.030 0.009	5.339 1.068	0 00009316 0 00048652	0.072148 0.020597	-0.036	2.09	91.67	5.89	13.479 0.788	167.4 9.3
1050	65.670 12.061	4.136 0 757	1.215 0.252	5.219 0.969	0.036 0.014	5.920 1.184	0.00023748 0.00143019	0 069299 0.111876	0.128	2.31	83.84	3.29	13 418 3 942	166.7 46.8
1200	57.891 20.397	2.813 0.984	1.007 0.373	12 596 4.426	0.061 0.026	9.653 1.931	0.00052469 0.00128759	0 058253 0.069721	0.274	8.19	68.65	2.24	14 505 9 289	179.5 109.5

All volumes are x 10^{-9} cm^3 NTP. All errors are 2 x standard error.

considered the best estimate of the time of cooling of the southern part of this batholith.

Hornblende from a hornblende-phyric dike (93GNX18-6-3) intruding the Bonanza Group has an integrated date of 167±13 Ma . However, the two highest temperature steps yield a plateau date of 177±6 Ma. The data yield an inverse isochron age of 176±6 Ma and suggest that this low-potassium amphibole contains initial argon with a non-atmospheric ratio. The plateau date of 177±6 Ma is considered the best estimate of the age of this dike.

BIOTITE

The three biotite separates contain appreciable intergrown chlorite which is believed to be responsible for their anomalously low estimated potassium contents (<3% K). The heating experiments yield distinctively hump-shaped age spectra. Following Ruffet *et al.* (1991), only the "shoulders" of the hump were used to calculate the plateau segment date which is taken as a maximum estimate of the cooling age for biotite in these rocks.

Biotite from the Glenlion stock (93GNX7-4) has an integrated date of 173±4 Ma. The plateau date and the inverse isochron date agree within analytical uncertainty at 174±3 Ma and 173±9 Ma, respectively. The 174±3 Ma plateau date for 48% of the ^{39}Ar released is believed to be the best estimate of the cooling age for this biotite.

Biotite from the Rupert stock (93GNX9-10) yields an integrated date of 174±2 Ma. This spectrum has the most pronounced hump-shape and only 24% of the ^{39}Ar released defines the shoulders of the hump. The three steps involved define a plateau date of 177±5 Ma. A poor inverse isochron date of 179±27 Ma is in agreement with the plateau date which is considered to be a maximum cooling age for biotite in this pluton.

Biotite from the southern margin of the Nahwitti batholith (93GNX25-2) yields an integrated date of 176±4 Ma. This date is 10 Ma older than the hornblende date for the same rock. The spectrum has an extreme hump-shape and only one step defines a plateau segment date of *circa* 167 Ma. The fact that biotite and hornblende in this rock show a reversal of the age discordance normally observed suggests that the biotite contains excess argon. An inverse isochron (Figure 4) for the biotite supports this conclusion and reveals two-components of initial argon. Most of the steps with dates greater than the hornblende date plot on a line with an initial ^{40}Ar/^{36}Ar ratio of 1099 and yield a date of 165±18 Ma. This date is analytically indistinguishable from the hornblende date of 166±4 Ma and is the preferred biotite cooling age for this part of the batholith.

PLAGIOCLASE

Plagioclase from the Glenlion stock (93GNX7-4) has an integrated date of 156±10 Ma and a plateau date of 156±11 Ma for 73% of the ^{39}Ar released. An inverse isochron (not shown) for this experiment reveals two components of initial argon and yields a poorly constrained date of 141±38 Ma. The best cooling age for this sample is regarded as the plateau date of 156±11 Ma.

SUMMARY OF RESULTS AND DISCUSSION

The ^{40}Ar/^{39}Ar results presented here give some insight into the thermal history of the region and place certain constraints on the age of intrusion. The hornblende separates typically yield the best plateau dates whereas the biotites give more complex argon-release spectra.

The dates for hornblende (176±3 Ma) and biotite (174±3 Ma) in the Glenlion stock are analytically indistinguishable and suggest rapid cooling *circa* 175 Ma from the closure temperature of hornblende (*ca.* 500°C; McDougall and Harrison, 1988) through the closure temperature of biotite (*ca.* 300°C; McDougall and Harrison, 1988). This is consistent with the small apparent size of this body and the relatively shallow level of emplacement. The latter observations also suggest that intrusion occurred *circa* 176 Ma. The significance of the younger plagioclase date (156±11 Ma) is not presently clear. It may indicate an episode of Late Jurassic, low-temperature thermal overprinting that would presumably reflect the zeolite to prehnite-pumpellyite facies regional metamorphism in the area, or slow cooling following emplacement through the imputed closure temperature of plagioclase (*ca.* 225°C; McDougall and Harrison, 1988, page 23).

The hornblende (166±4 Ma) and biotite (165±18 Ma) dates for the southern part of the Nahwitti batholith are concordant, but the imprecision of the biotite date precludes firm conclusions regarding the post-emplacement cooling history of this part of the intrusion. The dates are, however, consistent with the fairly rapid cooling deduced above for the Glenlion stock and neither spectrum shows evidence of later thermal overprinting. Conventional K-Ar dates on hornblende (156±8 Ma) and biotite (166±6 and 171±6 Ma) were also obtained from samples collected at the southern margin of the Nahwitti batholith (data summarized by Muller *et al.*, 1974. These determinations are comparable to ours.

The age of the Rupert stock is problematic. A previous K-Ar determination yielded an apparent biotite cooling age of 156±6 Ma, significantly younger than our date (Muller *et al.*, 1974). In addition, a Rb-Sr whole-rock isochron date of 180±20 Ma (University of British Columbia Geochronological Database) has been obtained for the quartz feldspar porphyry dike at the Island Copper mine that appears to be a lateral offshoot of the Rupert stock. Although the Rb-Sr isochron date would generally be preferred as the age of emplacement, the analytical uncertainty is considerable. The maximum cooling age of biotite (174±2 Ma), as estimated from an extremely hump-shaped age spectrum, could conceivably be of the order of 10 Ma greater than the hornblende cooling age for this rock if the ^{40}Ar/^{39}Ar systematics are similar to those observed for biotite in the Nahwitti batholith. These considerations would loosely constrain the age of intrusion of the Rupert stock to be between about 180 and 160 Ma.

The hornblende date (177±6 Ma) for the porphyritic dike supports the contention that these rocks are higher level equivalents of the Island Plutonic Suite. Because the hornblende porphyry was emplaced as a quickly chilled dike in thinly bedded intervolcanic sandstones prior to their complete lithification, the hornblende date is regarded as a good approximation to the age of emplacement which may well have occurred while younger strata within the Bonanza Group were still being deposited (discussed below).

In summary, in the Quatsino - Port McNeill map area, $^{40}Ar/^{39}Ar$ age spectra of mineral separates from granitoids of the Island Plutonic Suite provide evidence for two distinct ages of emplacement, *circa* 176 and 166 Ma. Biotite and hornblende dates are essentially concordant and this is consistent with rapid cooling over the approximate temperature interval 500°C to 300°C. There is no evidence in the spectra of post-Jurassic thermal overprinting and it appears that chloritization of biotite occurred soon after emplacement. In fact, a significantly younger plagioclase date (*ca.* 156 Ma) in one of the older plutons may represent the close of zeolite to prehnite-pumpellyite grade regional metamorphism. Although not conclusive, it does seem that certain dikes intruding the Bonanza Group are apophyses of some of the plutons.

Finally, it is worth noting that the $^{40}Ar/^{39}Ar$ step-heating experiments demonstrate the existance of excess argon in some samples, implying that previous K-Ar dates must be used with caution. There are several other K-Ar biotite and hornblende dates in the region. Two K-Ar determinations on biotite from Hepler Creek and the northern margin of the Wanokana batholith underlying the central part of the map area between Holberg Inlet and Nahwitti Lake, yield dates of 148±5 and 161±5 Ma, respectively (cf. Muller *et al.*, 1974). In addition, Panteleyev and Koyanagi (1994 and this volume) have reported a new K-Ar date of 168±4 Ma and a $^{40}Ar/^{39}Ar$ date of *circa* 173 Ma for hornblende from the northern margin of this batholith, as well as a $^{40}Ar/^{39}Ar$. date of *circa* 172 Ma for hornblende from the Hushamu area (Figure 2). In light of the preceding interpretations of the $^{40}Ar/^{39}Ar$ age spectra, the hornblende dates might be expected to yield the best approximation to the actual age of intrusion. Thus it would appear that emplacement of the Wanokana batholith occurred between the two ages of intrusion recognized earlier.

HOW YOUNG IS BONANZA VOLCANISM?

We alluded earlier to the fact that Jurassic granitoids seem to be younger than the volcanics based on the disparate ages provided by isotopic dates for the Island Plutonic Suite (*ca.* 184-103 Ma; Toarcian to mid-Cretaceous) on the one hand, and paleontological control in sedimentary rocks of the Bonanza Group (Sinemurian-Pliensbachian; 203-187 Ma) on the other. This discrepancy may be more apparent than real, as discussed below.

Recently, Haggart and Tipper (1994) identified marine fossils from the Bonanza Group that were collected in a quarry east of Rupert Inlet (Figure 2). Outcrop in this area is scarce, but regional mapping reported by Nixon *et al.* (1994) and Hammack *et al.* (1995) places this locality near the base of the Bonanza succession (and possibly within it). The succession totals some several tens of metres of noncalcareous siltstone, shale and mudstone intercalated, in the lower part of the quarry, with crystal tuffs, and in the upper part of the quarry, with lithic and crystal lithic tuffs with lapilli-size clasts of predominantly mafic to intermediate volcanic lithologies. The fauna they identified were collected from the lower part of the succession and include ammonites and bivalves that indicate a middle early Sinemurian age (*ca.* 200 Ma).

Within the basal part of the Bonanza sequence exposed in the pit of the Island Copper mine, marine sedimentary rocks intercalated with lithic-rich tuffs and minor flows(?) have yielded trigoniid bivalves of Aalenian age (Poulton, 1980; Poulton and Tipper, 1991). These marine fossil occurrences are the youngest presently known in the Bonanza Group and clearly indicate that the basal part of the tuff-sediment sequence extends into the earliest Middle Jurassic.

In the vicinity of the Pemberton Hills (Figure 2), the subaqueously deposited basal Bonanza tuffs and sediments are overlain by a thick succession of mafic to felsic subaerial flows and tuffs with minor intercalated sedimentary strata (Nixon *et al.*, 1994). Although stratigraphic continuity has been disrupted by intrusion of the composite Wanokana batholith, rhyolitic flow-dome complexes and ash-flow tuffs exposed in the Pemberton Hills appear towards the top of the succession (Figure 2; Nixon *et al.*, 1994). This rhyolitic unit can be traced east to the shores of Holberg Inlet where a "Bonanza andesite" collected by K. E. Northcote yielded a whole-rock K-Ar date of 163±6 Ma (Bathonian). This "andesite" is a finely crystalline hornblende-bearing rock with fairly fresh feldspars, and although associated with silicic volcanics, contact relationships were not observed so that it could be a dike (K. E. Northcote, personal communication 1994). This Middle Jurassic sample was considered to have been reset by a later thermal overprint (University of British Columbia Geochronological Database). However, as discussed previously, there is no evidence for such an event in the $^{40}Ar/^{39}Ar$ age spectra studied to date. While argon loss remains a possibility, this date fits stratigraphic assignments and may indeed be valid. If this rock is in fact part of a dike, it would place a minimum age limit only on this part of the Bonanza Group.

Panteleyev *et al.* (1995) also provide evidence for the apparent youth of the Bonanza Group in the form of new $^{40}Ar/^{39}Ar$ dates for alunites that formed during acid sulphate alteration of the Pemberton Hills rhyolite unit. The alunite age spectra are complex. Two alunites gave maximum plateau ages ranging from *circa* 167 to 160 Ma (latest Bajocian to earliest Callovian), and two gave significantly younger maximum ages of *circa* 145-150 Ma (earliest Cretaceous). The oldest dates are considered to represent primary hydrothermal alunite that formed as a replacement of feldspar phenocrysts and as euhedral crystals in vugs, whereas the younger alunites are all interpreted to be supergene. Geological considerations suggest that the acid sulphate alteration occurred penecontemporaneously with extrusion of rhyolitic hostrocks, and may also be linked to emplacement of certain members of the Island Plutonic Suite (Panteleyev and Koyanagi, 1994; Nixon *et al.*, 1994). Although the $^{40}Ar/^{39}Ar$ systematics of alunite age spectra are not well known, the primary alunite maximum plateau date is consistent with a Middle Jurassic age for the upper part of the Bonanza succession.

From the preceding discussion, it is evident that the younger, predominantly subaerial part of the Bonanza Group in the Quatsino - Port McNeill area is younger than Aalenian. The available stratigraphic, paleontological and geochronological data currently suggest that Bonanza volcanism began in the early Lower Jurassic (Sinemurian-Pliensbachian) and extended well into the Middle Jurassic (Bathonian or younger). Accordingly, the upper part of the Bonanza Group would be equivalent in age to the youngest members of the Island Plutonic Suite in the area (*ca.* 166 Ma). Samples of rhyolitic lavas and ash-flow tuffs in the Bonanza Group are currently being prepared for U-Pb zircon geochronometry in order to further test these inferences.

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NOTES

$^{40}Ar/^{39}Ar$ AGES OF HYDROTHERMAL MINERALS IN ACID SULPHATE-ALTERED BONANZA VOLCANICS, NORTHERN VANCOUVER ISLAND (NTS 92L/12)

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KEYWORDS: Geochronology, Bonanza volcanics, hydrothermal alteration, rhyolite, Vancouver Island, alunite, acid sulphate, Island Plutonic Suite, $^{40}Ar/^{39}Ar$ dating

INTRODUCTION

The occurrence of acid sulphate, advanced argillic alteration in extensive zones within Bonanza volcanic rocks in Northern Vancouver Island has been long known (Clapp, 1913, 1915). The alteration zones have been examined at various times for their precious and base metal potential as well as for sources of various industrial minerals. The most extensive recent exploration has been carried out to the north of Holberg Inlet and west of Island Copper mine (Figure 1) by BHP Minerals Limited and associated companies, and in the recent past by BHP Minerals' corporate predecessors. Ministry work in the belt of altered Bonanza rocks has been conducted since 1991, primarily to investigate relationships between subvolcanic intrusions and related, high-level advanced argillic alteration. This setting is considered to be 'transitional' between porphyry copper and epithermal environments. This work has been discussed by Panteleyev (1992) and Panteleyev and Koyanagi (1993, 1994). The $^{40}Ar/^{39}Ar$ data reported here provide ages for hydrothermal minerals in altered rocks within the belt of Bonanza rocks to the north of Holberg Inlet and to the west of Island Copper mine. If the hydrothermal minerals are products of subvolcanic hydrothermal activity, their ages should be similar to that of the Bonanza (rhyolite) hostrocks and the supposedly coeval Island intrusions. A conventional K-Ar date obtained on hornblende from the Mead Creek stock, a typical intrusion of the Island Plutonic Suite, is 168±4 Ma (Panteleyev and Koyanagi (1994).

The $^{40}Ar/^{39}Ar$ dating technique is a variation of the K-Ar method in which samples are irradiated with fast neutrons to convert ^{39}K to ^{39}Ar. The argon is extracted by incremental step-heating to fusion, and the resulting gas is processed much as in the conventional K-Ar technique. Cumulative ^{39}Ar released and apparent age are presented in the form of age spectrum plots (Figure 2). A 'plateau age' is defined by contiguous steps that together comprise more than 50% of the total ^{39}Ar gas released, provided

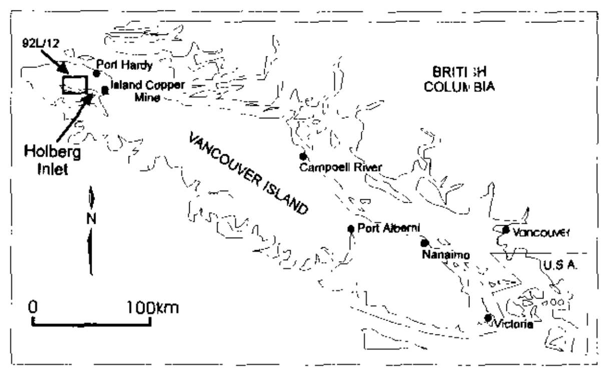

Figure 1: Location Map

that they exhibit no diffeences in apparent age beyond that expected from experimental uncertainty. Detailed discussions of the $^{40}Ar/^{39}Ar$ method, among many, are by Lanphere *et al.* (1981), Parrish and Roddick (1985), McDougall and Harrison (1988) and Reynolds (1992).

SAMPLING AND ANALYTICAL METHODS

Seven samples were selected for $^{40}Ar/^{39}Ar$ dating. The sample suite includes two hornblendes, one from the copper-mineralized Hushamu stock (91AP12/49), and the other from the Mead Creek stock (92AP3/[illegible]-7) located about 3 kilometres to the northeast; a hydrothermal mica from the Hushamu stock; and four alunite concentrates from acid-leached rhyolitic Bonanza volcanic rocks in the Pemberton Hills and southern Mount McIntosh (Table 1). The alunites exhibit differences in their appearance and habit. Two of the samples (92AP-EC-150 and 92AP15/4-73a) contain well crystallized, euhedral grains, one formed as vug fillings, the other as replacement of feldspar phenocrysts. The other two are earthy, compact, white to pink in colour and occur in patches and irregular masses as replacements of porous bedded rocks and vein fillings. The differences in habit of hypogene and supergene alunites have been outlined by Sillitoe (1994).

Clean mineral concentrates were prepared for all samples and purity was checked by X-ray analysis. All argon isotopic analyses were made using a VG 3600 mass spectrometer coupled to an internal tantalum resistance furnace of the double-vacuum type. Hornblende

TABLE 1: $^{40}Ar/^{39}Ar$ SAMPLE DESCRIPTIONS

Sample Number	UTM Zone 9 Easting	UTM Zone 9 Northing	Location	Mineral Analyzed	Description
91AP12/49	-----	-----	Hushamu stock	hornblende	Hushamu stock, possibly dike
91AP-12/50	581000	5614660	Hushamu stock 1700 Road	sericite, quartz	bleached and clay-altered fault zone in pyritic zeolite-rich diorite, sericite mineral separate
92AP-EC-150	-----	-----	South McIntosh	alunite, minor topaz	DDH EC-150, South McIntosh drill core, silica rock with alunite-filled vugs, (collected by J. Fleming)
92AP15/1-71B	585999	5609291	Youghpan Creek	alunite	thin-bedded tuffs, pink/tan patches along bedding
92AP15/2-72B	585758	5609490	Youghpan Creek	alunite	relict tuff/breccia, massive silica hydrothermal overprint; pink, massive, earthy, fracture filling is alunite
92AP15/4-73a	585166	5610046	West Youghpan Creek	alunite	clay-altered basalt, remnant feldspars, breccia at base of silicified knob
92AP3/1-7	583839	5615892	Mead Creek stock	hornblende	hornblende mineral separate from fresh diorite

***This age corresponds to a 168±4 conventional K-Ar date (Panteleyev and Koyanagi, 1994)**

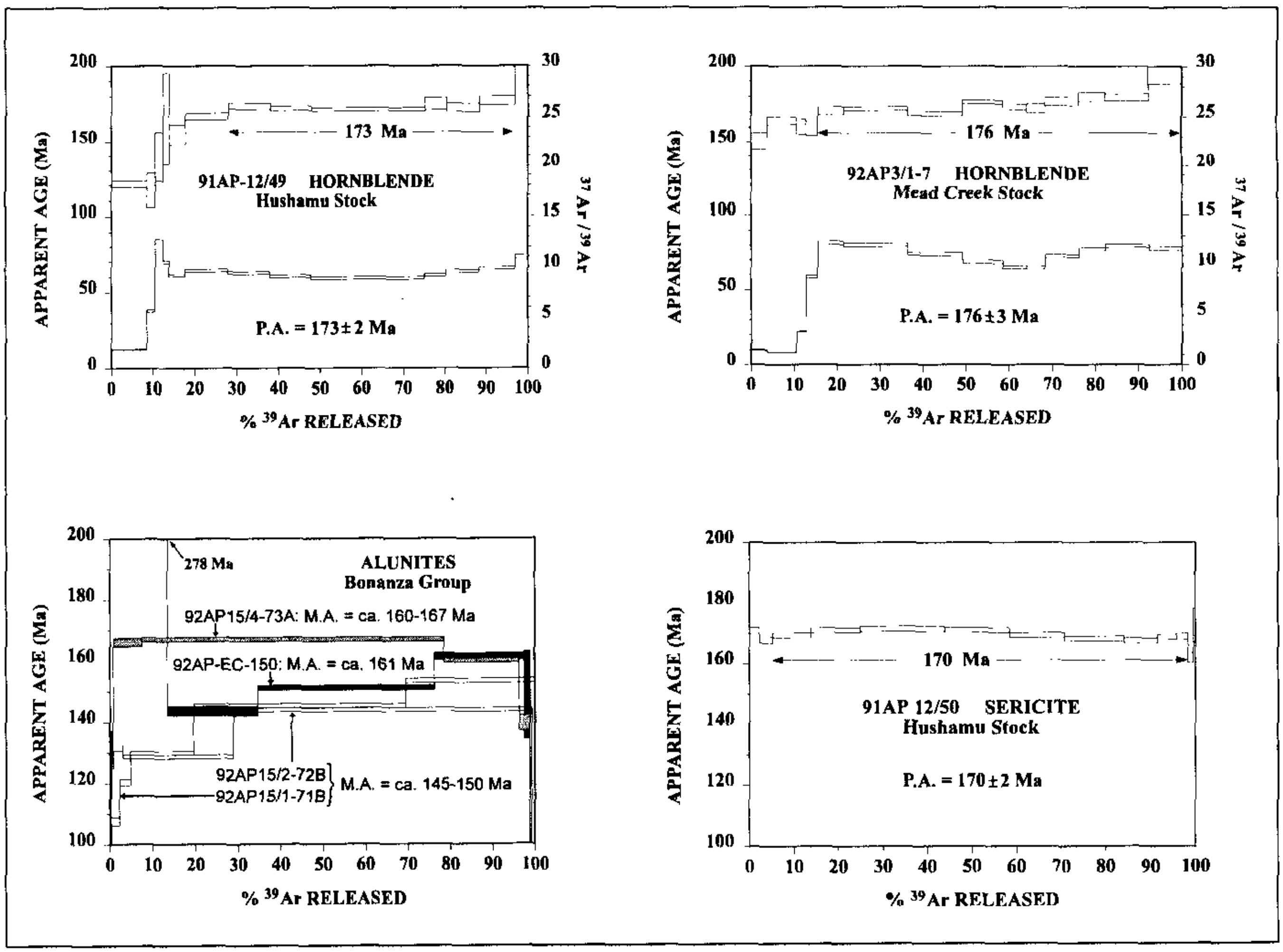

Figure 2. Age spectrum diagrams and $^{37}Ar/^{39}Ar$ ratio plots. Half-heights of open rectangles designate the 1σ relative (between-step) uncertainties. Age spectra for the two well-crystallized alunites are stippled. P.A. indicates 'plateau age'; M.A. is maximum age of segment. All errors are quoted at the 2σ level of confidence.

TABLE 2: ANALYTICAL DATA

Temp °C	mV ^{39}Ar	%^{39}Ar	AGE (Ma)	AGE +/-	%ATM	^{37}Ar/^{39}Ar	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	%IIC
Sample 91AP12/49 Hornblende									
750	16.8	8.3	120.8	2.1	33.2	1.87	0.001125	0.022353	0.59
900	4.1	2.0	116.9	11.3	56.6	5.70	0.001918	0.015000	1.86
950	3.7	1.8	139.5	16.8	58.6	12.53	0.001984	0.011936	3.55
975	2.9	1.4	164.8	30.5	48.6	10.49	0.001646	0.012453	2.61
1000	7.6	3.8	155.0	6.7	38.1	9.16	0.001291	0.015992	2.39
1025	20.6	10.2	167.3	2.1	22.0	9.62	0.000747	0.018605	2.36
1050	20.0	10.0	173.8	1.8	13.6	9.38	0.000463	0.019801	2.24
1075	19.7	9.8	172.4	1.4	12.0	9.06	0.000409	0.020341	2.17
1100	54.9	27.3	171.7	1.0	7.7	8.86	0.000262	0.021425	2.13
1125	10.1	5.0	175.3	3.9	21.6	9.19	0.000732	0.017817	2.18
1200	16.0	8.0	172.8	2.7	24.8	9.54	0.000840	0.017351	2.28
1275	17.2	8.5	177.3	2.7	31.2	9.84	0.001057	0.015446	2.31
1350	6.4	3.2	287.2	13.8	54.7	10.99	0.001853	0.006081	1.83
Total Gas Age = 169.5 Ma; J = 0.02321									
Sample 91AP12/50 Sericite									
550	52.8	2.1	170.9	0.9	7.8	0.00	0.000266	0.020462	0.00
600	76.8	3.0	167.7	0.9	5.7	0.00	0.000195	0.021347	0.00
660	213.0	8.5	169.3	0.8	1.8	0.00	0.000063	0.022002	0.00
700	276.8	11.0	171.1	0.8	1.8	0.00	0.000063	0.021771	0.00
750	474.0	18.9	171.5	0.8	1.0	0.00	0.000035	0.021899	0.00
780	362.2	14.5	171.1	0.8	1.3	0.00	0.000047	0.021876	0.00
810	306.3	12.2	169.4	0.8	1.1	0.00	0.000040	0.022150	0.00
850	334.2	13.3	168.2	0.7	1.7	0.00	0.000059	0.022188	0.00
890	183.6	7.3	167.6	0.8	3.1	0.00	0.000105	0.021971	0.00
950	105.8	4.2	168.8	0.8	4.1	0.00	0.000139	0.021568	0.00
1025	67.2	2.6	168.9	1.0	8.1	0.00	0.000274	0.020667	0.00
1100	27.9	1.1	161.8	1.6	22.8	0.00	0.000772	0.018143	0.00
1200	14.6	0.5	173.6	4.6	34.7	0.00	0.001174	0.014266	0.00
Total Gas Age = 169.8 Ma; J = 0.002208									
Sample 92AP-EC-150 Alunite									
525	29.7	13.3	277.6	25.2	85.1	0.07	0.002882	0.001821	0.01
550	47.0	21.1	143.6	1.5	29.0	0.01	0.000984	0.017486	0.00
575	92.6	41.6	151.2	0.8	9.8	0.01	0.000331	0.021072	0.00
600	47.2	21.2	161.2	1.1	12.5	0.05	0.000423	0.019116	0.01
625	3.1	1.3	148.6	14.2	55.8	0.70	0.001890	0.010502	0.17
800	2.6	1.1	---	---	---	0.85	0.003479	0.010665	2.38
Total Gas Age = 167.3 Ma; J = 0.002044									
Sample 92AP15/1-71B Alunite									
500	27.4	2.2	107.4	1.4	30.0	0.12	0.001016	0.023345	0.04
525	30.9	2.5	120.2	0.9	10.6	0.03	0.000360	0.026543	0.01
550	181.6	14.8	129.8	0.6	2.7	0.02	0.000092	0.026706	0.00
575	610.9	49.8	145.3	0.6	0.6	0.02	0.000021	0.024269	0.00
600	372.3	30.3	153.4	0.7	0.8	0.03	0.000027	0.022885	0.00
625	0.7	0.0	65.5	105.0	86.2	0.97	0.002919	0.007610	0.47
700	2.0	0.1	63.8	24.7	86.9	0.39	0.002941	0.007427	0.19
Total Gas Age = 143.8 Ma; J = 0.002049									
Sample 92AP15/2-72B Alunite									
550	70.9	3.0	131.5	0.8	16.4	0.03	0.000557	0.022520	0.00
575	604.4	25.8	128.5	0.6	2.1	0.01	0.000072	0.026998	0.00
600	1646.8	70.3	143.9	0.6	2.0	0.02	0.000068	0.024048	0.00
625	12.4	0.5	77.3	3.0	57.0	0.46	0.001931	0.019970	0.02
800	5.8	0.2	151.5	22.4	87.4	0.27	0.002959	0.002917	0.06
Total Gas Age = 139.2 Ma; J = 0.002039									
Sample 92AP15/4-73A Alunite									
450	4.2	0.2	---	---	---	1.15	0.003546	0.009063	1.57
500	7.0	0.4	131.0	6.1	52.9	0.17	0.001792	0.012743	0.04
550	96.9	6.5	166.0	1.4	10.0	0.09	0.000341	0.019033	0.02
600	1044.[illegible]	71.0	166.9	0.7	1.0	0.04	0.000035	0.020819	0.00
625	261.[illegible]	17.7	160.0	0.7	5.3	0.04	0.000181	0.020819	0.01
700	36.[illegible]	2.4	139.6	2.5	49.3	0.09	0.001670	0.012837	0.02
1000	19.7	1.3	54.2	4.1	79.4	0.21	0.002688	0.013738	0.12
Total Gas Age = 162.8 Ma; J = 0.002041									
Sample 92AP3/1-7 Hornblende									
750	19.0	3.8	150.3	5.6	65.8	1.52	0.002227	0.008784	0.39
900	33.8	6.7	164.3	2.6	39.6	1.25	0.001342	0.014133	0.30
950	11.1	2.2	160.3	4.9	46.1	3.37	0.001560	0.012958	0.83
1000	13.5	2.7	159.0	4.7	48.5	8.82	0.001642	0.012476	2.19
1025	29.4	5.9	170.8	2.4	31.2	12.24	0.001058	0.015467	2.88
1050	74.2	14.8	172.1	1.2	20.0	12.07	0.000677	0.017851	2.82
1075	63.6	12.7	168.9	1.2	17.8	11.09	0.000606	0.018693	2.63
1100	46.8	9.4	176.5	1.2	11.9	10.28	0.000405	0.019130	2.36
1125	27.5	5.5	173.1	1.6	17.2	9.76	0.000583	0.018367	2.27
1150	21.1	4.2	172.5	3.0	23.1	9.68	0.000784	0.017100	2.26
1200	38.6	7.7	176.9	2.5	35.9	10.90	0.001216	0.013896	2.50
1250	30.8	6.1	179.9	2.8	39.2	11.60	0.001330	0.012933	2.62
1325	50.3	10.0	179.5	2.1	35.0	11.98	0.001187	0.013864	2.71
1400	38.0	7.6	194.9	7.2	68.7	11.71	0.002328	0.006110	2.49
Total Gas Age = 173.5 Ma; J = 0.002235									

Error estimates at 1σ level; %IIC = Interfering Isotopes Correction
^{37}Ar/^{39}Ar, ^{36}Ar/^{40}Ar, and ^{39}Ar/^{40}Ar ratios are corrected for interfering isotopes
--- not determined

MMhb-1, with an assumed age of 520±2 Ma (Sampson and Alexander, 1987), was the standard used for all analyses. Other experimental procedures follow those described by Muecke *et al.* (1988). Analytical data are presented in Tables 1 and 2.

INTERPRETATION

Roughly the first 10% of gas released from both hornblendes yielded relatively young and variable apparent ages and low apparent $^{37}Ar/^{39}Ar$ (proportional to Ca/K) ratios. Subsequent gas defined an age plateau at 173±2 (2σ) Ma for 91AP12/49 and a near plateau at 176±3 (2σ) Ma for 92AP3/1-7, both characterized by relatively high and uniform $^{37}Ar/^{39}Ar$ ratios, and hence probably the best estimates of the ages of the hornblendes. The age spectrum obtained for the hydrothermal sericite sample 91AP12/50 is concordant at 170±2 (2σ) Ma over all but the first and last few per cent of gas released. The four alunites yielded relatively discordant age spectra. The least discordant alunite, 92AP15/4-73A, one of the samples that has well crystallized grains, has an apparent age between 160 and 167 Ma over 95% of the gas release. The remaining three alunite spectra have apparent age gradients, a pattern generally attributed to gas loss resulting from one or more later thermal events. The maximum age attained by 92AP-EC-150, the other well crystallized sample, is 161 Ma. Maximum ages attained by the two poorly-crystallized samples are lower at *circa* 145 to 150 Ma.

DISCUSSION

Analytically distinguishable differences in apparent age were detected in this suite of hornblende, sericite and alunite samples. The age range is at least *circa* 173-176 Ma from the amphibole data to *circa* 160-165 Ma from alunite data. The younger 160-170 Ma ages are probable lower limits for the times of late-stage hydrothermal alteration. Still younger ages from the poorly crystallized alunites are consistent with textural criteria that distinguish a later supergene origin. Similar age spectra are described by Vasconcelos *et al.* (1994), including discussions of supergene alunite and jarosite specimens. Thermal events subsequent to all of these may be reflected in the early gas release from these two alunites and from one of the hornblendes.

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NOTES

INVESTIGATION OF A NATURAL ACID ROCK DRAINAGE AND AN ANOMALOUS MERCURY-BEARING STREAM, NORTHERN VANCOUVER ISLAND (92L/12, 102I/9)

By S.J. Sibbick and K.A. Laurus

KEYWORDS: exploration geochemistry, environmental geochemistry, acid rock drainage, pH, sulphate, mercury, copper, northern Vancouver Island, Hushamu, Macjack River, Regional Geochemical Survey, moss mat, stream sediment.

INTRODUCTION

As part of the exploration geochemistry component of an integrated northern Vancouver Island project (Panteleyev *et al.*, 1994), detailed studies were undertaken in two areas with unusual geochemical features. These included a strongly acidic stream draining acid-sulphate altered rocks which has not been disturbed by human activity (South McIntosh) and a stream having the highest reported mercury concentration in stream sediments from the Regional Geochemical Survey (RGS) database (Macjack River) (Figure 1). The goals of this study are to determine the relationship of these anomalous concentrations to their bedrock sources, to document natural occurrences of potentially deleterious metal concentrations, and to develop geochemical models which describe the occurrence and behavior of these metals.

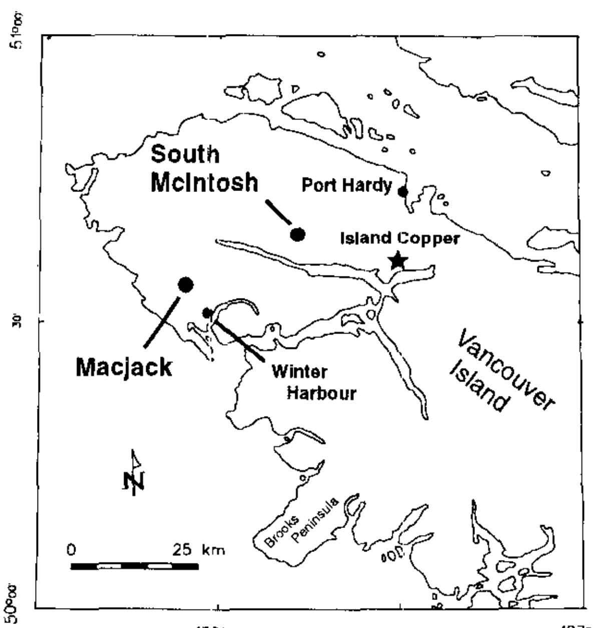

Figure 1. Location of South McIntosh and Macjack study areas, northern Vancouver Island.

NATURALLY ACIDIC STREAM - SOUTH McINTOSH AREA

Koyanagi and Panteleyev (1993, 1994) discovered numerous strongly acidic (pH< 4.0) stream waters that drain areas of acid-sulphate altered bedrock in the Red Dog - Hushamu - Pemberton Hills area. This same area also has potential for porphyry, transitional and epithermal base and precious metal mineralization (Panteleyev, 1992; Panteleyev and Koyanagi 1993, 1994). Regional Geochemical Survey data from this area report some of the lowest pH values measured in stream waters in the province (Hushamu Creek pH 3.9; Youghpan Creek pH 4.2). To further document the controls on natural acid generation and its behavior within a stream environment, a tributary of Hushamu Creek draining the South McIntosh area was selected for detailed investigation (Figure 1). Draining the eastern flank of a ridge known locally as the South McIntosh for a distance of about 1 kilometre, the creek drains an unlogged watershed mainly underlain by pyritic, propylitically altered andesites of the Bonanza Group. A zone of advanced argillic acid-sulphate alteration, containing significant quantities of sulphide (pyrite and marcasite), is exposed in the upper 200 metres of the watershed. An initial survey of this stream (sample EC91AP-19) reported a pH of 3.8 and a sulphate concentration of 39 ppm (Koyanagi and Panteleyev, 1993). Subsequent resampling of this stream has produced similar results (Koyanagi and Panteleyev, 1994).

In the South McIntosh study, sample sites were established at intervals along the stream and above the confluence of tributaries draining into it. Filtered and unfiltered waters and, where available, stream sediment, moss-mat, bank and bedrock samples were collected at each site. In-field water measurements were made for pH, conductivity and total dissolved solids (TDS) using a portable Corning CheckMate™ 90 microprocessor-based meter. Additional field measurements were made for sulphate, free and total acidity, carbon dioxide, total hardness and dissolved oxygen. Acid-washed 250-millilitre plastic bottles were used to collect water samples, in triplicate, at each site. Water samples were refrigerated after collection. One of each sample trio was filtered and acidified with nitric acid in the laboratory. Water samples, together with measurements of pH, conductivity and TDS were repeatedly taken from a

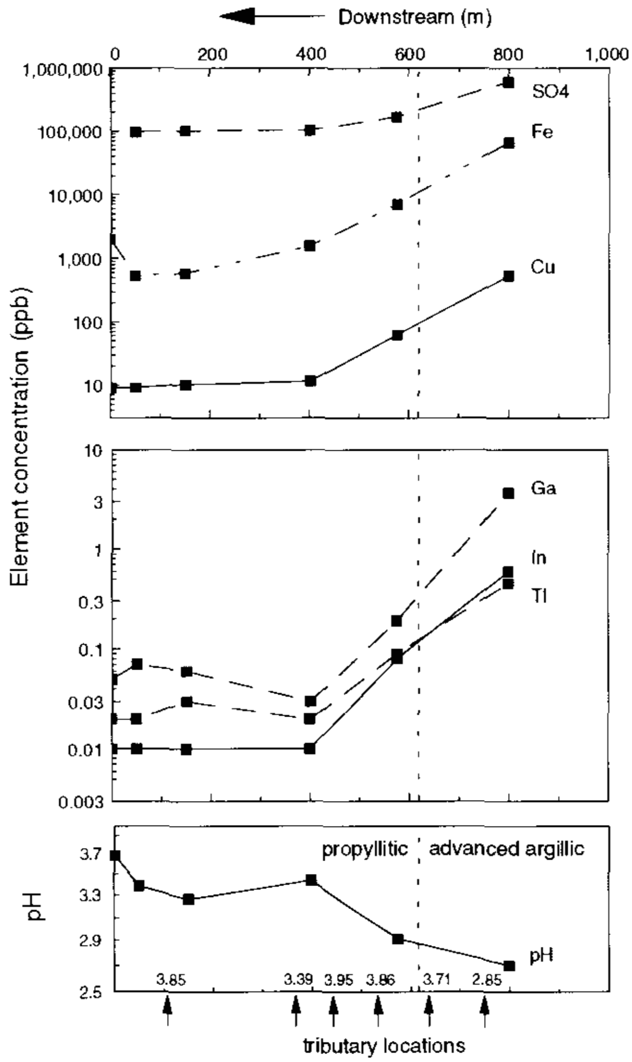

Figure 2. Downstream dispersion patterns of selected elements. Tributary confluences marked with arrows.

single site during the month of July, to study temporal variation.

Sediment samples were dried at room temperature and dry sieved to -177+62.5 microns and -62.5 microns. Rock samples were pulverized and ground in a tungsten carbide ring mill. Filtered and unfiltered water samples were analyzed for minor and major elements by ICP-MS and ICP-AES, respectively. Sulphate analyses were performed on unfiltered water samples. Stream sediment, moss-mat sediment, bank and rock samples were analyzed by INAA and by a four-acid digestion (HNO_3, HCl, $HClO_4$ and HF) plus ICP-AES analysis. Major element oxides were determined by a lithium boride fusion, nitric acid (LiBO-HNO_3) digestion and ICP-AES analysis. Analytical duplicates and standards were inserted at the laboratory before analysis.

Preliminary results suggest that stream acidity and dissolved metal content are strongly related to the style of bedrock alteration. Median pH of the stream and its tributaries is 3.4. Rapid increases in pH and decreases in conductivity, TDS and sulphate were observed in waters flowing from advanced argillic altered bedrock to propylitically altered bedrock (Figure 2). pH values of 2.7 to 2.8 measured in stream water flowing from and over advanced argillic altered bedrock rose to a pH of 3.4 within 200 metres downstream from the contact.

High concentrations of dissolved copper and iron decrease downstream from acid-sulphate altered bedrock (Figure 2). Dilution by tributary streams and a decrease in the amount of metal dissolved from bedrock probably account for the observed changes. Interestingly, concentrations of gallium (Ga), indium (In) and thallium (Tl) were observed to increase by an order of magnitude in waters flowing from the area of advanced argillic alteration (Figure 2). These elements may serve as potential pathfinders for acid sulphate alteration and its associated mineralization. Comparison of these data with the paired unfiltered samples suggests that almost all of the metal in these waters exists in the dissolved form as cations.

ANOMALOUS MERCURY CONCENTRATIONS - MACJACK RIVER AREA

A belt of anomalous (>250 ppb) mercury concentrations, 20 kilometres wide, extends up the west coast of Vancouver Island from the Brooks Peninsula region northwestwards towards Cape Scott. These anomalous concentrations appear to be spatially associated with a series of northwest-trending faults interpreted to be Tertiary age. Mercury is a known pathfinder for epithermal precious metal mineralization as well as a common product of fault-related venting of crustal volatiles. Northwest of Winter Harbour, RGS site (883007, NTS 102I/9), a tributary of the Macjack River, reports the highest mercury concentration in the province (20 000 ppb). Apart from prior logging activity on the lower western half of the watershed, no other human activity was observed. This catchment was investigated in order to determine the potential source of the mercury anomaly and to determine if any other media (soils, waters and vegetation) are similarly anomalous.

Moss-mat samples were collected from RGS site 883007, upstream from the site, and all streams in the vicinity (Figure 3). Stream sediment, moss-mat, humus (decomposed organic soil material) and rock samples were collected at regular intervals upstream from site MM04. Bank samples were also taken where available. Stream water samples and in-field water measurements were taken at the original RGS site and at sites MM03 and MM04. Moss-mat and water samples were also taken at two sites along the Macjack River. One soil profile was sampled within the drainage, near site MM02.

Sample preparation was carried out at the B.C. Geological Survey Branch laboratory. Sediment samples were air dried and dry sieved into five size fractions: -1000+500, -500+250, -250+125, -125+62.5 and -62.5 microns. Moss-mat vegetation remaining from the sieving process was thoroughly washed to remove any adhering mineral grains. Rock samples were pulverized and ground in a tungsten carbide ring mill. Analytical duplicates and standards were inserted at the laboratory before analysis. Filtered and unfiltered stream waters were analyzed for 22 elements by ICP-AES and for mercury by cold vapour AAS. Unfiltered waters were also analyzed for sulphate. Stream sediment, moss-mat sediment, moss-mat vegetation and rock samples were analyzed for 35 elements by INAA, 32 elements by ICP-AES and mercury by aqua regia cold vapour AAS. Humus samples were analyzed for mercury by aqua regia cold vapour AAS.

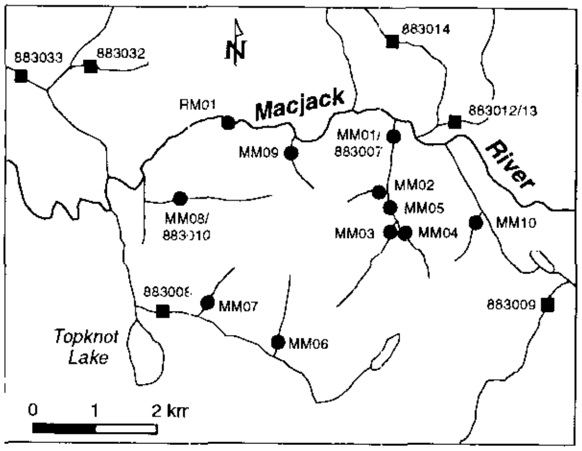

Figure 3. Location of original RGS sample sites and new sample sites, Macjack River area.

Initial results indicate that the highest mercury concentrations are found in moss-mat sediments (Table 1). Resampling of RGS site 883007 (sample MM01) produced a comparable but lower mercury concentration (16 900 ppb). Higher values were reported for samples upstream from this site. Moss-mat vegetation contains significant but lower mercury values (110 to 450 ppb). Smith (1986) found comparable levels of mercury in stream mosses in Alaska. Based on a poor correlation with the percentage of non organic material (ash) within the sample these levels were attributed to uptake of mercury by inter- and extra-cellular biochemical reactions. However, the present lack of data on the ash content of the mosses in this study does not preclude the presence of fine-grained mercury-bearing particles adhering to the vegetation as a possible explanation. Stream waters contain significant levels of mercury (0.8 to 1.6 ppb). These values are near or above the approved level (1 ppb) for drinking water (Pommen, 1989). Of note is sample RM01, taken from the Macjack River, which contains 1.6 ppb mercury. Analysis of wet-sieved size fractions from one moss-mat sediment sample (MM04) shows a distinct partitioning of mercury and suggests that mercury within the sediment exists in a discrete particulate form (Figure 4). High concentrations in samples MM04, MM05 and MM01 which increase systematically upstream suggest that the source of the mercury lies upstream from site MM04 (Figure 3). Geochemical analyses of samples from this area are pending.

TABLE 1
MERCURY CONCENTRATIONS IN VARIOUS MEDIA FROM THE MACJACK RIVER AREA

	Mercury (ppb)		
Sample	Moss-mat Sediment	Moss-mat Vegetation	Water (Filtered)
MM01	16900	210	1.0
MM02	7050	110	
MM03	170	150	0.8
MM04	34600	450	1.2
MM05	25300	190	
MM06	1100	140	
MM07	210	150	
MM08	1200	230	
MM09	3950	280	
MM10	3350	190	
RM01	200		1.6
RGS Data	(moss-mat sediment)		
Sample	Hg (ppb)	Sample	Hg (ppb)
883007	20000	883013	[illegible]10
883008	2100	883014	90
883009	3200	883032	700
883010	700	883033	200
883012	120		

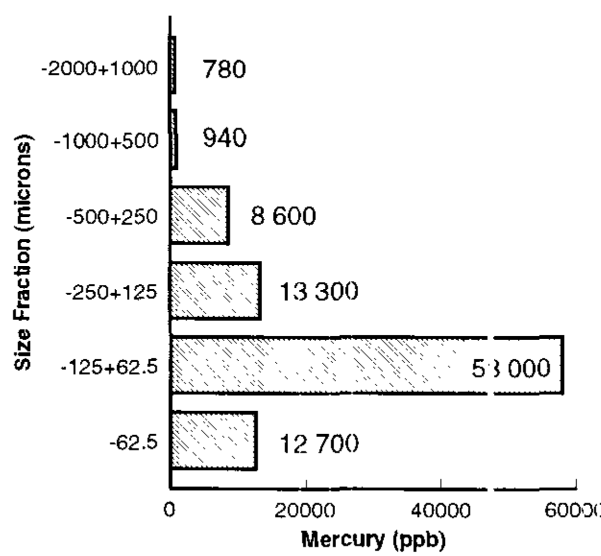

Figure 4. Partitioning of mercury between size fractions, sample MM04.

CONCLUSIONS

Rapid changes in pH and dissolved metal concentrations of natural waters emanating from a natural acid rock drainage source are apparently strongly controlled by the composition of the underlying bedrock and the presence of diluting water from tributaries. Anomalous mercury concentrations at RGS Site 883007 in the Macjack River area appear to have a discrete natural source upstream from sample site MM04. Future work on both sites will focus on analysing new and existing data to develop models of metal dispersion for application to mineral exploration and environmental assessment.

ACKNOWLEDGMENTS

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VOLCANISM IN THE MIDDLE ALDRIDGE FORMATION, PURCELL SUPERGROUP, SOUTHEASTERN BRITISH COLUMBIA

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(Contribution No. 21, Sullivan-Aldridge Project)

KEYWORDS: Purcell Supergroup, Aldridge Formation, volcanism, volcaniclastics, St. Joe tuff, fragmentals.

INTRODUCTION

The Aldridge Formation in southeastern British Columbia is the basal unit of the Purcell Supergroup, a thick sequence of predominantly clastic and carbonate rocks of Middle Proterozoic age. The base of the Purcell Supergroup is not exposed in Canada; in the United States it is inferred to rest unconformably on Archean and Proterozoic basement crust (Winston and Link, 1993). It is overlain unconformably by Upper Proterozoic Windermere Group or by lower Paleozoic clastic or carbonate rocks.

The Purcell Supergroup comprises dominantly turbidite deposits of the Aldridge Formation, overlain by shallow-water clastic rocks of the Creston Formation and carbonate rocks of the Kitchener Formation. Upper Purcell rocks are dominated by shallow-water to locally subaerial clastic rocks, with a prominent basaltic unit, the Nicol Creek Formation, exposed in the eastern Purcell Mountains and the Rocky Mountains.

The Aldridge Formation is intruded by a number of thick and continuous gabbroic sills and dikes, referred to as the Moyie sills. These were locally deposited in wet, unconsolidated sediments, and therefore record a magmatic event during Aldridge sedimentation (Höy, 1989). However, despite the interpreted high-level intrusion of voluminous amounts of gabbroic material, volcanic equivalents have not, until now, been well documented or described. This report describes an example of volcaniclastic rocks within the Aldridge Formation and identifies several other possible occurrences.

REGIONAL GEOLOGY

The Purcell Supergroup is exposed in the core of the Purcell anticlinorium in the Purcell Mountains, and in the Foreland thrust and fold belt in the Western Ranges of the Rocky Mountains.

The Aldridge Formation is exposed in the hangingwalls of a number of prominent, northeast-trending, reverse tear faults in the Purcell Mountains. The formation comprises three main divisions: the lower Aldridge includes generally thin-bedded, rusty weathering turbidites with thick sections of massive to laminated siltstone and argillite and a prominent succession of grey weathering, more proximal turbidites, referred to as the footwall quartzites; the middle Aldridge comprises grey weathering, thicker bedded turbidites with common rusty weathering, thinner bedded siltstone successions; and the upper Aldridge comprises massive to laminated argillite and silty argillite. Evidence of shallow-water features within the Aldridge is lacking. The Moyie sills occur at two main stratigraphic intervals: throughout the lower Aldridge and in the middle part of the middle Aldridge.

Correlative rocks in the Northern Hughes Range east of the Rocky Mountain Trench comprise fluvial, alluvial fan and deltaic deposits of the Fort Steele Formation, overlain by a heterogeneous, more carbonate-rich succession with pronounced facies changes indicative of growth faulting (Höy, 1993). The transition between the contrasting facies of the Northern Hughes Range and the Purcell Mountains to the west and Southern Hughes Range marks the edge of the Purcell basin in early Purcell time.

The Aldridge Formation hosts a number of important mineral deposits. The Sullivan mine, at the transition between the lower and middle Aldridge, is a large, stratabound lead-zinc-silver sedex deposit. Numerous vein deposits, including St. Eugene and Bull River, occur throughout the Aldridge, and a number of stratabound copper-cobalt deposits, including Sheep Creek and the Blackbird deposits, occur in correlative rocks in the United States. The Moyie sills, intruded during Aldridge sedimentation, have been suggested to have a genetic link to mineral deposition (Hamilton, 1984; Höy, 1993). This underscores the importance of recognizing other forms of igneous activity within Aldridge rocks.

VOLCANICLASTIC UNITS

The location of inferred volcaniclastic rocks within the Aldridge Formation is shown in Figure 1. The four widely separated occurrences all comprise clastic units, with small clasts of presumed volcanic origin in either a finer grained tuffaceous or epiclastic matrix. The St. Joe tuff and the Mark Creek and Wild Horse fragmentals are at approximately the same stratigraphic level, below a prominent fine-grained laminated marker unit in the upper part of the middle Aldridge (Figure 2). The stratigraphic position of the Elephant Creek fragmental is not as well defined, but it is interpreted to be approximately 80 metres lower. Hence, these volcaniclastic units appear to record at least two separate periods of magmatic activity during Aldridge sedimentation.

ST. JOE TUFF

The St. Joe tuff is the thickest and best exposed of the volcaniclastic units in the Aldridge Formation. It is a discordant zone of fragmentals that cuts across middle Aldridge

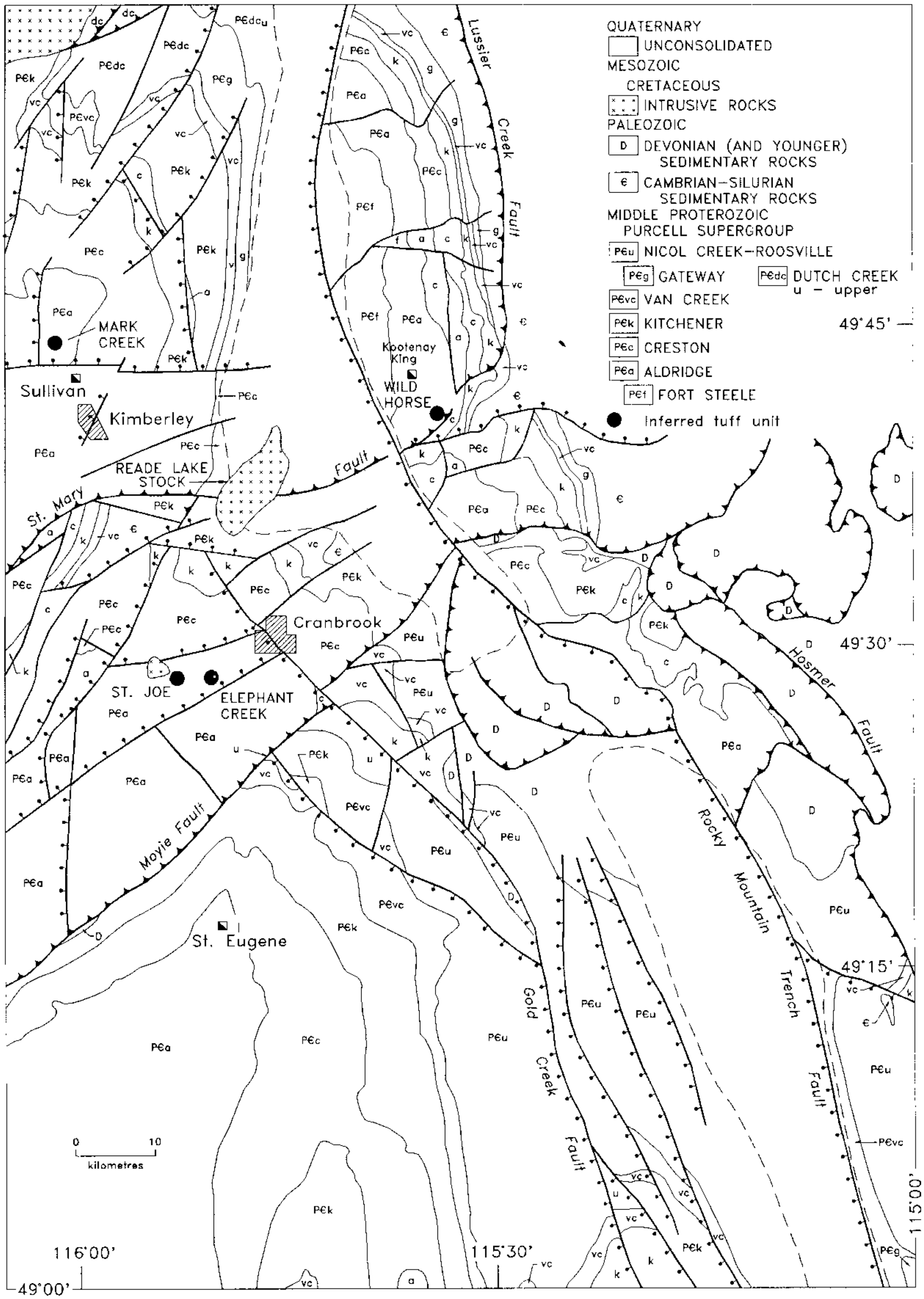

Figure 1. Geological map of the Fernie west-half map-area, showing locations of the known and inferred middle Aldridge volcaniclastic units (base map from Höy, 1993).

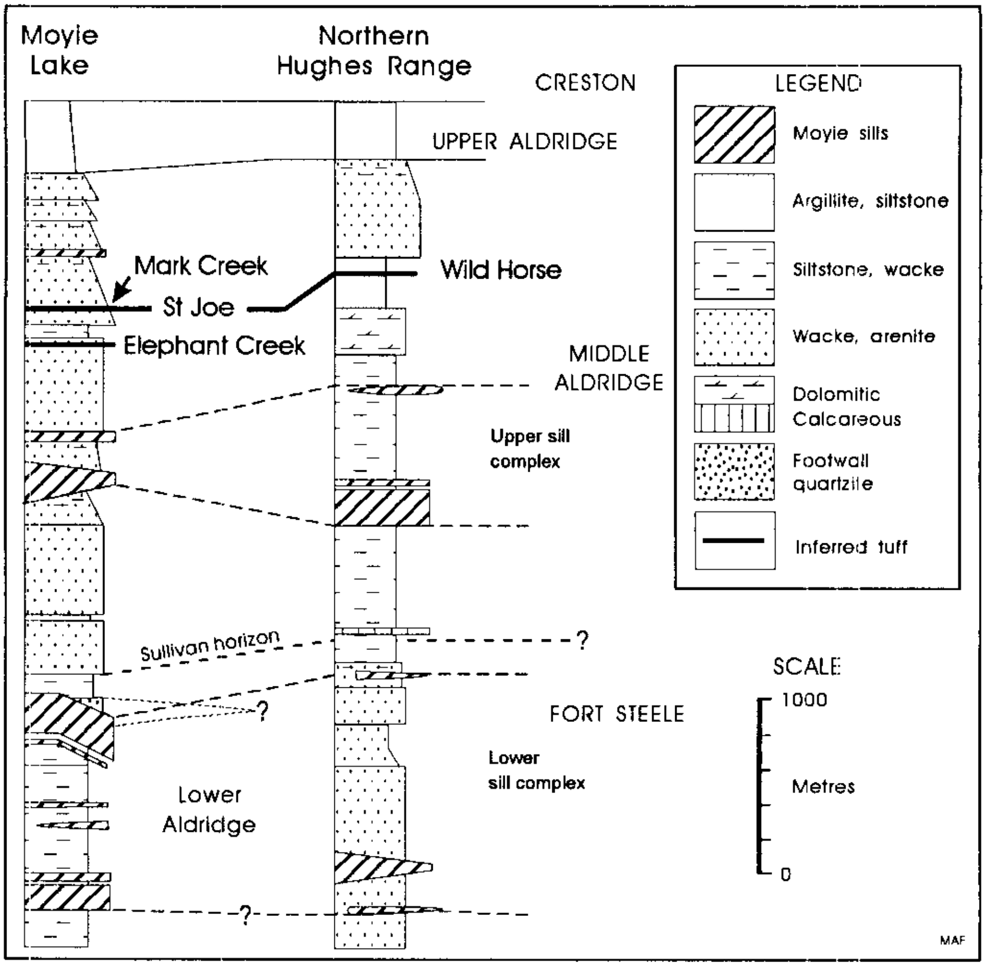

Figure 2. Schematic sections of the Aldridge Formation, showing distribution of Moyie sills and stratigraphic position of volcaniclastic units.

turbidites and is overlain conformably by laminated argillaceous siltstone.

The St. Joe tuff is cut by a small lead-zinc-silver vein that has been intermittently explored since the turn of the century by underground work, trenching and diamond drilling. The most recent exploration, by Cominco Ltd. in the mid-1980s and by Consolidated Ramrod Gold Inc. in 1993 and 1994, included detailed surface mapping (Pighin, 1982; 1983) and diamond drilling to test for both vein and possible sedex style mineralization; a second (sedimentary) fragmental unit, the Lower St. Joe, approximately 100 metres stratigraphically lower, contains small sulphide and tourmalinite clasts (Pighin, 1983; Turner *et al.*, 1993). The Lower St. Joe fragmental is overlain by a thin, discordant sulphide lens and underlain by patchy tourmalinized argillite. It is not described further in this report.

The St. Joe tuff is located approximately 8 kilometres southwest of Cranbrook on the heavily wooded slopes of a small creek that drains westward into Kiakho Creek. Access is by the four-wheel-drive Fassifern road that exits Highway 3 south of Cranbrook.

REGIONAL GEOLOGY

The St. Joe tuff is in gently dipping, thick-bedded turbidite layers in the upper part of the middle Aldridge. It is conformably overlain by a laminated, silty argillite marker unit.

The fragmental is less than a kilometre south of the Cranbrook fault, an east-northeast-trending normal fault. Other similar trending faults, including the St. Mary, Boulder Creek and Moyie faults, have documented or inferred Middle Proterozoic movements, and hence it is possible that the Cranbrook fault is also the locus of an Aldridge-age growth fault. The fault is cut by an Early Cretaceous quartz monzonite intrusion, the Kiakho stock (Höy and van der Heyden, 1989).

DETAILED GEOLOGY

A detailed surface map of the St. Joe tuff is shown in Figure 3, measured sections in Figure 4 and a schematic north-south section in Figure 5. The location of diamond-drill hole 94-6 (ddh 94-6) and analyzed samples are also shown on Figure 3.

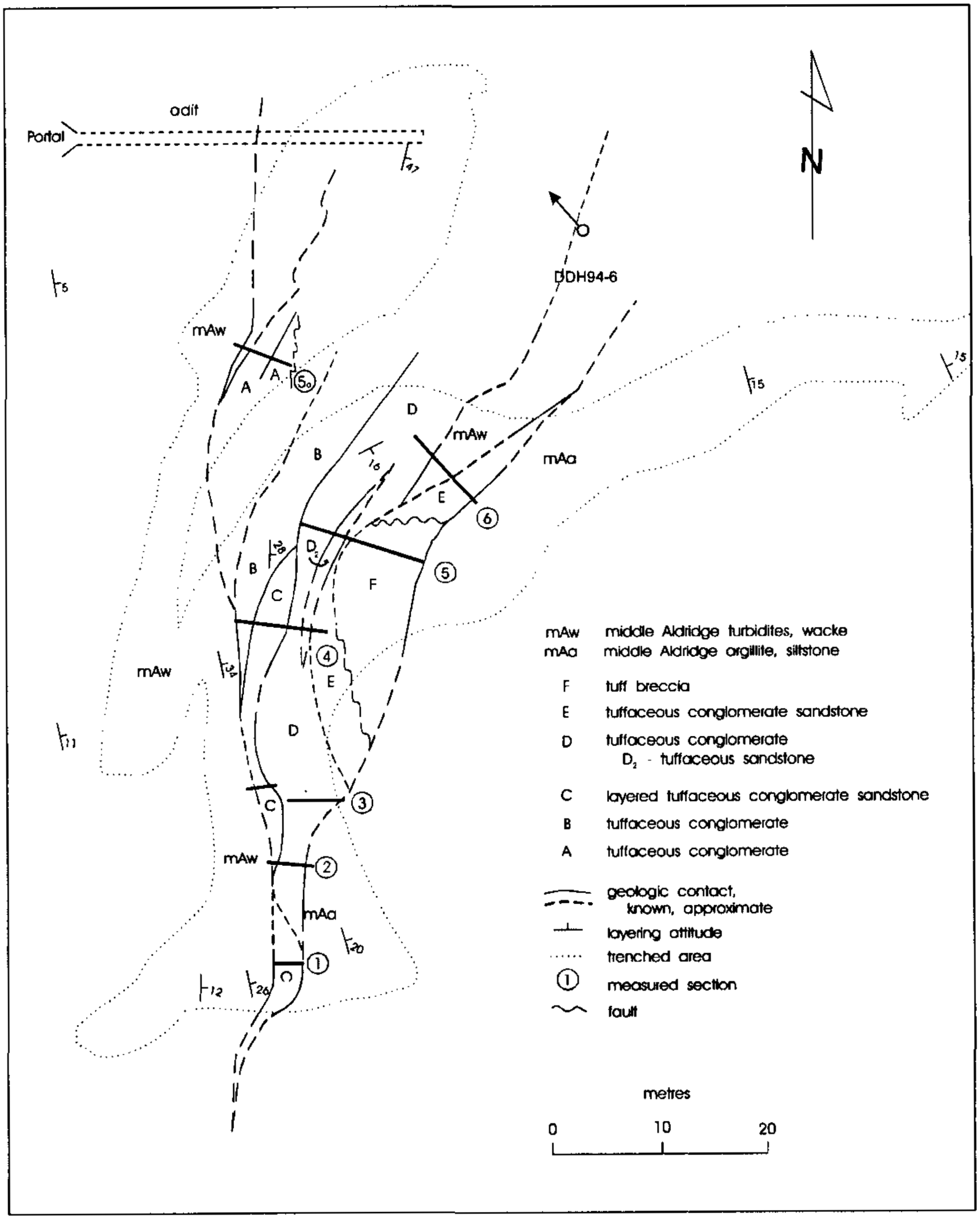

Figure 3. Geological map of the St. Joe tuff (modifed from Pighin, 1983).

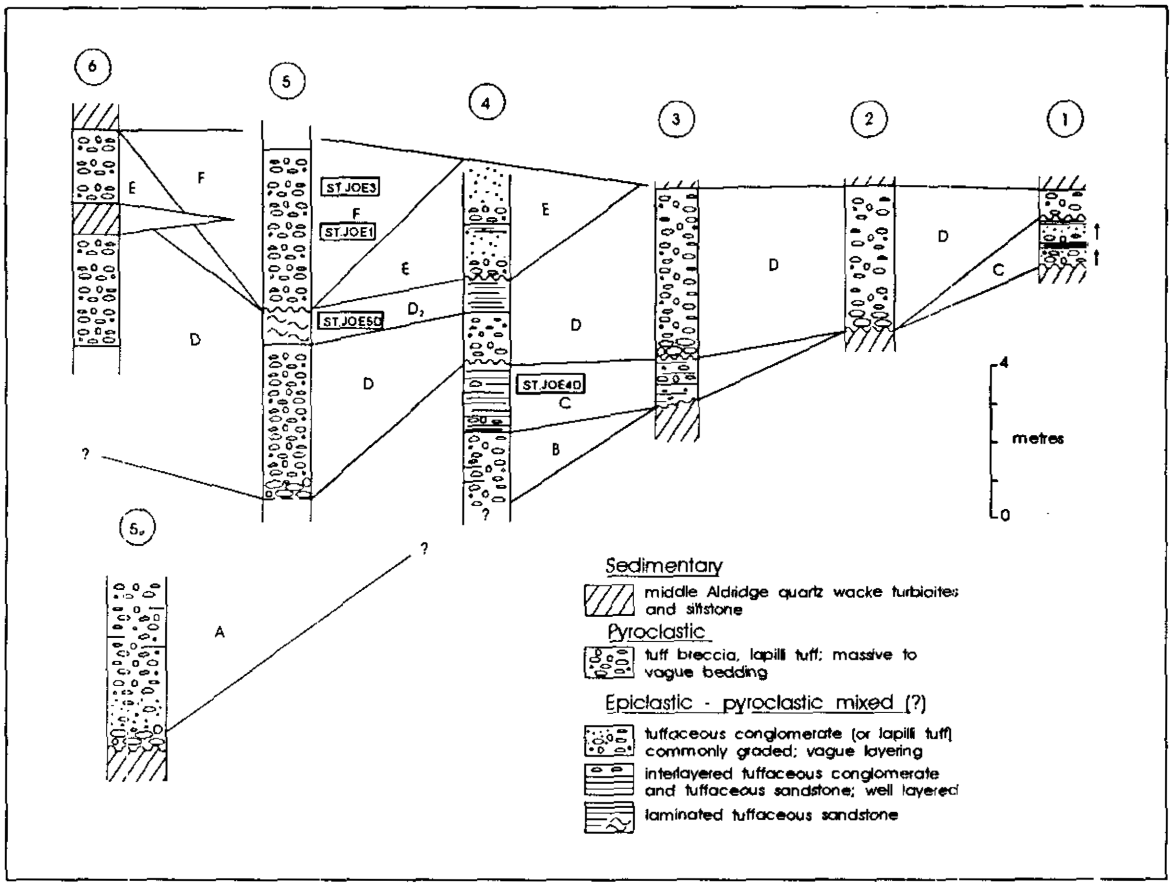

Figure 4. Measured sections through the St. Joe tuff, sections are located on Figure 3.

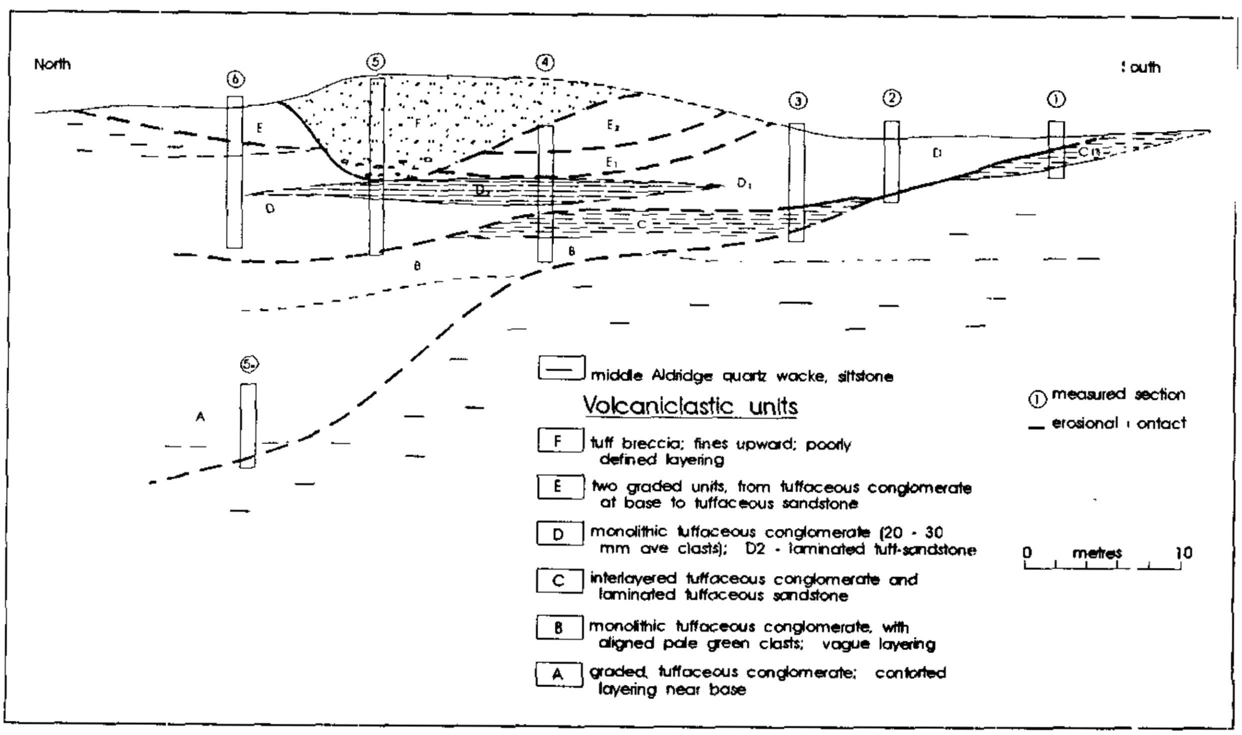

Figure 5. An interpretive north-south section through the St. Joe tuff.

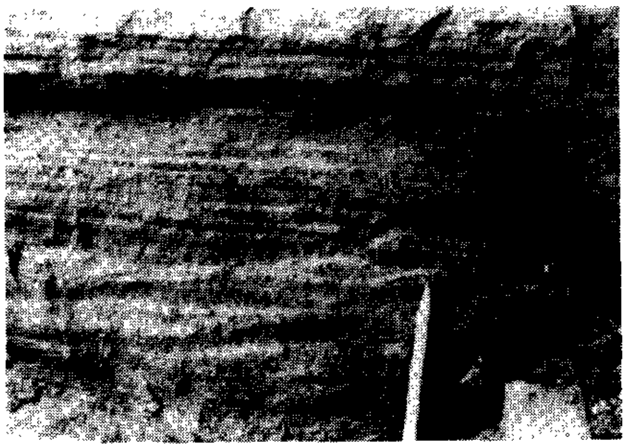

Photo 1. St. Joe tuff, section 4, unit C: well layered lapilli tuff and laminated tuffaceous sandstone(?); note general fining-upward nature of unit, occasional large isolated clasts, and locally low-angle crossbeds

Photo 2. St. Joe tuff, section 4, unit E?; contorted tuffaceous sandstone(?) layer near the base of a graded lapilli tuff - tuffaceous sandstone sequence.

Photo 3. St. Joe tuff, section 4, unit E; large disrupted (rotated) block near the base of Unit E; note normal layering above wedge and disrupted massive unit below; (pencil scale).

The map and sections show that the St. Joe tuff comprises a number of fining-upward cycles, each with a coarse base that scours the underlying unit, and each generally capped by a finer grained laminated or massive unit. The tuff succession pinches out to the south; its maximum thickness in the northern part of the trench and in ddh 94-6 is approximately 22 metres.

The measured sections (Figure 4) clearly show the graded nature of individual units (Photo 1) and truncations by successively younger units. The lowest unit (A, section 5a, Figure 4) is a fining-upward sequence with a sharp base that scours underlying, locally contorted massive turbidites. Clast sizes decrease up-section into a massive clastic unit that contains abundant aligned, angular 1 to 2-centimetre, pale green and pale grey clasts. Unit B, exposed in section 4 and in the lower part of hole 94-6, is similar to the top of unit A and hence may be correlative as shown in Figure 4. It is overlain gradationally by unit C, a layered succession of generally finer grained clastics that contains occassional large clasts and occassional coarse layers similar to those of unit B. Occassional low-angle crossbeds indicate current activity. A similar exposure at the base of the most southern section (1) suggests that the original thickness of unit C may have been at least 8 metres. Units A to C comprise a thick fining-upward succession at the base of the St. Joe volcaniclastic succession.

In thin section, pale grey clasts are dominated by extremely fine crystalline silicates, minor biotite and trace calcite. Mineralogy of the silicates is not known, but scanning electron microscope analyses (Pighin, 1982) suggests that they are predominantly plagioclase rather than quartz. Dark green clasts are composed primarily of chlorite. Clast matrix includes abundant biotite, commonly rimming clasts, plagioclase, quartz and minor calcite and pyrrhotite. Unit C consists mainly of subangular, broken quartz grains, plagioclase, aligned biotite and chlorite, and intergranular calcite.

Unit D scours the underlying volcaniclastic units, removing a considerable portion of unit C in sections 3 and 4, and part of unit B in section 5. It comprises a monolithic fragmental with 2 to 3-centimetre, pale green, aligned angular clasts. It is generally massive, although some grading is apparent as coarse clasts are more common near the base. A laminated, pale green sandstone within the unit (unit D2) suggests that D may comprise two separate volcaniclastic sequences with possibly an upper fine-grained unit largely removed by scouring at the base of unit E. A drill intersection (ddh 94-6) shows that the top of unit D comprises closely packed aligned clasts in a white calcite matrix. Calcite also occurs in cores of many of the clasts, but is not present as late veinlets. This habit suggests that calcite is an early mineral, related to fragmentation, rather than a late alteration phase.

In thin section, the pale green clasts of unit D are similar to the green clasts of unit B, composed mainly of chlorite. The matrix is also similar, but typically contains more dispersed calcite.

Units E1 and E2 comprise two fining-upward sequences, each with a coarse volcaniclastic unit at the base (with clasts greater than 10 cm diameter) and capped by a massive to vaguely laminated, pale green tuffaceous siltstone. Layering in the base of unit E1 is locally highly contorted and disrupted (Photos 2 and 3).

The coarsest unit (unit F) occurs near the top of the volcaniclastic succession (Figure 5). Subrounded blocks up to 10 centimetres in long dimension occur within a finer grained, granular matrix. Occassional clasts have wel -defined rims, comprising dominantly chlorite and minor plagioclase (Photo 4).

The clasts have variable compositions and textures; none, however, are similar in texture to the coarse Moyie sills. Some clasts are dominantly chlorite (Photo 5) whereas others contain feldspar and (?)quartz phenocrysts; others comprise a fine granular mixture of dominantly feldspar and chlorite. The groundmass is primarily broken feldspar and quartz crystals with abundant biotite and chlorite.

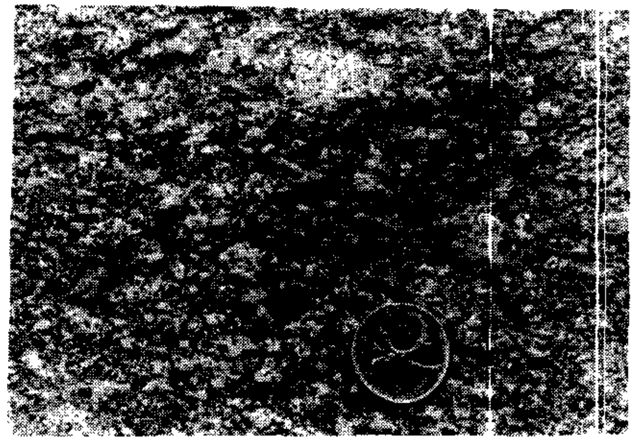

Photo 5. St. Joe tuff, section 2, unit D; monoli hic lapilli tuff comprising angular, fine-grained, mafic chlorite clasts within a dominantly feldspar-chlorite tuffaceous matrix.

GEOCHEMISTRY

Analyses of a number of hand samples of the St. Joe tuff, located on Figure 4, are given in Table 1. A major element alkali-silica plot of these samples, and others analyzed by Cominco Ltd. (Pighin, 1983), shows that the tuffs are subalkaline, with two populations, one with less than 60% SiO_2 and a second with greater than 65% SiO_2 (Figure 6). On a Jensen cation plot, most tuff samples plot in the high-iron tholeiite field (Figure 7), similar to most anylyzed Moyie sill samples (Höy, 1989), whereas the more siliceous samples are calcalkaline basaltic and andesitic in composition.

Plots of less mobile trace and minor elements also suggest two populations of analyzed St. Joe tuff samples. On a SiO_2-Zr/TiO_2 diagram, two samples plot within the rhyodacite-dacite field and two within the andesite field (Figure 8). However, on a Zr/TiO_2 *versus* Nb/Y diagram (Figure 9), the separation between these compositions is not as marked and the more felsic units plot near the andesite-dacite boundary. Therefore, it is possible that the higher silica content of a number of the St. Joe samples reflects alteration, with addition of silica. However, the analyses do reflect the two recognized clast populations: mafic chlorite-rich clasts and the more felsic feldspar-dominated clasts.

For comparative purposes, an analyses of a Moyie sill sample is plotted on some of these diagrams. More mafic

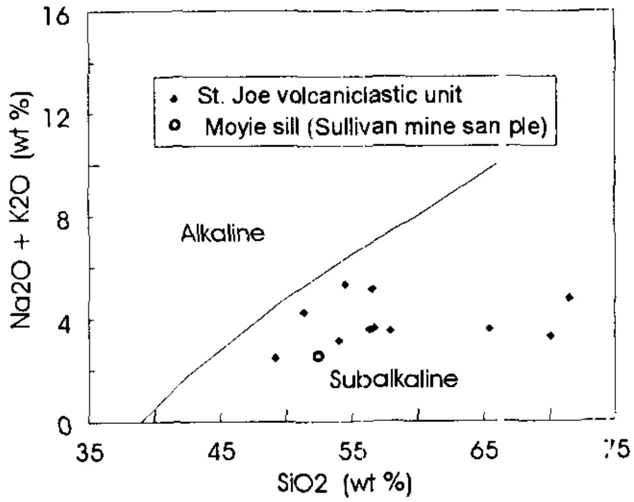

Figure 6. Alkali-silica plot (in weight percent) of samples of the St. Joe tuff; analysis of a Moyie sill, the footwall sill at the Sullivan deposit, is also shown (plot after Irvine and Barager, 1971).

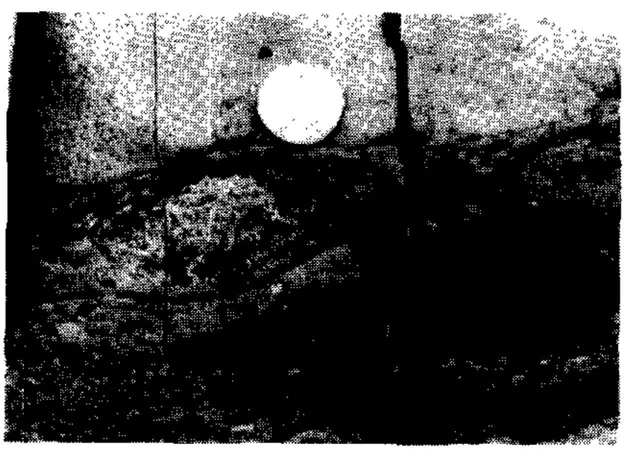

Photo 4. St. Joe tuff, section 4, unit F; mafic chlorite-plagioclase-rich clasts with fine-grained, laminated chlorite rims.

tuff members are similar in major element chemistry to Moyie sills but less mobile trace element chemistry indicates that the tuffs are dominantly andesitic in contrast with basaltic Moyie sill compositions (*see* Höy, 1989).

Metal values are anomalous in the St. Joe tuffs. In particular, mafic tuffs of units E and F contain on average 240 ppm Cu (5 samples), considerably higher than the average values for adjacent Aldridge metasediments (43 ppm, 15 samples; Pighin, 1983). Average metal contents of all twenty analyzed tuff samples are 134 ppm Cu, 151 ppm Zn and 51 ppm Pb.

SUMMARY AND DISCUSSION

The St. Joe occurrence comprises a number of graded sequences, each with a coarse base that scours and locally deforms underlying units, overlain by a massive to vaguely bedded monolithic fragmental, and capped by a finer

TABLE 1. ANALYSES OF SAMPLES FROM THE ST. JOE TUFF

Lab Number	Sample Number	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	SUM %
42636	St.Joe1	54.06	1.37	14.64	14.24	0.12	6.71	0.33	2.76	0.38	0.06	99.12
42963	St. Joe3	71.45	0.56	12.39	5.73	0.04	2.07	0.81	4.22	0.56	0.56	99.72
45128	St. Joe4D	70.07	0.56	11.84	7.85	0.11	2.82	1.46	2.63	0.69	0.04	99.81
45129	St. Joe5D	56.35	1.27	14.31	12.87	0.10	5.88	0.57	3.30	0.30	0.25	99.36
Lab Number	**Sample Number**	**Sr (ppm)**	**Rb (ppm)**	**Zr (ppm)**	**Y (ppm)**	**Nb (ppm)**	**Ta (ppm)**	**Ce (ppm)**	**Cs (ppm)**	**La (ppm)**	**Sc (ppm)**	**V (ppm)**
42636	St.Joe1	35	10	216	15	10	15	-	-	-	-	-
42963	St. Joe3	176	24	149	32	10	15	37	32	17	32	231
45128	St. Joe4D	169	31	164	48	7	15	70	-	20	13	100
45129	St. Joe5D	32	105	182	31	11	15	55	-	28	28	278

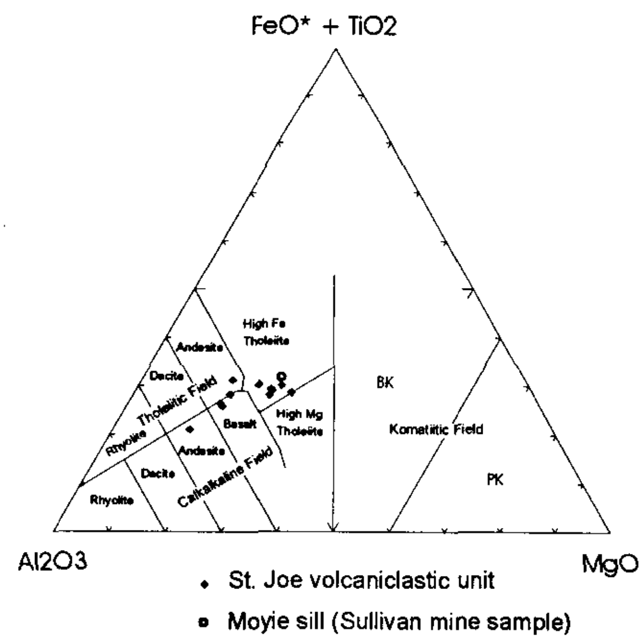

Figure 7. Jensen cation plot of samples of the St. Joe tuff, and a sample of the footwall sill at the Sullivan deposit; (plot after Jensen, 1976).

grained, generally well-bedded unit. Clasts within units are typically monolithic, comprising pale green chlorite with minor amounts of plagioclase. Some clasts, particularly near the base of the succession, are pale grey and dominated by plagioclase and biotite rather than chlorite. Some volcaniclastic units are finer grained but are also typically graded. They are mineralogically similar to the groundmass of unit F, with abundant feldspar and quartz crystals and numerous small angular, aligned pale green chlorite-rich clasts.

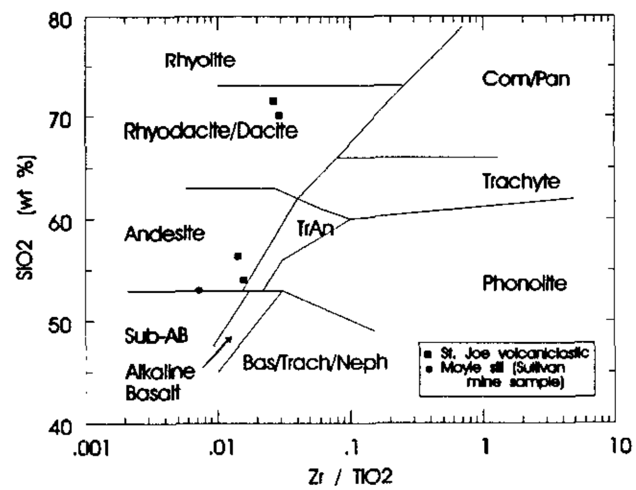

Figure 8. An SiO_2 versus Zr/TiO_2 plot of St. Joe tuff samples (plot after Winchester and Floyd, 1977).

The dominant monolithic character of the clasts, their unusual mineralogy, distinct from any known Aldridge metasediments, and their angularity, support interpretation as a volcanic unit. The abundance of chlorite and the broken feldspar and quartz grains in the groundmass also support this interpretation. Scouring, rip-up of underlying units, and minor crossbedding indicate deposition as a channel complex. The restricted occurrence of the unit, angularity of clasts, and general lack of contamination by Aldridge metasediments, suggests that it may have been deposited reasonably close to a source area.

The volcaniclastic may represent a pyroclastic deposit or, possibly, a hyaloclastite formed by quenching. Distinction between these deposit types is difficult, particularly after reworking and regional greenschist metamorphism.

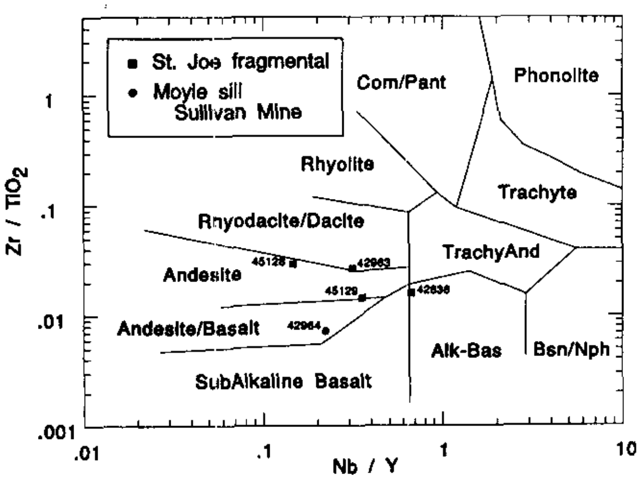

Figure 9. A Zr/Ti versus Nb/Y plot of St. Joe tuff samples (plot after Winchester and Floyd, 1977).

Lack of recognized lava flows, granularity of some (?)juvenile fragments, their abundance and possible armoured textures suggest pyroclastic deposition. Furthermore, lack or absence of vesicules in clasts suggests phreatomagmatic rather than magmatic explosions.

Hence, it is concluded that the deposit comprises dominantly water-lain lapilli and crystal tuff with possibly a tuffaceous conglomerate and tuffaceous sandstone component. Clasts with chloritic rims may be armoured lapilli with alteration of glass to chlorite or may reflect alteration envelopes around pyroclasts. Chloritic clasts may originally have been mafic glass shards whereas pale grey clasts are interpreted to be more felsic lapilli.

The St. Joe volcaniclastic deposit is one of the few known volcanic units within the Aldridge Formation. However, as it in the same stratigraphic succession that hosts the thick accumulations of possibly comagmatic sills, the Moyie intrusions, it may record fragmentation of magma injected to a higher level or possibly a shallower water environment. Although subaqeous venting of tuffs can occur to water depths of greater than 2000 metres, it is much more likely to occur at much shallower depths (<1 km; McBirney, 1963). The presence of quartz, possibly even as phenocrysts, and the major and trace element chemistry suggest a more fractionated magma source than the Moyie sills.

OTHER INFERRED VOLCANICLASTIC UNITS

WILD HORSE RIVER

The Wild Horse River fragmental was discovered by D. Pighin in 1987 during detailed mapping of a lead-zinc vein, the Judy-Lu. It is located on the west bank of Wild Horse River on the walls of the trenched vein and extends for a few metres in natural outcrops. It comprises a light brown weathering layer, 10 to 15 centimetres thick, within strongly cleaved, dark grey to black, middle Aldridge argillite. The succession is overturned, trending north and dipping steeply to the west. Its exact stratigraphic position is not known, but extrapolation to the north (Höy, 1993) indicates that it is near the base of unit A2 of the middle Aldridge, a similar stratigraphic position to the St. Joe tuff (*see* Figure 2).

In hand sample, the Wild Horse River fragmental comprises a variety of small clasts in a light green matrix. The most abundant are 1 to 5-millimetre pale yellow-green angular clasts that are flattened parallel to foliation (Photo 6). They comprise fine-grained feldpspar with minor chlorite and muscovite. Angular, brown shale clasts and quartzitic fragments are rare. The matrix is dominantly feldspar, chlorite, muscovite and minor carbonate (dolomite?) that produces a brown weathering surface. Clasts are matrix supported, comprising approximately 20% of the rock.

Petrographic and scanning electron microscope analyses of one of the pale yellow-green clasts by McLeod (1987) suggest a volcanic origin:

"One fragment has the shape of a tear drop and is about 2 cm in diameter. This fragment has a chilled volcanic-microlitic texture on its edges ... The chilled margins consist of potash feldspar, plagioclase and iron oxide. The core is composed of plagioclase, pyrrhotite and biotite."

Due to limited exposure and intense deformation, it is difficult to interpret the origin of the Wild Horse River fragmental. It is a clastic, layer-parallel unit that is unlike known sedimentary fragmentals in the Aldridge Formation. The clasts are not similar to exposures of Moyie sills and therefore it is interpreted to be a tuffaceous unit. It may be a distal lapilli tuff, or possibly an epiclastic deposit formed by erosion or reworking of a volcanic rock.

MARK CREEK

The Mark Creek fragmental was discovered by A. Hagen in 1979 during regional mapping and exploration by Cominco Ltd. for sedex mineralization in the Aldridge Formation. It is exposed in a number of small isolated outcrops, covering a strike length of a few hundred metres, on the wooded slopes of Mark Creek approximately 3 kilometres northwest of the Sullivan deposit and 2 kilometres north of the Kimberley fault (Figure 1). The exposures are at the same stratigraphic level as the St. Joe tuff, just below a laminated siltstone marker unit.

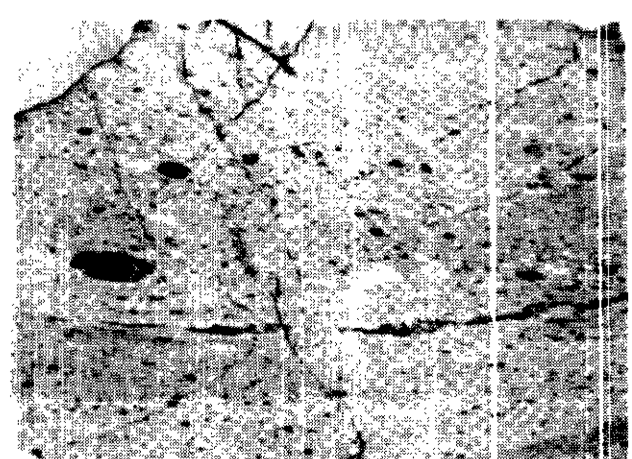

Photo 6. Hand sample from the Wild Horse River showing.

Fragmental outcrops are massive and rusty weathering. Neither layering nor grading are apparant. Fragmental samples are also massive, comprising dark grey, fine-grained siltstone containing isolated, flattened, pale grey and, less commonly, dark grey siltstone clasts, up to a centimetre in length.

In thin section, clasts are dominated by a fine-grained mosaic of feldspar and quartz, with abundant fine muscovite, coarser biotite and variable amounts of chlorite, epidote and opaques. Occassional clasts (or clots?) comprise dominantly chlorite and feldspar. The matrix to clasts is a mixture of feldspar, quartz, aligned fine muscovite, minor chlorite, epidote and pyrrhotite.

This fragmental appears to be dominantly of sedimentary origin. However, the variety of clasts is not typical of most small Aldridge fragmentals, which are dominated by clasts similar in composition to the matrix. Its similar stratigraphic position to the St. Joe tuff and the occurrence of chlorite-rich clasts suggest that it may have a volcanic component.

ELEPHANT CREEK

The Elephant Creek fragmental comprises a small trenched exposure, 10 to 15 metres across, just north of Highway 3a (Figure 1). Based on correlation of marker layers within the Aldridge Formation, it occurs approximately 80 metres stratigraphically lower than the St. Joe tuff. It is similar to the Mark Creek showing, comprising small, angular, pale grey granular clasts in a feldspathic matrix. Rare green clasts, composed dominantly of chlorite, may have a volcanic origin. However, the bulk of both matrix and clasts appears to have a sedimentary origin, and therefore it is classified as conglomerate with a possible tuffaceous component.

SUMMARY AND DISCUSSION

Although magmatism is now well documented during deposition of the Aldridge Formation and development of the Purcell Basin, with intrusion of the Moyie sills (Höy, 1989, 1993), evidence of extrusive activity is rare. Nash and Hahn (1989) describe thin biotite-rich layers within the Yellowjacket Formation in the Blackbird Mining District, Idaho that are interpreted to be mafic metavolcanic rocks. Their average composition (including analyses of related mafic sills) indicates that they are considerably more alkaline than most of the Moyie sills and the St. Joe tuff. However, they are similar in composition to alkalic sills in the Mount Mahon area south of Yahk that are inferred to be part of the Moyie sill suite (Höy, 1989).

Three of the four occurrences of inferred volcaniclastic rocks in the Aldridge Formation are at or close to one stratigraphic level, approximately 1450 metres above the base of the middle Aldridge, and hence are interpreted to record a single period of volcanism. This stratigraphic level records turbidite deposition that immediately preceded a period of relative quiescence and deposition of several metres of dark laminated siltstone.

The distribution of Aldridge volcaniclastics reflects a small number of minor vents, the largest near the St. Joe tuff, the thickest and most proximal of the known occurrences. Failure to recognize them elsewhere within the Aldridge may reflect the environment during deposition; associated rapid turbidite deposition may largely mask all but the thickest and coarsest accumulations.

The St. Joe tuffs record deposition as successive channel deposits and hence suggest epiclastic deposition. However, clasts with fine mafic rims suggestive of armoured lapilli, and broken angular feldspar and quartz grains, suggest clasts may be pyroclasts. It is, therefore, suggested that the St. Joe occurrence is a reworked volcanic tuff. As subaerial deposits are not recognized at this stratigraphic level (or at any other within the Aldridge Formation) the deposit is interpreted to be a subaqueous pyroclastic deposit.

Mafic pyroclastic rocks are common within subaerial environments, and generally restricted to depths of a less than a few hundred metres in submarine (or subaqueous) environments, suggesting that this stratigraphic level may record a widespread regression in middle Aldridge time. A similar but stratigraphically lower regression is described by Cressman (1989) in correlative Prichard Formation rocks in Montana.

The andesitic to possibly dacitic composition of a component of the St. Joe tuffs is unusual for Aldridge magmatism. Moyie sills have a mafic composition, either tholeiitic or transitional. However, it is possible that granophyre, identified in the Crossport C sill in Idaho (Bishop, 1974) may record a more felsic differentiate.

Other evidence for more felsic Aldridge magmatism may be recorded in a boulder conglomerate in the Chipka Creek area southeast of Cranbrook (Höy, 1993). The conglomerate records extensional tectonics during Sheppard Formation deposition and contains clasts of feldspar porphyry that contain zircons that have yielded a preliminary U-Pb date that is similar to the age of the Moyie sills (J. Gabites, personal communication, 1994). Hence, it is possible that mafic magmatism, recorded as Moyie sills, may have a more felsic component that is recorded as pyroclastic volcanism. It is not known if these tuffs are related temporally to intrusion of either the upper or lower sill complex, or record a separate period of Aldridge magmatism.

The St. Joe horizon also records a period of regional low-grade hydrothermal mineralization in the Aldridge with elevated base metal abundances, particularly copper, which are up to four times the background levels of normal Aldridge sediments, and a small crosscutting lead-zinc-silver vein. As well, a small massive sulphide occurrence and tourmalinization occur within a sedimentary fragmental unit approximately 100 metres below the St. Joe tuff (Pighin, 1983; Turner *et al.*, 1993). In the Blackbird District, Idaho, stratabound copper-cobalt deposits and tourmalinization are closely associated with mafic sills and inferred metavolcanic units. The volcaniclastic units, including the St. Joe tuffs, may record extensional tectonics with development of growth faults that acted as conduits for mineralizing solutions localizing base and precious metal occurrences.

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NOTES

VINE - A MIDDLE PROTEROZOIC MASSIVE SULPHIDE VEIN, PURCELL SUPERGROUP, SOUTHEASTERN BRITISH COLUMBIA (82G/5W)

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(Contribution No. 20, Sullivan-Aldridge Project)

KEYWORDS: Economic geology, Middle Proterozoic, Purcell Supergroup, Aldridge Formation, massive sulphide vein, lead-zinc-silver.

INTRODUCTION

The Vine prospect is a steeply dipping, massive pyrrhotite base and precious metal vein deposit that cuts across gently dipping lower and middle Aldridge siltstones and wackes in the Purcell anticlinorium in southeastern British Columbia. It is owned 90% by Consolidated Ramrod Gold Corporation and 10% by Cominco Ltd.

The deposit is located in the Peavine Creek valley approximately 3 kilometres north of Moyie Lake and 11 kilometres south of Cranbrook (Figure 1). It is readily accessible via a 4.5-kilometre gravel road, the Hidden Valley road, that leaves Highway 3a just east of the Moyie River bridge at the Moyie Lake Provincial Park. The St. Eugene silver vein, worked extensively in the early 1900s, is located on the east shore of Moyie Lake, approximately 12 kilometres farther south.

The initial discovery of the Vine deposit in 1976, by D. Pighin while working for Cominco Ltd., consisted of a number of massive sulphide boulders scattered within a thin layer of glacial till. Subsequent work by Cominco consisted of trenching, which exposed the massive sulphide vein, reconnaissance VLF-EM geophysics to trace a fault structure that controlled the vein, and four diamond-drill holes.

Kokanee Explorations Ltd. (since acquired by Consolidated Ramrod Gold) began an exploration program on the Vine property in May, 1989 that included geophysical and geochemical surveys, geological mapping, trenching and 14 368 metres of diamond drilling (Photo 1). Trenching exposed the vein for over 150 metres along strike, and the geochemical and geophysical surveys indicated that the Vine structure continue for more than 4 kilometres. Subsequent mapping and drilling has more clearly defined this structure and recognized the importance of a gabbro dike that closely follows the fault structure. The drilling indicates that the vein is continuously mineralized along a strike length of at least a kilometre and to a depth of 800 metres; it remains open in both depth and strike.

More detailed fill-in drilling in 1990 outlined three main zones, defined as thicker and higher grade areas within the Vine vein. These include the Upper Trench area, the Val zone and the "41" area. Drill-indicated reserves in these zones, released by Kokanee Exploration in 1991, are outlined in Table 1:

TABLE 1
RESERVE FIGURES, VINE DEPOSIT (1991)*

	Tonnes (000)	Lead (%)	Zinc (%)	Silver (g/t)	Gold (g/t)
Proven	240	5.20	2.24	67.23	1.92
Probable	307	4.22	2.51	39.77	1.75
Possible	820				

**diluted to a 2.44-metre mining width*
Source: (Pighin, 1991)

This paper describes the structural and stratigraphic controls of the Vine vein system, its mineralogy and chemistry, and compares it to other hydrothermal systems in the Aldridge Formation. It also describes briefly the stratigraphy of the Sullivan horizon and immediately adjacent units, thus allowing speculation regarding regional facies changes in this important interval.

REGIONAL GEOLOGY

STRATIGRAPHY

The Vine vein is within the Aldridge Formation of the Middle Proterozoic Purcell Supergroup. The formation comprises in excess of 4000 metres of coarse to fine clastic rocks, dominantly turbidites, deposited in a developing extensional basin in an intracratonic setting (Winston *et al.*, 1984). The formation is divided into three divisions (Figure 2). The lower Aldridge consists mainly of rusty weathering, thin-bedded argillaceous siltstone with occassional sections of coarse, more massive turbidite wackes. It is overlain by the middle Aldridge, comprising approximately 3000 metres of grey-weathering, thick to thin-bedded turbidites with some intercalated, well laminated siltstone marker units.

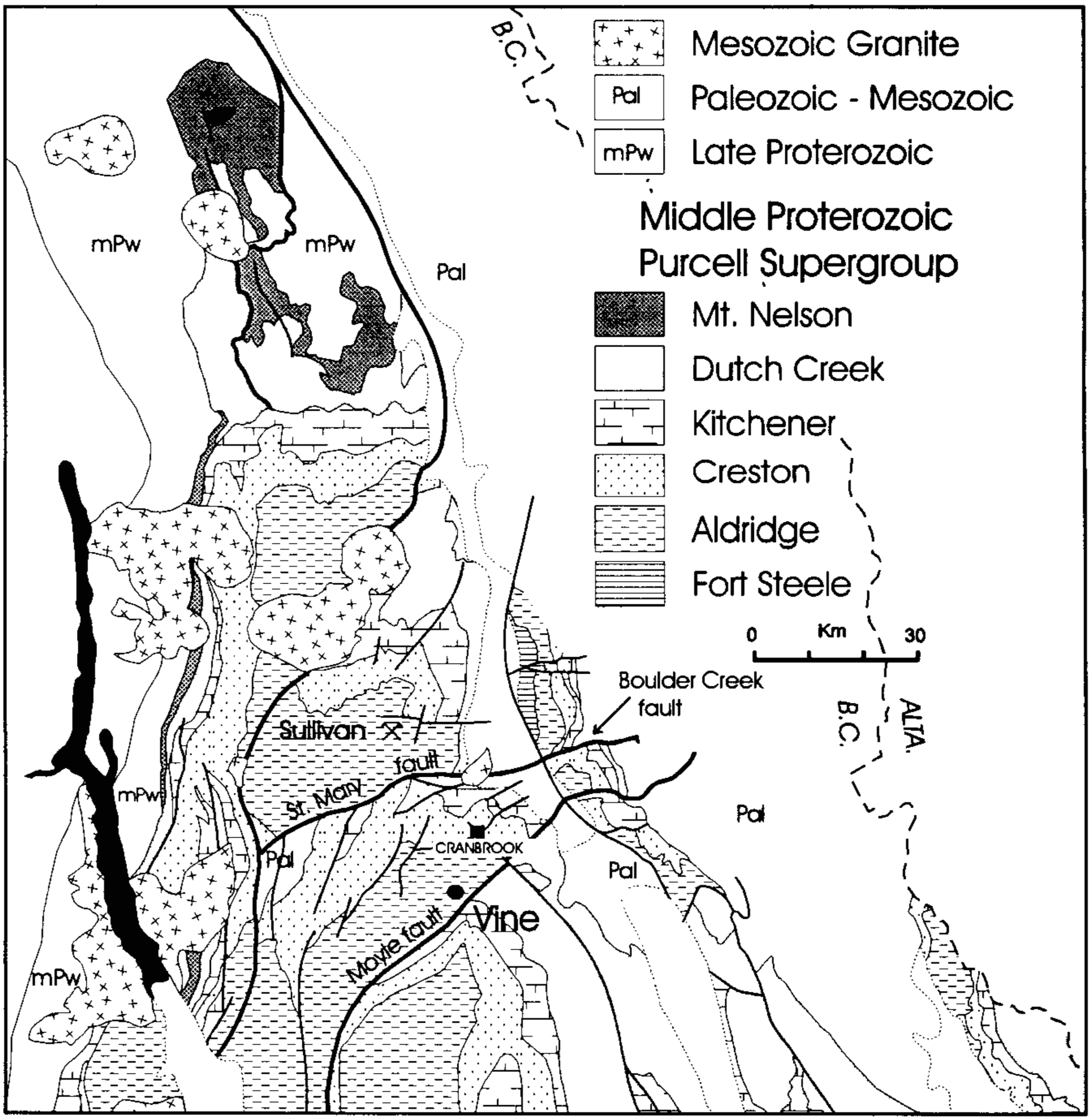

Figure 1. Regional geology map showing the location of the Vine deposit area within the Purcell anticlinorium, southestern British Columbia.

Photo 1. View of trenching, Vine deposit, in July, 1994.

The upper Aldridge comprises 500 metres of massive to faintly laminated argillite and argillaceous siltstone.

A number of thick gabbro sills, the Moyie sills, intrude the upper part of the lower Aldridge and the middle of the middle Aldridge. Contact features indicate that some of these sills were intruded into wet, unconsolidated to partially consolidated sediments, indicating magmatism accompanied extensional tectonics during development of the basin (Höy, 1989, 1993). Uranium-lead dating of these sills (1445±11 Ma, Höy, 1989; 1465 Ma, Anderson and Davis, in preparation) therefore constrain the early age of the Purcell basin and its contained mineral deposits.

The Aldridge Formation is overlain by shallow-water to locally subaerial argillite, siltstone and quartzite of the Creston Formation (Figure 2), interpreted to represent mudflats and alluvial apron deposits that were fed from braided streams in the south, southwest and northeast (Winston and Link, 1993). These latter deposits are recognized in the northern Hughes Range and are characterized by clean white, crossbedded and flat-laminated quartz sands. Overlying carbonate rocks of the Kitchener Formation are dominantly shallow-water deposits; prominent cyclical sedimentation in correlative rocks of the Helena Formation in Montana are interpreted to record periodic expansion and shrinkage of a Purcell (Belt) lake (Winston and Link, 1993).

Upper Purcell rocks include shallow-water carbonate and clastic rocks, deposited in a similar setting to those of the Creston and Kitchener formations and, along the eastern margin of the Purcell-Belt basin, a sequence of dominantly subaerial basalts of the Nicol Creek Formation (McMechan *et al.*, 1980; Höy, 1993). South of the Moyie fault, Purcell Supergroup rocks are overlain unconformably by Devonian carbonates of the Fairholme Group; north of the Moyie fault, Lower Cambrian shale and quartzite overlie the Purcell Supergroup.

STRUCTURE

The Vine deposit lies within the core of the Purcell anticlinorium, a broad north-trending structure cored by Purcell Supergroup rocks and flanked by Late Proterozoic, Early Cambrian or Devonian rocks (Figure). The deposit is in a structural panel that is underlain to the south by the Moyie fault, a right-lateral reverse fault that extends east across the Rocky Mountain Trench as the Dibble Creek fault, and overlain to the north by the St. Mary fault.

These northeast-trending faults, and their extensions east of the Rocky Mountain Trench, have a complex and

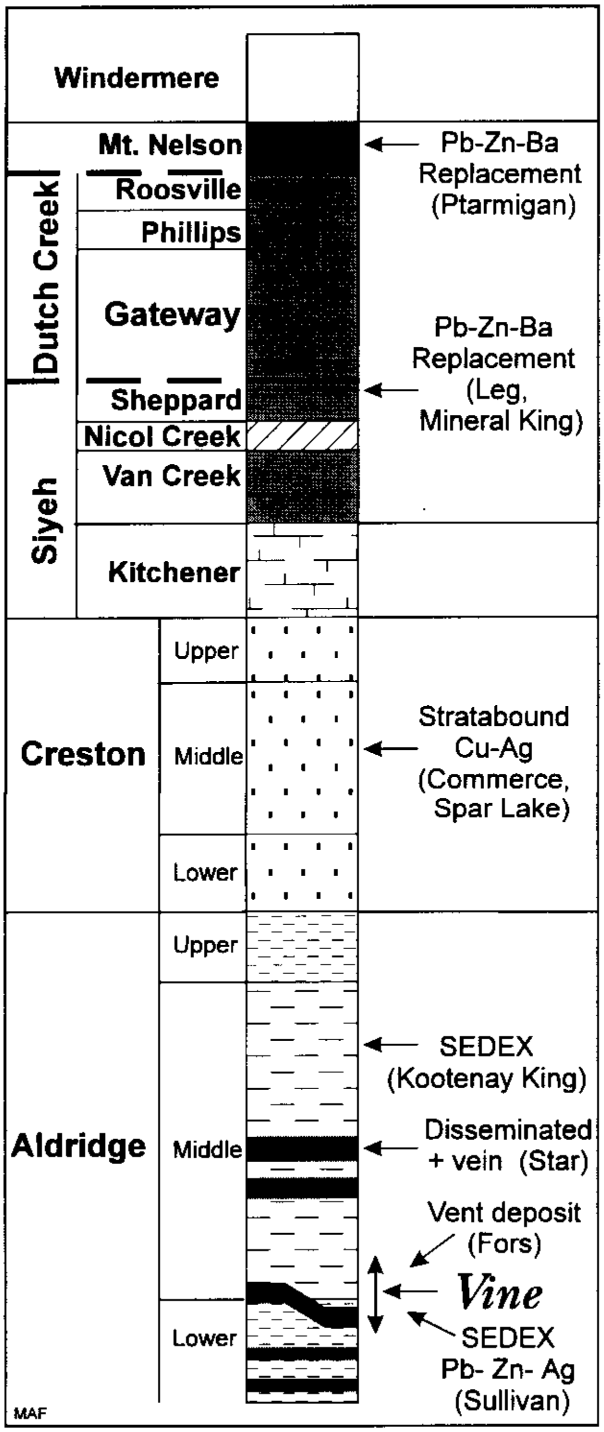

Figure 2. Purcell Supergroup stratigraphic column, showing position of Vine deposit and other important deposits within Purcell Supergroup rocks.

extended history of movement recognized by prominent facies and thickness changes in sedimentary units across them. Prominent facies changes within Aldridge rocks near the Boulder Creek fault, the eastern extension of the St. Mary fault (Figure 1), indicate that it coincides approximately with the faulted eastern margin of the Purcell basin (Höy, 1993). The Moyie fault is the locus of a faulted southern margin of the late Proterozoic Windermere basin (Lis and Price, 1976) and marks the northern margin of a pre-Devonian tectonic high referred to as Montania (Leech, 1962). Evidence for a Middle Proterozoic structure along the antecedent of the Moyie fault is less well documented. However, anomalous thicknesses of Middle Proterozoic Moyie sills, subtle but persistent thickness changes within Aldridge rocks, comparisons with the similarly oriented St. Mary fault, and concentrations of mid-Proterozoic hydrothermal mineralization near the fault, suggest that it may also follow the locus of an earlier Middle Proterozoic structure.

The Moyie anticline, a doubly plunging anticlinal fold, dominates the structure of the Moyie block south of the Moyie fault (Figure 1). Both the Midway and St. Eugene vein deposits occur in Aldridge rocks in the core of the anticline. The fault is locally marked by a zone of intense shearing, up to several hundred metres wide, that dips northwest at 60° to 70° (Figure 3).

Aldridge rocks in the immediate hangingwall of the Moyie fault are locally folded into a series of tight and locally overturned folds with commonly well developed axial planar cleavage. These die out rapidly to the northwest; the Vine deposit, located less than 2 kilometres from the Moyie fault, is in gently north dipping Aldridge metasediments which locally have a weakly developed crosscutting penetrative cleavage.

PROPERTY GEOLOGY

The geological map of the Vine deposit area, shown in Figure 3, shows the northwest trend of the Vine vein structure within northeast-trending lower and middle Aldridge metasediments. It is parallel to a number of northwest trending faults with west-side-down normal displacements of a few tens to a few hundred metres. A late fault within the Vine structure is projected southeastward, cutting across intense shearing and folding in the hangingwall of the Moyie fault.

A more detailed surface plan of the Vine occurrence is shown in Figure 4 and cross-sections in Figures 5 and 6. Figure 4 is developed mainly from trenching and drilling; natural outcrops in the immediate vicinity of the vein are few.

DETAILED STRATIGRAPHY

Stratigraphic sections of the wallrocks of the Vine vein are shown in the cross-sections of Figures 5 and 6. The vein straddles the boundary between the lower and middle Aldridge, the approximate stratigraphic position of the Sullivan sedex deposit. These Aldridge metasediments strike northeast and dip 15° to 20° northwest.

The host succession comprises four main units: a lower quartzite succession, a siltstone succession, a laminated argillite succession, and an upper quartzite succession. Based on detailed correlation of marker units within the upper quartzite unit, the composite host succession can be correlated with Aldridge Formation elsewhere, including that in the vicinity of the Sullivan deposit.

The transition between the lower and the middle Aldridge occurs at the top of the laminated argillite unit;

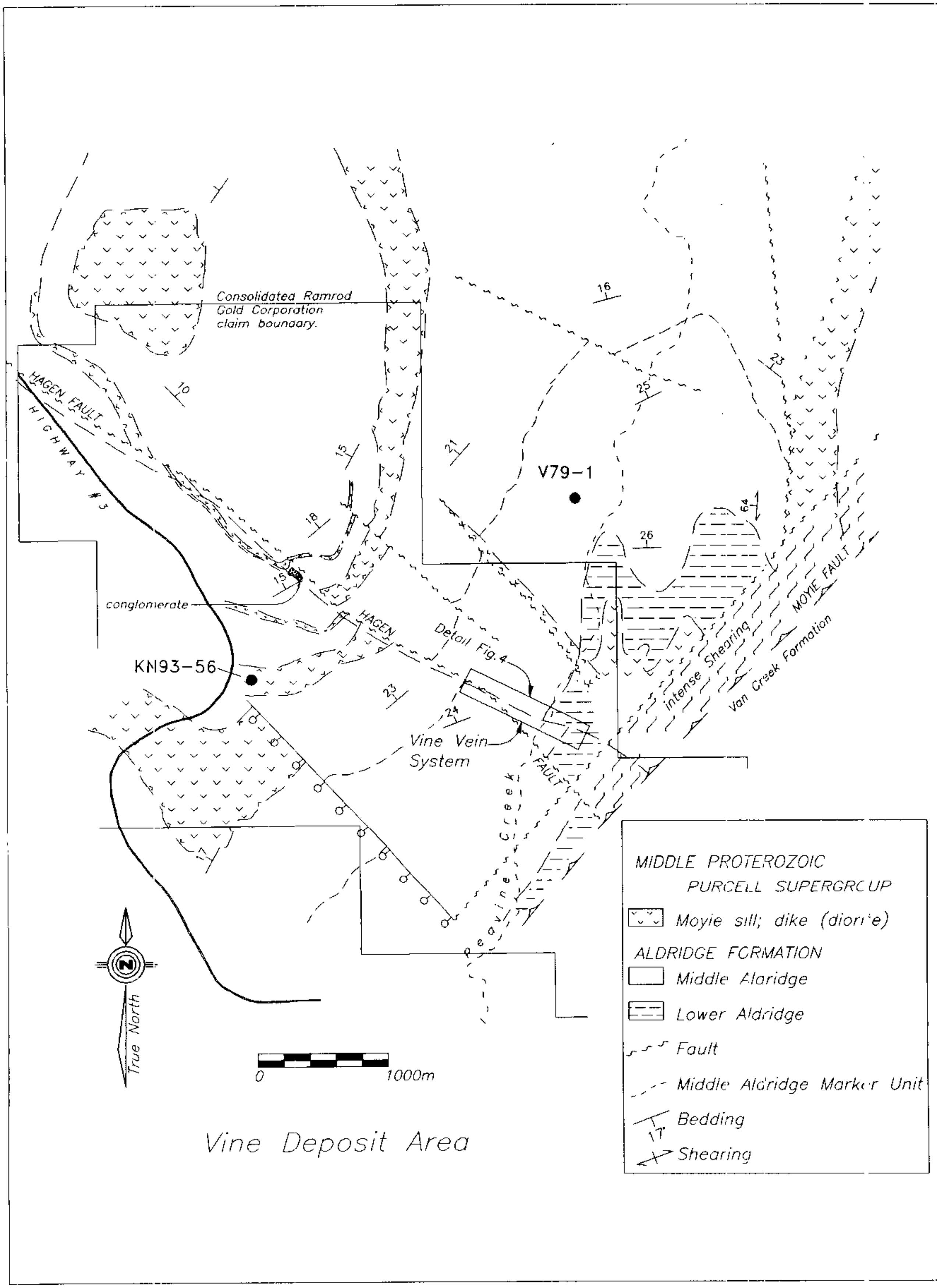

Figure 3. Surface geology map, Vine deposit area (from Pighin, 1991).

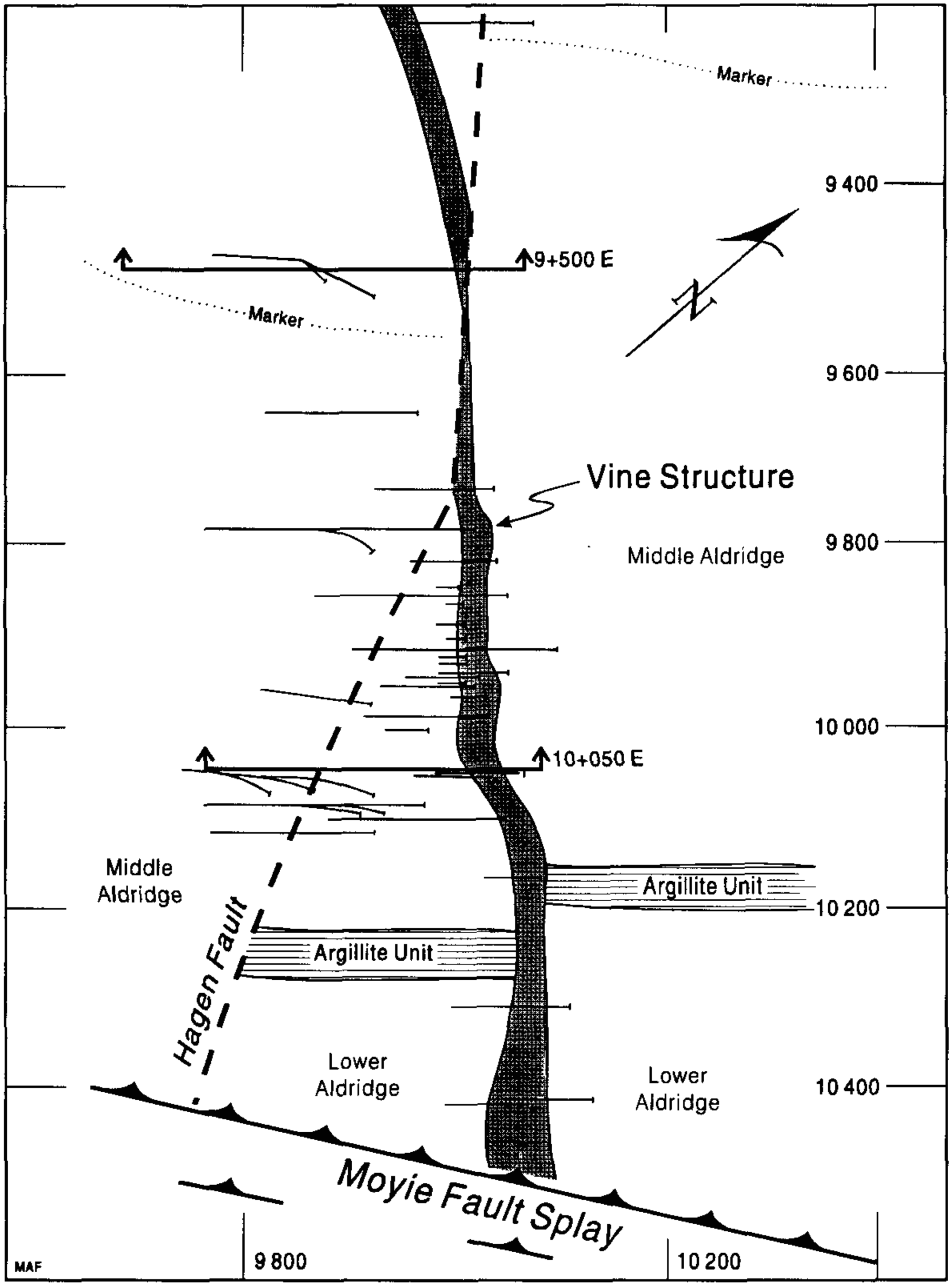

Figure 4. Surface drill plan and simplified surface geology, Vine deposit; *see* Figure 3 for location (after Pighin, 1991).

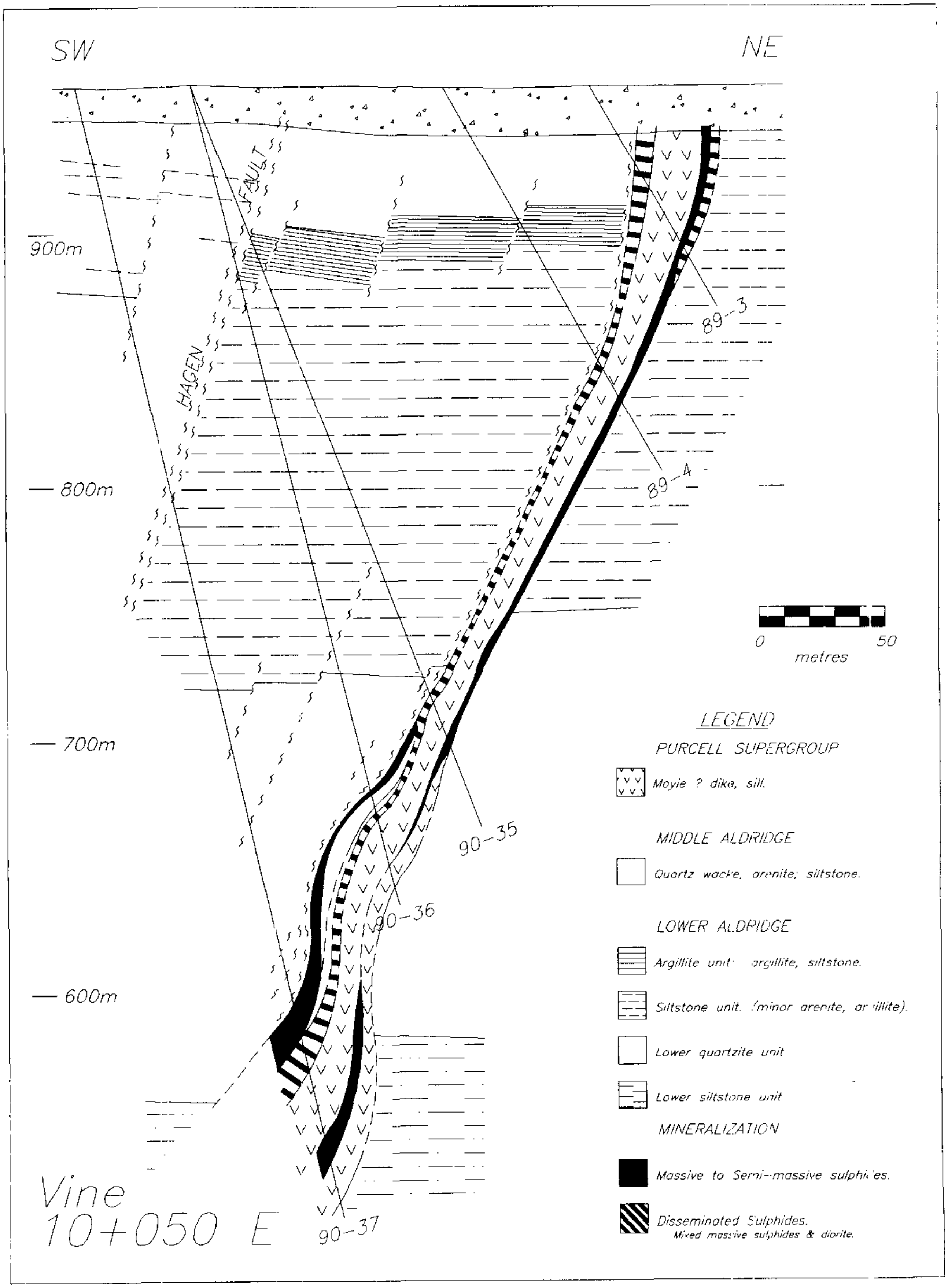

Figure 5. Section 10+050 E Vine deposit; *see* Figure 4 for location (after Pighin, 1991).

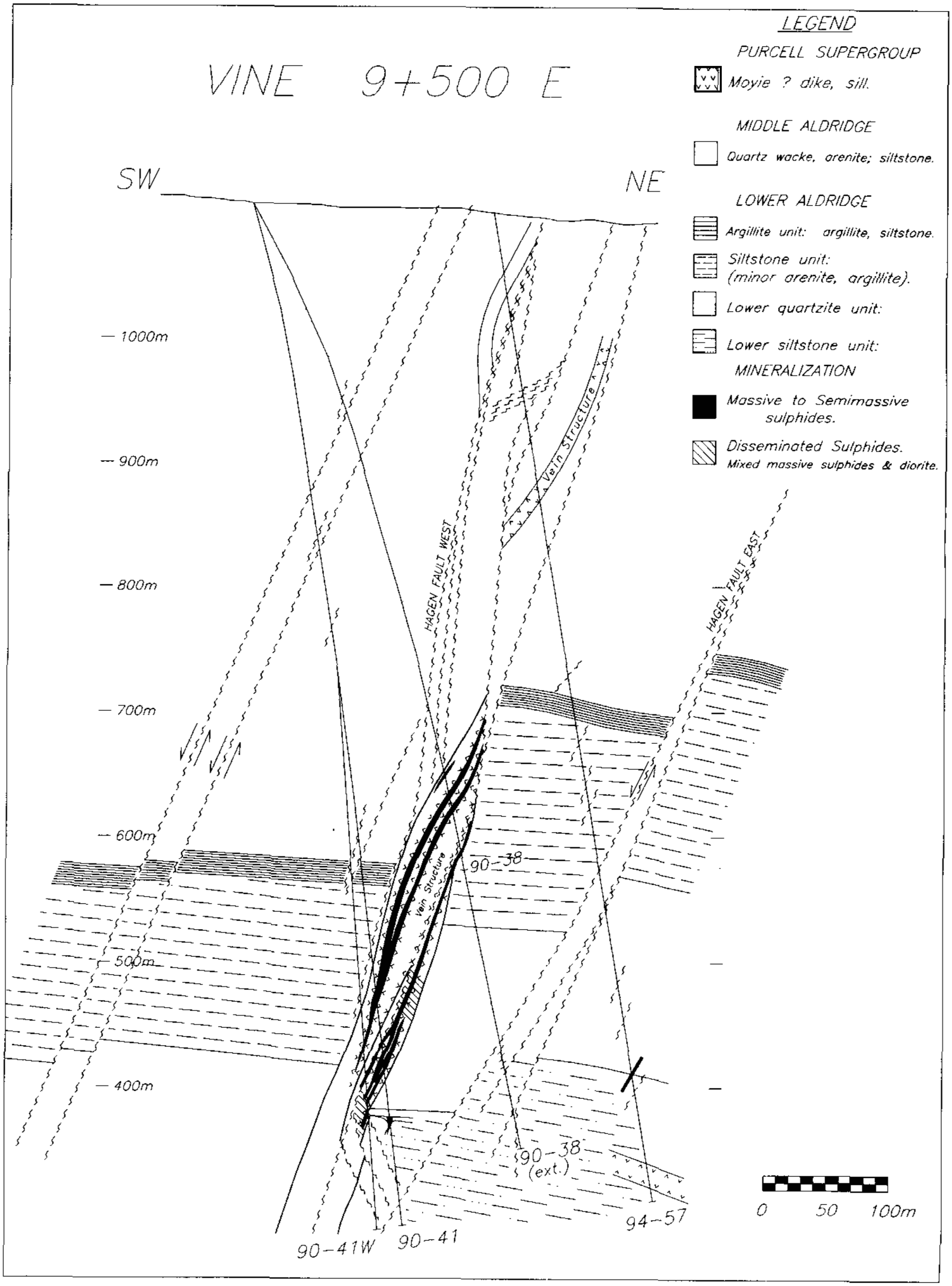

Figure 6. Section 9+500 E, Vine deposit; *see* Figure 4 for location (after Pighin, 1991).

the laminated argillite unit correlates with the Sullivan horizon, and the lower quartzite unit with the footwall quartzites of the Sullivan mine area.

LOWER QUARTZITE UNIT (LOWER ALDRIDGE)

The lower quartzite unit comprises approximately 150 metres of thick to medium-bedded, massive to locally graded quartz wacke and arenite. Argillite partings between beds are uncommon. Thin-bedded siltstone units, generally less than a metre thick, occur locally. The top of the unit is marked by 10 to 15 centimetres of laminated grey siltstone with varying amounts of disseminated to locally laminated pyrite. A similar unit occurs approximately 100 metres below the top of the unit.

SILTSTONE UNIT (LOWER ALDRIDGE)

The lower siltstone unit comprises approximately 150 metres of thin to medium-bedded siltstone and wacke. Individual beds may be massive, poorly graded or vaguely laminated. Beds are typically grey coloured although abundant fine-grained metamorphic biotite produces a purple cast. The siltstone contains more pyrrhotite (3 to 4%) and is generally finer grained and thinner bedded than the underlying quartzite unit or the basal part of the middle Aldridge. It contains occassional thin, laminated silty argillite layers and, in the top 3 to 4 metres, thin fine-grained quartz arenite and wacke units similar to those that characterize the lower quartzite unit.

ARGILLITE UNIT (LOWER ALDRIDGE)

The argillite unit, referred to as the Sullivan horizon in the Sullivan deposit area (Hamilton *et al.*, 1982) is a massive to laminated silty argillite and siltstone succession up to 20 metres thick. Biotite and pyrrhotite are ubiquitous, and particularly abundant in the more argillaceous intervals. They commonly define the parallel-laminated nature of the unit.

Thin, massive to graded, grey siltstone layers occur throughout the unit. Minor crossbedding occurs in some of these layers. Conspicuous dark-light laminations are present in some siltstone units; the bottom 2 metres of the argillite unit in diamond-drill hole 89-4 (Figure 5) is particularly well laminated, with up to 50% pyrrhotite in the darker laminae. This laminated interval is similar to the mineralized horizon on Concentrator Hill just east of Kimberley, which is the distal expression of the Sullivan deposit.

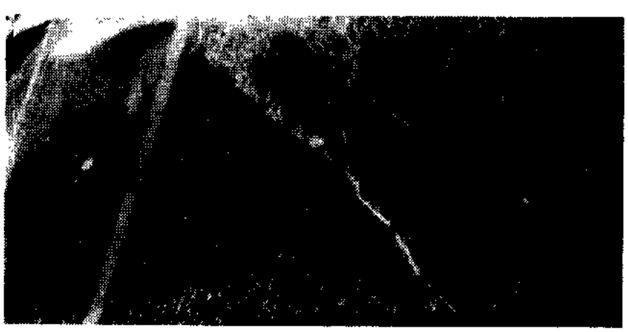

Photo 2. Dispersed pyrrhotite forming vague laminations in otherwise massive argillite, base of argillite unit (Sullivan horizon) (ddh 41, 564.8 m; sample width - 9 cm).

Sulphides, particularly pyrrhotite and minor pyrite, occur throughout as disseminated grains and occassionally in thin millimetre-thick laminations. Rare disseminated grains of sphalerite and galena are recognized in sections where pyrrhotite laminations occur. Highest abundances occur in a 2 to 3-metre section in the lower third of the argillite unit. Within this interval, zinc analyses of 2000 to 3000 ppm and lead analyses of 500 to 1000 ppm are common (in 20 cm intervals). A persistent section, up to 10 centimetres thick near the bottom of the argillite unit, contains up to 20% sulphides, dominantly pyrrhotite and trace sphalerite (Photo 2).

The true thickness of the argillite unit varies from approximately 11 metres to just over 20 metres with a hinge located along the Vine structure. Northeast of Vine, in diamond-drill hole V79-1, the unit is 19.4 metres thick (D. Anderson, personal communication, 1994); to the west, in hole KN93-56, it is also approximately 20 metres thick. However, in drill intersections in the hangingwall of the Vine structure, the argillite unit averages between 15 and 16 metres, in contrast to the more typical 20 metres immediately to the east in the footwall. This suggests that the Vine structure may have had a seafloor topographic expression during Sullivan time, with a high located immediately to the west. As the Vine fault is occupied by a Moyie dike and a small, crudely layered conglomeratic unit occurs adjacent to the structure higher in the Aldridge (Figure 3), the structure is interpreted to be a minor north-northwest trending growth fault during Aldridge deposition.

Approximately 5 kilometres south-southwest of the Vine deposit, near Munroe Lake, numerous drill intersections indicate that the Sullivan horizon is marked by up to 50 metres of fragmentals that define a northeast-trending depression that parallels the Moyie fault. This suggests that the Moyie fault may also be the approximate trace of a Middle Proterozoic fault.

In summary, both thickness and lithologic variations of units deposited at the lower-middle Aldridge transition support a model for increasing structural subsidence to the west during Sullivan time, controlled in part by an antecedent of the Moyie fault, and interrupted by small northwest-trending growth faults such as the Vine structure. The Vine structure was reactivated later in middle Aldridge time, with deposition of the fragmental unit along its northwest extension; it controlled the emplacement of a Moyie dike and the Vine massive sulphide vein.

UPPER QUARTZITE SUCCESSION (MIDDLE ALDRIDGE)

A succession of well bedded quartz wackes that overlies the argillite unit is similar to the base of the middle Aldridge elsewhere in the Purcell Supergroup. It comprises medium-grained quartz arenites, wackes and minor siltstones. Grading is common, vague irregular laminations occur within some beds, and crossbeds are locally recognized. Two laminated siltstone intervals within the basal middle Aldridge are conspicuous marker units that allow correlation of drill intersections. Minor sections within the upper quartzite are similar to the typical thinner bedded siltstone unit of the lower Aldridge.

STRUCTURE

The dominant structure on the property is the Vine vein stucture, now marked by a normal fault that dips 70° to 80° west and has a dip-slip displacement of approximately 80 metres. It contains the Vine vein and a prominent gabbro dike that is mineralogically similar to the Moyie sills. This late fault, referred to as the Vine fault, is a splay of the Hagen fault, also a west-side down normal fault. The Hagen fault cuts at least 1500 metres of Aldridge stratigraphy and can be traced northwest for about 6 kilometres (Figure 3). To the south, both the Vine and the Hagen faults appear to be truncated by the Moyie fault.

The Vine fault is a complex zone, 10 to 60 metres wide, with numerous zones of brecciation and gouge that cut altered gabbro and early sulphide mineralization, and locally leave remnant elongate inclusions of altered Aldridge metasediments within it. It appears to record an extended period of movement beginning before the mineralizing event and continuing after it. Locally, intense shearing is cut by both massive sulphide veining and the gabbro dike. As described below, the veining has a complex history, with early vein material brecciated and sheared, then cut by late sulphide veining and finally, barren, calcite-rich veins. Coarse, angular, vuggy breccia overprints the early Vine structure, recording a late, essentially parallel fault structure with west-side-down normal movement.

The host Aldridge stratigraphy appears to control, in part, both the attitude of the Vine structure and the thickness of sulphide veins. The structure is commonly refracted to steeper dips within the more competent lower quartzite unit, where dips are locally near vertical. Massive sulphide vein mineralization is commonly considerably thicker within these more steeply dipping zones.

MINERALIZATION

The dominant and most conspicuous mineralization on the Vine property is the Vine vein. However, disseminated sulphides and elevated base metal and silver values in the argillite unit at the top of the lower Aldridge, the same stratigraphic level as the Sullivan deposit, and recognized growth faulting in the area, suggest the potential for local massive sulphide deposition. The Fors deposit, located 7 kilometres southwest of the Vine, is a small high-grade lead-zinc-silver vein and sedex deposit in the overlying middle Aldridge Formation (Britton and Pighin, 1995, this volume). Evidence of mineralization is not apparant at this stratigraphic level in the immediate Vine area.

VINE VEIN SYSTEM

The Vine vein system comprises a number of massive to semimassive sulphide-calcite-quartz veins within the Vine structure. These are largely concentrated in the hangingwall and footwall, with generally thinner and less discontinous veins in gabbro closer to the centre of the structure (Figures 5 and 6). Locally, it appears that faulting within the Vine structure has repeated the mineralized system, producing an anomalously thick mineralized interval (DDH 90-41, Figure 6).

The dominant sulphides are pyrrhotite, sphalerite, galena, arsenopyrite and pyrite in a quartz-calcite and minor chlorite gangue. Alteration is generally intense, though typically confined to a few tens of metres from the Vine structure. The following sections describe sulphide mineralogy and alteration in detail.

MINERALOGY

Pyrrhotite is the dominant sulphide within the massive sulphide vein system. It occurs intimately intergrown with brown sphalerite and, less commonly, galena in a quartz-calcite gangue (Photos 3 and 4). The massive sulphides range from coarse grained to mylonitized, with numerous floating, rounded to elongate quartz eyes. In thin section, massive pyrrhotite typically contains many small inclusions of sphalerite, galena, chalcopyrite and rarely pyrite. Pyrrhotite may also occur as veins, with quartz and dark chlorite gangue, that cut earlier massive sulphides; thin, late pyrrhotite veinlets commonly have dark chlorite envelopes.

Pyrite is generally not abundant. Minor pyrite occurs intergrown with the massive sulphides, suggesting early development. However, most pyrite occurs as isolated subhedral grains within the massive sulphides or in late crosscutting, thin to relatively massive veins a centimetre

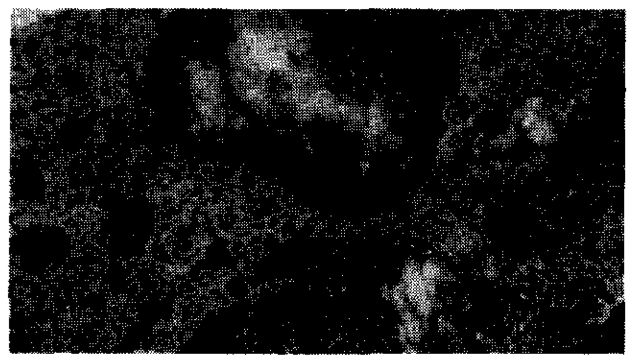

Photo 3. Vine massive sulphide; dominantly pyrrhotite swirled around rounded quartz inclusions. Pyrrhotite contains minor arsenopyrite grains and chalcopyrite occurs along margins of quartz. Lower quartz clasts contains abundant, disseminated subhedral arsenopyrite (ddh 36, 290.7 m; sample width - 9 cm).

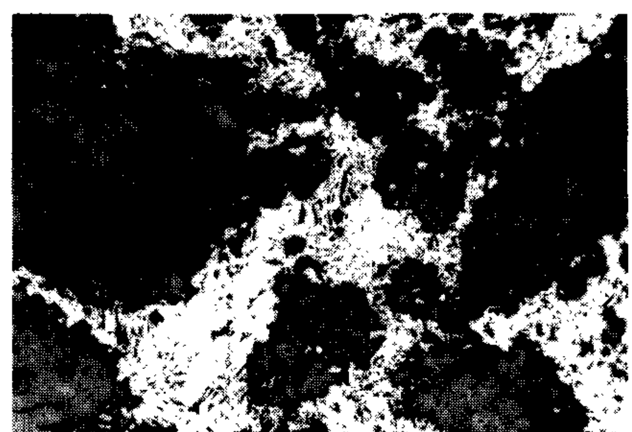

Photo 4. Photomicrograph (reflected light) of intergrown pyrrhotite and galena in a quartz (dark) matrix (ddh 41, 659.3 m; field of view: 5 mm).

thick, commonly with calcite and occassionally with chalcopyrite. Vein margins tend to be diffuse with pyrrhotite, suggesting replacement of the pyrrhotite, but sharp with other sulphides (Photos 5 and 6).

Arsenopyrite is locally a common and abundant sulphide. It occurs as small disseminated euhedral grains within quartz eyes (Photo 7) and within sheared siliceous (quartz) material. It also found occassionaly as floating isolated grains within massive pyrrhotite or pyrite; in thin section, arsenopyrite grains commonly have corroded margins

Photo 5. Late calcite-pyrite±pyrrhotite vein cutting sericite-altered metasediment with disseminated and vein pyrrhotite (ddh 41, 658 m; sample width - 10 cm).

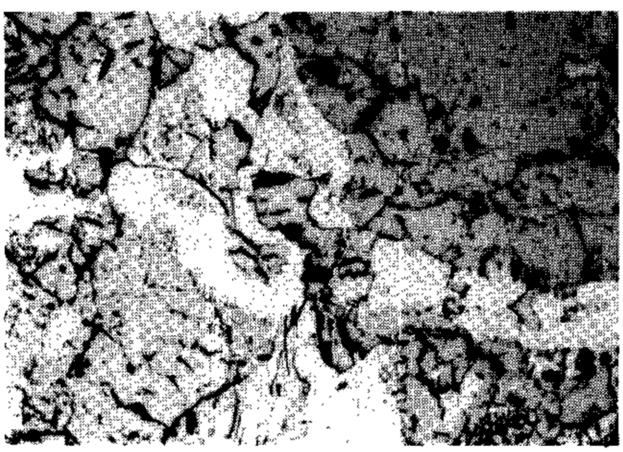

Photo 6. Photomicrograph (reflected light) of pyrite vein cutting massive pyrrhotite; note reaction between pyrrhotite and pyrite and angular broken galena within pyrite vein (ddh 41, 720.8 m; field of view: 5 mm).

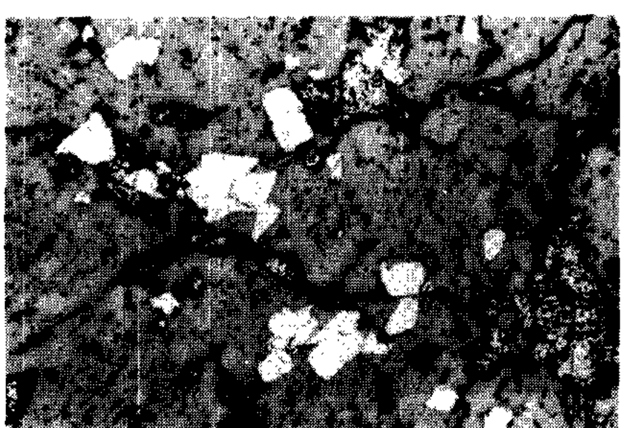

Photo 7. Photomicrograph (reflected light) of subhedral arsenopyrite (light) in quartz; note later veining of pyrrhotite (ddh 37, 368.8 m; field of view: 5 mm).

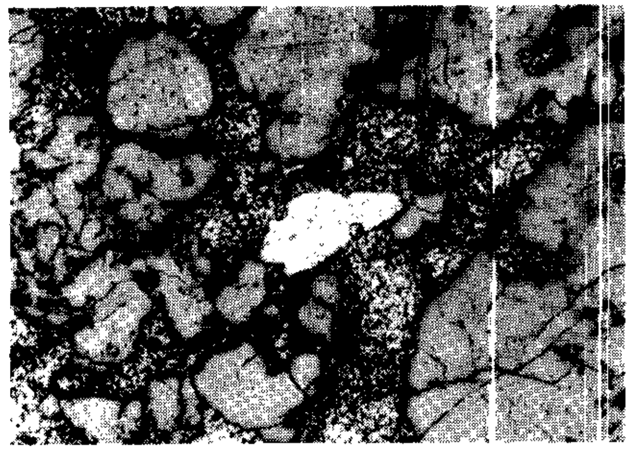

Photo 8. Photomicrograph (reflected light) of corroded arsenopyrite grain in massive pyrrhotite; note subrounded grains of quartz (ddh 41, 659.3 m; field of view: 5 mm).

suggesting early growth (Photo 8). Arsenopyrite is also noted rarely in massive, brecciated veins. These have not been observed cutting other massive sulphides. These relationships are consistent with arsenopyrite being one of the early formed sulphides. Occurrences in quartz eyes may be the remnants of early quartz-arsenopyrite veins that were subsequently broken, sheared and incorporated into the massive sulphides forming durchbewegung textures.

Chalcopyrite occurs as a minor constituent in the massive sulphide vein, commonly closely intergrown with pyrrhotite and other sulphides. It also occurs in the pressure shadows of enclosed silicate fragments and in many thin, wispy crosscutting hairline fractures.

ALTERATION

The dominant alteration minerals within and adjacent to the Vine vein system include sericite, calcite, chlorite, quartz and minor albite. Biotite is a regional metamorphic mineral, reflecting regional greenschist metamorphism. It is not present in alteration assemblages within or immediately adjacent to the vein. Sericite, with or without chlorite, carbonate and silicate alteration are associated with sulphide mineralization; alteration envelopes are cut by late calcite±pyrite veins.

Biotite is ubiquitous in all argillaceous siltstone units, locally forming a penetrative cleavage, or in more competent quartzitic units, giving a purple cast to the rock. In metasediments adjacent to the Vine vein, biotite occurs as fine disseminated, randomly oriented grains. Closer to the vein, it is intergrown with and finally replaced by sericite.

Sericite occurs in a number of different habits. A minor amount is present as fine-grained euhedral grains with the regional metamorphic biotite. This may record regional potassium alteration, related to the Vine vein system, as has been documunted in the Sullivan - North Star Hill area (Leitch *et al.*, 1991). Immediately adjacent to the Vine vein, patchy, white "bleaching" of Aldridge metasediments is due to intense sericitization. Similar pale green to white coloration around microfractures is due to fine-grained

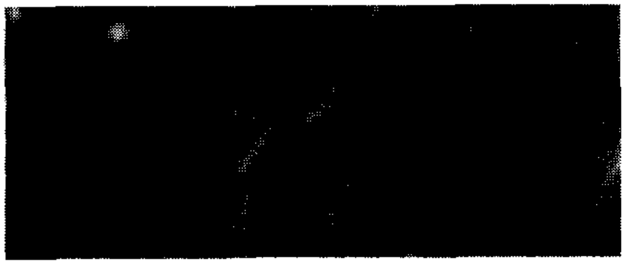

Photo 9. Early "bleached" sericite±pale green chlorite envelopes surrounding a network of microfractures that cut biotite siltstone (ddh 38, 488 m; sample width - 9 cm).

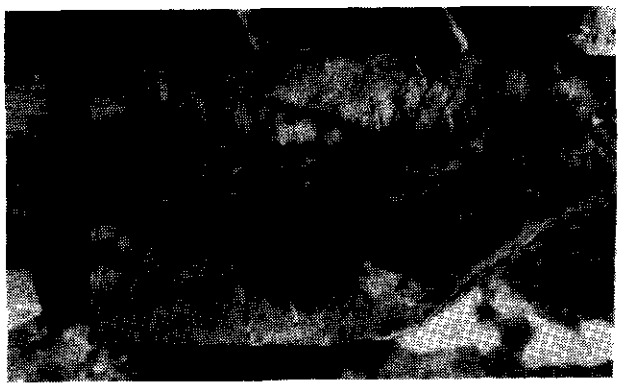

Photo 10. Pyrrhotite-galena-quartz vein cutting sericite altered siltstone; note dark chlorite alteration envelope around sulphide vein and early "bleached" sericite fractures (ddh39, 558.4 m; sample width - 8 cm).

sericite±pale chlorite alteration (Photo 9). This sericite± chlorite alteration is commonly cut by sulphide veins.

Early chlorite, associated with sericite, is a high-magnesium variety. In thin section, it occurs as small, pale green to colourless anhedral grains, interstitial to quartz, with moderate to high relief and anomalous blue birefringence. It commonly forms envelopes around early sulphide veins (Photo 10). Minor dark green chlorite occurs as gangue within the massive sulphides and in late chlorite±pyrrhotite veins that cut other massive sulphides. One sulphide-quartz vein has a distinctive zoned envelope: it comprises massive sulphide, quartz and chlorite, with a pale green chloritic envelope surrounded by a thick, intensely sericitized envelope. These relationships suggest early magnesium chlorite-sericite alteration, followed by more iron-rich chlorite alteration associated with sulphide mineralization.

Quartz occurs as gangue within massive sulphide veins, as included quartz eyes, and in late veins. Disseminated arsenopyrite in the quartz eyes, the abraded nature of many of these eyes, and common undulose extinction and possible deformation lamellae of the quartz grains, suggest that they are broken, rounded fragments of early vein mineralization. The most abundant gangue mineral in much of the massive sulphide vein system is clear to white, coarse-grained quartz. It is also often sheared and recrystallized. Minor quartz also occurs in small, late sulphide-free veins that are locally intensely brecciated.

Calcite typically occurs intergrown with quartz as a minor to locally dominant gangue in the massive sulphide veins. It also occurs with pyrite in late crosscutting veinlets, and barren, vuggy calcite forms the matrix to late fault breccias.

Albite occurs as a white, fine-grained granular alteration, recognized in both drill core and on surface. It is possibly related to Moyie dike emplacement as suggested by Turner and Leitch (1992). It is similar to albitic alteration recognized elsewhere in Aldridge rocks, in thin section characterized by untwinned crystals (C.H.B. Leitch, personal communication, 1994).

SUMMARY

Mineral and alteration assemblages indicate that the Vine vein is a complex system that is both spatially and temporally associated with movements on the Vine structure. An early, premineralization, growth fault that became the locus for gabbro dike emplacement, Vine mineralization and finally, late normal faulting, is suggested by the occurrence of a small bedded conglomerate that lies on the northwest extension of the Vine fault (Figure 3).

Early alteration, related to the Vine vein, included sericitization, locally intense and pervasive immediately adjacent to the vein and as thin bleached hairline stringers farther away. This appears to overprint biotite metamorphism, suggesting that the vein formed in the waning stages of regional metamorphism or possibly later. However, Leitch et al., (1991) argue that the regional disappearance of biotite in the Sullivan area reflects premetamorphic alteration producing a rock composition conducive to sericite rather than biotite growth during regional metamorphism.

The earliest recognized sulphide mineralization includes arsenopyrite with quartz, now preserved as remnant eyes within later massive sulphide mineralization as well as in isolated veins. Massive sulphide vein mineralization, dominantly pyrrhotite, sphalerite and galena with minor chalcopyrite and arsenopyrite, in a quartz-calcite and iron chlorite gangue, and locally with dark chlorite envelopes has a multistage development. Earlier massive sulphide veins are commonly cut by similar late veins. Many have a mylonitic fabric with durchbewegung textures, while others are massive and clearly cut sheared hostrocks, indicating late syntectonic deposition.

Late pyrite veins, with calcite and quartz, cut the massive sulphide veins. Associated faulting commonly produces a vuggy, angular breccia suggesting that these veins, and possibly late pyrite overgrowths, record remobilization of sulphides during late normal faulting. Coarse, sparry calcite matrix and barren calcite±quartz veins are also associated with this late faulting.

DISCUSSION

The Vine vein is an unusual massive sulphide base and precious metal vein system that cuts Middle Proterozoic turbidites and argillites of the Aldridge Formation. It comprises massive pyrrhotite, sphalerite and galena with minor arsenopyrite and chalcopyrite in a quartz-carbonate-chlorite gangue. It appears to overprint regional biotite metamorphism as well as sericite - magnesium chlorite alteration and early quartz-arsenopyrite veining, and is cut by late brecciation associated with pyrite, calcite and minor quartz.

The absolute age of the Vine vein is not known. Lead-lead isotope data from galena are similar to that of other Middle Proterozoic deposits (Cominco Ltd., unpublished internal report). However, the main sulphide mineralization appears to cut a regional metamorphic fabric that is related to the *ca.* 1350 Ma East Kootenay orogeny (McMechan and Price, 1982; Höy, 1993). Magmatic activity - intrusion of the Hellroaring Creek stock and other alkaline stocks - and folds with a penetrative axial planar cleavage are associated with this event in the St. Mary Lake area west of Kimberley. We suggest, therefore, that the Vine vein, and possibly other base and precious metal veins such as the St. Eugene, with Middle Proterozoic Pb-Pb isotopic signatures and possible late to post-tectonic emplacement, may record a hydrothermal event related to the East Kootenay orogeny.

The Vine vein system follows a northwest-trending structure that appears to have been active since Aldridge time, forming the locus for intrusion of a Middle Proterozoic Moyie dike, sulphide mineralization and both syn and post-mineralization faulting. This Middle Proterozoic structure trends northwest, at high angles to well documented northeast-trending Proterozoic structures, recognized as the antecedents of the Moyie and St. Mary faults. It parallels other mineralized northwest-trending structures, including those at the St. Eugene and Midway deposits, and numerous northwest-trending faults. Furthermore, this trend parallels approximately both the Aldridge basin margin and basin axis (Höy, 1993) as well as the axis of Moyie sill intrusions (Cressman, 1989). North of the St. Mary fault, however, regional structures strike more northerly, as do most Middle Proterozoic mineralizing trends, including the Sullivan - North star corridor (Höy, 1984; Turner *et al.*, 1993) and vein deposits such as Estella.

In conclusion, we suggest that some early northwest-trending extensional faults, initially developed during opening of the Purcell (Belt) basin, were reactivated as late faults and became the locus for base and precious metal vein mineralization such as the Vine deposit. Prominent northeast-trending structures reflect basement anisotropy that locally and markedly modified distribution of Aldridge sediments and, on a regional scale, controlled distribution of middle Proterozoic sulphide deposits (Höy, 1982).

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FORS - A PROTEROZOIC SEDIMENTARY EXHALATIVE BASE METAL DEPOSIT, PURCELL SUPERGROUP, SOUTHEASTERN BRITISH COLUMBIA (82G/5W)

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INTRODUCTION

The 1992 discovery of high-grade base and precious metal mineralization at the Fors property rekindled interest in the Middle Proterozoic Aldridge Formation and provides a new exploration target. Argentiferous lead-zinc mineralization occurs at the top of a discordant zone of pebble wacke or fragmental in middle Aldridge sandstone and mudstone.

Sulphide mineralization consists of pyrrhotite, sphalerite, galena, arsenopyrite, pyrite, chalcopyrite, and bismuthinite in stratiform, semimassive to massive lenses, as well as disseminations and veins. Scheelite is a local accessory. Gold values range up to 0.7 gram per tonne; silver to 734 grams per tonne. Drill-hole intersections of up to 25% combined lead and zinc over 1 metre have been reported; no tonnage estimates are available. The deposit is unusual in having extensive and varied alteration assemblages dominated by plagioclase, biotite, tourmaline, white mica, carbonate, tremolite-actinolite, talc and silica.

The Fors deposit is thought to be the product of sporadic hydrothermal activity along a cylindrical conduit, possibly following a growth fault, in well bedded but weakly consolidated sediments. Fluids moving along this conduit transported sediment upwards to create a "sand volcano" with a fragmental pipe in its core and a structureless sandy edifice on the seafloor. Changes in composition and volumes of hydrothermal fluid, together with ingress of sea water, account for the variety of alteration minerals. Sulphide minerals were deposited at two or three intervals during the evolution of this pipe. Timing of mineralization and alteration may coincide with the emplacement of a thick gabbroic sill 400 metres below the deposit.

This description of the geology, mineralization and alteration of the Fors discovery is based on three weeks' fieldwork in the summer of 1994 (JMB) and periodic surface exploration and drilling since 1966 (DLP). It supplements a brief earlier description by Höy *et al.* (1993). Since the discovery does not crop out, this description is based entirely on examination of drill core.

LOCATION, ACCESS AND EXPLORATION HISTORY

The Fors prospect (MINFILE 082GSW0[illegible]5) is located 17 kilometres southwest of Cranbrook, near the northern end of Moyie Lake, at latitude 49°22'N and longitude 115°53'W (Figure 1). Access is by paved and gravel roads from Highway 3/95.

Early in 1966, Helg Fors of Kimberley discovered lead-zinc mineralized float on logging roads near Little Lamb Creek. Subsequent prospecting by David Pighin and Ernest Pinchbeck on behalf of the Consolidated Mining and Smelting Company of Canada, Limited (now Cominco Ltd.) discovered the Main showing, a 1.2 by 13.7 metre lens of bedded lead-zinc sulphides (Webber, 1978b). Cominco staked the discovery as the Helg and Helg No. 1 to 4 groups comprising 158 claims (Gifford, 1966).

Follow-up work by Cominco in 1966, 1969, 1977, 1979, 1982 and 1983 included prospecting, trenching, surface geological mapping, geophysical surveys (gravity, magnetic, electromagnetics (DIGHEM, UTEM)) and soil and stream sediment geochemistry (Gifford, 1966; Currie, 1969; Fraser, 1977; Webber, 1977; Lajoie, 1979; Waskett-Myers, 1983). Anomalies were tested in 1967 and 1978 with at least five shallow and two deeper diamond drill holes totaling 944 metres (Webber, 1978a,b). No mineralization of economic interest was encountered and eventually the Helg claims were allowed to lapse.

L.D. Morgan restaked the area in 1987 and 1988 and optioned the property to Placer Dome Inc. which prospected, mapped and sampled from May to July, 1989. No further work was recommended (Maheux, 1990).

In autumn 1992, Chapleau Resources Limited and Barkhor Resources Limited optioned the property and commenced a diamond drilling program operated by Kokanee Explorations Limited (later Consolidated Ramrod Gold Corporation). The first drill hole (F92-1) was collared at the Main showing and intersected thin zones of disseminated to massive sulphide mineralization over a stratigraphic interval of 42 metres (Klewchuk, 1993). The highest grade intercept was 1 metre of massive sulphides with 9.35% Pb, 16.4% Zn, 0.09% Cd and 98 g/t Ag (The Northern Miner, December 7, 1992).

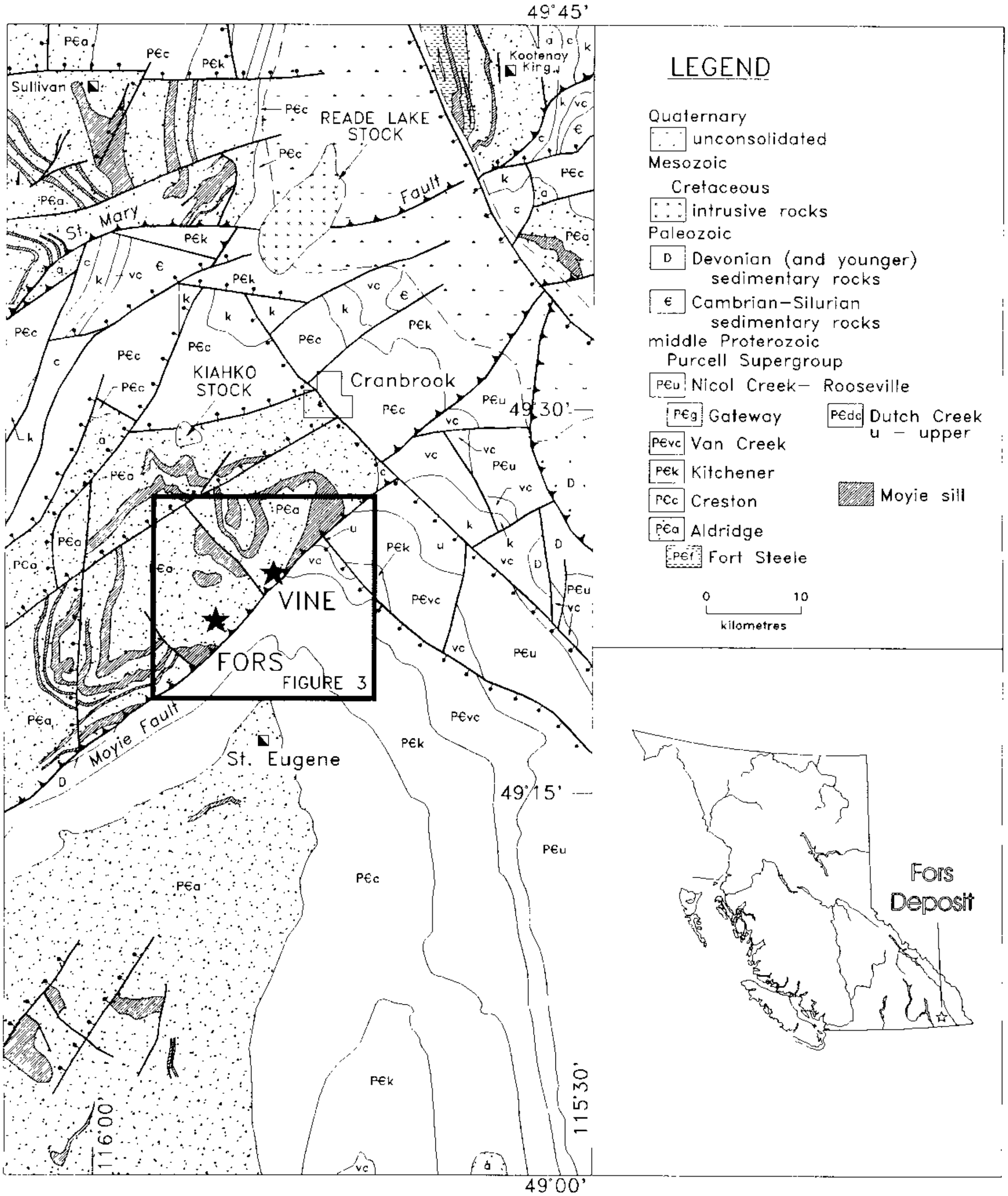

Figure 1. Regional geology and deposit location.

Diamond drilling on the Fors property continued until May 1994. Concurrent with this drilling, other exploration targets were defined by geophysical surveys (PEM and magnetometer) and geological modelling. These targets include sulphide-enriched sedimentary and concordant fragmental rocks near the lower-middle Aldridge contact (at the same stratigraphic horizon as the Sullivan deposit) and quartz-sulphide veins similar to the Vine vein located 8 kilometres to the northeast. (Höy and Pighin, 1995, this volume). A total of 12 169.7 metres (in 30 holes) has been drilled on the property to date, of which 2440 metres (12 holes) tested the extent of the 1992 discovery.

REGIONAL SETTING

The Moyie Lake area is underlain mainly by siliciclastic and lesser carbonate sedimentary rocks of the Middle Proterozoic Purcell Supergroup (Höy, 1993). They are exposed in a broad, northeasterly plunging anticlinorium that has been dissected by high-angle normal and reverse faults (Figure 1).

Earliest regional deformation occurred in Late Proterozoic time. Compressional tectonic activity during the Jura-Cretaceous Laramide orogeny that formed the Rocky Mountain fold and thrust belt, transported Purcell Supergroup strata as much as 300 kilometres eastwards (Price, 1981). Most recent tectonic activity consisted of Eocene extensional faulting.

The northeasterly trending Moyie fault bisects the area shown in Figure 2. It is a high-angle reverse fault with an estimated right-lateral displacement of 9 to 12 kilometres and dip displacement of 4 to 7 kilometres (Höy, 1993). It brings older, Aldridge Frmation strata into contact with younger, Kitchener strata. The Fors deposit is in the hangingwall of this fault.

Intrusion of gabbroic to dioritic magma nearly contemporaneous with sedimentation has resulted in the laterally extensive Moyie sills that form a significant part of the lower and middle Aldridge sections (Höy, 1993).

GEOLOGY OF THE FORS-VINE AREA

The Fors-Vine area is underlain by gently to moderately north to northeast-dipping strata of the lower and middle divisions of the Aldridge Formation that have been intruded by mafic Moyie sills (Figure 2). Three main sills occur on the property. Two of these, and a series of distinctive laminated mudstone marker beds, provide controls for stratigraphic correlation.

Deformation is mostly limited to gentle open folds. Bedding is locally deflected into the plane of crossfaults. More widespread shearing and tight folding occur along the Moyie fault zone (Höy and Diakow, 1982). The northeast-striking Moyie fault defines the southern limit of prospective ground. Minor northwest and west-striking high-angle faults break the stratigraphic sequence into a mosaic of structurally homogeneous blocks. Movement on these faults is typically in the order of tens to a few hundreds of metres.

Metamorphic grade is at most upper greenschist facies (Höy, 1993). Temperature and pressure estimates for the Sullivan mine area are 440±50°C and 300±100 megapascals (3±1 kilobars), with high carbon dioxide and low water fluids (De Paoli and Pattison, 1993), and 375°C and 450±100 megapascals (Lydon and Reardon, 1993). Metamorphism is attributed to burial. Despite metamorphic effects, primary sedimentary structures are very well preserved. Only where there has been intense hydrothermal alteration or deformation are they obliterated.

STRATIGRAPHY

The oldest rocks on the property are siltstones, quartzites and silty argillites of the lower Aldridge Formation. At Fors they crop out in a thin wedge along the Moyie fault (Figure 2) against which they have been folded. They are distinguished by rusty weathering, thin planar bedding and coarse reddish biotite porphyroblasts that parallel bedding and grow at random angles to it. Near the top of this unit (at the stratigraphic equivalent of the Sullivan horizon) is a concordant layer of pebble-wacke or fragmental up to 50 metres thick, thickening to the northeast away from the Fors deposit.

Middle Aldridge sedimentary rocks consist of fine-grained, grey or grey-green quartzofeldspathic sandstones (mostly wackes, some arenites), siltstones and argillites with variable amounts of porphyroblastic biotite and white mica (sericite or muscovite), pyrrhotite and pyrite (Leitch *et al.*, 1991). They were deposited as monotonous sequences of interbedded AE turbidites that can be broadly divided into a series of fining-upwards cycles (Höy, 1993). Coarser grained sequences tend to be medium bedded (10 to 30 cm); finer grained strata are thinly to very thinly bedded. Despite good bedding, individual layers or groups of beds lack distinguishing characteristics so that correlation between even closely spaced drill holes is very difficult.

Primary sedimentary structures in the middle Aldridge are well preserved and abundant. Bedding, the most common, is defined by mineral trains such as biotite flakes, pyrrhotite laminae, monazite, sphene and organic carbon. Fining upward sequences, interbedding and crossbedding are common. Slumps, ball and pillow structures, load and traction marks, rip-up clasts, tool marks and sole marks typical of turbidites also occur locally.

A pipe-shaped body of coarsely clastic material, referred to here as a discordant fragmental, occurs at depth (Figure 3). It consists of sand to pebble-sized clasts of sandstone and siltstone in a silty to sandy matrix. Most clasts are subrounded to subangular and matrix supported. The unit is up to 100 metres in diameter and 300 metres high.

A sequence of nearly massive fine-grained sediments, 30 to 60 metres thick, was recognized by early workers near the Main showing. It consists of "intermixed quartzitic and argillaceous material with a zone of abundant pyrrhotite" in which "bedding is either lacking or obscure" (Gifford, 1966).

We interpret both the discordant fragmental and this massive unit as products of dewatering phenomena that channeled fluids upwards in response to increasing hydrostatic and lithostatic loads. Fluid pathways may have been

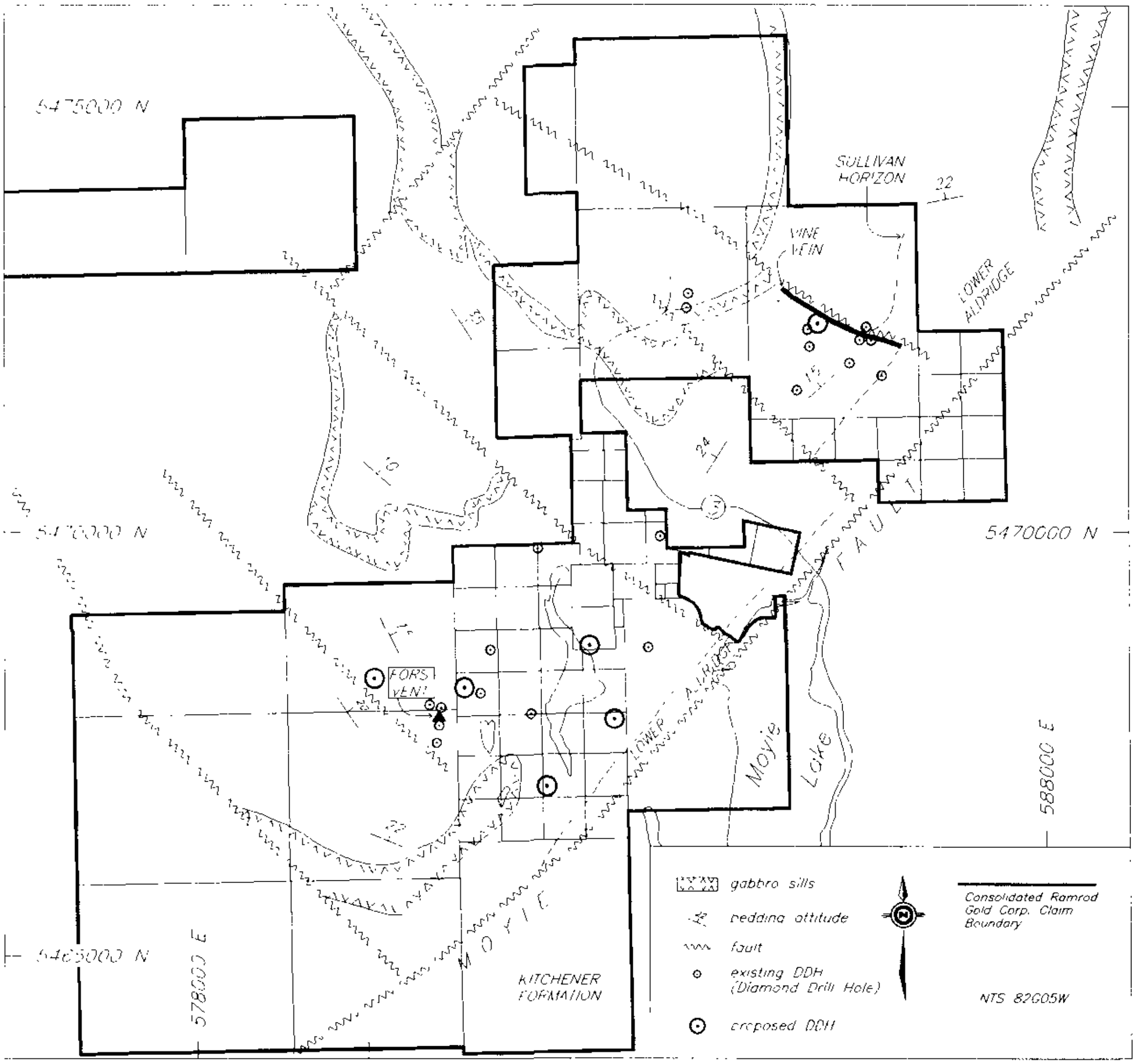

Figure 2. Geology of the Fors - Vine area.

localized by growth faults which would have provided the initial permeability. The clastic or massive fabrics result from either hydraulic milling of poorly consolidated sediments by upwelling fluids, or venting of a slurry of mud and sand onto the seafloor, forming a volcano-like edifice.

Several mafic sills intrude Aldridge Formation strata. The deepest intrudes near the lower-middle Aldridge contact and is at least 250 metres thick. At its closest it is 350 metres below the top of the Fors deposit (Figure 3). Two other sills are stratigraphically above the Fors deposit (Figure 2). All the sills are are assigned to the Moyie suite (Höy, 1993) on the basis of stratigraphic position and petrographic similarity. They are Middle Proterozoic and are thought to be penecontemporaneous with sedimentation (Höy, 1993).

Rare lamprophyre dikes, a few metres thick, have been intersected by drilling. They are dark grey with phenocrysts of coarse-grained black biotite. They are probably Early Cretaceous (Höy, 1993).

ALTERATION

A remarkable feature of this deposit is the extent and intensity of alteration assemblages, both associated with sulphide mineralization and apart from it. Most alteration effects are attributed to hydrothermal fluids interacting with unconsolidated sediments, in the synsedimentary to early diagenetic stages of the evolution of these rocks, before final lithification. Evidence for this comes from altered clasts occurring in an unaltered matrix, the strong influence of bedding and primary porosity on alteration. and ptygmatic folding in early-formed sulphide veins, due to compaction.

Alteration types are described in terms of their present (metamorphic) mineralogy. The reader should keep in mind

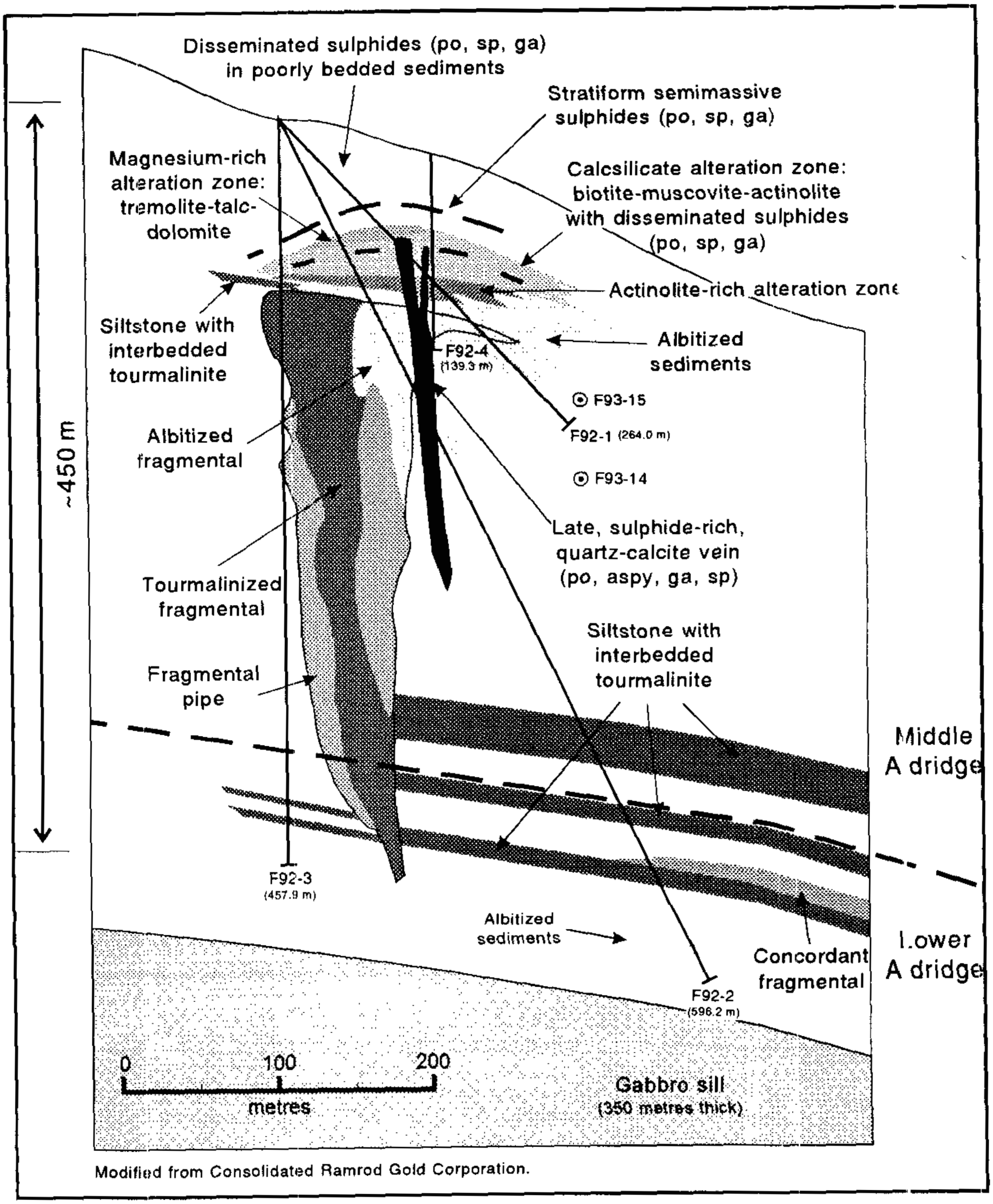

Figure 3. Fors deposit: schematic cross-section.

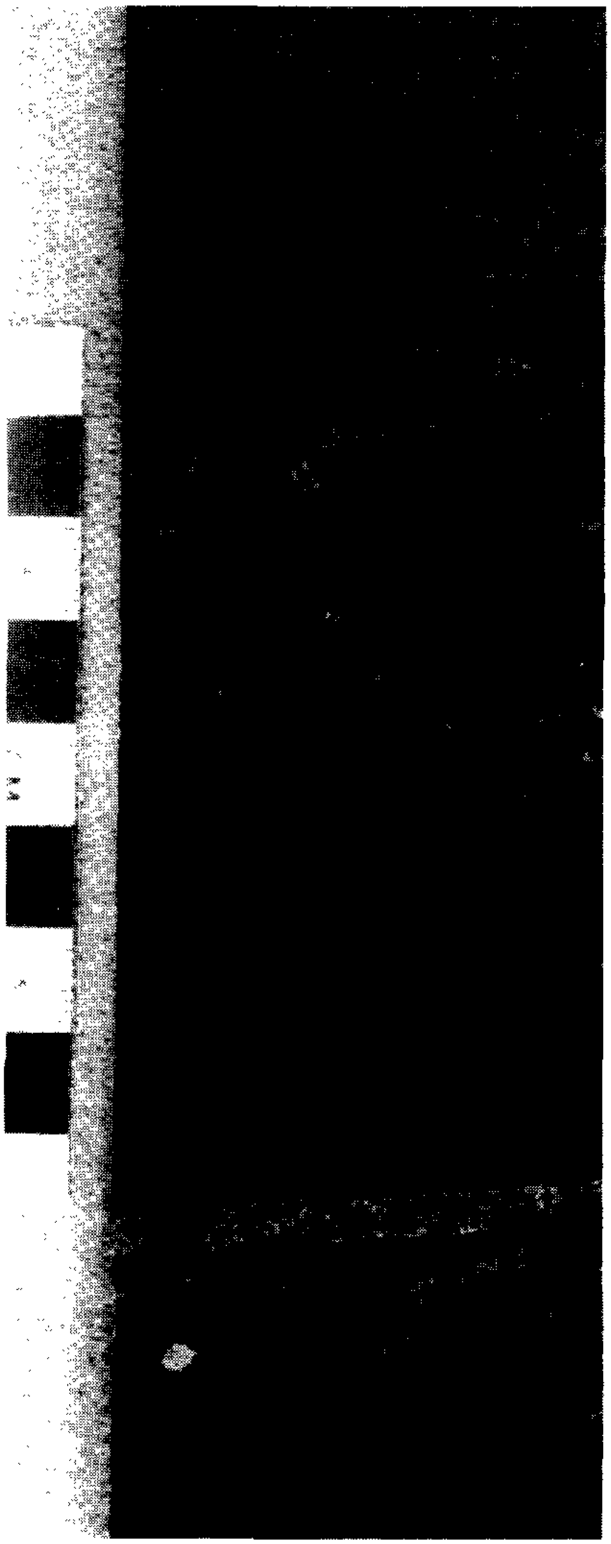

Photo 1. Bedded iron-rich tourmaline alteration in lower Aldridge mudstone with pale manganese-rich garnet porphyroblasts (ddh F93-3, 433.5 m).

the caveat of Shaw *et al.* (1993a, b) that this mineralogy probably differs from that which developed during hydrothermal activity. "Actinolite-altered" does not necessarily mean that hydrothermal fluids produced actinolite. More

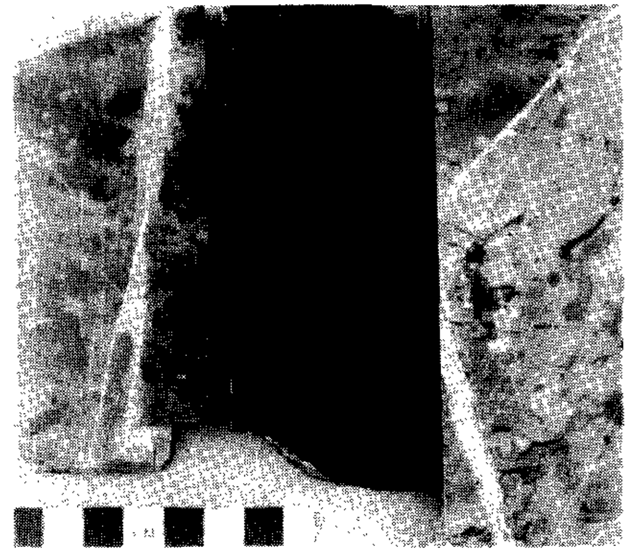

Photo 2. Tourmaline alteration in discordant fragmental, with quartz veins. Light coloured pieces have pale brown, magnesium-rich tourmaline; centre piece is unaltered (left to right: ddh F93-3, 100.2 m, 179.1 m, and 210.1 m).

likely, actinolite results from the metamorphism of precursor minerals, such as sulphates, carbonates and clays, that formed during alteration.

The deposit is crudely mushroom shaped (Figure 3). Its stem consists of an alteration zone (tourmaline and plagioclase) within and around the fragmental pipe. Its cap lies immediately above the pipe and comprises plagioclase-biotite, calcsilicate and mica alteration assemblages with disseminated to bedded sulphides. Both stem and cap are cut by a thick, late-stage, sulphide-rich vein.

Based on field observations, alteration can be grouped into six main associations:tourmaline; plagioclase-biotite-garnet; biotite; calcsilicate; sericite; and silica. Figure 3 illustrates their distribution.

Tourmaline alteration consists of partial to almost complete replacement of original sedimentary material by microscopic grains of tourmaline. The resulting rock is hard and cherty in appearance, typically with a conchoidal fracture in the most altered rocks. Individual grains of tourmaline are seldom visible to the naked eye: grain size rarely exceeds 100 microns (Leitch *et al.*, 1991).

Two types of tourmaline alteration occur at Fors (Photos 1, 2). The first and probably oldest is bedded black tourmaline (iron-rich; schorl) that preferentially affects argillaceous layers. Bedded tourmalinization is volumetrically small. As much as 30% of a section may be strongly tourmalinized. More typically it affects argillite beds up to 5 to 10 centimetres per metre of section. Bedded tourmalinite is locally associated with small, white managnese-rich garnets (<0.5 mm).

Two lines of evidence indicate this is an early stage of alteration. First it is overprinted by most other types of alteration. Second, tourmalinized argillite occurs as contorted rip-up clasts in siltstone, which suggests either extremely

Photo 3. Plagioclase-biotite-garnet alteration: pervasive, texture-destructive patches and veins (left to right: ddh F92-2, 175.2 m, 228.0 m, 238.7 m).

selective replacement or else that clays were altered before being incorporated in turbidite flows. Rare, dark tourmaline clasts also occur in the discordant fragmental. A model for bedded tourmaline alteration is that ascending boron-rich hydrothermal solutions pass through coarser sediments to become trapped by less permeable clay-rich strata, reacting with them to form conformable sheets of tourmalinite (Slack, 1993).

The second type is light to dark brown (magnesium-rich; dravite). It is mainly confined to the discordant fragmental in which both clasts and matrix are altered (Photo 2). Both types are locally associated with a little pyrrhotite, more rarely with arsenopyrite, sphalerite and galena.

Plagioclase-biotite±garnet alteration affects large volumes of rock, including part of the fragmental pipe and bedded sediments surrounding it. It appears to be assymetrically distributed around the pipe, skewed to the northeast. It is pervasive and texture destructive, and results in an aphanitic to very finely granular, mottled grey, white and pink rock (Photo 3). Where biotite is common it can resemble coarse granite (Photo 4). It occurs as veins, patches, hairline fractures and broad diffuse areas. Its contacts are sharp to gradational. Garnets associated with this style of alteration are pale pink, up to 2 millimetres in diameter, and may be selectively replaced by calcite or sericite.

This form of alteration is usually referred to as albitization as, regionally, the composition of the feldspar is sodic plagioclase. However calcic plagioclase with anorthite contents up to An_{50} have been observed at Fors (C.H.B. Leitch, personal communication, 1994) and may be more widespread. Its weakest effects consist of a bleaching of the protolith and an increase in black to dark brown biotite. Strongest alteration is paper-white, finely granular, almost monomineralic plagioclase. Pink to liver-coloured zones occur as extensive patches within the mainly pale rocks. These may be areas enriched in potassium feldspar or microscopic inclusions of metamorphic biotite. The pink zones are typically cut by pale hairline veinlets, at high angles to relict bedding, of a later stage mineral, possibly albite.

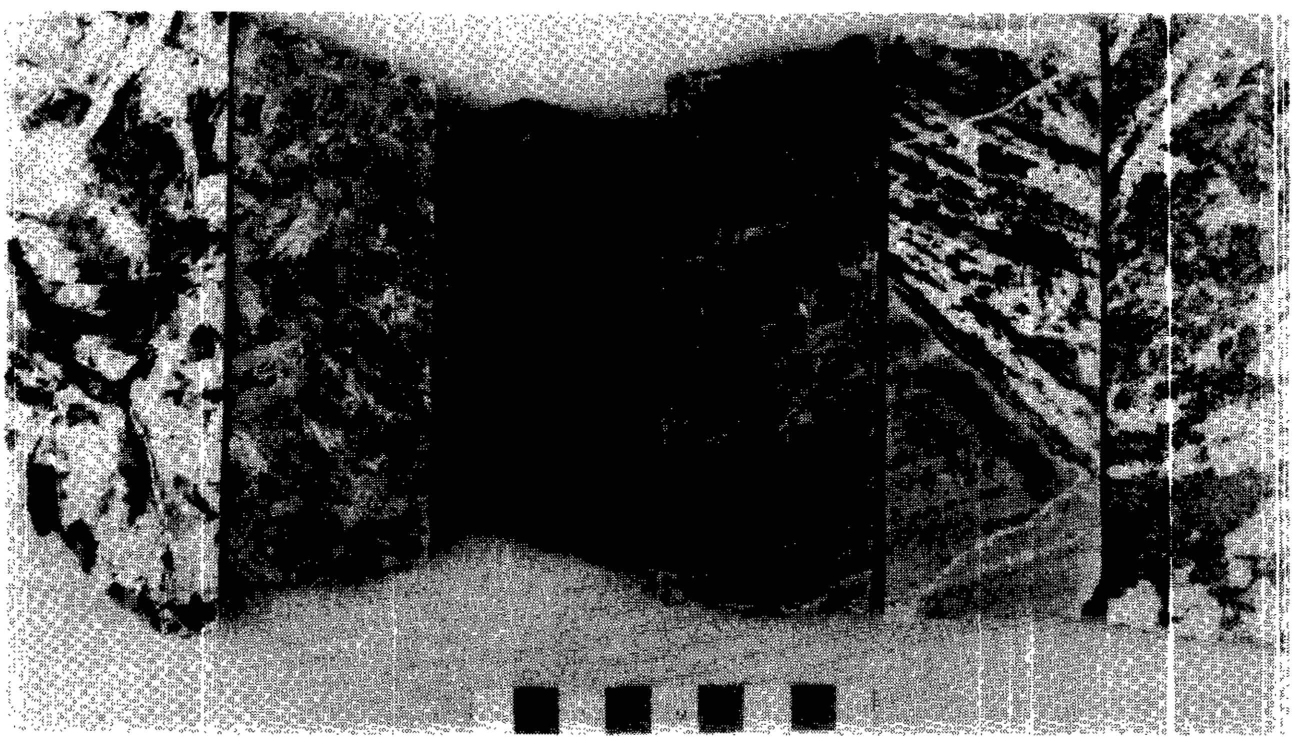

Photo 4. Alteration mineralogies and textures in the calcsilicate alteration cap ("vent horizon"). From left to right assemblages are: tremolite-talc-dolomite; massive tremolite-actinolite; massive brown biotite; biotite replaced by actinolite; plagioclase-biotite-(garnet) alteration cutting bedded, albitized sediments; and coarse, granitic-textured plagioclase-biotite alteration (left to right: ddh F93-10, 49.2 m, 54.1 m, 58.2 m, 61.0 m, 68.5 m, and 71.0 m).

Pyrrhotite is common in plagioclase-altered rocks and it preferentially replaces biotite. The paragenesis of this assemblage is uncertain. In one location pyrrhotite is pseudomorphous after biotite porphyryoblasts that grew at random angles across bedding. This indicates late, perhaps post-metamorphic, redistribution of phases.

Biotite and calcsilicate alteration are mainly confined to the cap of the deposit, which consists of complexly interlayed, coarse-grained assemblages of micas (pale to bronzy brown biotite and muscovite), amphiboles (actinolite and tremolite) and carbonate minerals (calcite and dolomite). Because these minerals form 100% of the rock it is thought that this zone may represent a hydrothermal vent area. The cap or vent horizon is crudely stratified with a nearly massive zone of actinolite at its base, a biotite-rich zone in the middle and a thin magnesium-rich zone (talc-tremolite-dolomite) at the top. The range of textures found is shown in Photo 4. The cap is up to 200 metres in diameter and 30 metres thick.

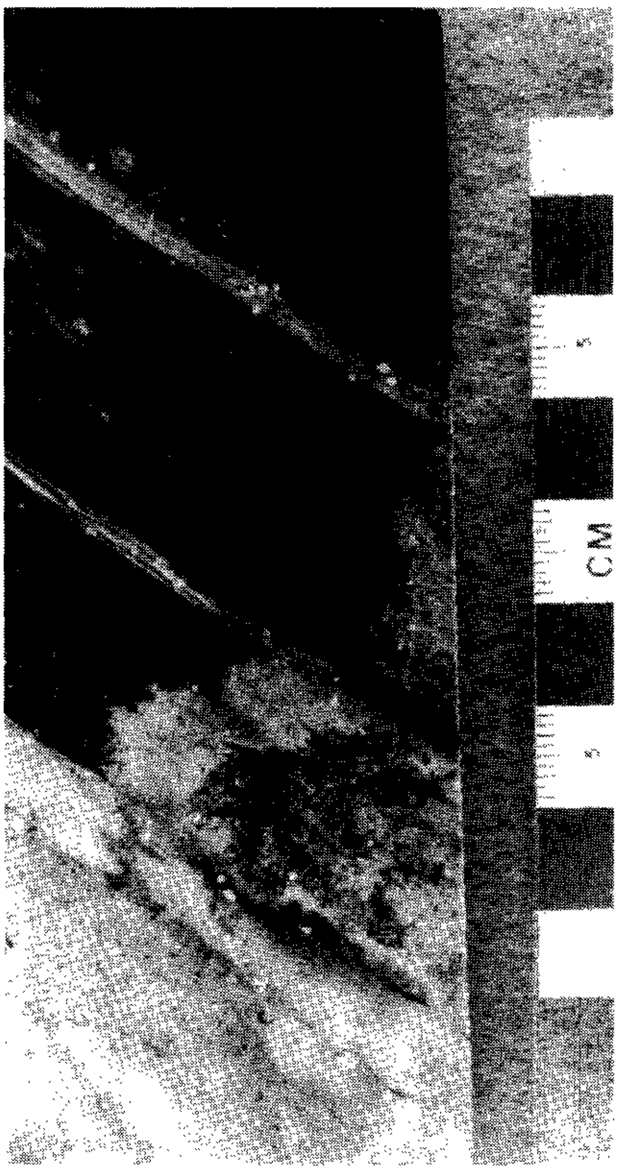

Photo 5. Sericite alteration in thinly bedded middle Aldridge mudstone showing both texture-destructive and layer-parallel styles. The small white spots are relict garnets. (ddh F92-2, 260.5 m.).

Actinolite (light to medium green, fibrous amphibole) is more widespread than tremolite (white, fibrous amphibole). It occurs as very coarse grained (up to 2 cm) monomineralic lenses, up to 3 metres thick, near the base of the calcsilicate cap. It also occurs away from the calcsilicate cap, where it always appears pseudomorphous after biotite.

Tremolite occurs mainly in association with dolomite and the talc-rich zone at the top of the calcsilicate alteration cap. It has a similar coarse-grained acicular habit, and like actinolite, also appears to be replacing biotite.

Talc occurs as dark green, irregularly shaped, soft waxy masses up to 10 centimetres long, intergrown with tremolite and dolomite (Photo 4). It appears to be confined to the upper edge of the calcsilicate alteration cap and may be partially metamorphosed to antigorite.

Sericite alteration occurs as a distal aureole around the other alteration assemblages at depth and above the bedded sulphide zone, up to and including the Main showing, where it is associated with silicification. Locally it is texture destructive and pervasive but more commonly it is confined to bedding planes in porous, feldspathic units (Photo 5). It is distinguished by its pale green colour and its softness. Pale pink garnets up to 2 millimetres in diameter also occur within sericitic alteration zones, but garnets are quite commonly replaced by sericite (note: In this report "sericite" is used for aphanitic white mica; "muscovite" for grains visible to the unaided eye).

Silica alteration occurs in two ways. First, it forms irregular zones apparently confined to strata that overlie the calcsilicate alteration cap, up to at least the stratigraphic level of the Main showing where it was identified by Maheux (1990). Second, it forms thin envelopes around late-stage quartz veins. In the first case, silicified core is blue-grey, hard, and has a diffusely granular appearance. In the second it is milky white, finely granular to aphanitic (chalcedonic). Silicification has been tentatively identified elsewhere in drill core (Klewchuk, 1993) but because of its similarities to plagioclase alteration more work is required to document its occurrence. It is noteworthy that silicification is rare to unknown at the Sullivan mine. Leitch *et al.* (1991) found no introduction of quartz due to alteration.

SULPHIDE DEPOSITS

Zones of almost massive sulphides are rare. They occur in two forms: stratiform and vein. Drilling to date has not been able to demonstrate strong lateral continuity in either. Thickest and highest grade drill intersections were encountered in hole F92-1.

Conformable massive sulphides consist of fine to coarse-grained pyrrhotite, sphalerite and galena within a plagioclase-biotite-sericite or actinolite-rich envelope (Photo 6). The sulphides locally contain coarse (to 8 mm) clasts of transparent quartz and have a cataclastic fabric. Upper and lower contacts approximate bedding in the enclosing sediments. A maximum thickness of 2 metres was intersected. The stratiform sulphide zone lies a few metres above the top of the calcsilicate alteration cap (Figure 3).

A semimassive sulphide vein almost 2 metres thick, with a calcite-quartz gangue, cuts an actinolite-rich alteration zone. The vein consists mainly of granular pyrrhotite rimmed by arsenopyrite, with variable amounts of sphalerite and galena and accessory scheelite, chalcopyrite and bismuthinite (Photo 7). One intercept returned 734 g/t Ag, 16.7% Pb, and 5.40% Zn over 0.3 metre.

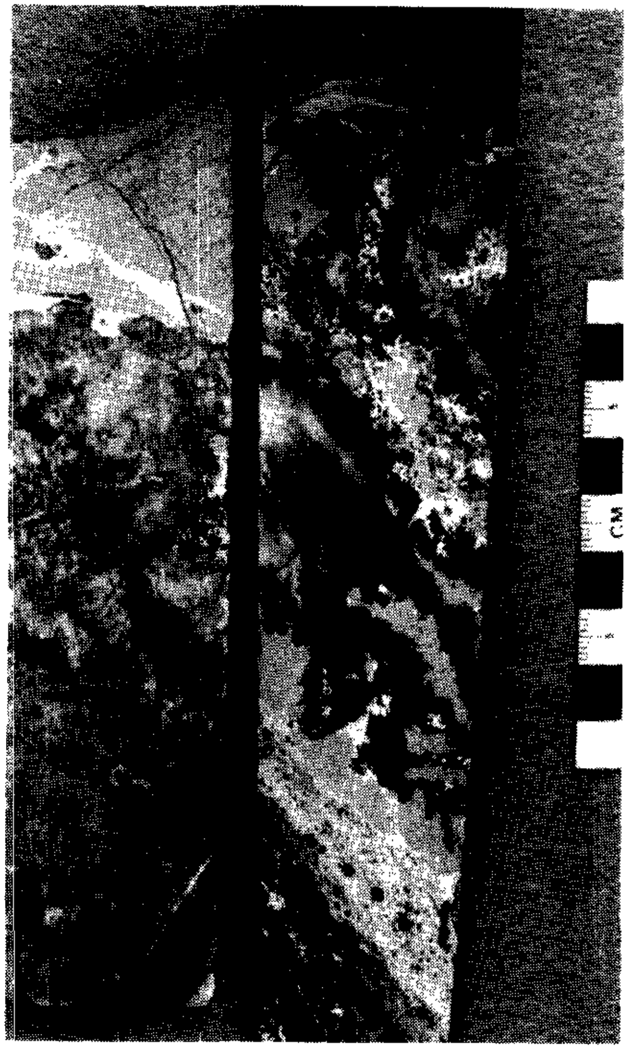

Photo 6. Massive sphalerite, galena and pyrrhotite with a quartz, plagioclase, actinolite and biotite envelope (left to right: ddh F92-1, 63.5 m and 78.0 m).

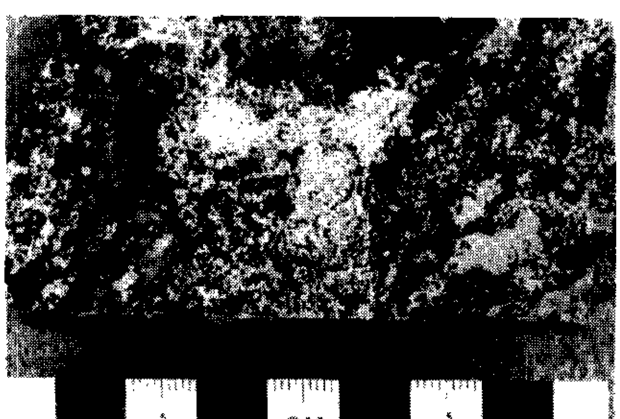

Photo 7. Semimassive arsenopyrite, pyrrhotite±scheelite, with a calcite, quartz and actinolite envelope (ddh F92-1, 101.6 m).

Low-grade zones of sulphides are, on the other hand, quite widespread. They consist of disseminations, stringers, veins, small semimassive to massive stratiform lenses and irregular patches of mainly pyrrhotite, with subordinate amounts of sphalerite, galena, pyrite, and rare arsenopyrite, chalcopyrite and bismuthinite. Pyrrhotite also occurs as ubiquitous hairline laminae that define bedding. Several generations of sulphide mineralization are required to account for the variety of habits and textures found.

DEPOSIT MODEL

In order to synthesize our field observations, we offer the following genetic model for the Fors deposit as a working hypothesis.

1) Pelagic, turbidite sedimentation with entrained organics and iron in a fault-controlled graben or half graben results in a thick sequence of poorly consolidated sediments.

2) Dewatering of the sedimentary pile in response to increasing hydrostatic and lithostatic loads results in the development of a fragmental pipe which acts as a long-lived conduit for the upward migration of fluids. The pipe may have formed in the hangingwall of a growth fault. Parallel and conjugate fractures related to this fault may have contributed additional pathways for fluid migration. The pipe functioned as a conduit at least until the time of formation of the bedded sulphides above the calcsilicate zone and probably until after the formation of the Main showing, now exposed at surface. The upper limit of coarse fragmentals appears to lie just below the calcsilicate cap which may represent a sedimentary-exhalative vent deposit. Less vigorous dewatering may have produced the massive unit near the Main showing.

3) Tourmalinizing fluids (of uncertain provenance) preferentially travel along beds and up the fragmental pipe. It appears they changed chemistry with time: most bedded tourmalinites are schorlitic (iron rich); however much of the pipe is brown to pale brown, dravitic (magnesium rich).

4) Albitizing fluids ascend. These locally overprint bedded tourmaline-altered rocks but mainly spread laterally away from the pipe to the northeast.

5) Potassium, iron and magnesium-rich fluids deposit biotite (or biotite precursor minerals) in the main part of the vent horizon.

6) Late carbonate-rich fluids flooding along parasitic or antithetic structures overprint biotite (precursors) to produce actinolite (precursor) assemblages and deposits of sulphides. At least two pulses are required: the first to produce semimassive to massive, locally stratiform lead-zinc-silver-rich mineralization with a high base metal to iron ratio. The second pulse to produce veins enriched in arsenic, tungsten, silver and bismuth, as well as zinc, lead and iron.

7) Downward circulating seawater mixes with upwelling carbonate-rich fluids to produce magnesium-en-

riched assemblages including talc, tremolite and dolomite (precursors) at the top of the alteration cap, and possibly the *magnesium-rich tourmalinites found in the upper part of the* fragmental pipe.

8) A later pulse of hydrothermal fluids causes sericite (silica) alteration with minor sulphides in the sedimentary package that overlies the bedded sulphide zone and forms the *Main showing*.

9) Heat and fluids for hydrothermal alteration and mineralization may have been provided by the intrusion of thick mafic sills into wet sediments.

10) Finally, regional metamorphism creates the present silicate mineralogy and redistributes some sulphides.

CONCLUSION

The Fors prospect is a well preserved example of a small, high-grade lead-zinc-silver sedimentary exhalative and vein deposit hosted by Middle Proterozoic Aldridge Formation. It is associated with an unusually strong alteration assemblage variously dominated by plagioclase, biotite, tourmaline, white mica, carbonate, tremolite-actinolite, talc and silica. It is a blind discovery that resulted from drill-testing a geological model of low-grade mineralization found at surface.

It provides a new exploration target in the Sullivan camp, having some similarities to the Sullivan deposit and some important differences. Similarities include the presence of such Sullivan indicators as bedded sulphides, fragmental units that locally carry sulphide-bearing and tourmalinized clasts, garnet porphyroblasts, and tourmaline and albite alteration. Differences are that it is located outside the Sullivan corridor, is stratigraphically higher, has unusual alteration assemblages, and has elevated silver, gold, tungsten and arsenic.

The deposit deserves further study and would make an excellent project for a graduate student interested in water-rock interactions. Very good core storage, logging and rock cutting facilities exist at the field office of Consolidated Ramrod Gold Corporation to support such work.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of several people who made this study possible. First, we wish to thank Consolidated Ramrod Gold Corporation for permission to publish proprietary information. Second, for stimulating geological discussions, we thank Derek Brown, Trygve Höy and David Lefebure of the B.C. Geological Survey Branch, Craig Leitch and Robert Turner of the Geological Survey of Canada, and John Slack of the United States Geological Survey. Last, we are grateful to Rick Anselmo, Mike Fournier and Pat Stinson who assisted with the figures, Dick Player who prepared the photos and Doreen Fehr for layout and typesetting.

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NOTES

GEOLOGICAL MAPPING OF THE YAHK MAP AREA, SOUTHEASTERN BRITISH COLUMBIA: AN UPDATE (82F/1)

By D.A. Brown and P. Stinson

(Contribution No. 18, Sullivan-Aldridge Project)

KEYWORDS: Proterozoic, lower Purcell Supergroup, tourmalinite, ultrabasic breccia dikes.

INTRODUCTION

This article summarizes new findings of the East Kootenay project after completion of 2 months of fieldwork in the Yahk map area (82F/1) in 1994. The project was initiated in 1993 to provide 1:50 000-scale geological maps with improved stratigraphic correlations, and to stimulate base metal exploration southwest of the Sullivan mine. Work in 1994 focused on fill-in traverses and measured sections to complete mapping of the Yahk sheet. and the Iron Range Mountain study (Stinson and Brown, 1995, this volume). The regional geological setting and 1993 preliminary results were summarized by Brown *et al.* (1994); two 1:50 000-scale maps are now available (Brown, 1995a, b).

Mapping in the 1994 field season was extended to the west into metamorphosed, polydeformed Purcell Supergroup strata underlying the Creston map area (82F/2; see Brown *et al.*, this volume), and collectively, the two map areas provide an excellent opportunity to study the transition from hinterland (parautochthonous strata of the Purcell anticlinorium) to orogen (deformed North American miogeocline strata of the Kootenay Arc). This project contributes to the Sullivan-Aldridge project, a multidisciplinary research effort involving the Geological Survey of Canada, Geological Survey Branch, United States Geological Survey, four universities, Cominco Ltd. and Consolidated Ramrod Gold Corporation.

PREVIOUS WORK

Geological mapping in the Nelson East Half map area was completed in 1938 by the Geological Survey of Canada (Rice, 1941). Farther east, the Fernie West Half map area was initially mapped by Daly (1912a), Schofield (1915) and Rice (1937), and later, Leech (1960) completed a 1:126 720-scale map (1"=2 mile). Recent 1:250 000 and 1:100 000-scale mapping has been published to the east and north by Höy (1993) and Reesor (1993), and south of the international boundary by Harrison *et al.* (1992), Aadland and Bennett (1979) and Stoffel *et al.* (1991; Figure 1a). A new 1:250 000-scale coloured compilation map of the entire British Columbian Purcell anticlinorium is now available (Höy *et al.*, 1995a). More detailed mapping adjoining the Yahk map area includes work by Burmester (1985), Miller (1983) and Reesor (1981; Figure 1b).

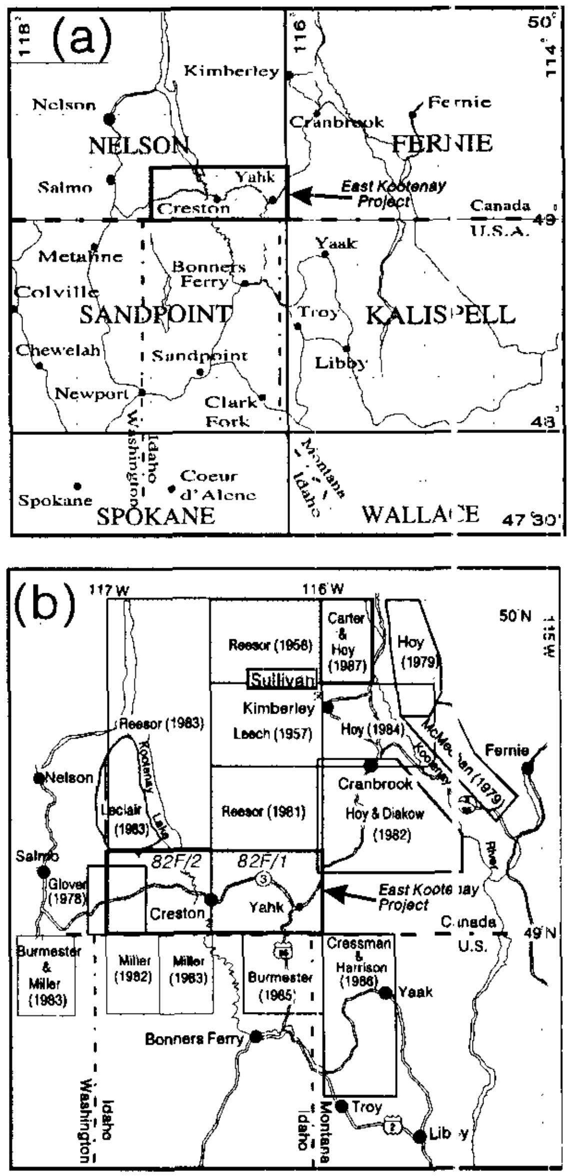
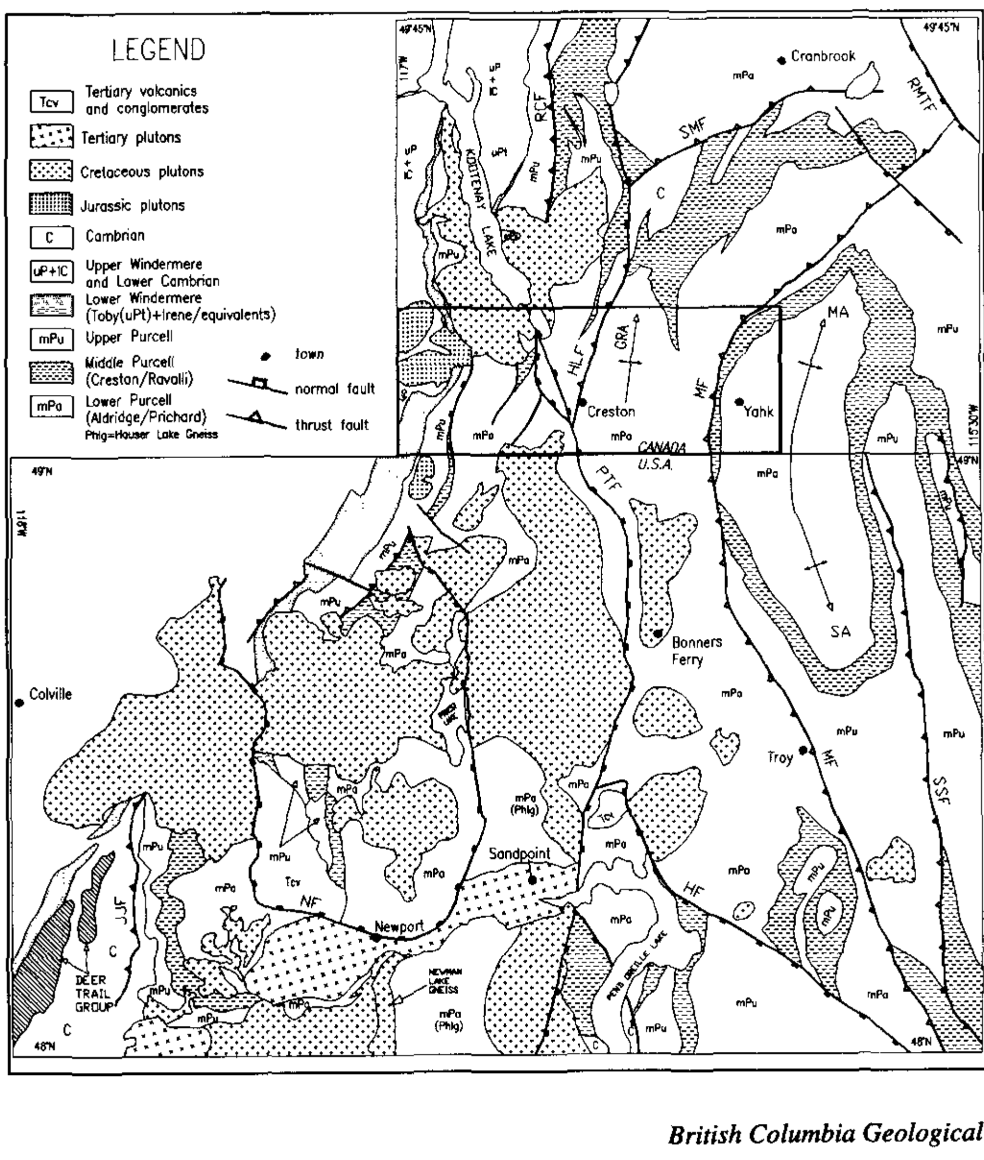


Figure 1. Location of the Yahk and Creston map areas (dark hatched rectangle) relative to areas of previously published geologic maps. (a) The 1:250 000, 1:126 720 or 1:100 000-scale map coverage includes: Fernie West-half (82G/West) -- Leech (1958, 1960), Höy and Carter (1988), Höy (1993); Nelson East-half (82F/east) -- Rice (1941), Reesor (1993). Sandpoint -- Aadland and Bennett (1979); Kalispell -- Harrison *et al.* (1992); Spokane -- Griggs (1973), Stoffel *et al.* (1991) Wallace -- Harrison *et al.* (1986). (b) The 1:50 000, 1:48 000 and 1:25 000-scale maps in the immediate vicinity of the Yahk and Creston map areas include: Burmester (1985), Burmester and Miller (1983), Cressman and Harrison (1986), Glover (1978), Höy and Diakow (1982), Miller (1982, 1983), Reesor (1981, 1983).

GEOLOGICAL SETTING

The Proterozoic Purcell Supergroup (Belt Supergroup in the United States), a siliciclastic and carbonate sediment sequence at least 12 kilometres thick, accumulated in a pericratonic basin between about 1500 and 1350 Ma ago. It is preserved in an area 750 kilometres long and 550 kilometres wide, extending from southeastern British Columbia to eastern Washington, Idaho and western Montana. In British Columbia, the Purcell Supergroup is exposed in the Purcell anticlinorium, a broad, gently north-plunging structural culmination (Figure 2). The stratigraphic nomenclature for the Purcell Supergroup varies across the basin; this article adopts divisions used in the east-half of the Nelson map area (Reesor, 1983; Höy, 1993).

Purcell sedimentation may have ended with the onset of the **East Kootenay orogeny**, a metamorphic and structural event between 1350 and 1300 Ma (McMechan and Price, 1982). Within the basin, syn-Aldridge tectonism is evidenced by early faults and emplacement of the Moyie intrusions. A Late Proterozoic extensional event, the **Goat River orogeny** (800-900 Ma), resulted in rifting (block faulting), erosion of up to 4 kilometres of Purcell strata, and initiation of the Cordilleran miogeocline with deposition of the Windermere Supergroup (Lis and Price, 1976; Price, 1984). By the Middle Jurassic, collision of allochthonous terranes from the west (**Columbian orogeny**; Terrane I; Monger *et al.*, 1982) onto the western margin of North America produced deformation, metamorphism and plutonism that affected the western edge of the Purcell Supergroup. Docking of Terrane II to North America resulted in another compressional event in the Cretaceous to early Tertiary (**Laramide orogeny**, *circa* 100-70 Ma) that produced the dominant folds and thrust faults in the map area. Strata were transported to the east on west-dipping thrust faults that extended into the cratonic basement (Cook and Van der Velden, in press) producing the Purcell anticlinorium with Proterozoic strata in its core. Emplacement of several large, syntectonic and post-tectonic Cretaceous plutons accompanied this event. Some of the plutons plugged folds and thrusts; for example, the St. Mary fault zone is plugged by the Reade Lake stock and the Hall Lake fault is occupied by the White Creek batholith (Price, 1981; Archibald *et al.*, 1983; Höy, 1993). Reactivation of some of the Cretaceous thrust faults during Eocene extension is locally important, notably west of the Yahk map area (see Brown *et al.*, 1995, this volume).



STRATIGRAPHY

The Yahk map area is underlain largely by the Aldridge Formation, the lowermost division of the Purcell Supergroup (Figure 3). The Creston Formation (about 2300 m thick; Reesor, 1983) gradationally overlies the Aldridge Formation. The overlying Kitchener Formation includes the lowermost significant carbonate accumulations in the Purcell succession. The Aldridge, Creston and Kitchener formations are the equivalents to the Prichard and Ravalli groups, and Wallace and Helena formations in the United States, respectively.

LOWER ALDRIDGE – RAMPARTS FACIES

Strata equivalent to the lower Aldridge Formation occur in the map area, based on stratigraphic distance below the lowest middle Aldridge marker laminite, lack of any markers in over 700 metres of stratigraphy, and presence of numerous Moyie sills. However, the outcrops are unlike the typical rusty weathering, thin-bedded siltstone and argillite of the lower Aldridge Formation farther east in the basin. They are generally thick-bedded, grey-weathering (non-rusty), quartzitic wackes, and called "Ramparts facies" for their type locality east of Creston, along the Ramparts below Mount Thompson (D. Anderson, personal communication, 1994; Photo 1).

The Ramparts facies consists primarily of distinct, light grey to buff, medium to fine-grained quartzitic wackes with lesser green-grey argillites. The thick to medium-bedded wacke forms prominent cliffs or ribs along hillsides. Unlike the type locality, the rocks carry no pyrrhotite, except for the extreme base of the Ramparts exposure southeast of Creston. Locally, the quartzitic units are crossbedded, graded and/or laminated. Some beds are lenticular in outcrop and show cut-and-fill features suggestive of channel deposits and shallow water deposition. Beds tend to form amalgamated sets that fine upward. Between the sets are sequences of more thinly bedded quartz wacke and argillite. Bedding is wavy and lenticular, showing features of current activity (ripple crosslamination; Photo 2) and loading (load ripples and flames). This wavy bedform indicates more current activity than has been suggested for typical lower Aldridge in the Kimberley area to the northeast. Euhedral to subhedral pits on the weathered surfaces of argillite beds contain remnants of a soft white mineral that may be pseudomorphs after gypsum(?), near Mount Thompson. The presence of gypsum would signify saline conditions, at least locally. In the same area, probable mud-chip breccia may indicate desiccation. Quartz wacke interbeds grade upward into more quartzofeldspathic and locally calcareous beds of the middle Aldridge Formation. The transition is subtle and difficult to map at 1:50 000 scale, partly due to the lack of exposure.

At Creston the Ramparts facies is estimated to be 700 metres thick, exposed as a flat-lying succession in the core of the Goat River anticline. To the east, Ramparts facies can be recognized at America Creek and at Hawkins Creek, where only about 150 metres are exposed at surface (the estimated total thickness is 400 metres; D. Anderson, personal communication, 1994). The Ramparts facies thickens toward the U.S. border then thins farther to the south (D. Anderson, personal communication, 1994). It also thins to the east and northeast. The Ramparts facies may be a proximal part of a turbidite fan that correlates in part with the lower Aldridge footwall quartzite exposed in the Sullivan area. This implies that the upper siltstone (distal turbidites) of the Sullivan area are replaced to the southwest by proximal to middle fan turbidites of the Ramparts facies.

Figure 2 (facing page). Generalized geological map of part of southern British Columbia, northern Washington, Idaho and Montana, emphasizing the distribution of the Purcell Supergroup, lower Windermere Supergroup (Toby and Irene formations) and major intrusive suites. Simplified Creston Formation distribution is illustrated to delineate major anticlines. Rectangle marks East Kootenay project area. Abbreviations: GRA = Goat River anticline, HF = Hope fault, HLF = Hall Lake fault, JJF = Jumpoff Joe fault, MA = Moyie anticline, MF = Moyie fault, NF = Newport fault, PTF = Purcell Trench fault, RCF = Redding Creek fault, RMTF = Rocky Mountain Trench fault, SMF = St. Mary fault, SSF = Snowshoe fault. Modified after Höy *et al.*, 1995, Miller (1982, 1983; Stoffel *et al.*, 1991, Harrison *et al.*, 1992).

Photo 1. View east to subhorizontal beds of quartzitic wacke of the Ramparts facies intruded by several gabbro sills exposed in cliff faces along the Ramparts, southeast of Creston. This is the type area for the facies, a proximal equivalent to the lower Aldridge Formation in the Sullivan area.

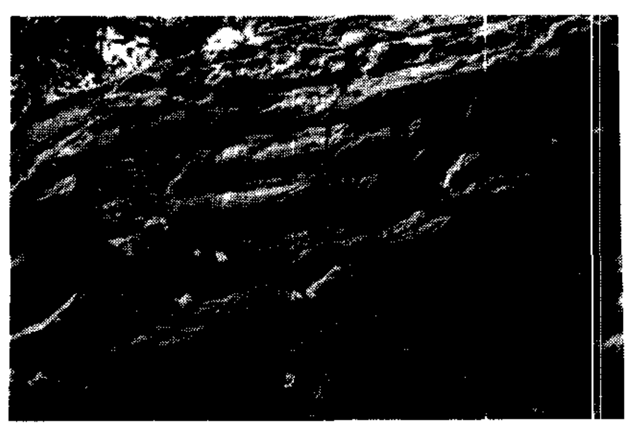


Photo 2. Brown-weathering bed bottom with asymmetric ripple marks, Ramparts facies about 5 kilometres south of Mount Thompson (5-centimetre diameter lens cap on top of block; PST94-200).

Figure 3. Simplified geology of the Yahk map area (82F/1), updated from Brown *et al.* (1994). Note Moyie sills south of Little Moyie River and south of Hawkins Creek appear anomalously thick because they are exposed along dip slopes.

MIDDLE ALDRIDGE

The middle Aldridge underlies most of the map area and comprises a thick sequence of fine siliciclastic rocks, dominantly planar-bedded, fine-grained quartzofeldspathic wacke to quartz wacke, with lesser argillite. It differs from the overlying Purcell Supergroup strata in that it was deposited in deeper water as turbidites, is intruded by numerous gabbro sills, contains extensive and distinctive marker units and has disseminated pyrrhotite throughout (Cressman, 1989; Höy, 1993). Medium-grained wacke is uncommon, and coarse-grained wacke is rare. Total thickness is at least 3000 metres, and may be as much as 4000 metres, based on estimates from map distribution. In contrast, the middle Aldridge in the Cranbrook area is about 2500 metres thick and farther north in the Sullivan mine area, only 2100 metres thick (Höy, 1993).

Isolated outcrops of sedimentary breccias and conglomerates ("fragmentals") are interpreted by Cominco geologists and others to be derived from fluidizing (dewatering) of consolidated to semi-consolidated sediments into crosscutting tabular bodies, sheet-like mounds and debris flows (Cominco staff geologists.; Turner *et al.*, 1992; Brown *et al.*, 1994; Höy, 1993; Cressman, 1989). A newly discovered fragmental locality, south of Yahk in King Creek, contains oblong wacke clasts up to 9 centimetres long. Clasts are concentrated along two horizons parallel to bedding.

IRISHMAN CREEK MEASURED SECTIONS

Two sections through parts of the middle Aldridge Formation were measured along Highway 3 on either side of Irishman Creek, in the northeast corner of the Yahk map area (Figures 3 and 4). Both sections are dominated by turbidites, with thin to thick planar, massive sand beds (Photo 3). Sediments associated with turbidity current processes are described by Walker (1979), and a regional discussion of the middle Aldridge Formation is given in Höy (1993).

In the eastern section (section 1), the bedding has a consistent dip to the west-northwest, and in the western section (section 2) the rocks have a variable, moderate dip to the west; the sections are on either side of a broad, gently north-plunging anticline, bisected by Irishman Creek (Figures 3 and 5). The base of section 2 is 200 to 300 metres stratigraphically above the top of section 1. Each section is broken by two to five normal faults; in every case offset across the faults is less than 2 metres based on bed-to-bed matches on either side of the faults.

The medium to fine-grained quartz wacke and wacke contains 10 to 20% fine-grained biotite, based on hand specimen examination, which is the metamorphic product of the original clay constituents. Lesser arenite and quartz arenite are interbedded with the wacke. The lithological consistency, particularly in section 1, is remarkable.

Individual sand beds range in thickness from several centimetres to over a metre. Internally, most of the beds are massive with faint parallel stratification towards their tops. These beds rhythmically alternate with sections of laminated siltstone 1 to 20 centimetres thick. The packages of thickest beds, mainly towards the top of section 1, are usually amalgamated; the fines of the previous turbidity current are completely eroded by the next turbidite. The amalgamated sand beds are up to 2 metres thick, with internal contacts only faintly visible. Thicker packages of laminated argillite and siltstone, deposited during quiescent periods in the basin, occur sporadically.

Sedimentary structures reflecting the turbidity current processes were observed; these include flute casts, and less common groove casts and bounce marks. Flame structures are present locally. Paleocurrent directions, bedforms, and lithologic variations are presented on the graphic sections (Figure 4). Most of the measured paleocurrent indicators trend northwest, after rotation to paleohorizontal. Where their asymmetry could be determined, they indicated currents to the north to northwest.

A thick sequence of siltstone and argillite towards the base of section 2 exhibits small-scale, well developed trough crossbedding and local flaser bedding. Foresets are composed of alternating light brown silt and black argillite. This section is near the top of the middle Aldridge and may indicate a regression, similar to the shallowing which resulted in the transition to upper Aldridge argillite. There are more turbidites above this unit, so it only represents a temporary change in depositional environment.

Each section has two Moyie sills. Section 1 was measured to the base of a sill 30 metres thick; it forms a steep cliff which marks the end of the exposure. The other, thinner sills have narrow chilled margins. The contacts of the two sills in section 2 are well exposed, and are concordant with bedding. The contacts are slightly sheared, as this part of the section is gently warped. The sills appear to have a zone of hornfels above their top contacts.

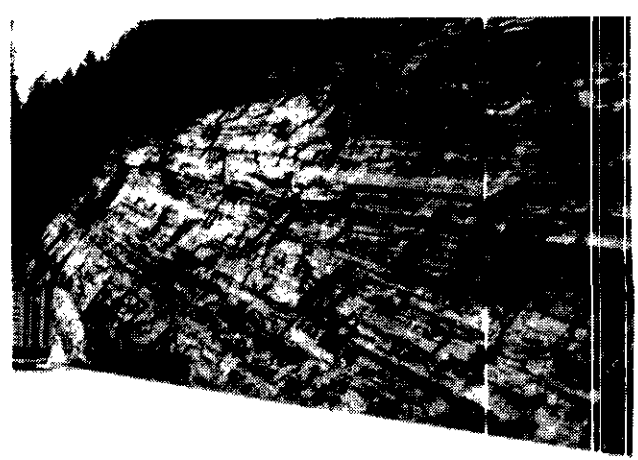


Photo 3. Part of the west Irishman Creek section illustrating planar bedforms and typical middle Aldridge formation exposure. Most of the photo corresponds to unit 28 on Figure 4. Rear of cattle truck for scale.

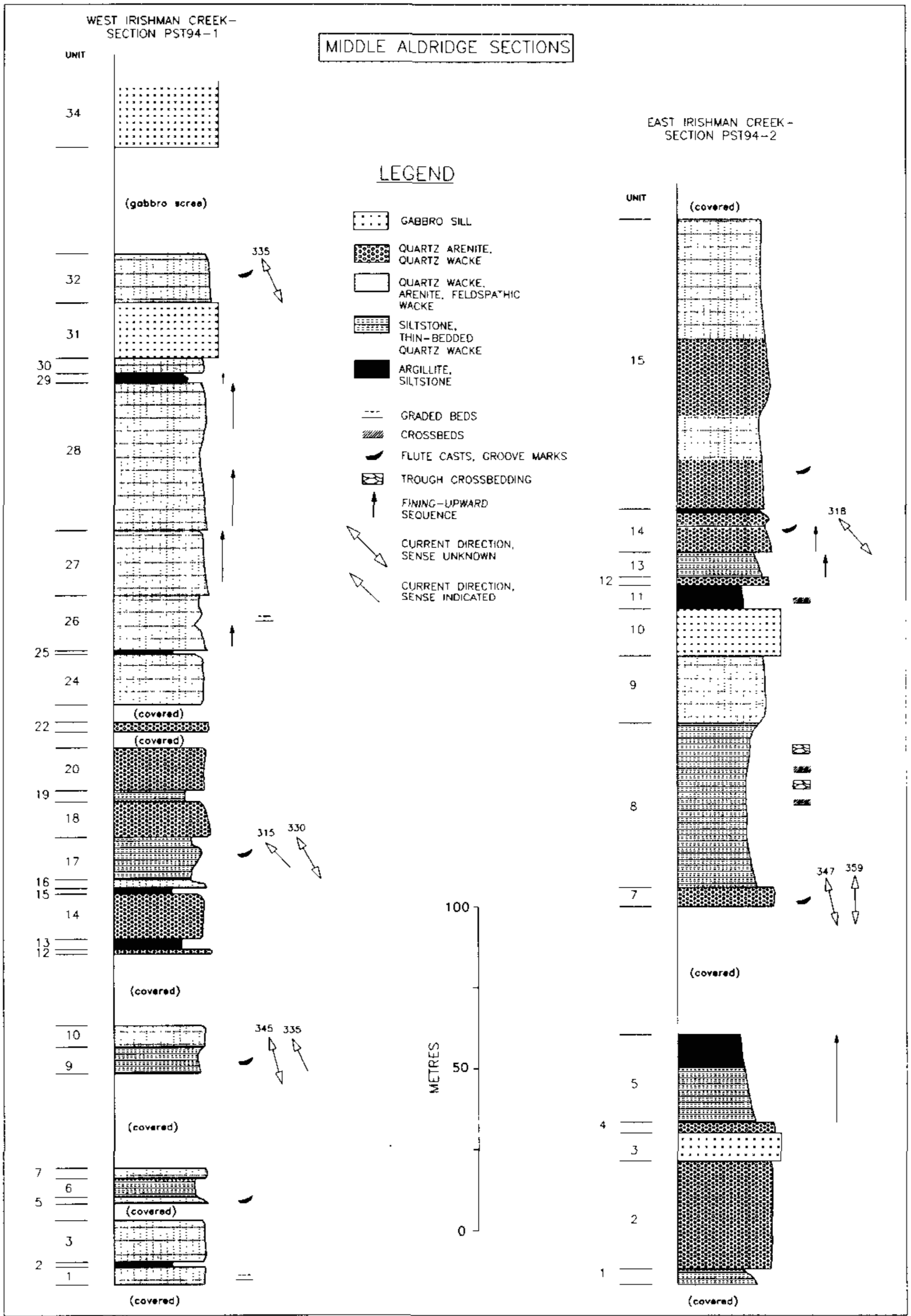


Figure 4. Measured sections of the middle Aldridge Formation at Irishman Creek, Highway 3. Locations of sections are shown on Figure 3. Unit numbers correspond to detailed divisions.

SHORTY CREEK AREA -- UNUSUAL FEATURES WITHIN THE ALDRIDGE FORMATION

Some unusual sedimentary and intrusive rocks crop out on a ridge above Shorty Creek, about 7 kilometres west of Kingsgate (Figure 3). The Shorty Creek succession consists of medium to fine-grained wacke, siltstone, minor argillite, rare limestone, and small, xenolithic, intermediate to mafic plugs and dikes. Beds dip gently to the northeast, parallel to bedding in the enclosing middle Aldridge Formation.

The lowest rocks, which overlie middle Aldridge wacke, are massive, faintly laminated black siltstone. Rarely exposed limestone occurs toward the top of the siltstone. It is massive, crystalline, but locally contains trains of round, 2 to 5-centimetre clasts of the same lithology. The origin of this limestone unit, its extent, and its relationship to the other rocks in this package are unknown. The black siltstone is overlain by greenish grey wacke and siltstone beds. The wacke is characterized by wavy, nonparallel beds from 3 to 25 centimetres thick. Internally, the beds are massive, or have a faint parallel stratification. Scours are common at the base of the beds. The sand grains are mainly angular, and consist of lithic grains and feldspar, although some beds are quartz rich. These rocks are interpreted to be epiclastic sandstones based on their green colour, crystal content and composition of lithic fragments. Rare, thick, massive beds of similar composition strongly resemble trachytic to andesitic lavas, but are more likely well indurated volcanic wacke.

Siltstone is exposed toward the top of the succession, and laminated siltstone is locally interbedded with wacke. The upper siltstone consists of alternating dark green and red-brown discontinuous beds. Greenish layers have up to 15% hornblende porphyroblasts, giving beds a spotty appearance. This is probably a contact metamorphic effect.

Several intrusions cut the Shorty Creek facies. A stock of medium-grained diorite, 30 metres wide, cuts the uppermost part of the section and is exposed in a large clearing which extends across the International Boundary. The intrusion contains numerous rounded inclusions of gabbro (autoliths?) and subrounded to angular xenoliths of wacke and siltstone. The inclusions are 1 to 20 centimetres wide, and most of the igneous ones have well developed reaction rims consisting mainly of feldspar. Notably, some of the igneous inclusions are sulphide and/or magnetite rich, forming rusty holes in the weathered outcrop surface. Two aphanitic, black, mafic dikes, 20 to 30 centimetres wide, were noted elsewhere in this package.

The Shorty Creek facies is anomalous for the Yahk map area, and appears to have a volcanic component. Several occurrences of volcanic rocks and associated mineralization in the middle Aldridge Formation are described by Höy *et al.* (1995, this volume). A tourmalinite occurrence crops out several kilometres southwest of the exposures described above. The Shorty Creek area deserves further study based on the anomalous, possibly volcaniclastic facies of the middle Aldridge Formation, possible relationships of such rocks to mineralization, and the possible association with tourmalinite alteration.

UPPER ALDRIDGE

The upper Aldridge Formation underlies about 10% of the Yahk map area in three areas, on the northwest limb of the Moyie anticline and the east and west limbs of the Goat River anticline (Figure 3). It is rusty, dark brown weathering, fissile argillaceous siltstone. It is grey to dark grey, thin-bedded to laminated, commonly containing distinctive white siltstone laminae (Reesor, 1981). Ripple marks are rare. Quartzofeldspathic wacke beds are very rare and thin (<10 cm). Talus derived from the fissile upper Aldridge forms chip-size fragments. Moyie sills are absent. The upper Aldridge reflects waning input of turbidites and final pelagic sedimentation prior to the shallowing of the Purcell (Belt) Basin, as represented by the Creston Formation.

Strata correlative with the upper Aldridge in the United States are informally called "lined rock" (Cressman, 1989). South of the Yahk map area, Burmester (1985) identifies a "lined argillite" unit, an equivalent to the upper Aldridge, that is conformably overlain by a "transition zone" unit, which correlates with the lower Creston Formation.

CRESTON FORMATION

The Creston Formation underlies about 15% of the Yahk map area: on the northwest limb of the Moyie anticline, along the north-trending Kingsgate graben that extends southward into Idaho and Montana (Figure 2), and on the eastern and western limbs of the Goat River anticline (Figure 3).

The Creston Formation, is divided into a lower argillaceous member (~1000 m thick), a middle quartzitic member (~1000 m thick) and an upper siltite and argillite (< 300 m thick). They correlate with the Burke, Revett and St. Regis formations of the Ravalli Group in the United States. The Creston Formation represents shallow-water, reworked deposits accumulated on northward prograding deltas or fans (Hrabar, 1973). The Revett Formation hosts stratabound copper-silver deposits (including Spar Lake, Montanore and Rock Creek) in the western Montana copper belt (Wells *et al.*, 1981; Balla, 1982, 1993) and in the Sage Creek area in the Lewis thrust sheet in southeast British Columbia.

The lower and middle Creston Formation produce a prominent aeromagnetic signature, most notably within the Moyie anticline. This is due to fine disseminated magnetite, and quartz-magnetite veinlets and stringers throughout. Thin irregular fractures (< 2 mm wide) are filled with black magnetite forming prominent veinlets in pale green phyllitic argillite in an outcrop of lower Creston along Highway 95, 5.5 kilometres south of Curzon. Speckled argillite with small euhedral magnetite crystals is common in the upper Burke Formation in the Montanore deposit area (Adkins, 1993).

KITCHENER FORMATION

The Kitchener Formation, defined by Daly (1905) and Schofield (1915), overlies the Creston Formation and comprises green dolomitic siltite, argillite and carbonaceous dolomite and limestone. It forms a succession 1800 metres thick (in the Nelson East Half area where mapped by Reesor, 1983) of shallow-water deposits that correlate with the middle Belt carbonate, the Wallace Formation to the south and the Helena Formation to the southeast. Molar tooth structures are common and stromatolites are locally important (Winston, 1986).

The formation is poorly exposed and fault bounded in the northeast corner of the Yahk map area, within the Moyie fault zone. Prominent but thin, brown-weathering dolomitic siltstone beds distinguish Kitchener Formation from Creston Formation here. Discontinuous dolomitic siltstones layers pit-out and produce rough and irregular, tan to brown weathered surfaces. Otherwise, the wavy bedded, pale green siltstone and argillaceous siltstone are similar to the Creston Formation.

MOYIE INTRUSIONS

Moyie intrusions, dominantly sills and rarely dikes, occur mainly within two stratigraphic intervals; the lower, and middle of the middle Aldridge formations. Therefore two main episodes of sill emplacement are proposed (Rice, 1941; Leech, 1957). Both sill packages occur in the Yahk map area, but aside from stratigraphic position, no distinct mineralogy or visible features were recognized to differentiate them in the field. The sills were discussed by Daly (1905, 1912a), Schofield (1915) and Rice (1937, 1941). Geochronometric and geochemical studies are ongoing by Gorton *et al.* (in preparation) and E. Anderson (Geological Survey of Canada) as part of the Sullivan-Aldridge project.

The fine to medium-grained sills range in composition from hornblende(±pyroxene) gabbro to hornblende quartz diorite and hornblendite, and they extend laterally over tens of kilometres. Mafic phenocryst contents vary up to 70%. Pyroxene is only found rarely as relict cores surrounded by amphibole, due to widespread deuteric alteration. Some of the thicker sills (>20 m) contain irregular patches of coarse pegmatitic hornblende and feldspar. Zones of granophyre are rare in the Yahk map area.

LOWER SILL PACKAGE

The lower sill package underlies three areas, Ramparts east of Creston, west of Kingsgate, and Hawkins Creek near Yahk (Figure 3). The sills in the Ramparts area are exposed along the prominent escarpment that rises about 1400 metres above the Creston valley (Photo 1). There are at least four sills here, comprising a cumulative thickness of at least 600 metres in a section about 1370 metres thick (43% sills). The thickness and number of sills decreases southward toward the U.S. border to about 250 metres (27% as two sills; D. Anderson, personal communication, 1994).

Moyie sills in the Hawkins Creek area appear to be thickest (albeit not well exposed) adjacent to an inferred northwest-trending fault, and to terminate abruptly to the northeast (Figure 3). The inferred fault may have formed in the Proterozoic and partially controlled the emplacement and distribution of the sill sequence. In this area, albite alteration with associated sedimentary fragmental units (south of Hawkins Creek), and several tourmalinite localities, including Mount Mahon, immediately east of the map area, indicate hydrothermal activity.

Five sills on Moyie Mountain west of Kingsgate intrude Ramparts facies. They were mapped and described as the "Moyie sills", now a widely used term, by Daly (1912a, p. 221-255). The sills correlate with the Crossport sill sequence studied by Bishop (1973). The Kingsgate sills are exposed along the International Boundary cut above 1220 metres elevation (Figures 13 and 14 and Photo 25 of Daly, 1912a). They can be traced northward for about 12 kilometres, where they are truncated by the Carroll fault (Figure 3).

The lower sill package comprises thicker individual sills that are less extensive or continuous compared to the upper sill package in the Yahk map area.

UPPER SILL PACKAGE

A conspicuous section in the middle of the middle Aldridge contains two to four prominent sills. This upper sill succession is well exposed south of Kid Creek, where a sequence of four sills is repeated by faulting. They have a cumulative thickness of about 240 metres in a section 1200 metres thick (960 m of sedimentary rocks and 5% sills). To the west, on Mount Kitchener, the same stratigraphic section contains two sills (Figure 3).

Most of the Moyie sills have no aeromagnetic signature; however, one sill does produce a strong anomaly, most prominent on Arrow Mountain near Creston. The anomalous response can be traced from south of Creston northward across the entire map area. It extends southward across the International Boundary at least 50 kilometres (D. Anderson, personal communication, 1994) and it is clear that the magnetic property of this sill is useful for regional correlation.

SILL EMPLACEMENT EFFECTS

Bleached, albitized metasedimentary rocks occur locally, such as on the Goat River road near Highway 93 (Figure 3; Turner *et al.*, 1992; Stop 1-8), and may be due to sill emplacement. A granophyre exposure related to "Purcell intrusive" was noted by Rice (1941, p. 26) along a trail up to Iron Range Mountain, but was not examined during this study. Another occurrence of albite alteration is exposed on a knob along the basal contact of a lower package Moyie sill, south of Yahk. Here a fragmental horizon occurs within the albitite zone (D. Anderson, personal communication, 1994).

ULTRABASIC DIKES

Several ultrabasic breccia dikes crop out on Iron Range Mountain. One dike, located 6 kilometres northwest of the town of Kitchener, is 12 to 15 centimetres wide, strikes north and has sharp, planar contacts. Dikes farther north on Iron Range Mountain have irregular outcrop patterns and are 0.3 to 1 metre wide. All the dikes have abundant, rounded inclusions of carbonate, possible ultramafic lithologies, and xenoliths of Aldridge Formation (Photo 4). The southernmost dike has 0.5 to 1-centimetre feldspar and biotite phenocrysts, while the other dikes have phlogopite megacrysts, some up to 8 centimetres across. Thin sections reveal that in every sample the groundmass and all non-carbonate inclusions are completely altered to fine-grained calcite and chlorite.

These rocks are difficult to classify. The southern dike may be a lamprophyre, based on the phenocryst types. The other dikes have petrographic similarities to diatreme breccias in the Golden area, which are ultramafic lamprophyre and alnoite (Pell, 1994, p. 77-89). The dikes on Iron Range Mountain may represent the root zones of eroded diatreme systems, as the variety and nature of inclusions in them indicate rapid emplacement. One of the dikes on the northern part of Iron Range Mountain yielded a Late Carboniferous K-Ar date of 301±10 Ma (D. Anderson, personal communication, 1994). Diatreme breccia and related rocks are known from several areas in the province (Pell, 1994). The Iron Range breccia dikes and similar rocks to the north in the Horsethief Creek area (Pope, 1989, p. 198-214) lie farther west than known diatreme breccias occurrences (Pell, 1994).

Photo 4. Green-weathering, ultrabasic breccia dike with phlogopite megacrysts and dull brown weathering, rounded, recessive carbonate inclusions, Iron Range Mountain, X-ray claim (PST94-LR.5).

REGIONAL STRUCTURAL SETTING

The Yahk map area includes two regional anticlines, the Moyie and Goat River anticlines, in the western half of the Purcell anticlinorium. The anticlines are separated by a disrupted zone that is bounded on the east by the Moyie fault, a regionally important transverse thrust fault. The fault trends obliquely across the anticlinorium and records a complex history beginning in the Proterozoic (Höy, 1979, 1993; McMechan, 1979, 1981). The structure may reflect the geometry of a structural weakness in the underlying continental basement along which the fault propagated and ramped up higher in the section. The basement anisotropy may correspond to northeast-trending boundaries of the cratonic blocks of different ages, in particular the Rimbey and Medicine Hat domains (cf. Figure 7 in Ross *et al.*, 1992).

YAHK MAP AREA STRUCTURES

The Yahk map area has been divided into three structural domains, separated by high-angle faults (Brown *et al.*, 1994). The eastern and western domains are dominated by broad, north-trending and gently north-plunging folds, the Moyie and the Goat River anticlines (Figure 5). Structural style is characterized by broad open folds and steep faults. Brittle fractures and weak, spaced cleavage are present throughout the map area, but penetrative fabrics occur adjacent to faults, especially the Moyie fault, and west of the Arrow fault The following section provides additional detail and some modification of previous ideas.

EASTERN DOMAIN

The eastern domain consists of a segment of the northwest limb and core of the Moyie-Sylvanite anticline, a doubly plunging, banana-shaped culmination that terminates 30 kilometres to the northeast (Höy, 1993) and 25 kilometres to the southeast (Harrison *et al.*, 1992; Figure 2). The northwest limb of the fold lies in the footwall of the Moyie fault, the thrust that carries the next imbricate sheet to the west including the Goat River anticline. The limb is disrupted locally by north-trending vertical faults with apparent sinistral offset, and a minor, open north-plunging fold near Irishman Creek. The core of the Moyie anticline is exposed east of the northeast-trending, down-to-the-northwest Yahk fault. The core comprises gently dipping strata with local open folds. However, strata in the core and on the northwest limb steepen abruptly and bend into a north trend approaching the Kingsgate fault, which bounds Creston Formation in the Kingsgate graben.

KINGSGATE GRABEN

The Kingsgate graben preserves Creston Formation in a north-trending belt that extends southward along the western flank of the Moyie anticline. It is bounded on the west by the Moyie fault; the zone of convergence with the

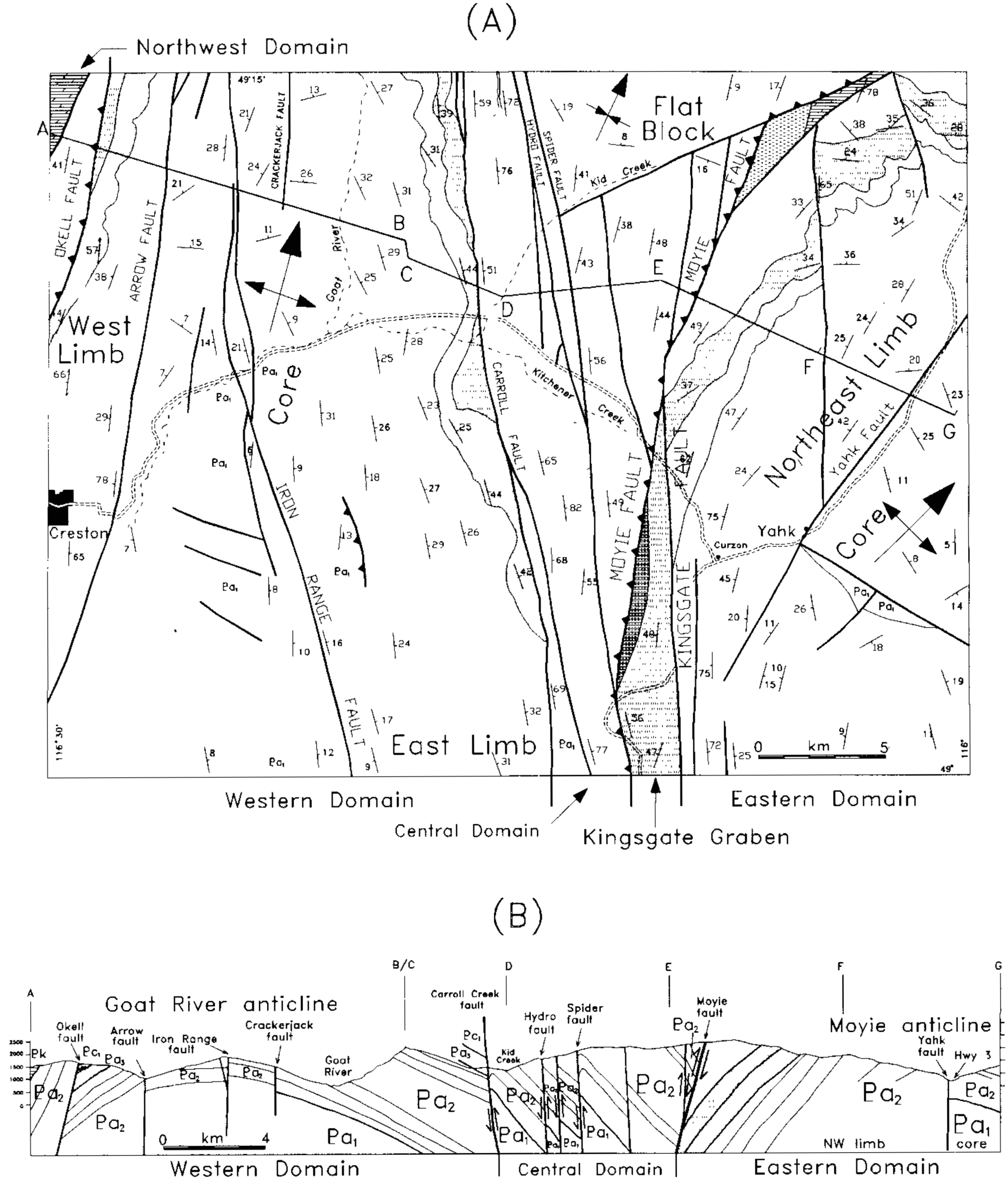


Figure 5. (a) Structural features of the Yahk map area, and (b) Schematic cross-section, modified from Brown *et al.* (1994)

Kingsgate fault to the north is poorly understood. A splay of the Kingsgate fault system is exposed along the Canadian Pacific railway tracks, 1 kilometre southwest of Curzon. Motion appears to be dip-slip based on rare, steeply plunging mineral-fibre slickensides. Bedding-cleavage intersections across the graben indicate that most of the Creston Formation within it comprises an east limb of a broad, faulted syncline, probably a truncated footwall syncline to the Moyie fault.

TRANSVERSE CONTRACTIONAL FAULTS – MOYIE FAULT

The Moyie fault extends from the east side of the Rocky Mountain Trench (Dibble Creek fault) southwestward through to the Yahk map area and into northern Idaho (Figure 2; Benvenuto and Price, 1979; Harrison *et al.*, 1992; Höy, 1993; Höy and Diakow, 1982; Leech, 1958; Reesor, 1981). Its arcuate trace is mimicked by the surface trend of the Moyie-Sylvanite anticline in the footwall at about 116° longitude.

The trace of the fault is defined by juxtaposition of middle Aldridge Formation against Creston or Kitchener formations, steepening of bedding attitudes, local tight folding and zones of intense cleavage. The best evidence of the fault in the Yahk map area comprises tight, upright moderately north plunging folds in middle Aldridge Formation, and a Moyie sill adjacent to openly folded middle Creston Formation, exposed along a ridge 10 kilometres north of Curzon. Here a series of parallel gullies is presumed to represent eroded zones of cataclasite and gouge. The fault, a zone of folded and faulted strata, at least 500 metres wide, bends to the north-northeast at this location. Farther northeast, at the headwaters of Kid Creek, lack of exposure precludes accurate delineation of the fault zone, but there appears to be a series of fault-bounded blocks of Kitchener Formation in the footwall of the main fault.

In the Yahk map area, the apparent west-side-up vertical throw is on the order of 1.0 to 1.5 kilometres. Sense and magnitude of displacement along the trace of the fault are predictably variable. Four kilometres of reverse dip-slip motion was estimated in the Cabinet Mountains (Fillipone and Yin, 1994) and about 12 kilometres of right-lateral movement was documented by Benvenuto and Price (1979) in the Fernie area. Timing of fault motion remains poorly constrained; pre-Devonian north-side-down and younger oblique reverse movement are suggested for the Dibble Creek fault (Leech, 1958). The latest movement on the Moyie fault is interpreted to be between 71 and 69 Ma, based on the age of muscovite neoblasts in the mylonitized western margin of the Dry Creek stock (Fillipone and Yin, 1994). The Moyie fault therefore has a complex and episodic history with variable character along its length.

CENTRAL DOMAIN

The central domain, bounded by the Moyie and Carroll faults, is an internally faulted horst-like block, underlain by lower and middle Aldridge Formation. It comprises a series of narrow, north-trending panels separated by steep faults, the most important being the Carroll, Spider and Hydro faults. The latter two are east-dipping reverse faults which repeat a sequence of sills and marker laminates. Dips within the block are moderate to steep, except for a flat-lying panel east of the Spider fault on the north side of Kid Creek. Minor folds are absent and cleavage is poorly developed, except adjacent to the bounding faults where tight and intense folding, with steeply plunging fold axes, is common, for example adjacent to major faults like the Moyie and Carroll. Most of the faults are steeply dipping but it is difficult to determine dip direction; they are either east-dipping reverse faults or west-dipping normal faults. A tentative interpretation is that they are subsidiary antithetic reverse faults related to the Moyie fault (Figure 5a).

An inferred fault in the Kid Creek valley separates the flat-lying block to the north from moderate-dipping strata in the central domain. Distribution of Moyie sills around an unnamed mountain and several gently dipping bedding attitudes characterize this block. It probably represents the core of a broad syncline that may extend to the north-northeast toward Cooper Lake (Grassy Mountain map area (82F/8); Reesor, 1981)

The Carroll fault down-drops lower Creston against middle Aldridge Formation. It consists of a bleached, clay-altered mylonitic rock that was exposed across a zone 2 metres wide by road building on the Star property (P. Ransom, personal communication, 1993). The Carroll and Iron Range faults are steeply dipping to vertical; Brown *et al.* (1994) inferred an east dip for the Carroll fault, but recently Cook and Van der Velden (in preparation) suggest it is a west-dipping normal fault. Although the dip direction is uncertain, there is agreement on the relative displacement across the fault.

WESTERN DOMAIN

The western domain comprises much of the Goat River anticline, plunging gently to the north, and where its eastern limb is truncated by the Carroll Kid fault. It is slightly asymmetric with a steeper and more foliated, west-dipping limb cut by the Okell fault. Like the Moyie anticline, lower Aldridge strata are exposed in the core of this fold. A contractional fault cuts the eastern limb of the anticline, 3 kilometres east of Mount Kitchener (Figure 3). Decimetre-scale, open to tight, southeast-verging folds developed in medium-bedded quartz wacke have moderate northwest-dipping axial planes, 2.5 kilometres southeast of Mount Thompson. A similar style of folding occurs in the hangingwall of the Moyie fault along the ridge 10.5 kilometres due north of Curzon. The core of the Goat River anticline is cut by two main north-trending faults, the Iron Range and Arrow faults. The Arrow fault is poorly exposed, but separates gently west-dipping strata from moderate to steeply west-dipping variably foliated rocks. It parallels Arrow Creek and is exposed near Creston as a zone of folded phyllitic wacke. The Iron Range fault is discussed in Stinson and Brown (1995, this volume).

NORTHWEST DOMAIN– WEST OF ARROW FAULT

An intense penetrative cleavage developed in quartz wacke occurs on the west limb of the Goat River anticline. It is well exposed along the Lakeview - Arrow Creek road, west of the Arrow fault. Gabbro sills are foliated and cut by discrete shear zones (chlorite schist) and abundant quartz-carbonate veins. The intense fabric may be related to the Okell fault, an east-directed contractional fault that places middle Aldridge on Creston and upper Aldridge formations (Figure 3). It is not well exposed but is marked by zones of tight folding and pervasive cleavage in its hangingwall in the Creston map area (Brown *et al.*, 1995, this volume). The fault extends northward into the Goat River valley where it may join with the St. Mary fault system (Reesor, 1981). Southward, it disappears under the thick Quaternary cover in the Creston Valley.

MINERAL OCCURRENCES AND ALTERATION

Sullivan-type sedex deposits are the prime exploration target throughout the Purcell Basin. The Sullivan deposit has been described by Hamilton *et al.* (1983), Höy (1984) and others. Recent studies by Leitch *et al.* (1991), Turner and Leitch (1992) and Leitch and Turner (1992) have refined the Sullivan model. Massive sulphide mineralization, tourmalinite, albite and muscovite alteration, manganese-rich garnet, sedimentary fragmental units and syndepositional sedimentary structures (slumps) and faults are characteristic features. Co-existing brown and black tourmalinite may discriminate potentially mineralized from barren tourmalinite showings (Slack, 1993). The Fors and Vine deposits, south of the Sullivan mine, near Moyie Lake, are exploration targets described elsewhere in this volume (Britton and Pighin, 1994, 1995, this volume; Höy and Pighin, 1995, this volume).

Several new alteration zones were discovered during the course of mapping and may warrant further prospecting. A knob of well exposed albite-flooded wacke and sedimentary fragmental within Ramparts facies crops out on the west side of Hawkins Creek in a logging clearing. Pervasive biotite flooding (with prominent biotite flakes weakly aligned perpendicular to bedding planes) of quartzofeldspathic wacke of the middle Aldridge below a sill 100 metres thick, is exposed along a new logging road directly south of the Highway 3 and 95 junction (Curzon). Some layers are so biotite rich they resemble a biotite lamprophyre (minette), however, relict bedding is still visible. The zone of biotite alteration extends southwest at least 300 metres. In another fragmental locality in King Creek, south of Yahk, clasts up to 20 centimetres long are supported in a wacke matrix. Pink garnet-rich beds on the south flank of Mount Mahon may correlate with similar beds farther south across Hawkins Creek. This garnet-rich horizon may be useful for detailed stratigraphic correlation (for locations, see Brown, 1995a).

TOURMALINITES

Tourmalinite occurrences are important because some are associated with lead-zinc mineralization, notably the Sullivan orebody. There are at least five stratiform or discordant tourmalinite occurrences in the Yahk map area (Figure 3). The stratiform occurrences are interpreted to have formed either by early diagenetic sub-seafloor replacement or by reaction between exhalative boron and aluminous sediments in a brine pool (Slack, 1993). Occurrences in the region have been studied by Ethier and Campbell (1977; Kingsgate and Mount Mahon), and divided into stratiform and discordant types by Slack (1993).

The Goatfell tourmalinite occurrence is the best known in the map area because it forms a pipe-like body exposed along part of a prominent knob visible from Highway 3, 6.25 kilometres northwest of Curzon. Argillite layers and rip-up fragments (2 to 10 mm long) within medium-grained quartzitic wacke are selectively replaced by tourmaline. The aphanitic, hard black tourmalinite forms concoidal fractures and looks like chert. In thin section, fine olive-brown tourmaline crystals are interstitial to quartz (Ethier and Campbell, 1977). Another tourmaline occurrence with associated arsenopyrite, pyrrhotite, pyrite and chalcopyrite was discovered 4 kilometres northwest of Goatfell in 1989 by Chevron Minerals Ltd. (Rebic, 1989).

Tourmaline fracture fillings in fine-grained quartzofeldspathic wacke, and replacement of mudstone layers and fragments are well exposed between Canuck and America creeks, southeast of Yahk at Monument 222 on the U.S. border (this is probably the Kingsgate site of Ethier and Campbell, 1977). The irregular fractures, up to 2 centimetres wide, are perpendicular to bedding. The angular tourmaline-rich mudstone fragments are interpreted to be rip-ups of local derivation and resemble those at Mount Mahon immediately east of the Yahk map area, as discussed by Ethier and Campbell (1977). A Moyie (gabbro) sill, 40 metres thick, crops out immediately below a gently southwest-dipping succession of middle Aldridge Formation at Monument 222.

Tourmalinite float, probably derived from Mount Mahon, was found southwest of Hawkins Creek. It is characterized by well bedded, aphanitic black tourmalinite dotted with small (<3 mm) brown, euhedral garnet crystals. The garnet is assumed to be a manganese-rich variety, perhaps formed in a brine pool by exhalative processes (Slack, 1993).

EXPLORATION ACTIVITY AND POTENTIAL

Drilling programs were completed on the Sun and Indigo claims in the Yahk map area, and a third conducted immediately to the east on the Canam property. The Sun claims, owned by David Wiklund of Creston and optioned to Hastings Management Ltd., cover a lead-zinc soil anomaly that was the target of a 300-metre drill hole. East-striking, steeply south-dipping galena-bearing quartz veins, up to 30 centimetres wide, are hosted by the middle Aldridge Formation. Cominco Ltd. completed soil geochemistry and an EM survey on the property in 1984. Later trenching exposed the quartz veins. Black argillites with some thin slump sheets are present.

The Indigo claim group lies north of the Moyie fault in the headwaters of Kid Creek. A vertical drill hole, started in 1993 (275 m), was extended to a depth of about 1020 metres in 1994. The hole, collared in the middle of the middle Aldridge, was drilled to the predicted lower-middle Aldridge contact. One narrow (2 cm), galena-bearing quartz vein was intersected at 960 metres. Bleached core with albite alteration occurs in numerous intercepts. A second drill hole was collared at the same site and directed 45° to the west for about 100 metres but encountered no visible mineralization or intense alteration.

The Hawkins Creek area remains attractive for exploration; the creek bisects the lower-middle Aldridge contact, there are numerous sills that change thickness rapidly across an inferred fault, and there are exposures of albitite alteration and fragmental rocks. In addition, drilling of coincident geochemical and geophysical anomalies encountered a zone of gouge, 15 centimetres wide, containing native silver and copper (34 100 g/t Ag and 10.3% Cu) in a drill hole on the ENG property (Stephenson, 1990). This supergene mineralization may be an indicator of a disseminated target. The Canam prospect comprises weakly disseminated sphalerite and galena and quartz-sulphide veinlets. Stratabound tourmalinites, local pervasive biotite alteration with patchy garnets are all within the middle Aldridge Formation (Anderson, 1991 and personal communication, 1994). The property lying immediately east of the Yahk map area, remains under exploration.

CONCLUSIONS

A summary of the results of fieldwork in the Yahk map area includes recognition of atypical lower Aldridge Formation, defined as the Ramparts facies. Two Moyie sill packages are indistinguishable except for stratigraphic position in Ramparts facies and in the middle of the Middle Aldridge. The Iron Range fault and an inferred northwest-trending fault in Hawkins Creek may define conduits for the emplacement of Moyie sills in the Ramparts and Hawkins Creek areas. Deformation and metamorphism in the Yahk map area increases abruptly west of Arrow fault. A north-trending array of Early Carboniferous(?) ultrabasic breccia dikes occurs near the Goat River valley. Sullivan-style mineralization indicators, including the lower-middle Aldridge contact (Sullivan horizon) at depth below much of the area, sulphide occurrences, albitite zones, fragmentals, and tourmalinites occur in the map area. The nearby Fors occurrence suggests targets in the middle Aldridge Formation also warrant exploration attention.

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NOTES

IRON RANGE DEPOSITS, SOUTHEASTERN BRITISH COLUMBIA (82F/1)

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(Contribution No. 27, Sullivan-Aldridge Project)

KEYWORDS: Economic geology, Proterozoic, Iron Range, albite alteration, breccias, hydrothermal iron oxide deposits.

INTRODUCTION

The Iron Range fault is a steeply dipping north-striking structure in the core of the Goat River anticline, east of Creston. It is characterized by strong alteration along its entire length, and locally, by high concentrations of iron oxide mineralization. Similar alteration was observed along minor subsidiary faults in the northwest and northeast parts of Iron Range Mountain. The main Iron Range deposit consists of the segment of the fault containing the richest iron mineralization and underlies the northern half of the ridge which makes up Iron Range Mountain. This area extends northward onto the Grassy Mountain sheet (82F/8).

The area of most substantial mineralization, where the fault zone runs along the northern part of the crest of Iron Range Mountain, was the focus of a detailed study involving 1:5000 mapping, sample collection, and thin section study of representative samples. The remainder of the Iron Range fault and subsidiary faults with similar alteration were examined and sampled during the course of regional mapping in the Yahk map area (Brown and Stinson, 1995, this volume).

REGIONAL GEOLOGY

Iron Range Mountain is underlain by sediments of the middle Aldridge Formation and several concordant Moyie sills which dip gently to the north and northwest (Figure 1). These rocks comprise the core of the Goat River anticline, a broad, gently north-plunging fold which underlies the west half of the Yahk map area (Brown and Stinson, 1995, this volume). The Iron Range fault is a northerly trending structure which cuts up-section from the International Boundary, in lower Aldridge Formation, to upper Aldridge Formation just north of the Yahk map area; further north it is cut by the Arrow thrust system (Reesor, 1981; Figure 1). It consists of a steeply dipping zone of deformation and mineralization varying in width from about 10 metres near the 49th Parallel to about 150 metres on the northern part of Iron Range Mountain. Net slip on the fault is minor in the main deposit area as sills are offset very little.

However, the amount of deformation and the complex relationships between deformation and mineralization point to a protracted, perhaps multistage history. There is evidence for both west-side-down movement and possibly both directions of strike-slip movement, based on rare kinematic indicators in the mineralized fault, local drag folding, and offsets of marker laminites (D. Anderson, Cominco Ltd., personal communication, 1994). Deformation in the surrounding rocks consists of penetrative cleavage, mainly in silty beds, and local metre-scale folding. Intersection lineations and fold axes in the rocks near the fault have a consistent moderate plunge to the north-northwest. This deformation is strongest near the fault and is probably related to it.

EXPLORATION HISTORY

The Iron Range prospect was discovered and staked in 1897. Over the next five years several shafts, adits, drill holes, and trenches were completed (Blakemore, 1902; Langley, 1922; Young and Uglow, 1926), none of which are preserved. Shafts and drill holes attained a maximum depth of 20 metres below the surface. Cominco Ltd. (then a subsidiary of Canadian Pacific Railways) acquired the main claim block on the northern part of Iron Range Mountain in 1939 and completed a major surface trenching program in 1957. All the exploration activity up to this point was aimed at evaluating the iron resource, which is potentially substantial. The claims remained CPR and Cominco Crown grants until 1994, when they were acquired by Discovery Consultants of Vernon who intend to evaluate the deposit's potential as an Olympic Dam type copper-gold-silver resource.

IRON MINERALIZATION

The intensity and types of mineralization and alteration vary over the length of the Iron Range fault. Mineralized zones can be broadly subdivided into the main deposit (most of the detailed study area), the La Grande zone (the southern part of the detailed study area, named after one of the claims), the Mount Thompson zone (the segment of the fault zone exposed east of the summit of Mount Thompson), and peripheral zones (the

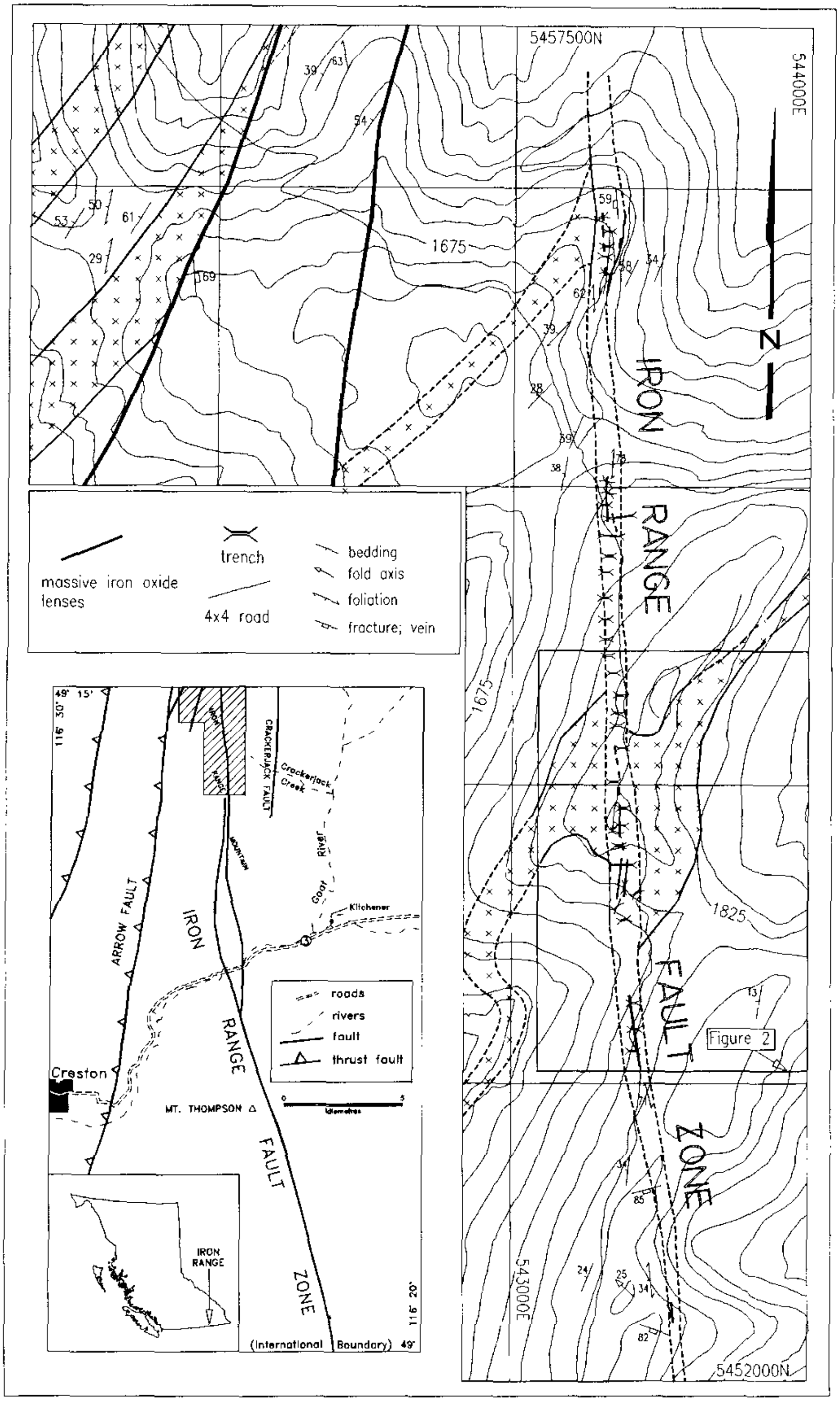

Figure 1. Simplified geological map of the main zone of the Iron Range deposit. Moyie sills are indicated by a cross hatch pattern. The widening of the sills near the fault is mainly a topographic effect. The location of Figure 2 is indicated by the labelled box. The contour interval is 30 metres, and the grid is a 1 kilometre UTM grid. The inset map is the west half of the Yahk map area (simplified from Brown and Stinson, 1995) with the location of the Iron Range map indicated by the hatched area

rest of the Iron Range fault and subsiduary faults). The main deposit produces a continuous, prominent aeromagnetic anomaly (Geological Survey of Canada, 1971).

MAIN ZONE

The main Iron Range deposit is contained within the widest segment of the fault zone. The deposit varies in width from approximately 60 to 150 metres and is at least 3 kilometres long. It runs from the Union Jack claim in the north to the Rhodesia claim in the south (MINFILE 082FSE014-20). This is the area explored by Cominco's 1957 trenching program. Bedrock is exposed in the less-deteriorated trenches; natural outcrop is very rare. Deformation fabrics, veining, and mineralized zones are all strongly aligned in the fault zone and are related to movement across it.

Lenses of massive hematite and magnetite occur along the length of the main zone. They range in width from 0.5 to 3 metres and pinch and swell substantially over their strike length. They are difficult to trace from trench to trench. Where nearly continuous exposure across the fault zone is preserved in trenches on the Maple Leaf claim, there are four parallel lenses spaced from 5 to 40 metres apart (Figure 2).

Most of the massive lenses are surrounded by wider *zones of hematite breccia*. Less commonly, massive iron oxide lenses cut foliated, sericitic sediments or gabbro. Breccia consists of fragments of albitite in a hematite-rich matrix. Contacts between the breccia and the

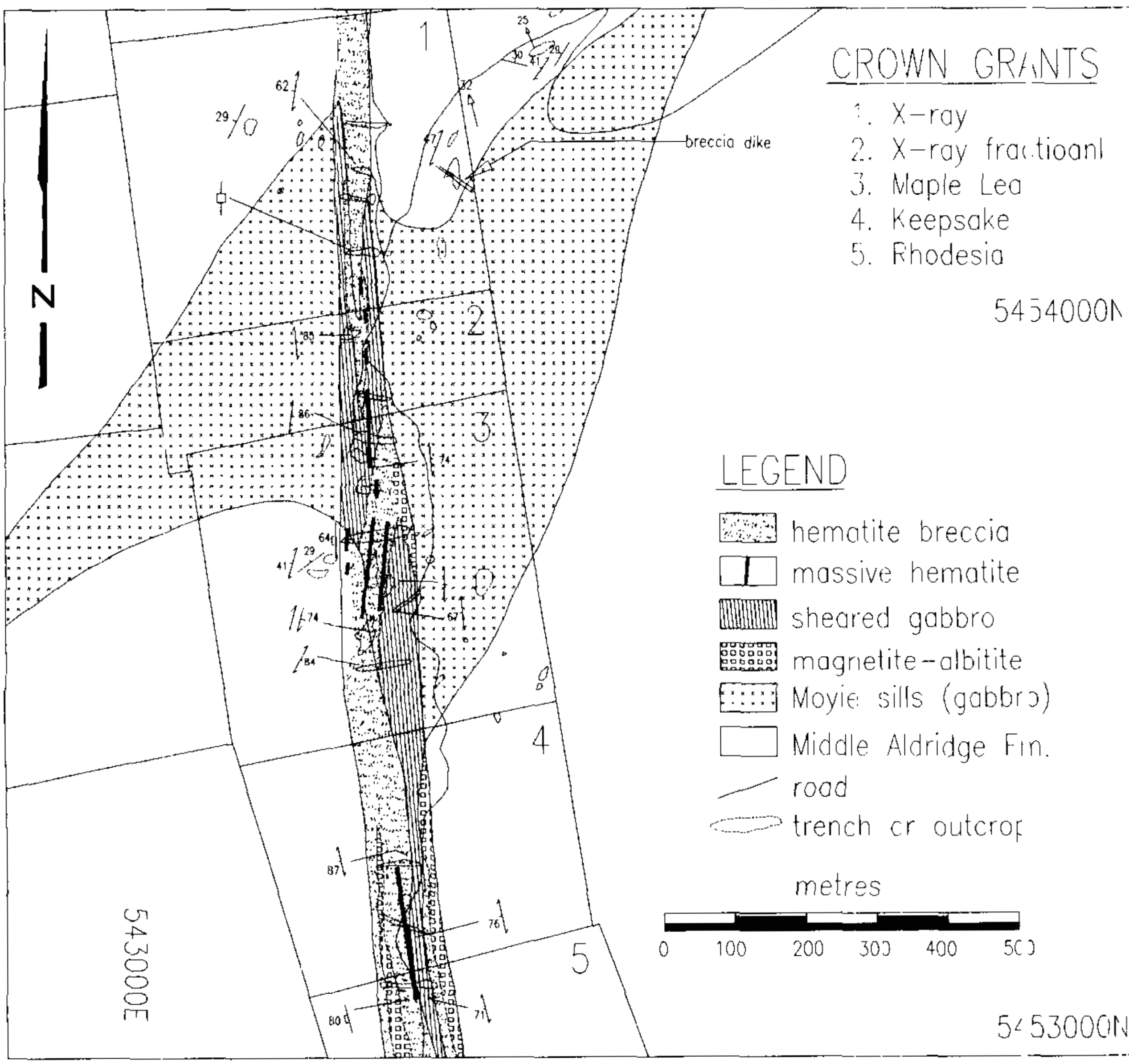

Figure 2. Detailed map of the part of the Iron Range fault and mineralization. See Figure 6 for location.

massive lenses are often gradational as the abundance of clasts diminishes into the lenses. Rare, small, angular fragments of albitite were observed in some of the lenses. Most of the massive lenses have envelopes of microbreccia 2 to 6 metres wide which have 70-80% hematite matrix surrounding angular clasts less than 1 centimetre across. Outward from the hematite-rich zones are wider breccia zones with 30 to 50% hematite as matrix and veins (Photos 1, 2). These breccias have a cataclastic texture. The original matrix is very fine grained fault gouge which is extensively replaced by hematite and minor magnetite. The massive lenses and surrounding breccias constitute the main iron resource of the Iron Range deposit.

The mineralogy of the lenses and breccias is dominantly hematite with variable amounts of magnetite. Thin sections show original magnetite abundances ranging from 5 to 30% as 0.5 to 2-millimetre euhedra. They are strongly pseudomorphed by hematite, with cores of magnetite remaining (Photo 3). The magnetite pseudomorphs sit in a matrix of fine-grained, often radiating, bladed hematite. Parts of the fault zone are occupied by unfractured albitite with disseminated to semimassive magnetite. Large magnetite euhedra (1-5 mm) form local, heavy disseminations, and fine-grained magnetite forms discontinuous veinlets and pods.

Photo 1. A cataclastic breccia from the main Iron Range deposit. The fracture filling is largely hematite and the rest is albitite (hand sample DBR93-220). The large dark spots are lichen. Flare pen for scale.

Sulphide minerals are rare in the Iron Range fault, with the exception of the northernmost trenches. In these trenches there is up to 3 or 4% pyrite as anhedral blebs in the hematite-magnetite lenses and breccias. Traces of chalcopyrite(?) were seen in hand sample but were not found in thin sections. In the remainder of the Iron Range, sulphides were not seen in outcrop or hand sample but some thin sections have tiny blebs of pyrite (<100 μm) within quartz veins. Some pyritic quartz veins with silicic alteration halos occur near the Iron Range fault; their orientations are oblique to the fault. Also, a short distance to the east of the fault on the northern part of Iron Range Mountain, there is an old pit with sulphide-bearing (pyrite-chalcopyrite-galena) quartz vein material in its dump (David Wiklund, Creston, personal communication, 1994). These veins may be related to the pyrite occurrences within the fault.

Foliated gabbro occupies much the width of the fault zone. Mineralization within the gabbro consists of some massive hematite lenses, foliation-parallel veins and zones of disseminated hematite and magnetite, rarer crosscutting breccia veins, and a background level of about 0.5 to 1% disseminated magnetite. The gabbro - iron oxide lens contacts are typically covered by overburden. Where exposed, there are zones of bleaching (albitite?) up to 30 centimetres wide and quartz veins lining the contacts. Crosscutting breccia veins were observed along the margins of the fault zone where strongly foliated gabbro grades into unsheared gabbro of the Moyie sills. The veins are very irregular and contain angular fragments of altered gabbro in a hematitic matrix. Some breccia veins are spatially associated with irregular zones of crosscutting albitic alteration. Disseminated magnetite is ubiquitous in the sheared gabbro, sufficient to be easily detected with a hand magnet. Most of the Moyie sills in the area do not attract a hand magnet and do not register on the regional aeromagnetic map.

Late, white quartz veins cut across all other rock types. The veins are several millimetres to several centimetres wide and most are parallel to the trend of the fault zone. Quartz growth is generally in the plane of the veins and some have several centimetres of shear movement. Some veins contain hematite crystals or angular fragments of massive hematite, apparently plucked from older veins and lenses. Magnetite is present in some quartz veins. These veins are interpreted as having been emplaced late in the deformational history of the fault, representing the last effects of the Iron Range hydrothermal system.

Photo 2. Hematite-filled breccia veins cutting albitite. The veins are parallel to the fault zone. Hematite fillings and veins are interpreted to postdate the initial brecciation. (PST94-I.R.23)

LA GRANDE ZONE

The La Grande zone is the segment of the Iron Range fault in the detailed study area south of the main zone (corresponding to MINFILE 082SE021-028). There the fault zone runs about 250 metres east of the ridge top and is not trenched; it is only exposed where it crosses side ridges. The fault zone appears to be 20 to 40 metres wide but the full width is not exposed. The fault in this area is a zone of quartz veining with variable iron oxide content in a more diffuse zone of grey quartz-hematite alteration. Iron content locally reaches grades approaching that of the massive lenses in the main deposit but over narrower widths (<1 m). This quartz-hematite mineralization is crosscut by late white quartz veins, as in the main deposit. In the La Grande zone the late veins are more common but are less often characterized by shear textures. Locally these veins contain up to 4% hematite, sometimes as 1 to 2-millimetre, platy euhedra.

MOUNT THOMPSON ZONE

South of Highway 3, a magnetite-rich zone crops out on a ridge top approximately 1.5 kilometres south-southeast of Mount Thompson. A zone of albitite, 1 to 2 metres wide, with disseminated to semimassive magnetite, cuts north-south through nearly flat-lying sediments. A wider surrounding zone has irregular hematite-filled fractures. In this area the fault changes from a single wide zone, as on Iron Range Mountain, to an anastamosing set of faults that are locally intruded by gabbro dikes. The individual faults are difficult to trace southward as outcrop becomes very scarce.

CRACKERJACK FAULT

A fault to the east of the main zone (Crackerjack fault; inset map in Figure 1) has a narrow zone (>5 m wide) of hematite-albitite breccia in one location, immediately to the north of Crackerjack Creek (Dean Barron, personal communication, 1994). One grab sample of the richest mineralization assayed [illegible]4% Fe_2O_3. The width of this zone and its extent along the fault are unknown due to poor exposure.

ALTERATION

Several alteration types are associated with the Iron Range deposit. Albite alteration is associated with the highest iron grades. In the main deposit, fine-grained, sugary albite alteration extends over most of the width of the fault zone. Albite alteration is confined to the fault

Photo 3. Photomicrograph showing euhedral magnetite grains in a matrix of bladed hematite. The magnetite grains are almost entirely pseudomorphed by hematite. The slightly darker core of the larger grain is residual magnetite. The field of view is approximately 0.75 by 1.25 mm. Reflected light, plane polarized. (PST94-I.R.11)

zone, except for rare apophyses which extend 1 to 2 metres into poorly foliated gabbro at the eastern contact of the main deposit. Although this alteration primarily affects sedimentary rocks in the fault zone, it is locally well developed in gabbro and, over the length of the fault, is only strongly developed near gabbro. Elsewhere early alteration in the fault zone is silicic.

Gabbro bodies within the fault zone are strongly foliated parallel to strike and are characterized by very strong chlorite alteration formed prior to, or during, shearing. The deformation fabric, seen in thin section, has porphyroclasts of plagioclase wrapped in fine-grained, commonly foliated chlorite. Weak S-C fabrics (Lister and Snoke, 1984) in foliated chlorite indicate west-side-down dip-slip movement. This contrasts with the completely brittle deformation of the albitite and may be attributable to the different competencies and response to stress of the lithologies during deformation. Locally the gabbro is bleached white by albitic alteration.

Sericitic alteration extends outward from the fault zone for about 500 to 1000 metres. The sericitic overprint is best developed in silty beds and is associated with the locally well developed cleavage. In addition to sericite, irregular veins and knots of quartz, epidote, and chlorite were observed in several outcrops of sandstone 100 metres to west of the trenches on the X-ray claim. Sericitic alteration was noted in only one locality in the fault zone, at its western edge on the Maple Leaf claim. There it is associated with a very strong, slaty cleavage developed parallel to the fault. This sericitic slate encloses the westernmost massive hematite lens (Figure 2).

Other alteration associated with the Iron Range fault is minor. Weak, rusty surface stain is present throughout the area, but this is a regional characteristic of the middle and upper Aldridge rocks, due to ubiquitous disseminated pyrrhotite (Höy, 1993). Mafic minerals within the gabbro sills near the fault zone have some chlorite overprint, but it is much weaker than within the fault zone.

Away from the parts of the Iron Range fault and subsidiary faults which have significant iron mineralization in surface exposures, the faults are characterized by a zone of cataclasis and silicic and/or albitic alteration 10 to 20 metres wide. Chloritic alteration was noted in several locations, all near intersections with Moyie sills. Examples are near the International Boundary, and on two faults on the northeast flank of Iron Range Mountain (in 82F/8).

PARAGENESIS AND RELATIONSHIP OF MINERALIZATION TO DEFORMATION

The origin of the Iron Range deposits is strongly linked to deformation in the Iron Range fault zone. Deformation can be separated into three episodes which may represent three stages of a continuous deformation. These are related to different stages in the evolution of the iron oxide mineralization. This is summarized in a paragenetic diagram (Figure 3).

The timing of the first movements on the Iron Range fault is difficult to determine. It is possible that it was originally a growth fault and served as a conduit for feeder dikes to the Moyie sills. The basis for this interpretation is the thick accumulation of sills in this part of the basin (Brown and Stinson, 1995, this volume). Also, much of the deformed material in the fault zone is gabbro, forming long narrow bodies. These have been interpreted as dikes (Blakemore, 1902; Langley, 1922; Young and Uglow, 1926). Within the main deposit, however, at least some of the gabbro bodies are sills that have been stretched into the plane of the fault zone, forming large drag folds and possibly sheath folds (Figure 2). The apparent thickening of the sills near the fault in the detail map area is mainly an effect of topography, but may be partly due to minor shearing along the margins of the main fault zone. If the sheared gabbros are deformed sills, then motion on the Iron Range fault probably began well after the deposition and burial of the Aldridge Formation. Pre-mineralization movement on the fault is inferred from the initial localization of albitite alteration along a narrow, crosscutting zone in the Aldridge sediments.

Albite alteration in the Aldridge Formation is usually the result of hydrothermal activity related to the intrusion of Moyie sills into relatively unconsolidated, water-saturated sediments at shallow levels below the sea-floor (Höy, 1993). The very strong albite alteration in

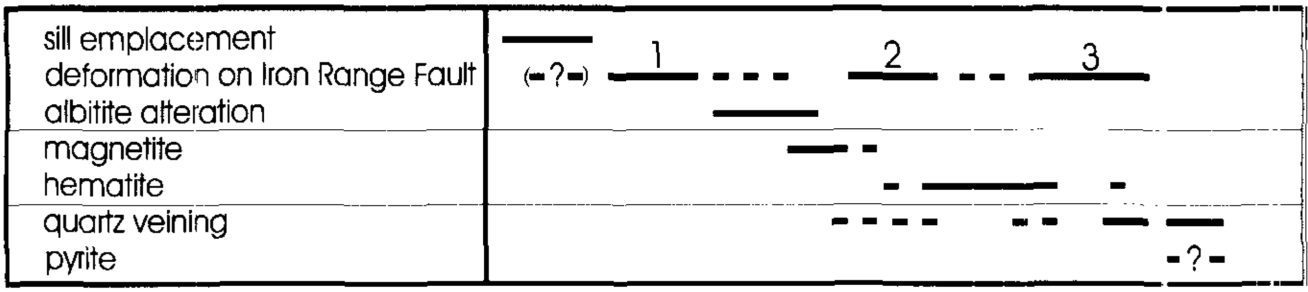

Figure 3. Diagram illustrating paragenetic sequence for the Iron Range deposit. Numbers refer to deformational episodes: (1) Initiation of the Iron Range fault and formation of hydrothermal conduit; (2) Cataclasis of albitite and shearing of gabbro; (3) Further cataclasis and shearing of iron ore.

the main Iron Range deposit is confined to the fault zone, although it is only developed in and around gabbro bodies. Initial magnetite mineralization is interpreted to have occurred with the albitic alteration, perhaps late in this episode. This mineralization is only well developed where subsequent brecciation is weak and shear fabrics are lacking. Magnetite precipitation continued into the next recognizable stage in the evolution of the Iron Range fault.

The main deformation episode followed the albite alteration. In the wide fault zone this consisted of extensive cataclastic brecciation of albitite, foliation development in gabbro, and local development of slaty cleavage in sericitized sediments. The albitite microbreccias are cataclasite (>50% matrix), the breccias are protocataclasite (<50% matrix), and gabbro within the fault zone is locally mylonitic, according to the definitions of Sibson (1977). This variation in deformational style between the different lithologies indicates that this episode occurred at several kilometres depth; cataclastic deformation can occur at depths up to about 5 kilometres (Ramsay and Huber, 1987, p. 584)

This deformation acted as ground preparation for hematite mineralization, although these events may have overlapped to some extent. Fine-grained hematite formed large, fault-parallel lenses and replaced fault gouge in the breccias. This episode began with magnetite deposition, but hematite replaced magnetite and is far more abundant. This change indicates that the fluids became increasingly oxidizing early in this main stage of iron mineralization.

Deformation continued after the main mineralizing episode, resulting in the formation of fractures, shear veins, and local ductile deformation of hematite-rich rocks. Quartz-filled shear veins, with vein-parallel mineral growth and offsets across them, are common along the length of the fault. They crosscut all other lithologies, including early silicified rocks in the La Grande area. Rare extension veins with mineral growth perpendicular to the vein walls were also observed. These vein textures resemble the vein associations in mesothermal, shear zone hosted gold deposits (Roberts, 1987), and may have formed in similar conditions. The iron oxide content of these veins is low. Local, well developed S-C fabrics in hematite breccias are associated with shear veins. Locally, hematite veins are brecciated and filled by quartz. Sulphide-bearing quartz veins, although not shear veins, may have been emplaced during this stage in the deposit evolution or they may be later and unrelated to the iron oxide mineralization.

The deformation style and alteration of the Iron Range fault and subsidiary faults is unusual compared to other faults in the surrounding area (Brown and Stinson, 1995, this volume). These characteristics, and the possible connection to the Moyie sills, indicate that the fault is old, maybe Proterozoic, and perhaps contemporaneous with early movements on the Moyie and St. Mary faults. The source of the large volume of iron contained in the Iron Range deposit is unknown. Potential sources include the Moyie sills and the basement of the Aldridge Formation.

COMPARISON TO OTHER MINERAL DEPOSITS

Hydrothermal iron deposits have received particular attention over the last few years, mainly due to the results of recent work on the Olympic Dam deposit in Australia. Early studies of the Olympic Dam, based on limited drilling information, interpreted the deposit as sedimentary breccias with mineralization and alteration largely due to diagenetic processes (Roberts and Hudson, 1983). Recent studies, based on extensive core logging and underground mapping, have established the hydrothermal nature of the breccias and described the evidence for near-surface hydrothermal brecciation within the host granitic batholith (Oreskes and Einaudi, 1990; Reeve *et al.*, 1990). Copper, gold, silver, uranium, and rare earth elements were deposited late in the evolution of the breccias, after significant iron metasomatism, and were enriched by supergene processes (Oreskes and Einaudi, 1990). These studies note that the core zone of the breccias is broadly associated with a topographic lineament which may reflect an underlying fault zone.

Recent studies propose that the Olympic Dam deposit has important similarities with certain other mineral deposits. This has resulted in the definition of a class of deposits; Olympic Dam type, or Proterozoic iron oxide (Cu-U-Au-REE; Hitzman *et al.*, 1992;

Lefebure, 1995, this volume). Canadian deposits included in this classification by these workers include the Wernecke breccias in Yukon Territory and deposits of the Great Bear magmatic zone in the Northwest Territories. One aspect of the deposit class is the alteration zoning, a summary of which is presented by Hitzman *et al.* (1992). They propose a typical pattern of albite-magnetite-actinolite grading upward and outward through a potassic zone to an outer hematite-sericite zone, with an intermediate zone of albite-sericite-magnetite alteration in sediment-hosted deposits. The Iron Range has an inner core zone of albite alteration and an outer envelope of sericite alteration corresponding to the deeper sodic alteration zone of this deposit class.

The Iron Range deposit has similarities to this broad class of mineral deposits and could reasonably be included in it. With respect to the Olympic Dam iron breccias, the main genetic differences appear to be the structural style, the origin of the brecciated hostrocks, and the greater depth of formation of the Iron Range deposit. However, enrichment in base and precious metals at Olympic Dam do not have a demonstrated corollary at Iron Range. It is interesting to note the possible fault control at depth at Olympic Dam (Oreskes and Einaudi, 1990), and to speculate that if this fault, or fault system, controlled the upward migration of hydrothermal fluids and metals, it might resemble the present level of exposure on Iron Range Mountain.

ACKNOWLEDGMENTS

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PRELIMINARY GEOLOGY OF THE CRESTON MAP AREA, SOUTHEASTERN BRITISH COLUMBIA (82F/2)

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(Contribution No. 22, Sullivan-Aldridge Project)

KEYWORDS: Proterozoic, Purcell, Windermere, Purcell Trench, Priest River Complex.

INTRODUCTION

This article summarizes preliminary results of the East Kootenay project after completion of one month of fieldwork in the Creston map area (82F/2) in 1994. The project will provide a new 1:50 000-scale geologic map (Open File 1995-15) and improved stratigraphic correlations. Mapping concentrated on extending work westward from the Yahk map area (Brown and Stinson, 1995, this volume), across the Creston valley and up to the Windermere Supergroup. The northwest third of the map sheet, underlain by Jurassic and Cretaceous plutons, was not studied

PREVIOUS WORK

The Creston map area lies along the International Boundary, in the southern part of the Nelson map area (82F). Initial geological investigations were undertaken by Daly (1912) as he surveyed the international border area in the early 1900s. Complete 1:250 000-scale coverage of the Nelson East Half map area was finished in 1938 (Rice, 1941). Recent 1:100 000-scale mapping of the region has been published by Reesor (1993; Figure 1). A new 1:250 000-scale coloured compilation map for the entire British Columbian Purcell anticlinorium is now available (Höy *et al.*, 1995).

Several theses have been completed in the vicinity of the Creston map area. Most notable is the detailed structural study by Glover (1978). His 1:25 000-scale map of the Summit Pass area overlaps the western part of the Creston map area and has been incorporated in this study (Figure 1). Stratigraphic divisions adopted by Glover (following those of Rice, 1941) are largely maintained here. A thesis by Barrett (1982) describes structures in the Bayonne batholith, along the northern edge of the Creston map area, that may be related to the Purcell Trench fault. Immediately north of the Creston map area, LeClair (1982, 1983) studied the area west of Kootenay Lake. Farther northeast, two theses examine in detail the upper Purcell and Windermere stratigraphy (Root, 1987; Pope, 1989). Significantly, these two works have substantially different interpretations of the upper

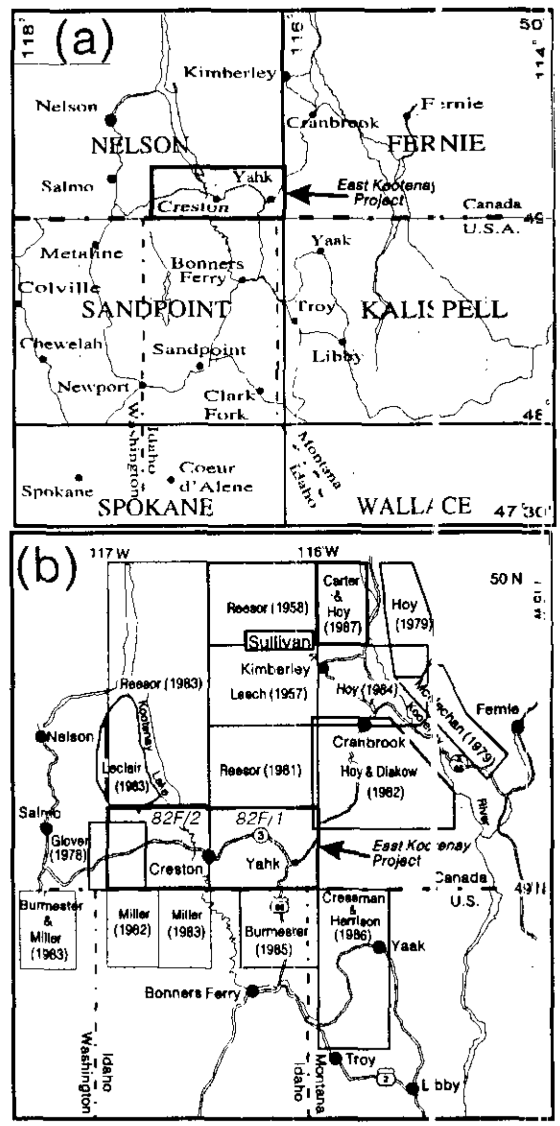

Figure 1. Location of the Creston and Yahk map areas (dark hatched rectangle) relative to areas of previously published geologic maps. (a) The 1:250 000, 1:126 720 or 1:100 000-scale map coverage includes: Fernie West-half (82G/west) -- Leech (1958, 1960), Höy and Carter (1988), Höy (1993); Nelson East-half (82F/east) -- Rice (1941) Reesor (1993); Sandpoint (82C) -- Miller (in preparation), Aadland and Bennett (1979); Kalispell (82B) -- Harrison *et al.* (1992); Spokane, Griggs (1973), Stoffel *et al.* (1991); Wallace -- Harrison *et al.* (1986). (b) The 1:50 000, 1:48 000 and 1:25 000-scale maps in the immediate vicinity of the Creston map area include: Burmester and Miller (1983), Glover (1978), Leclair (1983) and Miller (1982, 1983).

Purcell stratigraphy; Root proposes that the Mount Nelson Formation be included in the Windermere rather than Purcell Supergroup. A thorough geochronometric study of plutonic and metamorphic rocks in the Creston map area was completed by Archibald *et al.* (1983, 1984), including documentation of a Tertiary thermal event west of the Purcell Trench fault.

Mapping south of the International Boundary includes 1:250 000-scale maps by Aadland and Bennett (1979) and Stoffel *et al.* (1991; Figure 1a). More detailed mapping adjoining the Creston map area includes Miller (1982, 1983; Figure 1b) and a study of paragneiss along the west side of the Purcell Trench west of Bonners Ferry by Nevin (1966).

GEOLOGICAL SETTING

The map area straddles a structural and metamorphic transition from the Purcell anticlinorium to the Kootenay Arc and includes important structures such as the southern extension of the Hall Lake fault and the northern extension of the Purcell Trench fault (Figure 2). It provides a unique opportunity to map changes from low grade, broadly folded, unfoliated Purcell Supergroup strata of the anticlinorium into equivalent but higher metamorphic grade and polydeformed rocks. The Purcell Supergroup, a thick succession of siliciclastic and carbonate rocks of Middle Proterozoic age, is unconformably overlain to the west by the Upper Proterozoic Windermere Supergroup. Small Jurassic

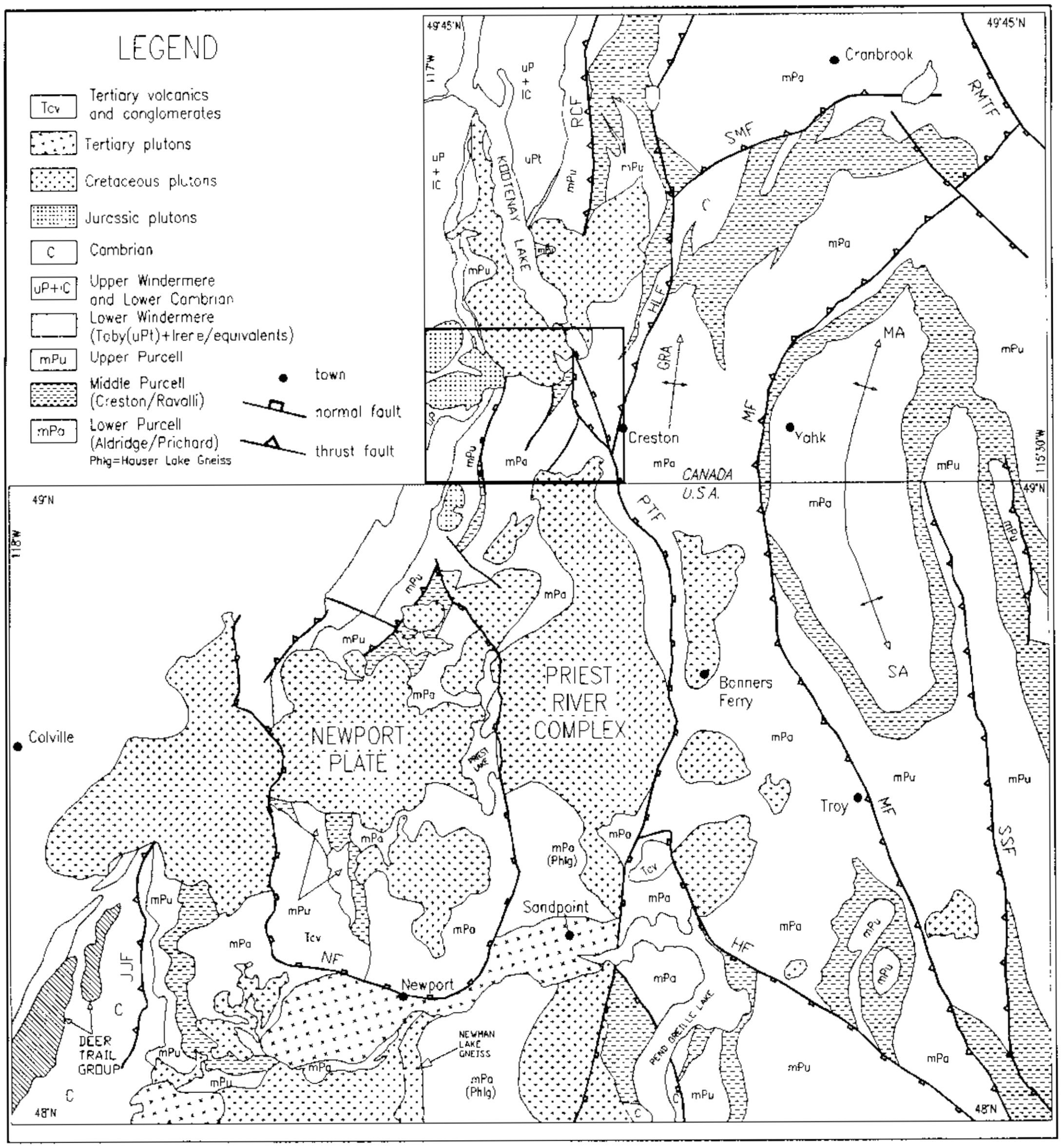

Figure 2. Generalized geological map of part of southern British Columbia, northern Washington, Idaho and Montana, emphasizing the distribution of the Purcell Supergroup, lower Windermere Supergroup (Toby and Irene formations) and major intrusive suites. Simplified Creston Formation distribution is illustrated to delineate major anticlines. Rectangle marks Creston map area. Abbreviations: GRA = Goat River anticline, HF = Hope fault, HLF = Hall Lake fault, JJF = Jumpoff Joe fault, MA = Moyie anticline, MF = Moyie fault, NF = Newport fault, PTF = Purcell Trench fault, RCF = Redding Creek fault, RMTF = Rocky Mountain Trench fault, SMF = St. Mary fault, SSF = Snowshoe fault. Modified after Höy *et al.*, 1995, Miller (1982, 1983), Stoffel *et al.* (1991) and Harrison *et al.* (1992).

plutons and extensive Cretaceous batholiths dominate regions north and south of the Creston map area. These plutons have been mapped by Daly (1912), Rice (1941), Reesor (1973, 1983, 1993) and Miller (1982, 1983), and studied by Archibald *et al.* (1983, 1984).

Most of the mapping focused on the Purcell Supergroup; with its tripartite subdivisions: lower (Aldridge and Creston formations), middle (Kitchener Formation), and upper (Dutch Creek and Mount Nelson formations; Figure 3). Stratigraphic distinctions and nomenclature problems arise in this part of the western Purcell Basin. For example, Kitchener and Siyeh formations are not distinguishable, unlike farther to the east, which led to the use of Kitchener-Siyeh Formation (Rice, 1941). In addition, important regional markers to the east (Nicol Creek Formation and Phillips Formation/Bonner Quartzite) are absent or rare. The Dutch Creek and Mount Nelson formations were originally defined by Walker (1926) in the Windermere area and have been extended south to the Creston map area. The Windermere Supergroup comprises up to 9 kilometres of polymictic conglomerate, volcanics, carbonate and siliciclastics. The lower units are generally

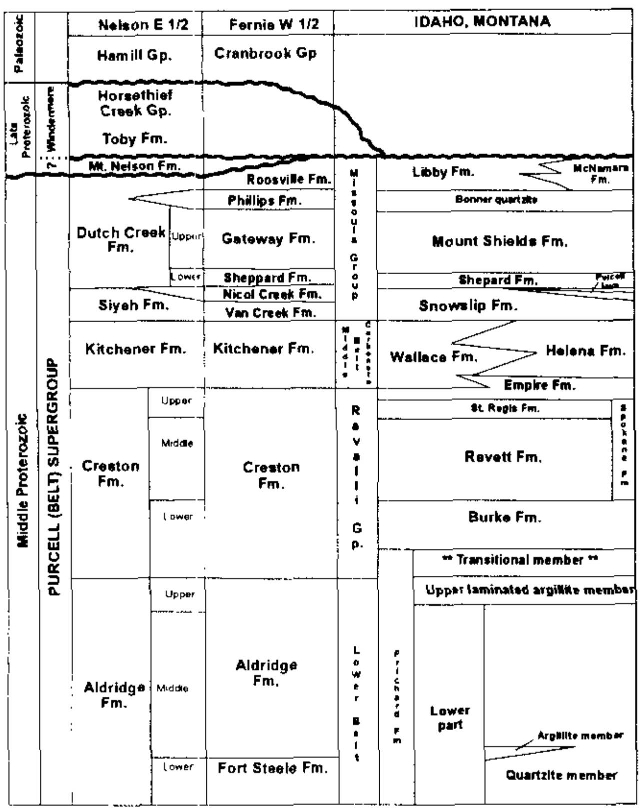

Figure 3. Table of formations for the Purcell Supergroup and their correlative units within the Belt Supergroup of Idaho and Montana. Nelson East Half from Rice (1941) and Reesor (1981, 1983); Fernie West Half from Leech (1958); Idaho and Montana from Harrison *et al.* (1992) and Harrison and Cressman (1993). The *transitional member* of the Prichard Formation (Cressman, 1989) correlates with lower Creston Formation.

interpreted to record a rifting event and are overlain by more extensive deep-water sediments believed to represent shelf progradation, although much debate continues about these reconstructions (Ross *et al.*, in preparation).

The Priest River Complex, a north-trending Eocene core complex, comprises Precambrian basement gneiss, metamorphosed Purcell/Belt strata, and deformed and massive Cretaceous plutons (Figure 2; Rehrig *et al.*, 1987). It also includes the Spokane Dome mylonite zone (Rhodes and Hyndman, 1984; Rhodes, 1986), and Hauser Lake gneiss. The northern end of the Priest River Complex comprises Cretaceous granitic rocks and amphibolite grade metamorphic rocks derived from the Aldridge/Prichard Formation. These granitic rocks are the West Creston and Corn Creek gneisses, and Rykert pluton (Daly, 1912; Miller, 1982; Archibald *et al.*, 1983, 1984; Figure 4).

STRATIGRAPHY OF THE CRESTON MAP AREA

PURCELL SUPERGROUP

ALDRIDGE FORMATION

The Aldridge Formation underlies about half of the Creston map area and changes character between discrete fault-bounded blocks. East of the Okell fault (Figure 4), Aldridge Formation is unfoliated and low metamorphic grade, similar to most of the Yahk map area. However, metamorphic grade and penetrative fabrics increase to the west, hindering subdivision of the formation and locally making correlations speculative. The rusty weathering (disseminated pyrite and pyrrhotite) characteristic of the Aldridge formation is a useful feature used to distinguish it from the grey-weathering metamorphosed Creston Formation. The more phyllitic and sericitic Aldridge Formation adjacent to faults can resemble the Creston Formation, for example 4.6 kilometres north of Creston on Highway 3A. More detailed mapping is needed to define the relationships between low and high-grade areas. Marker laminates have been identified in a few localities where metamorphic grade is low to moderate (D. Anderson, personal communication, 1994). Primary sedimentary structures (graded bedding, crossbedding flames and scouring) are evident locally in the lower grade blocks.

CRESTON FORMATION

The Creston Formation is undivided in the map area because of the superimposed deformation and metamorphism. Lower metamorphic grade exposures include waxy pale green and grey, thin-bedded to laminated argillite to siltstone couplets, phyllitic siltstone and quartz arenite, as exposed east of North Star Mountain (Figure 4). Local ripple marks indicate

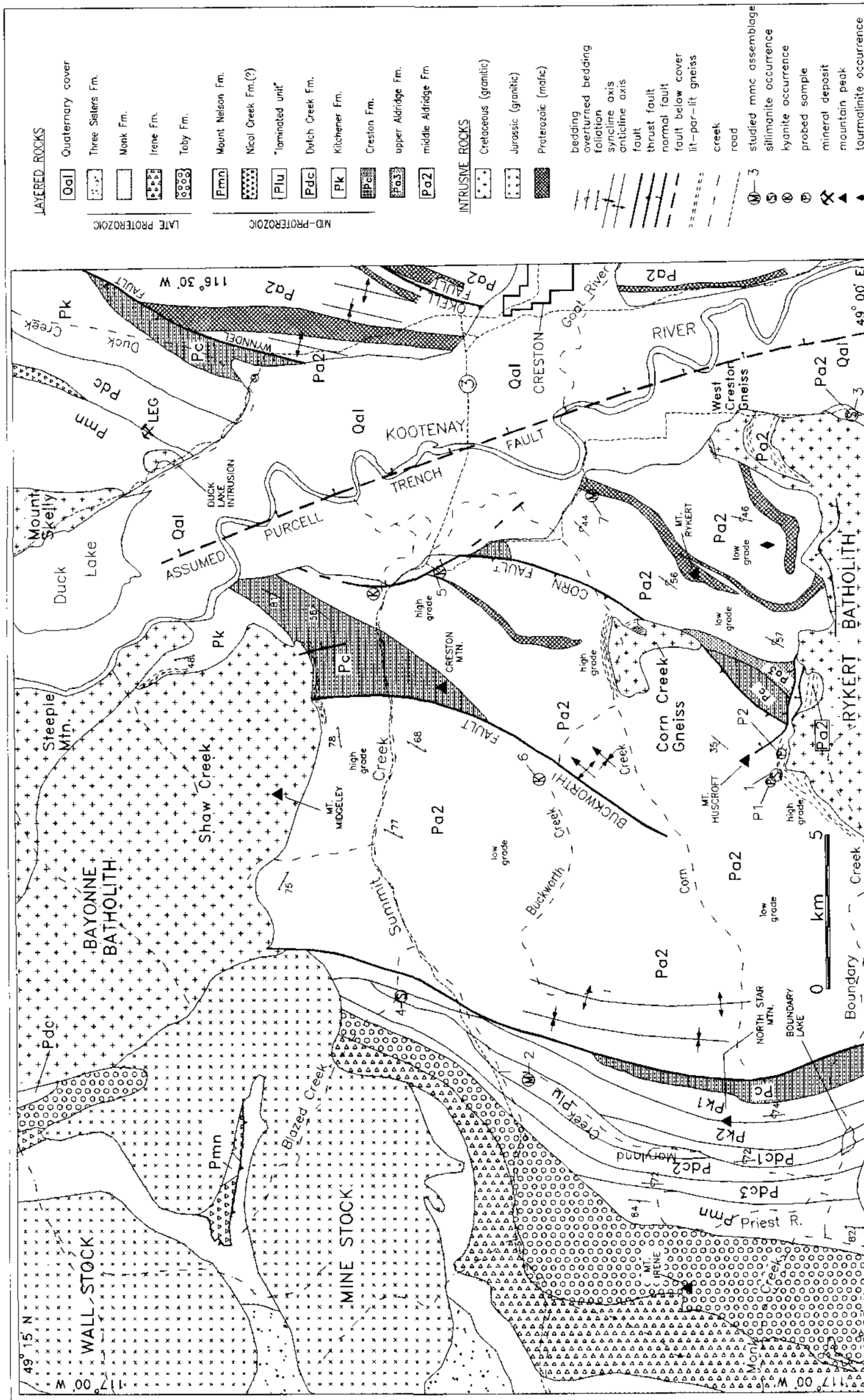

Figure 4. Simplified geology of the Creston map area (82F/02).

Photo 1. Thinly bedded quartz arenite with coarsely crenulated argillaceous interbeds, metamorphosed Creston Formation.

Photo 2. Cone-shaped stromatolite from the Kitchener Formation dolomite 900 metres east of North Star Mountain (DBR94-505).

deposition within fair-weather wave base. In this area the Creston Formation is overprinted by post-tectonic biotite porphyroblasts. The metamorphosed Creston Formation consists of non-rusty, light grey weathering, thin-bedded to laminated muscovite schist, biotite-muscovite-quartz schist and meta-arenite. Outcrops 2 kilometres west of the Summit Creek bridge along Highway 3 are typical. Bedding and more rarely crossbedding may be preserved, even where medium-grained schist with prominent phyllosilicate crenulation is developed (Photo 1).

The Creston Formation here in the northwestern part of the Purcell Basin is generally finer grained and thinner than the succession in the Yahk map area. The middle Creston Formation is known to produce strong aeromagnetic anomalies, for example, in the Moyie anticline (Brown and Stinson, 1995, this volume). A 1:250 000-scale aeromagnetic anomaly south of Wynndel suggests that the Creston Formation extends to the southwest under the Quaternary cover in the Kootenay valley. In the same area there is an odd pattern with two anomalies of unknown origin. Farther west, a faint and broad anomaly in the Maryland Creek area may also be correlated with Creston Formation and perhaps some mafic sills (discussed later).

KITCHENER FORMATION

Kitchener Formation consists of a basal carbonate unit and an upper argillite succession in the North Star Mountain area (Figure 4). The **lower carbonate unit** (Pk1) in the North Star Mountain area is a carbonate-rich succession about 1000 metres thick, dominated by dark brown to tan-weathering dolomitic phyllite, dolomite, dolomitic siltstone with minor limestone (marble), and lesser quartz arenite. Fine sericitic-rich layers are metamorphosed clayey layers. Pale greenish grey fissile dolomitic siltstone has a pitted weathered surface where pyrite cubes (up to 5%) have been dissolved. A pale green phyllitic siltstone and argillite facies within the carbonate thickens to the south. The medium to thick-bedded basal dolomite, east of North Star Mountain, contains rare domal and cone-shaped stromatolite mounds (Photo 2), up to 2 metres across, indicating shallow-water deposition. These stromatolites are reliable indicators of tops and indicate that the southeast-dipping section is overturned. The dolomite units produce deep red-brown soils that help delineate the dolomite horizons in areas of poor exposure. Fining-upward sequences, pinch and swell, and hummocky bedforms suggest deposition within storm wave base, slightly deeper than the Creston Formation.

A series of discontinuous **carbonate breccia horizons** occur in two areas, Wilds Creek and North Star Mountain. Those near Wilds Creek are part of a group of breccias that extend northward along the western edge of the Purcell anticlinorium (Brown and Krewchuk, 1995, this volume). On North Star Mountain, at least three irregular and discontinuous zones of breccia are exposed, however, their lateral extent is difficult to establish. The breccias in both localities have similar appearances, although, it is unclear whether they occupy the same stratigraphic position. The North Star Mountain breccia comprises angular dolomite fragments up to 25 centimetres long (average 2 to 5 cm), and rare subrounded white quartz and arenite fragments supported in a light brown to tan carbonate matrix. Grey argillite clasts occur sporadically. Surface exposures are roughly pitted due to differential weathering of the different carbonate and argillite fragments. The breccias are interpreted to be karst (solution collapse) features.

Above the carbonate succession (Pk1) is about 750 metres of dark grey **phyllitic argillite** (Pk2) that was not studied.

DUTCH CREEK FORMATION

The Dutch Creek Formation consists of a lower carbonate (Pdc1), overlain by an argillite succession (Pdc2) and locally a laminated unit (Plu), and capped by an upper carbonate (Pdc3).

The **lower carbonate** (Pdc1), dominated by dolomite, extends from the border northward 9 kilometres to Maryland Creek. It consists of thin to medium-bedded dolomite with green phyllitic layers. The central part is mainly massive, crumbly, grey argillaceous dolomite, with interbedded laminated dolomite. Locally, siliceous knots are common. Towards the top, it is mainly laminated argillaceous dolomite with pyrite porphyroblasts. This grades upward into light green-grey dolomitic argillite and grey to dark green argillite of the middle Dutch Creek unit (Plu). Near the top of the unit quartzite beds are interbedded with the dolomite.

A distinct unit, informally called the "laminated unit" (Plu) comprises well laminated siltstone that crops out in several locations. The alternating light grey and light green laminae give it a distinctive appearance. It is characterized by its soft, friable and even-bedded bedform. Uncracked, even clay to silt couplets are interbedded with thicker, continuous, flat-laminated sandstone layers. Siltstone layers are commonly attenuated and more deformed parts of the unit are chlorite-sericite phyllite. Planar crossbedding, climbing ripples and oscillation ripples were observed in some exposures (Photo 3). The outcrop 6 kilometres west of Blazed Creek along Highway 3, is marked by fine disseminated magnetite crystals. It appears to have an anomalously low metamorphic grade and is only locally crenulated. Towards the southern end of its interpreted extent it is mainly thin-bedded light grey to green siltstone, characterized by tabular bedsets with angular crosslaminations. This sediment type is not seen farther south, where the middle Dutch Creek Formation is entirely argillite.

An **argillite succession** (Pdc2), dominated by microlaminated sericitic phyllite with minor deeply weathered dolomitic beds less than 2 centimetres thick, separates dolomite horizons. It is a heterogeneous succession of black phyllitic argillite, pale green sericite schist and quartzitic schist. A small building stone quarry in quartzitic sericite schist operates intermittently north of Maryland Creek.

A succession of dolomite, argillite and quartzite (unit Pdc3) forms the uppermost unit of the Dutch Creek Formation in the Maryland Creek area. The first occurrence of a thick dolomite horizon (>1m) is taken to be the basal contact. Cream-coloured, pure, fissile dolomite and dolomitic siltstone are medium to thin bedded and include interbeds of microlaminated black graphitic argillite, similar to the underlying unit. Rare cryptoalgal laminations may be stromatolites. Laminated fine-grained orthoquartzite beds, up to 4 metres thick, are a small component of the section. Pure, light grey to white, fine-grained dolomite interbedded with thick (1 to 2 m) beds of limestone (marble) mark the top of the Dutch Creek Formation in the Maryland Creek area.

The dolomite is overlain by black to rusty brown weathering crenulated graphitic argillite. A massive dolomite bed, 1 to 2 metres thick, occurs within the laminated black argillite. It is unclear whether this argillite marks the top of the Dutch Creek Formation or the base of the Mount Nelson argillite unit.

MOUNT NELSON FORMATION

The Mount Nelson Formation consists mainly of dark coloured phyllitic argillite with interbedded quartzite and lesser dolomite, west of the uppermost Dutch Creek carbonate (Figure 4). The rusty brown to grey argillite is phyllitic and locally crenulated, so primary features are not preserved. Strata are mainly graphitic (shiny dark grey to black) or chloritic (dark green) and locally contain numerous quartz pods and layers, some of which may be flattened clasts (Photo 4). The argillite is interbedded with several layers of medium to coarse-grained vitreous quartzite (quartz sandstone) that appear to be continuous over several kilometres. The medium to thick-bedded quartzite layers are 2 to 50 metres thick and are much more resistant than the argillite, hence they form prominent outcrops. They weather white, grey, brown and pink, and constitute

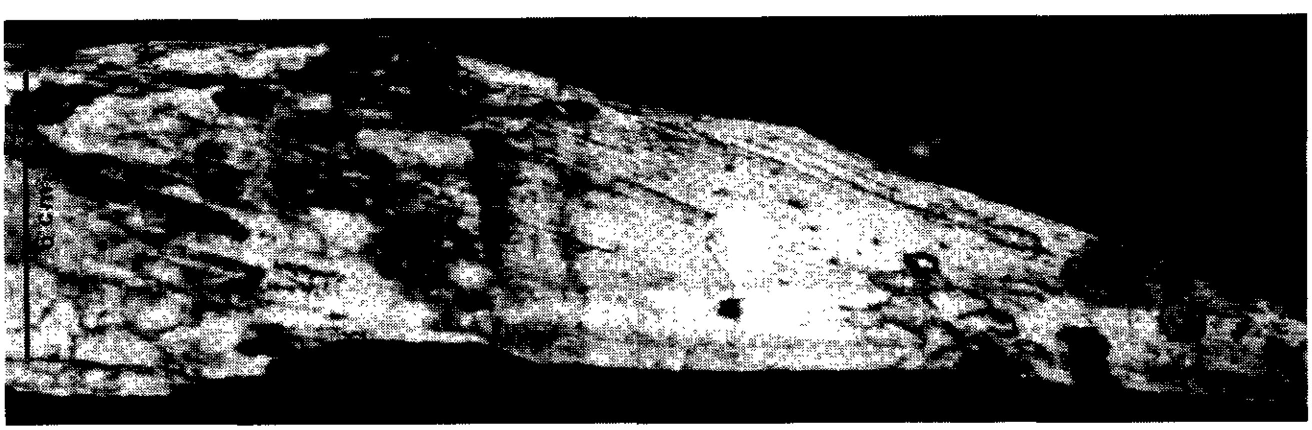

Photo 3. Planar crossbedding within the laminated unit.

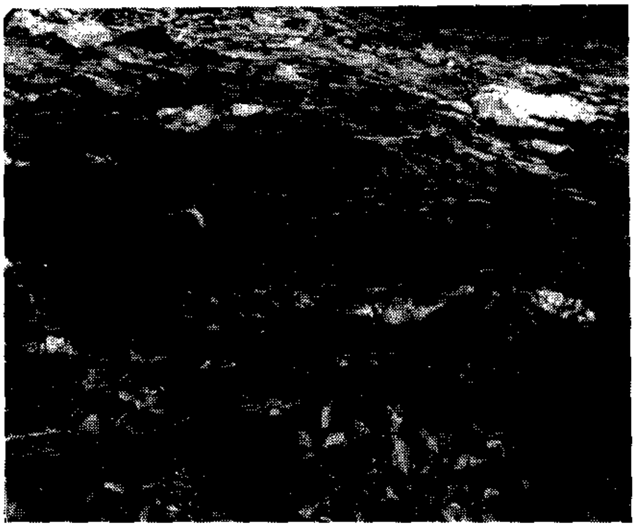

Photo 4. Deformed quartz fragments (possible clasts?) in argillite of the Mount Nelson Formation (PST94-296).

15% of the poorly exposed section. Rarely, a primary fabric consisting of tightly packed, rounded, blue quartz granules, is preserved. These are best preserved near the top of the Priest River canyon, 3 kilometres northwest of Boundary Lake. Less commonly, zones with numerous, large mudchips which are highly strained are present within the quartzite units. In the southernmost exposures just west of the Priest River canyon, quartzite is interbedded with buff dolomite.

Rare lenses of laminated, brown-weathering, silty dolomite up to several metres thick also occur within the Mount Nelson argillite. The continuity of the dolomites is difficult to determine compared to the quartzites, because they weather recessively. Several thicker dolomite units crop out in the southwest corner of the map area, truncated to the north by the unconformity at the base of the Toby Formation.

CORRELATION

Stratigraphic analysis completed around North Star Mountain strongly supports the correlation with the Deer Trail Group, which includes the Magnesite Belt of northeastern Washington (*see* Miller and Whipple, 1989) as first proposed by Glover (1978; Figure 5). The correlations would be: Kitchener argillite (Pk2) with the black and grey, clay and silt couplets of the Togo Formation; the lower Dutch Creek carbonate (Pdc1) with Edna Dolomites; argillite of the Dutch Creek Formation (Pdc2) with McHale Slate; Dutch Creek upper carbonate (Pdc3) with Stensgar Dolomite. Magnesite deposits are associated with the Stensgar Dolomite, and although the magnesite is remobilized, it is considered to be primary and associated with evaporitic facies (F.K. Miller, personal communication, 1994). In the northern part of the Purcell anticlinorium, the Mount Nelson Formation hosts the Brisco magnesite deposit (McCammon, 1965; Root, 1987).

The laminated unit resembles the Van Creek Formation of the eastern Purcell Supergroup as defined by McMechan *et al.* (1980) but, as mapped in the Creston area, it lies higher in the regional stratigraphy, above the Dutch Creek lower carbonate.

The Mount Nelson argillite and quartzite unit (Pmn), as mapped by Rice (1941) and Glover (1978), may correlate with the Buffalo Hump Formation, part of the Deer Trail Group of northeastern Washington. The correlation is based on the unusually coarse, quartz-rich sandstone and stratigraphic position within argillite and above a carbonate unit. Immediately south of the 49th Parallel, quartz-pebble sandstones within argillite west of the Continental Mountain pluton in northern Idaho have recently been included in the Buffalo Hump Formation (F.K. Miller, personal communication, 1994). Farther south, Buffalo Hump quartzite cuts down into the Stensgar Dolomite, implying an unconformity between the two units, perhaps analogous to the unconformity documented by Root (1987) at the base of the Mount Nelson. Late Proterozoic detrital zircon dates (circa 1.1 Ga) from the Buffalo Hump Formation, southeast of Colville (Figure 2), support a post-Purcell (Belt) Supergroup age of deposition (Ross *et al.* 1992). The quartzitic part of the Buffalo Hump Formation maybe the distal equivalent of the Phillips Formation (D. Winston, personal communication, 1994).

UPPER PROTEROZOIC WINDERMERE SUPERGROUP

PEBBLY ARGILLITE UNIT

A pebbly argillite unit, mapped this season, may represent a dropstone unit at the base of the Windermere Supergroup. This pyritic (1 to 5%), dark rusty brown weathering argillite lies above a Mount Nelson Formation carbonate horizon. The laminated argillite is distinguished from those in the Mount Nelson Formation by a marked increase in sulphide content, less penetrative fabric and presence of abundant pebbles. The isolated pebbles are supported in a black silty argillite matrix (Photo 5) and are interpreted to be ice-rafted dropstones. Pebbles of quartzite and dolomite predominate. Clast size and abundance increase up-section and the pebbly argillite apparently grades into polymictic conglomerate of the Toby Formation. The unit is exposed 4 kilometres southwest of the confluence of Summit and Maryland creeks, in more highly strained exposures on Highway 3, and along Placer Creek road at about the 1340-metre elevation. The unit appears to thin to the northeast. The argillite unit warrants careful study and better delineation.

The dropstone unit is tentatively correlated with basal Windermere Supergroup because of the inferred glacial environment at the time of deposition and its possible gradational contact with the Toby Formation.

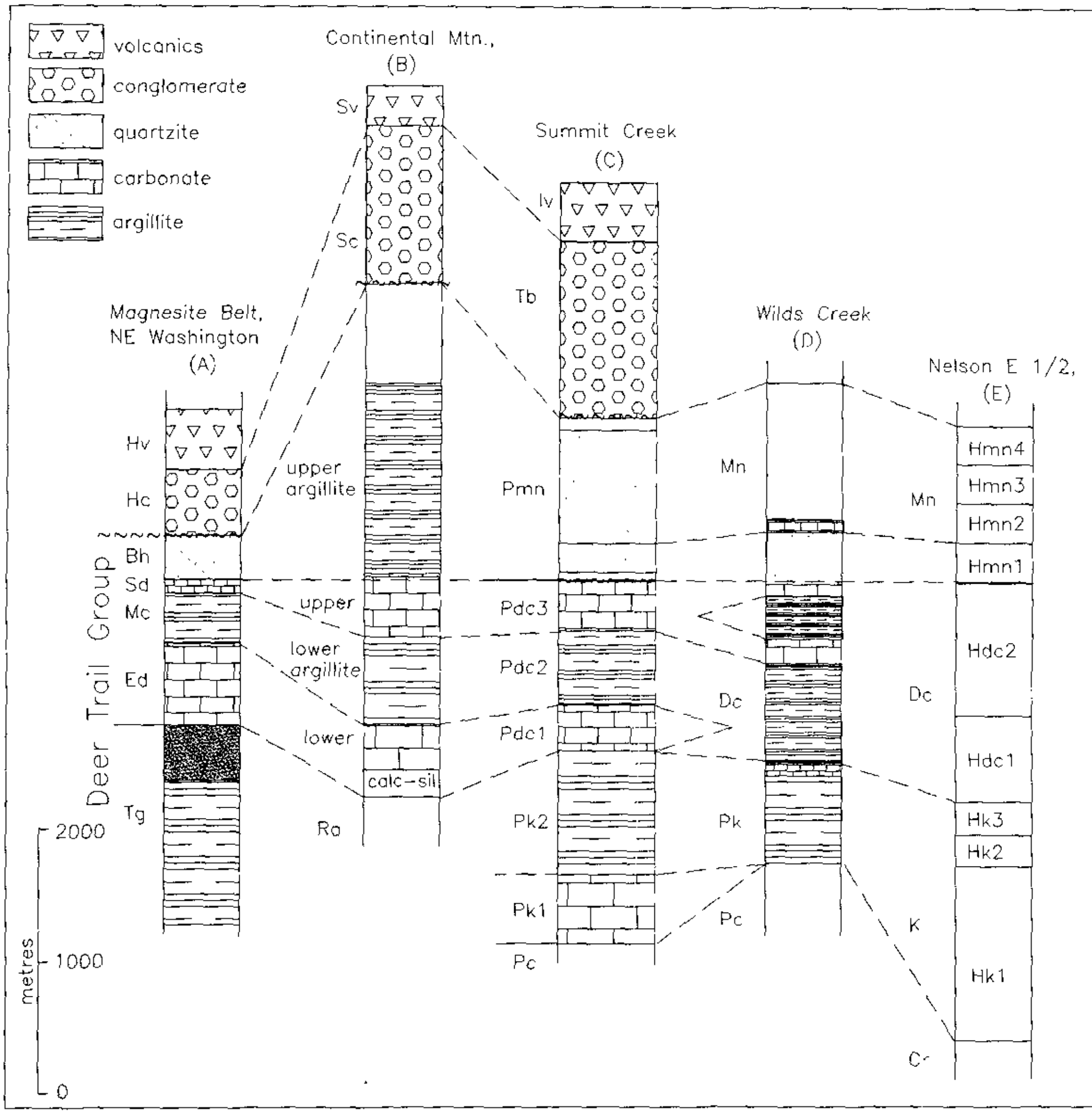

Figure 5. Comparison of schematic stratigraphic columns and potential correlations using the base of the Buffalo Hump Formation and possible correlatives as the datum. Columns A to C are correlated with reasonable confidence, however, comparisons of C to E remain speculative. Column references: (A) Miller and Whipple (1989), (B) Miller (1982; nomenclature has been revised since publication, therefore, it is not included here), (C) Glover (1978) and this report, (D) this report, (E) Reesor (1983). Abbreviations: Bh = Buffalo Hump Formation, Cr = Creston Formation, Dc = Dutch Creek Formation, Mn = Mount Nelson Formation, Ed = Edna Dolomite, Hc = Huckleberry conglomerate, Hv = Huckleberry volcanics, K = Kitchener Formation, Iv = Irene Formation, Mc = McHale Slate, Sc = Shedroof conglomerate, Sd = Stensgar Dolomite, Sc = Shedroof volcanics, Tb = Toby Formation, Tg = Togo Formation.

TOBY FORMATION

The Toby Formation comprises a syn-rift succession (Bennett, 1985) of diverse lithologies, including diamictites, polymictic conglomerate, pelite, carbonate, volcanic rocks, quartz sandstone and phyllite. It reaches a thickness of about 2050 metres along the U.S. border in the Creston map area (Glover, 1978, p. 27), although, it could be as much as 4 kilometres thick based on its map distribution. It thins rapidly to the north and south.

Toby Formation has been studied in detail along the length of the Cordillera by numerous workers and was briefly examined in this mapping project. Variably strained, polymictic conglomerate, pebble greywacke and sandstone dominate well exposed outcrops along Highway 3. Clasts are predominantly light grey to white quartzite and brown-weathering carbonate (mainly dolomite) with subordinate white quartz (vein material?) and phyllitic argillite. White quartzite clasts are up to about 1 metre long, but average between 10 and 20

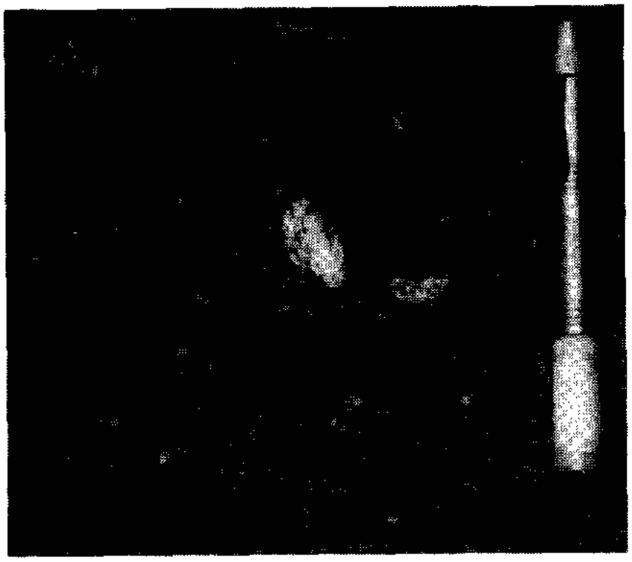

Photo 5. Quartzite pebble (possible dropstone?) in black argillite unit, interpreted to be basal Toby Formation (DBR94-236). Glacial striations are evident on the surface.

centimetres, though most are strongly flattened. Rare, large rounded clasts of granite and granitic gneiss (up to 60 by 60 cm) were observed towards the base of the Toby conglomerate, 10 kilometres south of Highway 3; granitic clasts were also noted west of the headwaters of the Priest River by Daly (1912). Most of the formation is well foliated and clasts are variably flattened (strain analysis was completed by Glover, 1978), but relict bedding is still evident from concentrations of clasts of similar sizes, and by colour differences related to changes in grain size of the matrix. Locally, the conglomerate has been reduced to a chlorite-sericite schist with faint ellipsoidal outlines of completely flattened clasts. These bands of intense deformation are probably shear zones.

Correlation

Daly (1912, p. 142) used the term "Irene Conglomerate Formation", and later Rice (1941) correlated it with the Toby Formation. To the south, the same unit is called the Shedroof conglomerate where it is up to 3250 metres thick in the Continental Mountain map area (Miller, 1982, p. 18). A thin sequence of Shedroof conglomerate and Leola volcanics also lies farther east, in the footwall of the northern extension of the Jumpoff Joe fault, 15 kilometres east of Sullivan Lake, Washington (Stoffel *et al.*, 1991). These conglomerates also correlate with the Huckleberry Formation (conglomerate member) of northeastern Washington.

Paleoenvironment

The depositional setting for the Toby conglomerate remains controversial. The glacial marine origin was proposed by Aalto (1971) and a nonglacial origin was suggested by Reesor (1973). Striated clasts have been reported between Invermere and Panorama which would support the glacial origin (G.M. Ross, personal communication, 1994). A combination of glacial and nonglacial deposition would accommodate the opposing views.

IRENE FORMATION

The Irene Formation comprises mafic volcanic rocks that gradationally overlie the Toby Formation along the western edge of the map area. The submarine tholeiitic flows (Bennett, 1985) locally display well developed pillows. The succession, at least 2000 metres thick, is schematically illustrated in Figure 6. Dark green massive flows and pillow basalt are common, with lesser mafic tuff and tuff breccia. Some of the pillows are unstrained and unaltered with chilled margins, chloritic selvages and minor intrapillow micrite (Photo 6). The closely packed pillows vary in size from 5 centimetres to 2 metres long and range in shape from circular to oblong. Chloritic fracture cleavage and epidote, iron carbonate, albite alteration patches are commonly developed. Subordinate lithic lapilli tuffs with pitted weathered surfaces, contain mafic fragments up to 20 centimetres long. Hyloclastite forms a minor component of the succession. Dolomite and dolomitic siltstone form two prominent units, each less than 20 metres thick, approximately 900 and 1800 metres above the base of the succession, immediately west of Mount Irene (Figure 6). Pale green tuff beds occur within the dolomites.

North of Highway 3, the bottom third of the Irene Formation consists of basaltic fragmental rocks, mainly breccia. Basaltic pebbles and cobbles are supported in a dark matrix with angular lithic fragments. The top two-thirds of the section consists mainly of pillow lava with some breccia and minor hyaloclastite. Several thin, aphanitic mafic sills and dikes were observed throughout the section. These are probably synvolcanic.

Age and Correlation

The Irene Formation correlates with the Leola Volcanics south of the border as described by Miller (1982) and the Huckleberry Formation (greenstone member) in northeast Washington, dated at about 762±44 Ma by the Sm-Nd isochron method (Devlin *et al.*, 1989).

Upper Conglomerate

The top of the Irene Formation is marked by a cobble to boulder conglomerate unit, 100 metres thick, exposed 3 kilometres west of Mount Irene (Photo 7). It can be traced northward from the border to Highway 3, where it crops out 28.3 kilometres west of the Summit Creek bridge, underneath the hydro transmission lines (Daly, 1912, p. 144; Glover, 1978). According to Daly (1912, p. 147) the dolomite clasts are locally oolitic and the largest angular clast measures 2.1 metres by 1.2 metres by 1 metre. Clasts are dominantly dolomite with lesser

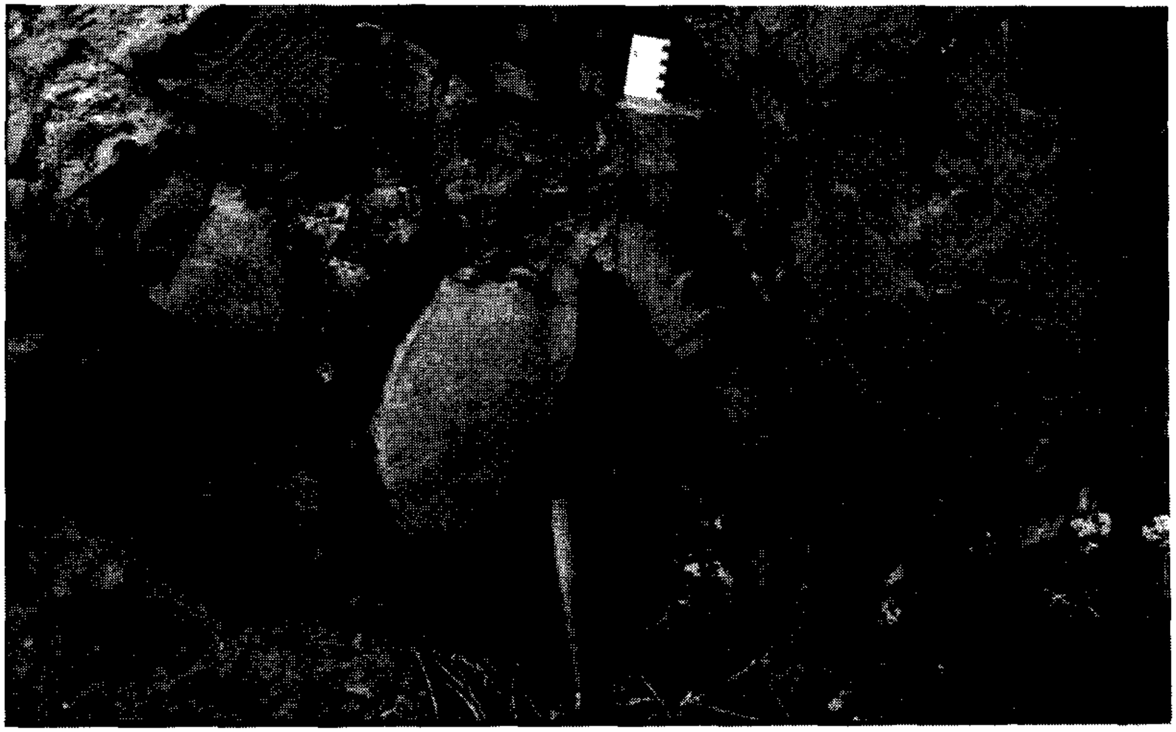

Photo 6. Well developed, unstrained pillow basalts of the Irene Formation (DBR94-564).

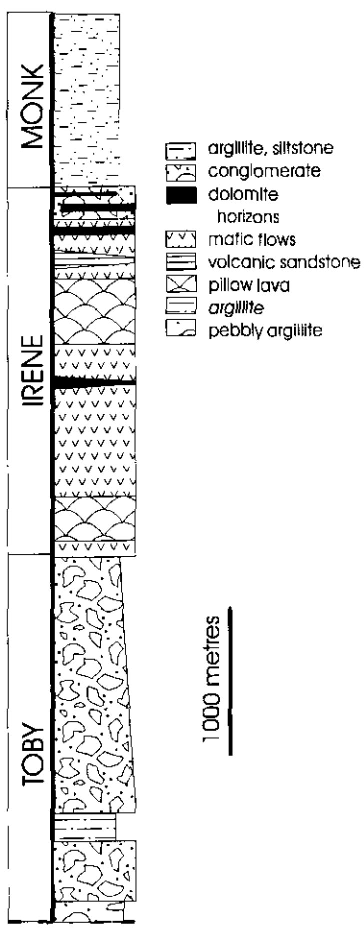

Figure 6. Composite schematic stratigraphic column of the Toby and Irene formations based on exposures along the unnamed ridge west of Mount Irene and near Highway 3.

rounded quartzite and rare brecciated dolomite, supported within a mauve to grey argillaceous matrix. No volcanic clasts were observed. Along Highway 3, the conglomerate unit comprises a 75-metre sequence of green pebbly wacke, pure dolomite, dolomite conglomerate, polymictic conglomerate cut by post-flattening granitic dikes, white limestone and capped with a quartz pebbly conglomerate. The conglomerate is overlain by the Monk Formation.

The provenance of the clasts is assumed to be cannibalistic erosion of the syn-Irene dolomite horizons, however, the apparent lack of any volcanic material, and a source for the quartzite, are problematic. Alternatively, the clasts may be derived from uplifted blocks of Mount Nelson and Dutch Creek strata. Additional study of clast compositions and size variations is required.

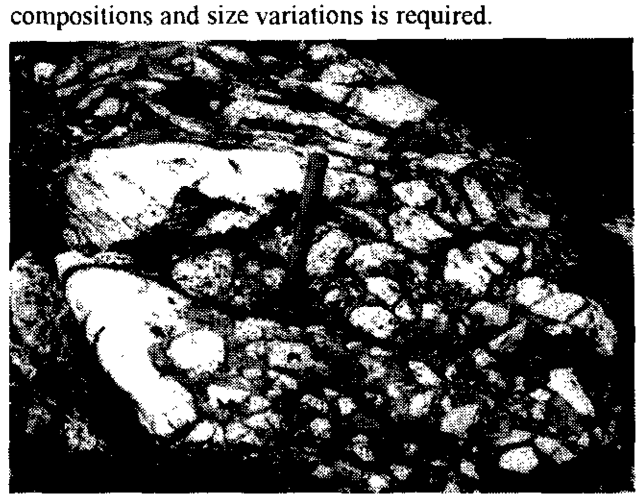

Photo 7. Matrix-supported dolomite conglomerate within the upper part of the Irene Formation (DBR94-561).

MONK FORMATION

The Monk Formation rests conformably on the Irene Formation and was examined briefly between Highway 3 and the southern contact of the Mine stock. Here it consists of fine-grained muscovite schist. Coarser muscovite-biotite schists with andalusite (and/or chloritoid?) porphyroblasts produce a spotted appearance. Towards the top of the observed section are thin-bedded quartz siltstone and sandstone couplets with rare granule-sized quartz grains. This may represent a gradual transition into the overlying grits of the Three Sisters Formation.

INTRUSIVE ROCKS

Proterozoic mafic sills and dikes are common in the middle Aldridge Formation and strata of the upper Purcell Supergroup. Younger plutonic rocks underlie the northwest half and part of the southern edge of the Creston map area. The middle Jurassic and Early Cretaceous plutons in the northwest corner were not examined during this project but have been studied by Archibald *et al.* (1983, 1984).

MOYIE SILLS – AMPHIBOLITE

A few of the dark green to black amphibolite layers discernible at 1:50 000 scale within the metamorphosed middle Aldridge Formation are depicted on Figure 4. The fine to medium-grained amphibole-rich rocks are interpreted to be metamorphosed Moyie sills as suggested by Daly (1912) and others. The amphibolites contain the mineral assemblage hornblende, plagioclase, quartz and staurolite. The amphibolite is commonly dotted with prominent pink garnet porphyroblasts. Due to ductile deformation west of the Creston valley, the sills are not as extensive or continuous as those to the east. East of the valley, thick sills near the town of Creston are cut by a network of quartz and quartz-carbonate veins that parallel and crosscut the chloritic foliation. These sills are continuous and display less ductile deformation.

MAFIC SILLS AND DIKES – NORTH STAR MOUNTAIN AREA

A series of mafic sills and dikes intrude upper Purcell Supergroup strata (Creston to Mount Nelson formations) near North Star Mountain, from the U.S. border northward to Highway 3. The narrow (15 cm to 5 m thick) black to dark green tabular bodies commonly parallel bedding and are therefore called sills, but locally they are discordant dikes. Some sills are magnetite rich and presumably produce the broad, moderate 1:250 000-scale aeromagnetic anomaly over the area. The sills comprise less than 5% of the section. Locally they contain rounded xenoliths of granitic gneiss.

As the mafic sills and dikes were emplaced into strata as young as Mount Nelson Formation, they may represent a magmatic event synchronous with Mount Nelson deposition or, more probably, they are feeders to the volcanic rocks of the Irene Formation.

MIDDLE JURASSIC – CONTINENTAL MOUNTAIN PLUTON

A biotite tonalite pluton is well exposed along the International Boundary cut southwest of Boundary Lake. The massive medium-grained tonalite forms the northern termination of the Continental Mountain pluton of Miller (1982). The tonalite contains ubiquitous epidote and trace hornblende (*ibid.*). Muscovite is common and may be a product of regional metamorphism that has affected the pluton (F.K. Miller, personal communication, 1994).

The age of emplacement of the pluton is interpreted to be at least 168 Ma, based on a titanite date and discordant zircon U-Pb data (J.L. Wooden, personal communication, 1994). The pluton yielded a biotite K-Ar date of 107 Ma (Miller and Engels 1975) and a trondhjemite phase on the east side of Continental Mountain produced biotite and muscovite K-Ar dates of 101 and 96 Ma (*ibid.*). These Cretaceous conventional K-Ar dates are interpreted to be cooling ages.

CRETACEOUS PLUTONS

Cretaceous intrusive rocks can be divided into large plutons (Bayonne batholith) and small sheet-like bodies (Corn Creek and West Creston gneisses). They are apparently coeval but contrast in mineralogy, tectonic fabric and size. The Bayonne batholith produces conspicuous donut-shaped aeromagnetic anomalies probably due to a mafic border phase.

BAYONNE BATHOLITH

The Bayonne batholith comprises at least three distinct plutons, Mount Skelly, Steeple Mountain and Shaw Creek (Daly, 1912, p. 289-296, Rice, 1941; Glover, 1978; Archibald *et al.*, 1983, 1984; Reesor, 1993). A two-mica granite called the Kootenay Landing granite by Barrett (1982) may correlate with part of the Steeple Mountain pluton. A small outlier south of the Mount Skelly pluton, here called the Duck Lake intrusion, was mapped immediately west of the lower reaches of Wilds Creek. This stock, 500 metres wide and 1500 metres long, comprises pale grey to white-weathering, massive, medium-grained hornblende biotite granite. Accessory minerals include trace amounts of honey-coloured titanite. Regional aeromagnetic data show that anomalously high values extend southward from the Bayonne batholith under the entire area, suggesting the Duck Lake intrusion is an offshoot of the Mount Skelly pluton.

The **Shaw Creek pluton** is light grey, massive biotite granite with potassium feldspar phenocrysts up to 2 centimetres long. A biotite-rich (>40% biotite) melanocratic phase of limited extent is locally foliated and contains biotite-rich granitic autoliths. Metasedimentary xenoliths are also exposed along Topaz Creek road. This phase is boudinaged then cut by muscovite-biotite-quartz-feldspar pegmatite.

Contacts of the Duck Lake intrusion are exposed on Highway 3A near Drywash Creek where fine-grained chlorite-biotite hornfels is well developed in meta-arenite and calcsilicate assemblages (epidote-chlorite-tremolite-diopside) of the Mount Nelson Formation. Dikes and sills extend into the host strata and there is no evidence of deformation along the intrusive contacts. This contrasts with the relationship of the Shaw Creek pluton to the west, across the Kootenay valley, where coarse mineral growth and penetrative deformation are evident.

The eastern contact of the Shaw Creek phase consists of rusty brown weathering, coarse-grained biotite-muscovite schist mixed with foliated granite (lit-par-lit gneiss) along the logging road 2.5 kilometres north of the Summit Creek bridge on Highway 3. Pods and lenses of quartz-feldspar-muscovite±biotite are interlayered with paragneiss (semipelite schist). The penetrative foliation dips moderately to the west, parallel to the intrusive contact. However, 200 metres northwest of the contact zone, the fabric is lost and the pluton comprises massive medium-grained, potassium feldspar megacrystic granite. The massive granite has been sampled for U-Pb dating and analyses are in progress. The southern contact of the Shaw Creek pluton is a heterogeneous zone of mixed granite sills and metasedimentary rocks (biotite schist), exposed along Topaz Creek road. In general, granite contacts parallel the phyllosilicate foliation.

PRIEST RIVER COMPLEX

The northern culmination of the Priest River Complex is represented by the Rykert batholith and two isolated gneissic bodies along the southern edge of the Creston map area (Figures 2 and 4).

RYKERT BATHOLITH

The Rykert batholith was named by Daly (1912, p. 284-287) and underlies about 27 square kilometres inside Canada, extending from the Creston valley 15 kilometres to the west. It has been referred to as Kaniksu batholith by Park and Cannon (1943), but it is recommended that this name be dropped because Kanisku Mountain actually lies farther west and is underlain by the Jurassic Continental Mountain pluton.

The light to dark grey weathering, biotite-rich granite is medium grained with coarse-grained layers rich in potassium feldspar megacrysts (some up to 7 cm long and well zoned). It is massive to variably foliated, commonly with dark grey mylonitic layers or gneissic layering. The two-mica granite is heterogeneous with a muscovite to biotite ratio of about 2:5 south of the border (Miller, 1983), although biotite and potassium feldspar contents vary greatly. Hornblende diorite xenoliths are rare. A homogeneous biotite granodiorite with no muscovite or garnet intrudes the two-mica phase of the Rykert batholith, 2.75 kilometres south of Mount Huscroft near Boundary Creek. The northwest edge of the pluton is a thick zone (>100 metres) of gneissic granite. The northeastern part of the batholith produces a strong, rectangular 1:250 000-scale aeromagnetic anomaly that extends to the northwest.

Age and Correlation

Correlative rocks south of the U.S. border include the Rykert granite and Shorty Peak pluton, that include porphyroblastic granitic gneiss (unit "gn"; Miller, 1983). The Newman Lake gneiss, biotite potassium feldspar megacrystic orthogneiss, dated at about 94 Ma (Armstrong *et al.*, 1987; Bickford *et al.*, 1985) may be equivalent to the Rykert batholith.

CORN CREEK GNEISS AND WEST CRESTON GNEISS

Two isolated granite gneiss bodies, the Corn Creek and West Creston, crop out west of the Creston valley and north of the Rykert batholith. The Corn Creek body was first recognized by Rice (1941), and later named the Corn Creek gneiss by Archibald *et al.* (1983). The West Creston gneiss is exposed 6 kilometres to the southwest, in the footwall of the Purcell Trench fault (Figure 4). Both gneisses are characterized by consistent gentle, north-dipping mylonitic foliations containing gently north-plunging stretching lineations. The granite orthogneisses comprise a series of sheet-like bodies (Photo 8) that may be part of a continuous north-dipping

Photo 8. Gneissic granite characteristic of the West Creston gneiss (DBR94-422). Pack for scale.

sheet extending north from Mount Rykert; the Corn Creek and West Creston gneisses and Rykert batholith may be linked at shallow depth below the surface.

Both bodies are pale grey weathering, two-mica granites with prominent gneissic layering. The leucocratic granite contains smoky quartz, garnet, muscovite and biotite. Narrow, lighter grey aplite and pegmatite dikes, layers and pods are abundant, cutting obliquely across the gneissic foliation. Biotite content of gneissic layers ranges from 0 to 25%. The Corn Creek gneiss covers less than 4 square kilometres and consists of at least three sheet-like bodies, exposed along the pipeline access road south of Corn Creek. Semi-concordant coarse-grained pegmatite (garnet, muscovite, potassium feldspar, plagioclase, quartz) layers and pods are isoclinally folded within the granite.

The West Creston gneiss underlies an area of less than 2 square kilometres along the western edge of the Creston valley (Photo 8). Its concordant contacts with the middle Aldridge Formation suggest. like the Corn Creek gneiss, is has a sill-like geometry, except for a band 300 metres wide that extends southward to the Rykert batholith. The northeastern contact zone with Aldridge Formation comprises about 15% pegmatite and abundant white quartz pods and layers. These rocks probably experienced partial melting.

Age and Correlation

Zircon and monazite U-Pb dating is in progress on samples from both gneisses, by Don Davis at the Royal Ontario Museum. A pluton in the Smith Creek area, south of Boundary Creek, correlative with part of the Corn Creek gneiss yielded a Cretaceous U-Pb date (J.L. Wooden, personal communication, 1994). Farther south, the Mount Spokane two-mica granite yielded dates between 72 and 92 Ma (Armstrong *et al.*, 1987) and 94 to 143 Ma (Bickford *et al.*, 1985) and may also correlate with Corn Creek gneiss. Conventional K-Ar techniques yield cooling or uplift dates ranging from 46.7 to 49.6 Ma (Archibald *et al.*, 1984). Similar concordant muscovite and biotite K-Ar dates between 50 and 55 Ma were obtained by Miller and Engels (1975). Correlative rocks south of the border are monzogranite of the Shorty Peak pluton and unit "gn" of Miller (1983).

Lit-par-lit gneiss unit

The border of the West Creston gneiss and Corn Creek gneiss is characterized by a zone of metasedimentary rocks (Aldridge Formation) intruded by a series of granitic sills (Figure 4). Amphibolite sills in the polydeformed areas are metamorphosed equivalents of the gabbro (Moyie) sills. The best exposures underlie the south-facing slope on the north side of Corn Creek. A series of at least five sills, comprising about 20% of the unit, forms prominent light grey weathering layers within the dark grey metasedimentary rocks. The two-mica, potassium feldspar megacrystic granite sills range from 0.5 to 20 metres thick, but average about 3 metres, and thin and thicken rapidly because they are boudinaged. The remainder of the section, meta-semipelites, is amphibolite grade and consists of plagioclase-muscovite-biotite-quartz schist (paragneiss locally). The same unit was mapped as "mixed rock" to the south by Miller (1983). This is the border zone of the Priest River Complex batholithic core. There is no fault at the contact between batholith and cover rocks in this area, in contrast to the southern Priest River Complex.

STRUCTURE

The following discussion of structural features in the Creston map area is divided into geographic areas that grossly correspond to structural domains. In the simplest terms there is an increase in metamorphic grade and intensity of deformation to the west, however, in detail things are more complicated. Penetrative phyllitic fabrics, local tight folding and overturned folds contrast with the broad, upright anticlinoria like the Goat River anticline and lack of fabrics in the Yahk map area (Brown and Stinson, 1995, this volume).

EAST OF PURCELL TRENCH FAULT

The southeast corner of the map area is largely covered by Quaternary deposits in the Creston valley, but isolated knolls expose the westernmost limb of the Goat River anticline and variably foliated middle Aldridge and Moyie sills southeast of the Okell fault (area 1 on Figure 7).

OKELL FAULT

The **Okell fault** is interpreted to be a major north-northwest-dipping, east-directed contractional fault that places middle Aldridge on Creston and upper Aldridge formations in the Yahk map area (*ibid.*). In addition, tight upright folds and pervasive cleavage are developed in wacke of the middle Aldridge Formation in its hangingwall (Photo 9). Folds with similar north-northwest-trending axes persist farther to the northwest. The Okell fault marks the boundary between less deformed, broad folds to the east, from phyllitic to sub-phyllitic tightly folded strata. The fault is presumed to be the southern extension of the Hall Lake/St. Mary fault system (see Reesor, 1981). To the south it is covered by thick Quaternary deposits in the Creston valley.

Farther north, a northeast-striking normal fault is required because of the truncation of a thick Moyie sill, and juxtaposition of middle Aldridge Formation against Creston Formation. This is named the **Wyndel fault**, although, it was not observed in outcrop. Northwest of the fault, the **Wilds Creek area** forms a homoclinal succession from Creston Formation to Mount Nelson Formation. Bedding and penetrative phyllitic chlorite-sericite foliations strike north-northwest and dip steeply

Photo 9. Tight folds with prominent fracture cleavage, 6 kilometres north of Creston along Lakeview road (DBR94-340). Outcrop is about 2 metres wide.

Photo 10. Photomicrograph of the metamorphic assemblage kyanite (ky), staurolite (st), sillimanite (sl), muscovite (mu) and biotite (bi) developed in semipelitic schist of the middle Aldridge Formation, indicating bathozone 4 (PST94-6). Photo is 2.0 millimetres wide.

to the east and locally to the west. The southeast dips and apparent northwest facing direction suggest the stratigraphic succession is overturned. Much of the structural style is controlled by competency contrasts of the different lithologies; tight chevron folds are abundant in the sericitic phyllite unit (see photos in Brown and Klewchuk, 1995, this volume). Folded, white bull quartz veins and pods are abundant in drill core, some form centimetre-scale fish-hook shapes. The mineralized carbonate is phyllitic but the enclosed carbonate breccia displays no tectonic fabric, perhaps due to local flow of the carbonate unit along its contact with other units.

PURCELL TRENCH FAULT

A brittle, high-level fault zone, consisting of lensoidal blocks of middle Aldridge Formation, surrounded by sheared, slickensided surfaces, is exposed 1.75 kilometres south of the Summit Creek bridge along Highway 3. Outcrops to the east are low-grade metawacke with fine phyllosilicate minerals defining a weak foliation. To the west, rocks are polydeformed with the assemblage kyanite, sillimanite, staurolite, muscovite, biotite, magnesium-rich chlorite, which indicates metamorphism in bathozone 4 (Figure 8; Tables 1 and 2; Photo 10; sample PST94-6). This is interpreted to be a major fault zone that juxtaposes high and low-grade Aldridge Formation and probably represents a splay of the Purcell Trench fault (Figure 4).

Minor northwest-striking, moderate northeast-dipping normal faults cut the Shaw Creek granite along the Topaz Creek road at about 1300 metres elevation. The granite is fractured across a zone 2 metres wide and is clay altered and limonitic weathering. These faults may also be part of the Purcell Trench system, a major geomorphic feature that extends from Coeur d'Alene, Idaho about 650 kilometres northward to the Rocky Mountain Trench (LeClair, 1982). Much of the lineament corresponds to the trace of a major fault (Rice, 1941; Miller, 1982; LeClair, 1982). Mylonite zones and brittle faults in the Steeple Mountain pluton are also probably part of the Purcell Trench fault system (Barrett, 1982).

WEST OF PURCELL TRENCH FAULT

The region west of the Purcell Trench fault is divided into five areas: the Mount Rykert overturned block, Summit Creek, headwaters of Corn Creek, North Star Mountain, and northern Priest River complex (Figure 7).

MOUNT RYKERT OVERTURNED BLOCK

A huge (kilometre scale), overturned limb of low metamorphic grade Aldridge and Creston formations underlies Mount Rykert west of Creston. This panel is traceable to the Purcell Trench fault on the east and is bounded by another fault on the west. The southern margin is probably a faulted contact with the Rykert pluton. The structure is defined by bedding-cleavage relationships, and inverted stratigraphy based on graded bedding, and Creston and upper Aldridge below middle Aldridge Formation. Additional evidence comes from middle Aldridge Formation marker laminates that are in reverse order in this block (D. Anderson, personal communication, 1995). Isoclinal folds and transposed bedding of argillite in the upper Aldridge Formation may be related to the fold structure. The inverted limb may be part of a family of west-directed structures as discussed by Fillipone and Yin (1994) in the Cabinet Mountains, for example the Snowshoe thrust system. The trace of the bounding fault to the west is poorly defined and it is not possible to say whether the Corn Creek gneiss plugs the fault or rides on it (Figure 4).

SUMMIT CREEK AREA

Polydeformed, amphibolite-grade middle Aldridge strata underlie a wide area along the lower reaches of Summit Creek and near the confluence of Corn and Buckworth creeks. Here, biotite-muscovite schist containing rare kyanite and staurolite has abundant deformed pegmatite pods and layers, and rare amphibolite (metamorphosed Moyie sills). Mesoscopic isoclinal folds with angular to rounded closures have axial planar (S_1) foliation that is refolded by at least one younger deformation, suggesting significant structural thickening in the area. The complex folding and interference patterns require additional mapping to resolve, and this would be difficult because of the lack of marker units other than rare Moyie sills. Multiphase pegmatite emplacement is suggested by different geometries and relationships to hostrocks. Most are concordant to bedding and foliation, some are infolded and boudinaged with the metasedimentary rocks, and some are massive.

The Blazed Creek fault was shown as a steeply dipping, north-striking fault cutting across the Summit Creek area with Creston Formation on the west and Aldridge Formation on the east by Rice (1941). The fault was interpreted by Glover (1978, p. 8) to be the probable southern extension of the St. Mary fault and was considered to be regionally significant, especially after being included on the tectonic assemblage map of the Cordillera (Wheeler and McFeely, 1991). However, our mapping has found no structural or stratigraphical evidence for the fault. Strata previously considered Creston Formation (Rice, 1941) are now thought to be metamorphosed Aldridge Formation. This conclusion is consistent with K-Ar dating which shows no sharp discontinuity in cooling ages across this area (*cf.* Archibald *et al.*, 1984).

The Buckworth fault is indicated by the juxtaposition of Creston Formation against Aldridge Formation north of Highway 3, as originally mapped by Rice (1941). However, Rice interpreted the fault to bend to the southeast at Creston Mountain. We believe that it trends to the southwest, based on the abrupt termination of a regional aeromagnetic anomaly northwest of Mount Rykert.

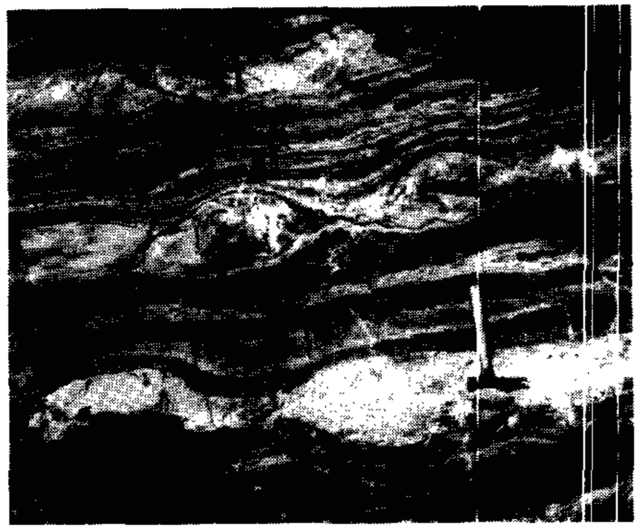

Photo 11. Boudinaged metasedimentary rock layers in high-grade rocks along the southern margin of the Shaw Creek pluton, 2 kilometres south of Mount Midgeley (DBR94-365).

Intense ductile deformation, including boudinage of metasedimentary rocks, is prominent adjacent to the Shaw Creek pluton, north of Highway 3 (Photo 11).

HEADWATERS OF CORN CREEK

An inferred north-trending fault lies immediately west of a series of parallel, north-trending, upright antiform-synform pairs (about 100 m wavelengths) that are developed in the Aldridge Formation at the headwaters of Corn Creek. If the fault is east dipping, then the folds may be in the hangingwall of the west-directed structure. The fault places Aldridge Formation on the overturned upper Purcell stratigraphy in the Maryland Creek/North Star Mountain area

NORTH STAR MOUNTAIN AREA

The North Star Mountain area comprises a homoclinal succession of overturned, steeply east-dipping, upper Purcell and Windermere rocks. The area is characterized by strongly cleaved to phyllitic argillite units with flattened clasts in the Toby Formation conglomerate (Glover, 1978). Fold closures were rarely observed, but centimetre-scale isoclines were noted in sericitic phyllite of the Kitchener argillite unit (Pk2).

NORTHERN PRIEST RIVER COMPLEX

Prominent mylonitic foliations and stretching lineations (L-S tectonites) characterize the northern flanks of the Corn Creek and West Creston gneisses, and Rykert pluton. The foliation planes comprise muscovite and biotite with quartz ribbons that define consistent north-plunging stretching lineations. Sheath folds are exposed in an outcrop along the pipeline near Corn Creek (Photo 12). Axial planes are parallel to the mylonitic foliation and fold axes are collinear to the stretching lineations. The folds occur in a layer of gneiss about 1 metre thick with coarse, potassium feldspar megacrystic granite above and below.

Mylonitic fabrics are also present in the metasedimentary rocks adjacent to the Rykert batholith, but are more difficult to recognize due to their finer grain size and more homogeneous texture when compared to granitic intrusions. This strain is part of the northern termination of the Priest River Complex, an Eocene extensional complex that is well developed to the south.

BRECCIA-MICROBRECCIA ZONES

A series of at least four oriented and aligned, isolated exposures of green to brown-weathering brecciated granite are interpreted to be cataclasite. They trend east and cut the northern margin of the Rykert batholith for a strike length of at least 5 kilometres (Figure 4). The waxy green, altered granite consists of fine to aphanitic chlorite-sericite-clay minerals with anastamosing fractures and as pervasive replacement of the host. The rough-weathering brecciated granite is fractured but remains coherent. Some of the zones have brittle fractures and limonitic staining. The cataclasite is a soft and friable recessive unit only exposed along road cuts. The widest zone is estimated to be about 100 metres across.

The chlorite breccia zones are interpreted to be down-to-the-north, brittle fault zones superimposed on the earlier ductile mylonitic fabrics. These zones are similar to chlorite microbreccia zones documented by Harms and Price (1992) and Rehrig *et al.* (1987), and could be part of the same extension episode.

METAMORPHISM

The distribution of metamorphic rocks and the metamorphic history are complex west of the Purcell Trench. The following preliminary observations are offered to stimulate further studies in the area.

CONTRAST OF METAMORPHIC GRADE ACROSS PURCELL TRENCH FAULT

In general, there is a pronounced increase in metamorphic grade across the Purcell Trench fault at several latitudes in the map area. Along the U.S. border, phyllitic metawacke of the Aldridge Formation is greenschist grade at the Rykerts border crossing, however, 4.5 kilometres to the west, middle Aldridge Formation is in the amphibolite facies (sillimanite, muscovite, biotite) near Boundary Creek. Fifteen kilometres to the north, the same contrast is noted along Highway 3 between the roadcut at Creston and the first outcrop west of the Creston valley. Here, a strand of the Purcell Trench fault juxtaposes sillimanite-kyanite-staurolite-muscovite-bearing semi-pelitic rocks (bathozone 4) against phyllitic semipelites to the east. A comparison of contact metamorphic effects across the northern edge of the map area reveals a similar contrast in metamorphic grade. The Skelly pluton and Duck Lake intrusion have narrow thermal aureoles with fine-grained biotite hornfels on the east side of the Purcell Trench, whereas the Shaw Creek pluton west of the trench has transformed the country rock into coarse-grained biotite schist with lit-par-lit injections extending at least 750 metres from the intrusive contacts.

The psammitic composition of the Aldridge Formation restricts the development of aluminosilicate minerals to relatively few localities. However, a preliminary study completed during the 1994 field season has been able to bracket the conditions of metamorphism and to delineate several regions of contrasting metamorphic grade which correlate with structural

Photo 12. Sheath fold in Corn Creek gneiss, view to south (DBR94-547).

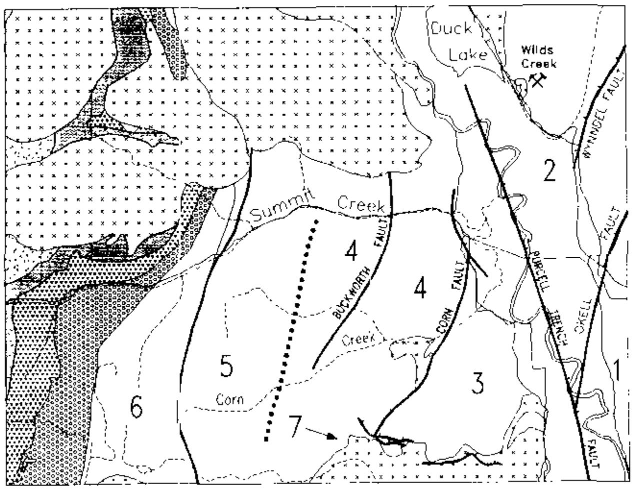

Figure 7. Structural blocks that comprise the Creston map area. These are based on preliminary and broad trends and by no means should they be considered as a rigorous structural analysis. 1 = west limb of the Goat River anticline; 2 = Wilds Creek block; 3 = Mount Rykert overturned block; 4 = Summit Creek; 5 = headwaters of Corn Creek; 6 = North Star Mountain; 7 = northern Priest River complex.

"blocks" already discussed (Figure 7). The area around Mount Rykert and along the western side of the study area is characterized by fine-grained phyllites and schists with small porphyroblasts of muscovite-chlorite (?) and biotite. The protoliths for these metasediments are recognizable as the Aldridge and Creston formations. These rocks appear to have been metamorphosed within the greenschist facies. Along the northern margin of the Rykert batholith, a north-dipping normal fault juxtaposes these low-grade metasedimentary rocks against the batholith.

The highest grade metamorphic rocks occur near granitic bodies such as the Rykert batholith, Corn Creek gneiss, and Bayonne batholith (Figure 4). A high-grade metamorphic domain also extends from the Corn Creek gneiss east to the Purcell Trench where the high-grade rocks have been faulted against low-grade rocks. Thus the changes in metamorphic grade appear to correlate well with the major compressional and extensional faults.

The predominant lithology within the highly metamorphosed metasedimentary rocks is fine-grained (0.25 - 0.75 mm) schists composed of muscovite, biotite, quartz, oligoclase with or without sillimanite and garnet. Garnet forms small (1 mm) idioblastic porphyroblasts. Staurolite forms large poikiloblasts which are intergrown with kyanite. Fine-grained sillimanite, muscovite and biotite define the dominant foliation which wraps around the porphyroblasts. In places, large kyanite porphyroblasts, up to several centimetres long, are embayed against biotite and quartz, but elsewhere, small, well formed crystals of kyanite lie within the foliation and are in contact with sillimanite. Rosettes of magnesium-rich chlorite occur as well. These relationships reveal that the growth of staurolite was within the stability field of kyanite. The textural relationships between kyanite and sillimanite suggest the early growth of kyanite and subsequent growth of both kyanite and sillimanite during creation of the primary foliation. This mineral assemblage is diagnostic of bathozone 4 (Carmichael, 1978).

Somewhat higher grade metamorphic rocks are exposed 2 kilometres northwest of Highway 3 up the Blazed Creek road, near the Mine stock (Figure 4). One pyritic specimen contains coarse-grained sillimanite and microcline, muscovite, biotite, plagioclase (An_{67})- quartz, titanite and tourmaline (Table 1; DBR94-77). The

TABLE 1
METAMORPHIC MINERAL ASSEMBLAGES AND ESTIMATED BATHOZONES (AFTER CARMICHAEL, 1978)

Map Number	Sample Number	Lithology	Assemblage	Bathozone
1	DBR-94-181	Schist	mu, bi, qt, pl	>2
2	DBR-94-83	Schist	mu, qt, pl?, rt, tr, bi	>2
3	PST-94-11	Schist	mu, bi, pl, qt,sl	2-5
4	DBR-94-77-2	Meta-tourmalinite	sl, ti, tr, pl, ks, mu, bi	2-5
5	PST-94-6	Schist	bi, mu, ky, sl, st, qt, rt, il, ch	4
6	PST-94-62A	Schist	ky, sl, st, pl, qt, bi, ch, rt, il	4
7	DBR-94-169	Amphibolite	bi, hb, pl, qt, gt, ch, ep, il	na

Locations of specimens are shown on Figure 4. Abbreviations: bi = biotite, ch chlorite, ep = epidote, hb = hornblende, il = ilmenite, ks = potassium feldspar, mu = muscovite, na = not available, pl = plagioclase, qt = quartz, rt = rutile, sl = sillimanite, st = staurolite, ti = titanite, tr = tourmaline.

enrichment in boron, reflected by the high concentration of tourmaline, suggests metamorphism of a tourmalinite. The apparent coexistence of sillimanite, microcline and muscovite suggests higher temperatures during metamorphism than during regional metamorphism to the south. Glover (1978) reports relict andalusite with kyanite and sillimanite to the west near the Mine stock, which is compatible with metamorphism within bathozone 3 to 4.

THERMOBAROMETRY

In order to further constrain the conditions of metamorphism across this region, microprobe analyses of co-existing metamorphic minerals from three specimens were completed. All minerals were analyzed with an ARL-SEMQ electron microprobe at Queen's University, using an energy-dispersive spectrometer operating at an accelerating voltage of 15 kilovolts. Each mineral was analyzed for a count-time of 200 seconds. Structural formulae were computed using APL software developed by D.M. Carmichael at Queen's University. Metamorphic temperatures and pressures were calculated using TWEQ software (Berman, 1991), the thermodynamic database of Berman (1990, 1988), and the activity models included with the program. Further details of the analytical procedure can be obtained from the authors upon request.

RESULTS

Selected results of the microprobe analyses are listed in Table 2. Two specimens were collected near Mount Huscroft (Figure 4), and co-existing sillimanite-biotite-muscovite-garnet-oligoclase in one sample and co-existing muscovite-biotite-oligoclase-garnet in the other were analyzed. Because of the low anorthite content of plagioclase, the pressures obtained are interpreted as maximum values. Specimen DBR94-185 yields 5-kilobar pressure and 575°C utilizing the composition of garnet cores. Garnet rim compositions yield slightly lower estimates near 3.9 kilobars and 535°C. Specimen DBR94-183 yields similar pressures and temperatures of metamorphism after adjustment of the partial pressure of water to 0.3.

Quantitative microprobe analyses were attempted on a garnet-bearing amphibolite collected 5 kilometres south of Highway 3 (site M7 on Figure 4). This specimen yielded unrealistic pressures of 9 kilobars and 6 kilobars utilizing garnet core and rim compositions, respectively (Table 2, DBR94-169). The garnet in this specimen appears to have developed preferentially along several quartz-filled fractures and may not be in chemical equilibrium with the plagioclase in the matrix of the amphibolite. An attempt to constrain the conditions of metamorphism east of the Purcell Trench was unsuccessful. The two specimens analysed yielded unrealistic estimates of pressure and temperature.

DISCUSSION

The specimens collected for the microprobe analyses near Mount Huscroft yield metamorphic pressures and temperatures which are compatible with estimates from other specimens using the bathozone scheme; together they suggest metamorphism within bathozone 4 (Figure 8; Carmichael, 1978). Thus both methods indicate peak metamorphism within bathozone 4 across much of the region west of Creston. Archibald *et al.* (1983) reported slightly higher conditions of metamorphism farther to the west-northwest in the Summit Creek area and adjacent to the Mine stock. However, the metamorphism they describe occurred prior to the mid-Cretaceous as reflected by K-Ar cooling dates. The rocks discussed here did not pass through the blocking temperature of argon in mica until between 55 and 47 Ma (Archibald *et al.*, 1984). The similarity in metamorphic grade, however, suggests that metamorphism across this region occurred at approximately the same time (mid-Jurassic) and the difference in mica cooling ages reflects differential uplift and cooling.

LOW GRADE AREA – MOUNT RYKERT OVERTURNED BLOCK

Some areas west of the Creston valley were metamorphosed at relatively low grades (greenschist). For example, black silty mudstone interbedded with siltstone and arenite display well preserved crossbedding,

TABLE 2
MICROPROBE RESULTS FROM SELECTED SPECIMENS FROM THE CRESTON MAP AREA

Map Number	Specimen	Rock type	Assemblage	Kilobars	Degrees (°C)	Comments
P1	DBR94-183	semi-pelite	gt, bi, mu, pl, qt	3.25	525	$aH_2O = 0.3$; gt rim
P2	DBR94-185	semi-pelite	gt, sl, bi, mu, pl, qt	5.00	575	gt core
				3.85	535	gt rim

Specimen locations are shown on Figure 4. Detailed microprobe data are available from the authors upon request. Abbreviations: bi=biotite, gt=garnet, mu=muscovite, pl= plagioclase, qt=quartz, sl=sillimanite.

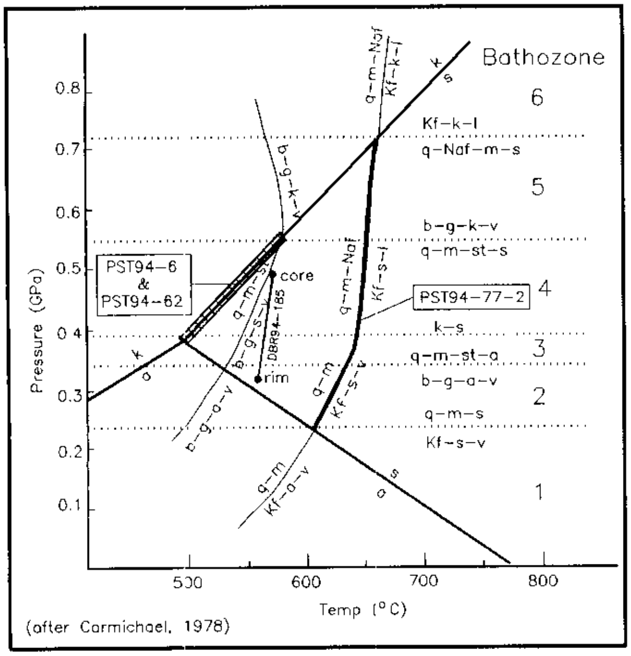

Figure 8. Pressure-temperature grid diagram for selected parts of the Creston map area.

graded beds and wavy bedding in much of the Mount Rykert area. The area is part of an overturned limb of a large, regional-scale fold, where penetrative fabrics and metamorphism are minor.

MINERAL OCCURRENCES AND EXPLORATION POTENTIAL

The Wilds Creek (Leg) stratabound zinc-barite deposit is the most important mineral occurrence in the Creston map area and is described by Brown and Klewchuk (1995, this volume). The Sullivan Two/Dodge property, a Sullivan-type sedex target west of Creston, covers sporadic and small galena-sphalerite-bearing quartz veins, and mudstone layers and mudchip breccia locally replaced by black tourmaline. These features generated exploration attention between 1984 and 1992 (Leask, 1992a, b). An eight-hole 900-metre drilling program was completed in 1990, and an additional 590 metres drilled in 1992 (Eldridge and Leask, 1991; Leask, 1992b). Farther north, the newly discovered meta-tourmalinite occurrence near Blazed Creek is currently mapped within the Kitchener Formation (site M7; Figure 4) and probably merits closer examination.

The regional stream sediment survey completed in 1977 detected several multi-element anomalies in an area underlain by basalt of the Irene Formation in the western part of the map area. An additional 35 stream sediment samples were collected during this mapping program and the results will be included in Open File 1995-15. Nine lithogeochemical grab samples of mineralized and altered lithologies have been submitted for geochemical analyses and the results will be tabulated in Open File 1995-15.

CONCLUSIONS

The area west of Creston is underlain by middle and upper Aldridge Formation and Creston Formation in domains of contrasting metamorphic grade. The Deer Trail Group and the stratigraphic succession around North Star Mountain are strongly correlative. The Dutch Creek dolomite (Pdc3) correlation with the Stensgar Dolomite implies some magnesite potential in the map area, as the Stensgar hosts numerous magnesite deposits in northeastern Washington. Elsewhere, however, correlations are hindered by variable metamorphism and deformation. The Wilds Creek area remains poorly correlated due largely to lack of exposure. In this northeast corner of the Creston map area, the stratabound zinc-lead-barite occurrence (Wilds Creek or Leg deposit) has regional significance. Potentially similar prospects along the western edge of the Purcell anticlinorium, some of which are under active exploration, include Mount Bohan (Hall property), LaFrance Creek (Wall and Dave claims) and past-producer Mineral King mine.

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NOTES

THE WILDS CREEK (LEG) ZINC-LEAD-BARITE DEPOSIT, SOUTHEASTERN BRITISH COLUMBIA: PRELIMINARY IDEAS (82F/2)

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(Contribution No. 23, Sullivan-Aldridge Project)

KEYWORDS: Proterozoic, Purcell Supergroup, carbonate breccia, stratabound zinc.

INTRODUCTION

This article summarizes a preliminary study of the Wilds Creek (Leg or Legion) deposit, undertaken concurrently with regional mapping of the surrounding Creston map area as summarized in Brown *et al.* (1995, this volume). The Wilds Creek deposit is one of a series of stratabound zinc-lead-barite prospects and mines in upper Purcell Supergroup stratigraphy along the western edge of the Purcell anticlinorium (Figure 1). These deposits are typically hosted in dolomitic units of the Dutch Creek Formation near the contact of the overlying Mount Nelson Formation, although the stratigraphic nomenclature and correlation varies with different workers. They are intensely foliated and structurally complex. The occurrences all lie in the hangingwall (west) of the Hall Lake fault. They have received various amounts of exploration attention and there is potential for other deposits, as illustrated by the Mineral King mine located about 100 kilometres north of Wilds Creek. It produced 1.210 million tonnes of ore with an average grade of 4.12% Zn, 1.76% Pb and 24.8 g/t Ag between 1956 and 1964 (B.C. Minister of Mines Annual Reports, 1956-1964). Seven days of mapping and drill core examination on the Wilds Creek property, located about 12 kilometres north-northwest of Creston, suggest characteristics that are of exploration significance for this part of the Belt Basin. Access to the property is by the Bathie Road and a new private logging road (locked gate) that crosses a network of older roads and overgrown trails.

REGIONAL SETTING

Stratigraphic nomenclature and subdivision of the western part of the upper Purcell Supergroup is hindered by several factors: a lack of prominent stratigraphic markers, lithologically similar units are repeated in the succession, and penetrative fabrics are more intense here compared to farther to the east. Early mapping by Rice (1941) identified Purcell Supergroup rocks, a northwest-facing succession of Creston, Kitchener-Siyeh, Dutch Creek and Mount Nelson formations, intruded by Mesozoic granite. Our stratigraphic divisions are based on the regional stratigraphic succession farther to the east; Reesor's new nomenclature is not adopted here because new names were proposed without explanation (Reesor, 1993). Farther north, in the Toby Creek area, recent thesis studies by Root (1987) and Pope (1989) suggest that the Mount Nelson Formation lies unconformably on the Dutch Creek Formation. The Mount Nelson Formation may therefore be an unconformity-bounded succession between the Purcell and Windermere supergroups.

PROPERTY WORK HISTORY

Galena and sphalerite were discovered in 1924 in a showing located on Wilds Creek at about 1000 metres elevation. The showing was drilled by Newmont Mining Corporation of Canada Limited (1954 - six holes), Sheep Creek Mines Limited (1961 - two holes), Aspen Grove Mines Limited (1964 - five holes), Legion Resources Ltd. (1989 - seven holes), Kokanee Explorations Ltd. (1990 - five holes; 1992 - nine holes), and Ramrod Exploration (1992 - nine holes). These programs amounted to a total of over 5000 metres of drilling. Estimated reserves, generated from investigations prior to 1965, were reported at about 136 000 tonnes grading 6% Zn across widths of 1 to 6 metres (Aho, 1964). In addition to drilling, several mapping, soil geochemistry and geophysical surveys (VLF-EM, IP, magnetic) have been completed.

STRATIGRAPHY

The property stratigraphy comprises nine, poorly exposed units (Figure 2; Photo 1): (1) sericitic phyllite; (2) thin-bedded black argillite and tan dolomitic siltstone; (3) chlorite-sericite phyllite with prominent but minor light grey quartzite beds; (4) argillite and dolomitic siltstone; (5) mineralized phyllitic dolomite and dolomitic siltstone; (6) dark grey phyllitic argillite and siltstone; (7) dolomite and limestone hosting the sphalerite-barite mineralization; (8) mafic volcanic rocks; and (9) quartzite. Most units are phyllitic and internally tightly folded, although unit contacts are not recognizably folded. The gross stratigraphic succession is a steeply southeast dipping, overturned homocline. An alternative interpretation that the two dolomitic horizons (units 2 and 4) are limbs of a tight, fault-bounded fold was suggested by Aho (1964). However, with new exposures and additional drilling it is now apparent that the dolomites are different. Correlation of these units with the regional stratigraphic column is hindered by poor exposure, faulting and folding; possible correspondences are: Kitchener Formation (units 1 to 2); Dutch Creek Formation (units 3 to 7); and Mount Nelson Formation (unit 9). Recognition of mafic rocks (unit 8) is significant as they may correlate with the Nicol Creek Formation or represent a previously undocumented volcanic episode. Summary descriptions of the main units bounding the ore and characteristics of the mineralization follow.

Two sequences of layered dolomite and impure quartzitic dolomite (units 5 and 7) host sulphides and are of prime economic interest. The **eastern dolomite** (unit 5) is more silicic and thinner than the recessive and poorly exposed dolomitic siltstone of unit 7 (at least 70 m thick). It comprises thin to very thinly layered silty dolomite and argillite. The **western dolomite** unit is a succession of white to cream-weathering, mottled grey to pale green impure dolomite, dolomitic siltstone with lesser interlayered green and maroon quartzitic phyllite and siltstone. The dolomite is commonly laminated to thinly layered, but locally it is massive. Disseminated pyrite (1 to 2%) occurs throughout the unit with rare, narrow pyrite lenses up to 10 centimetres thick. Baritic limestone is commonly associated with mineralized intervals within the unit. Tight to isoclinal minor folds are evident in drill core.

Distinctive carbonate breccia horizons (Photo 2; Figure 3) within the western dolomite horizon (unit 7) form an important marker unit. Several intervals of

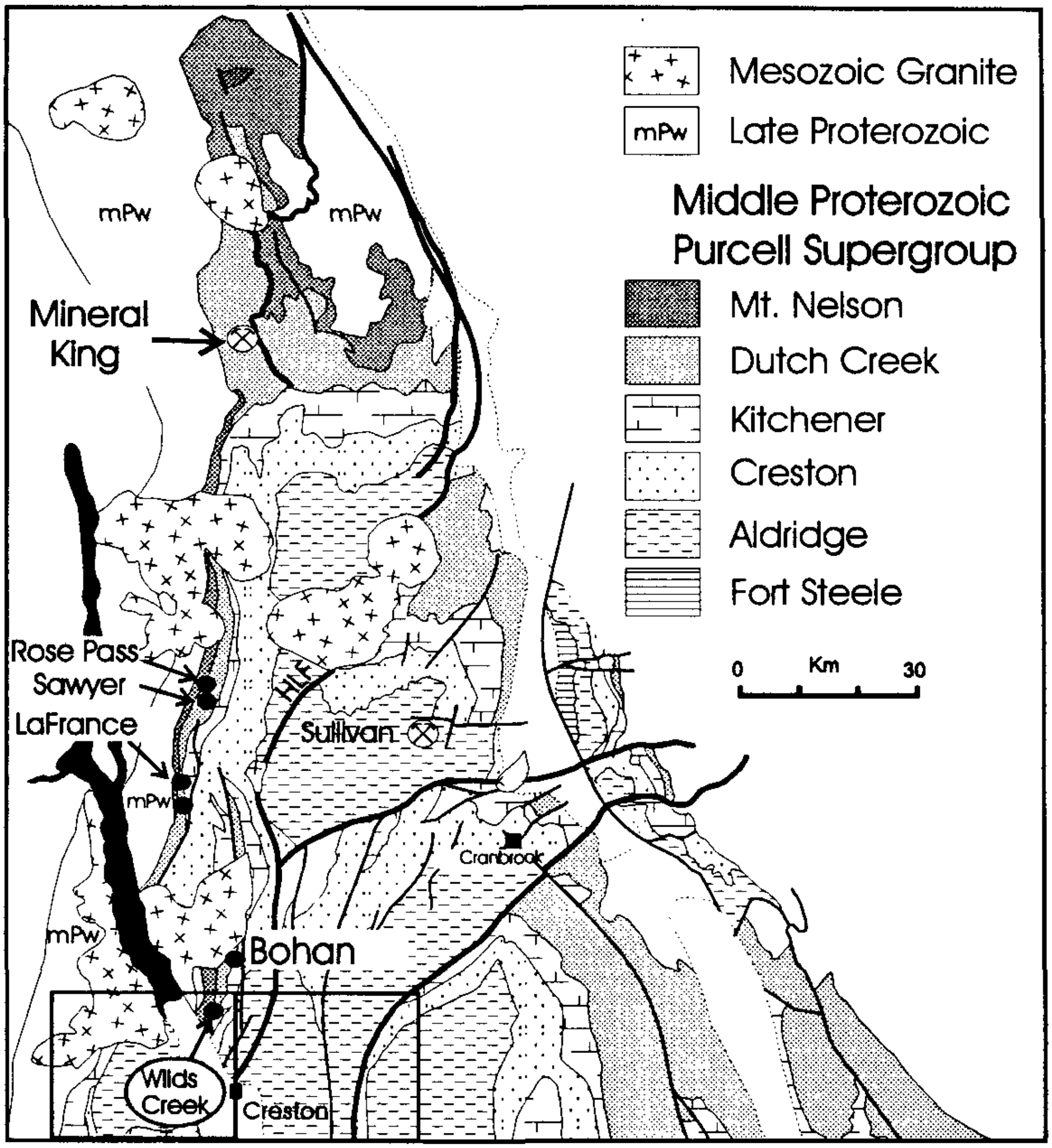

Figure 1. Regional distribution of stratabound zinc-lead-barite occurrences along the western flank of the Purcell anticlinorium. Rectangle outlines Yahk and Creston map areas (82F/1 and 2), mapped by East Kootenay project. HLF = Hall Lake fault. Map modified from Höy *et al.*, 1995.

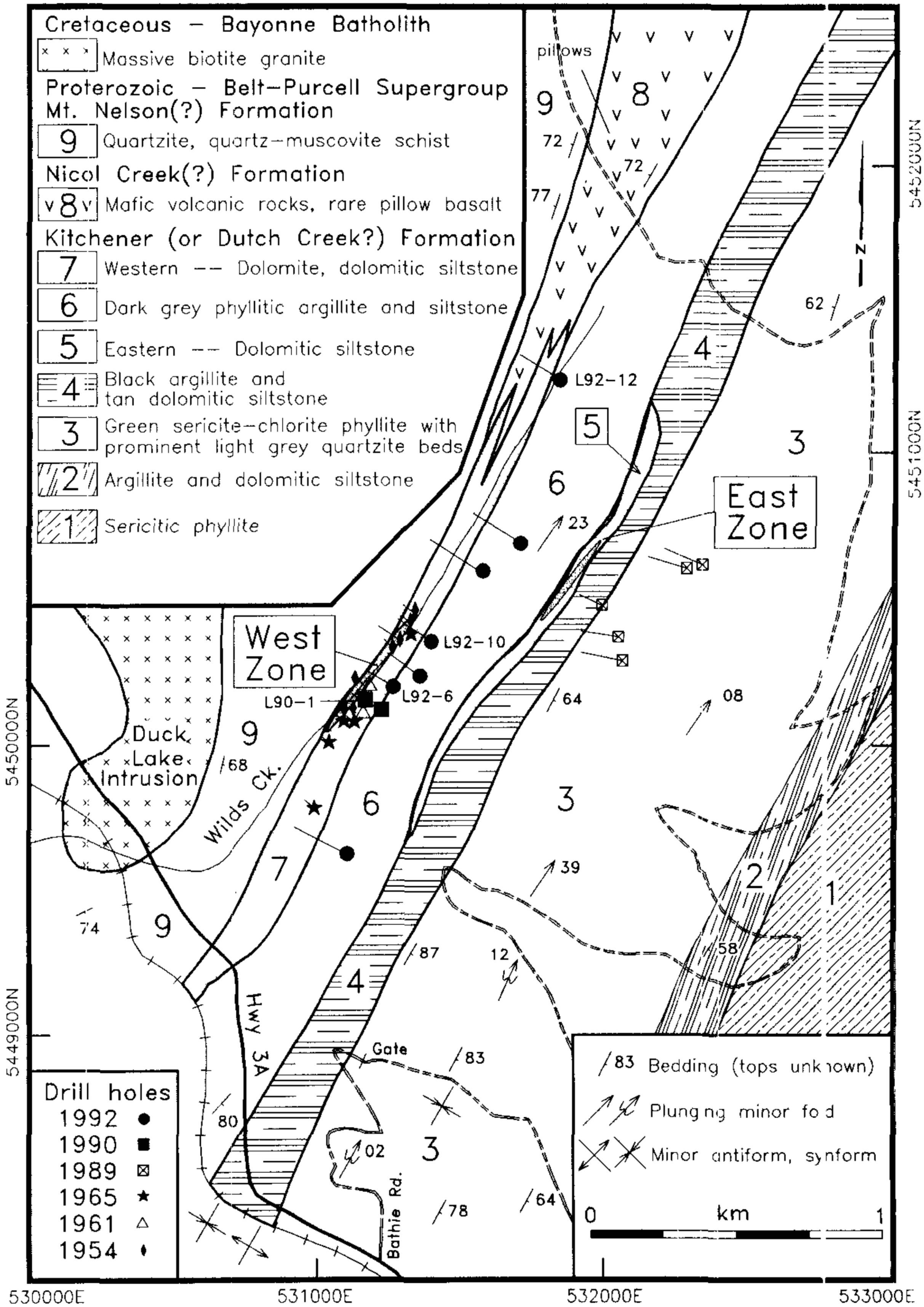

Figure 2. Simplified geology of the Wilds Creek (Leg) property.

Photo 1. View to northeast of the forested mountainside underlain by the poorly exposed Wilds Creek occurrence. Wilds Creek is shown by the white line and the town of Wynndel in the Duck Creek valley lies on the right side of the photo.

breccia up to 15 metres thick (apparent thickness), were intersected in drill core. This heterolithic breccia contains randomly oriented clasts a few millimetres to 15 centimetres long, supported in a carbonate matrix. The clasts form 30 to 70% of the rock and include angular argillite fragments, and subrounded quartz, dolomite and rare grey quartzite. Their relative proportions vary greatly, however dolomite and quartz dominate. A coarsening-upward (down the drill hole) accumulation of clasts was notable in one drill hole. The matrix-supported laminated argillite fragments weather out and contribute to the permeable character of this unit that now acts as an aquifer. Quartz fragments appear to be pieces of broken white quartz veins, perhaps derived from early diagenetic veins. Parts of the breccia are extremely vuggy and some are lined with quartz. The grey to white carbonate matrix is friable and soft. Locally, white quartz veins cut the breccia. Phyllitic siltstone layers occur within breccia units. At least three breccia horizons were intersected by drilling in this unit; they vary in apparent thickness from a few metres to 37 metres.

The breccia is thought to be a solution collapse (karst) deposit. Similar breccias occur at; the Mineral King mine, described by Pope (1989); Mount Bohan (Anderson, 1989); and LaFrance Creek (Slingsby, 1980; D. Wiklund, personal communication, 1994). Dolomite breccia is also exposed near North Star Mountain within strata currently included in the Kitchener Formation (see Brown *et al.*, 1995, this volume). Farther east in the Purcell (Belt) Basin, carbonate-rich sedimentary breccias occur within the basal part of the middle member of the Wallace Formation (Harrison *et al.*, 1986), perhaps they have a similar origin. If these breccias are karst deposits, they mark a regionally significant regression, where dolomite was subaerially exposed.

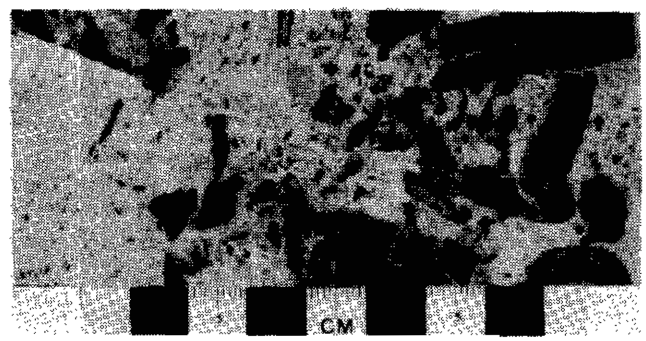

Photo 2. Dolomite breccia from the Wilds Creek deposit. (Hole L92-12, 231.3 m).

Variably foliated dark grey to silver argillite, interbedded with grey siltstone (unit 6), lies between units 5 and 7. The unit is recessive and poorly exposed. Individual laminae are discontinuous and irregular, probably due to tectonic attenuation. Minor interlayers of silty limestone occur locally. The unit exhibits small-scale tight folds in drill core.

A volcanic succession (unit 8) including probable pillow lavas (Photo 3) and associated tuffs is exposed along a new logging road north of the mineralized dolomite. The poorly developed pillows are up to 1 metre long with chloritic selvages, and locally contain plagioclase-porphyritic cores and amygdules. The brown-weathering, medium to fine-grained flows are dark green on fresh surfaces, and locally have oxidized flow tops seen in drill core. Fine pyrite euhedra (1 to 2%) are disseminated throughout the well foliated volcanics and magnetite concentrations occur locally. Prominent white plagioclase phenocrysts (15%) and rounded white amygdules (5%), filled with zeolites(?), are evident in drill core. Tuffs are deeply weathered, olive green to

Photo 3. Possible pillow lava exposed on a new logging road.

brown and friable. The 750-metre section exposed along the new logging road is dominated by recessive tuff and capped by about 75 metres of flows. The volcanic unit pinches out rapidly to the south, into flows 1 to 20 metres thick within dolomitic and siliciclastic rocks of unit 7.

An unmineralized, resistant, massive to thin-bedded quartzite and quartz-muscovite phyllite (unit 9) underlies the western edge of the property. Bedding dips steeply to the southeast. The fine to medium-grained well foliated quartzite is multicoloured - white, grey, pale green, mauve and maroon. It weathers grey to white and forms resistant outcrops. Some layers are more chloritic and probably represent argillaceous interbeds. The quartzitic succession may correlate with the base of the Mount Nelson Formation (Reesor, 1983); this contact is exposed in drill core and may be faulted.

INTRUSIVE ROCKS

A granitic stock, named here the Duck Lake intrusion, is about 500 metres wide and 1500 metres long and lies immediately west of the lower reaches of Wilds Creek. The massive biotite granite is related to the Cretaceous Bayonne batholith (Shaw Creek stock) that crops out farther to the northwest (Brown *et al.*, 1995, this volume). Calcsilicate assemblages, including coarse tremolite and biotite hornfels, are prominent in the southwestern part of the property. Regional aeromagnetic data show that anomalously high values extend southward from the Bayonne batholith under much of the property.

STRUCTURE

The Wilds Creek area lies on the west limb of the Goat River anticlinorium (Brown *et al.*, 1994) where it is part of a homoclinal succession from Creston Formation to Mount Nelson Formation. However, at the property scale the details are more complicated. On the property, bedding and penetrative phyllitic chlorite-sericite foliations strike north-northwest and dip steeply to the east (also locally to the west). The steep southeast dips and apparent northwest facing direction suggest the stratigraphic succession is overturned. Much of the structural style is controlled by competency contrasts of the different lithologies; tight chevron folds with gently north-plunging fold axes are abundant in the sericitic phyllite (unit 3; Photo 4) and transposed bedding is common in argillite units. Where macroscopic folds are not evident, bedding-cleavage relationships indicate tight folds within the green phyllite (unit 3). The mineralized carbonate (unit 7) is phyllitic but the enclosed carbonate breccia has no tectonic fabric, perhaps due to local flow of the carbonate unit along its contacts. Abrupt dip reversals in the quartzite (unit 9) suggest tight folding. Closures were not observed in outcrop, although millimetre to centimetre-scale chevron-style minor folds are evident in drill-core samples (Photo 5). The structural complexity of the property is illustrated by the variations in units and thicknesses, and difficulty in correlation between drill holes, even those holes collared at the same site.

Intense penetrative strain is evident in several polished samples of drill core. Pyrite euhedra fill brittle fractures (Photo 6a) or are disseminated along individual laminae (Photo 6b). Early quartz veins are folded with completely sheared limbs (intrafolial folds; Photo 6b).

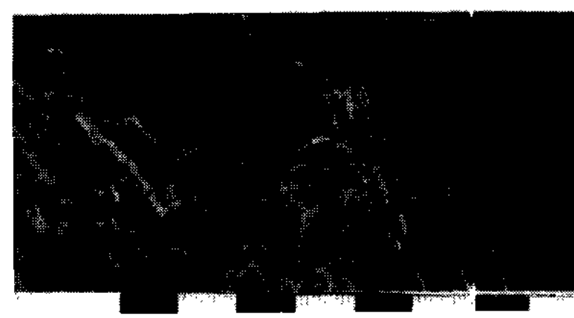

Photo 5. Drill-core sample showing tight chevron folds in fine-grained quartzite of unit 9 (Hole L92-6, 150 m).

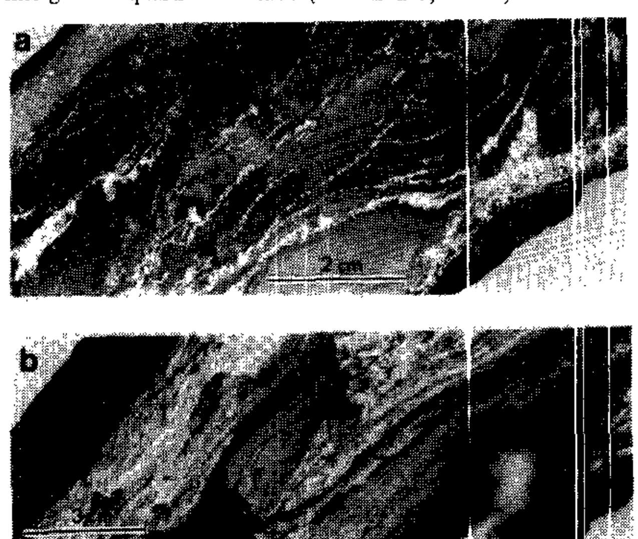

Photo 6. (a) Unmineralized, brecciated pale green silicic phyllite with pyrite introduced into the brittle fractures (Hole L90-1, 74.5 m). Faint laminations are probably relict primary bedding. The pressure shadow adjacent to quartz fragment is dominantly pyrite. (b) Highly strained dolomitic phyllite with rootless, folded quartz vein (Hole L90-1, 63.1 m). Possible S-C fabric is visible along left part of drill core.

Photo 4. Decimetre-scale tight chevron fold developed in unit 3 on the Wilds Creek property (DBR94-105).

MINERALIZATION

The two separate carbonate horizons host different styles of mineralization. The **East zone** was explored by the 1989 drilling program; the best intersection was 0.78% Zn across a 75-centimetre interval (Giroux, 1990). The zone is more intensely silicified than the Main Zone, with abundant quartz veinlets and stockwork hosted within the eastern dolomitic horizon (unit 5). It comprises pyrite with sporadic tetrahedrite, galena, sphalerite and chalcopyrite in the quartz veinlets and stockwork (*ibid.*).

The **Main zone** is at least 300 metres long and 2 to 3 metres thick as defined by drilling between about 850 to 1250 metres elevation (Figure 2). It lies within the western dolomitic horizon (unit 7) and comprises at least two intervals of stratabound sulphide-rich material, 30 to 75% pyrite and sphalerite. These intervals are bedding parallel, fine-grained pale yellow to red-brown sphalerite (up to 10% Zn) and fine to medium-grained pyrite within laminated baritic dolomitic limestone and calcareous quartzite and argillite (Figure 2; Photo 7a). The semimassive and layered sulphides (sphalerite and pyrite) in the silicic rock form narrow zones less than 25 centimetres thick. The layering, alternating pyrite and sphalerite-rich layers, may be a primary structure with a prominent, superimposed penetrative tectonic foliation. Disseminated pyrite is ubiquitous. Traces of galena (<1%) occur sporadically in dolomite layers. At surface the zone is intensely oxidized and poorly exposed. Mineralization is banded in the south and becomes more silicified and massive to the north (Giroux, 1990). Baritic dolomite is important in this horizon (Figure 3) and may correlate with 1.3 metres of bedded barite which is reported farther north, near LaFrance Creek (D. Wiklund, personal communication, 1994). Drilling in

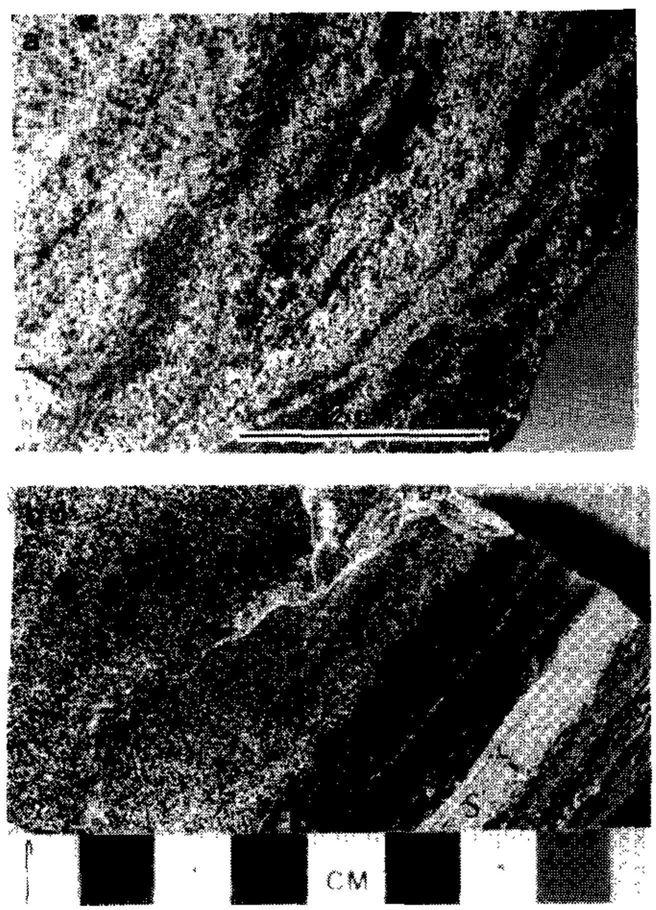

Photo 7. (a) Semimassive disseminated pyrite and sphalerite hosted in quartzitic siltstone (Hole L90-1, 80.0 m). This sample is from the interval of drill core that assayed 10.2% Zn over 2.6 metres. (b) Semimassive sulphide, disseminated pyrite with layered honey-coloured sphalerite ("S" on photo; Hole L92-6, 90.1 m). This sample is from a 1.1-metre drill-core interval that assayed 8.34% Zn, 0.74% Ag and 1.06% Ba.

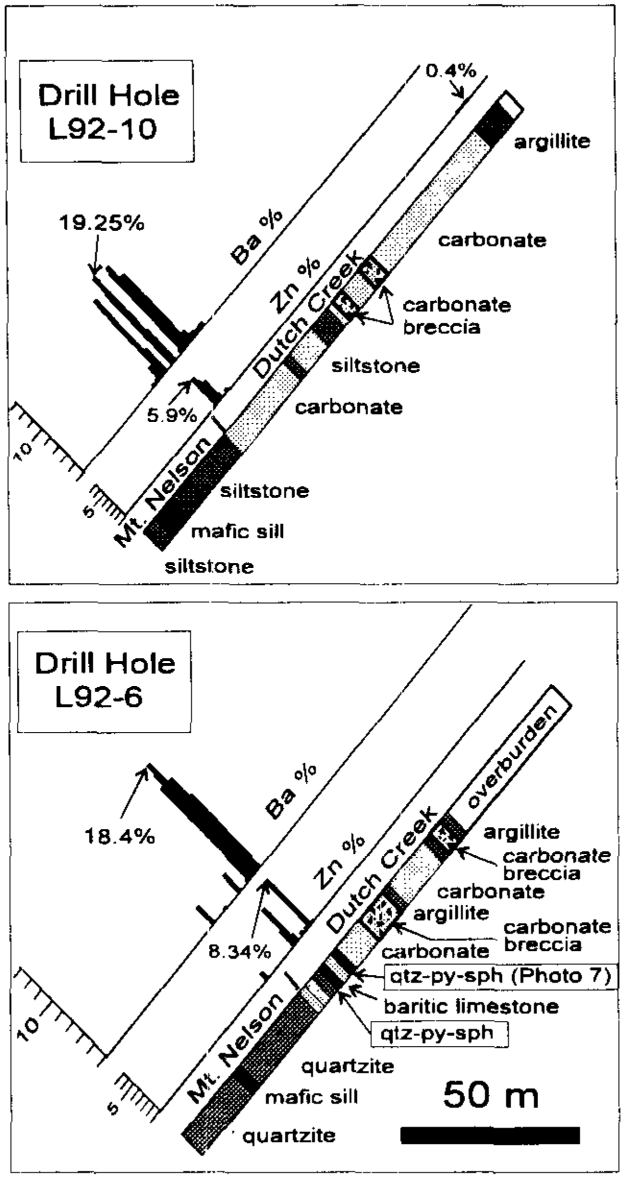

Figure 3. Simplified graphic drill-logs for two holes from the Wilds Creek (Leg) deposit, illustrating the association of barite with zinc mineralization.

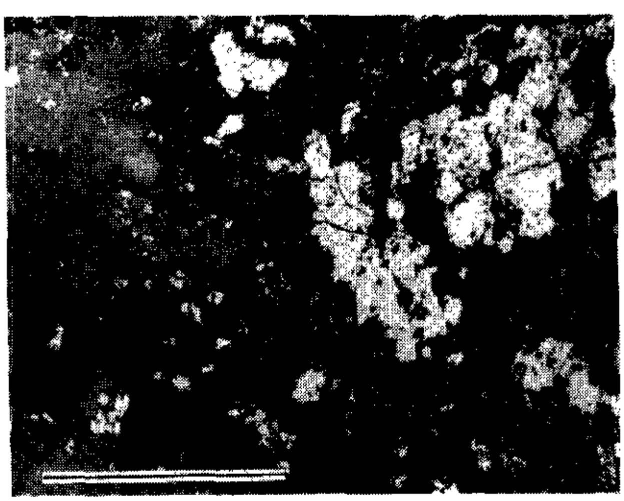

Photo 8. Pyrite blebs rimmed by magnetite within an epidote-rich gangue (Hole L90-1, 103.0 m).

Irregular patches of pyrite with reaction rims of magnetite and associated narrow intervals of epidote and diopside occur locally in dolomitic sediments (Photo 8). These patches also have associated tungsten and minor molybdenum (up to 200 ppm W and 130 ppm Mo). They are interpreted to be superimposed calcsilicate hornfels assemblages in the thermal aureole of the Duck Lake intrusion, an offshoot of the Shaw Creek stock.

PRELIMINARY MODEL

The stratabound main zone at Wilds Creek is intensely foliated and probably remobilized. Detailed mapping and isotopic studies are required to distinguish the two most probable models of ore deposition; sedex or replacement (manto). The stratabound zinc-lead-barite mineralization hosted by dolomite lies adjacent to mafic volcanics that thicken rapidly to the north. The rapid change in the thickness of the mafic volcanic rocks is speculated to be controlled by synvolcanic growth faults developed during rifting. This block faulting may have provided conduits for a hydrothermal system associated with volcanic activity that produced sedex style mineralization. The east zone could be a stringer feeder zone, although it was not examined in this study and its relationship to the main zone remains unclear. In this model, replacement and exhalative mineralization are predicted, depending upon where the hydrothermal fluid precipitates the ore (Figure 4).

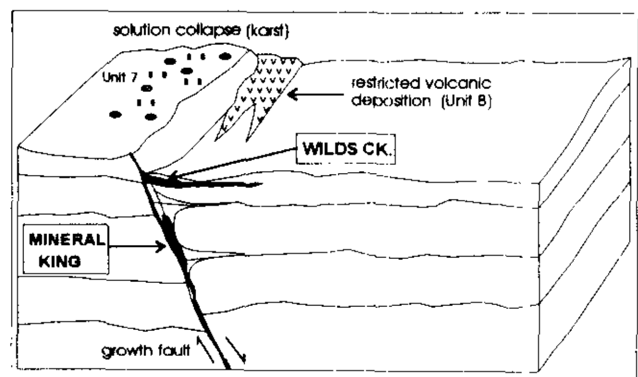

Figure 4. Preliminary depositional cartoon for the Wilds Creek deposit. The Mineral King mine, shown as a replacement-type deposit.

REGIONAL SIGNIFICANCE

The Wilds Creek deposit is one of several similar occurrences along the western margin of the Purcell anticlinorium, hosted by strata believed to be near the Dutch Creek - Mount Nelson formational contact (Figure 1). The next occurrence to the north is near Mount Bohan (Hall property), first staked after follow-up of a zinc-lead Regional Geochemical Survey stream sediment anomaly in Arrow Creek. It was drilled by Cominco Ltd. in 1989 (Klein, 1988; Anderson, 1989). Soil geochemical anomalies, geophysical responses and carbonate breccia on this property are similar to the Wilds Creek deposit; however, little mineralization was intersected. The Wall and Dave claims, owned by Eric and Jack Denny, and David Wiklund respectively (Callan, 1990), lie between LaFrance and Lockhart creeks and have been explored intermittently since 1900 (82F/7; Slingsby, 1981). A barite unit, over 1 metre thick, believed to be bedded, occurs on the Wall claims. Similar mineralization has been reported near Rose Pass and in recent prospecting discoveries associated with isoclinally folded silty dolomite on Sawyer and Baker creeks (H.P. Wilton, personal communication, 1994). Ore shoots at the Mineral King deposit were concentrated in fold closures, indicating that the ore has been remobilized; details of the deposit are provide by Fyles (1960) and Pope (1989). They considered the ore to be replacement or manto-type. Most of these deposits are structurally and stratigraphically complex; future exploration will require careful geological evaluation prior to drilling.

CONCLUSIONS

Several key points stem from the preliminary study of the Wilds Creek deposit. Exploration criteria for the Wilds Creek deposit can be summarized as follows. The top of the Dutch Creek near the Mount Nelson contact appears to be a critical stratigraphic interval. The local association of mineralization with silty dolomite, baritic dolomite and bedded barite that contain a carbonate breccia unit (possible karst) is important. The mafic volcanic rocks at Wilds Creek thicken abruptly, possibly due to synvolcanic faulting. Stratabound sphalerite and minor galena are hosted in dolomitic and baritic gangue. These occurrences produce strong lead, zinc and barium soil anomalies. Locally there is a spatial association with magnetic mafic volcanic rocks (flows and sills).

In terms of regional stratigraphic significance, two highlights are: recognition of mafic volcanic rocks representing either a western equivalent of the Nicol Creek Formation or a different, previously unrecognized, volcanic episode; and, the carbonate breccias (karst deposits) may indicate a regression.

ACKNOWLEDGMENTS

Geological data were also provided by Dean Barron of the East Kootenay project; his assistance is greatly appreciated. Discussions of ideas in the field with Doug Anderson, Trygve Höy, Craig Kennedy, Dave Pighin, Dave Wiklund and Paul Wilton were a great help in demonstrating the regional importance of these occurrences and associated carbonate breccias. Reviews of this manuscript were thoughtfully completed by David Lefebure, John Newell and Paul Wilton.

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GEOSCIENCE STUDIES IN THE INTERIOR PLATEAU REGION: BRITISH COLUMBIA GEOLOGICAL SURVEY 1994-95 ACTIVITIES

By B.R. Brown, S.J. Cook, L.J. Diakow, T.R. Giles, W. Jackaman, R.A. Lane, V.M. Levson, P.F. Matysek, T.G. Schroeter and I.C.L. Webster

(B.C. Ministry of Energy, Mines and Petroleum Resources Contribution to the Interior Plateau Program, Canada - British Columbia Mineral Development Agreement 1991 - 1995)

KEYWORDS: Interior Plateau, integrated project, regional geology, surficial geology, economic geology, lake sediment geochemistry, till geochemistry.

INTRODUCTION

The Interior Plateau program is a major multidisciplinary geoscience initiative that is funded under the guidelines of the Canada - British Columbia Mineral Development Agreement. Provincial contributions to the program are the responsibility of the Ministry of Energy, Mines and Petroleum Resources. The activities of the British Columbia Geological Survey Branch in the program are summarized here and details of studies conducted during the 1994 field season are provided in the papers that follow. Summaries of federal activities in the program are included in overview papers by Diakow and van der Heyden (1993) and Matysek and van der Heyden (1994).

Provincial activities have focused mainly on integrated bedrock and surficial geology mapping and till and lake sediment geochemical studies. A multidisciplinary approach has been highly successful and has led to the discovery of a number of new mineral prospects including the Tommy and Malaput occurrences (Diakow and Webster, 1994, Diakow *et al.*, 1994) and several coincident till and lake sediment anomalies with elevated concentrations of gold, silver, copper, arsenic, antimony, lead and/or zinc that are similar or higher than values in the same media at advanced prospects in the area (Levson *et al.*, 1994; Cook and Jackaman, 1994a, b; Cook *et al.*, in press).

Most of the provincial studies have been conducted in the Nechako River map area (NTS 93F) for several reasons. Outdated 1:250 000 bedrock mapping in the region has made it difficult to define important lithologic and structural controls for mineralization, and hindered geological syntheses and metallogenic studies. In addition, more than half of the area is drift covered and few detailed Quaternary geology studies have been conducted. There is also a need to develop and evaluate drift exploration models and geochemical exploration techniques applicable to drift-covered plateau regions, and to determine geochemical pathfinder elements and their significant thresholds in tills and lake sediments representative of mineralization in the Interior Plateau.

In order to address some of these problems the following objectives were established:

- define time-space relationships of stratigraphic units, plutonism, deformation and mineralization by completing 1:50 000 bedrock geology mapping;
- determine the geologic framework for known mineral deposits by identifying and evaluating metallotects and conducting detailed mineral deposit studies;
- determine the extent, thickness and stratigraphy of Quaternary units and collect provenance and glacial paleoflow data by completing 1:50 000 surficial geology mapping;
- delineate buried bedrock units and locate regions of potential mineralization in drift-covered areas by conducting regional lake sediment and till geochemical surveys;
- define models of glacial dispersal and evaluate the effects of surficial processes on geochemical distribution patterns by conducting detailed geochemical and surficial geology studies around areas of known mineralization;
- evaluate the response of different geochemical sampling techniques and sample media (biogeochemical, lake sediment, soils and drift) to known mineralization.

BEDROCK AND SURFICIAL MAPPING

A number of bedrock mapping surveys (Figure 1) have been conducted in the Nechako Plateau region to develop a better understanding of the stratigraphy, structure and geologic controls on mineralization. These studies have included bedrock mapping in the Natalkuz Lake area (Diakow *et al.*, 1993; Green and Diakow, 1993) and bedrock and surficial geology mapping in the Fawnie Creek (Diakow and Webster, 1994; Diakow *et al.*, 1994; Levson and Giles, 1994), Tsacha Lake (Diakow *et al.*, 1995a, b; Giles and Levson, 1995) and Chedakuz Creek (Diakow *et al.*, 1995a, c; Weary *et al.*, 1995) map areas (Giles *et al.*,1995, this volume). Surficial geology mapping in the Anahim Lake map area (NTS 93C) has also been completed for the Chilanko Forks and Chezacut map areas (Giles and Kerr, 1993; Kerr and Giles, 1993a, b) and the Clusko River and Toil Mountain areas (Proudfoot, 1993; Proudfoot and Allison, 1993a, b).

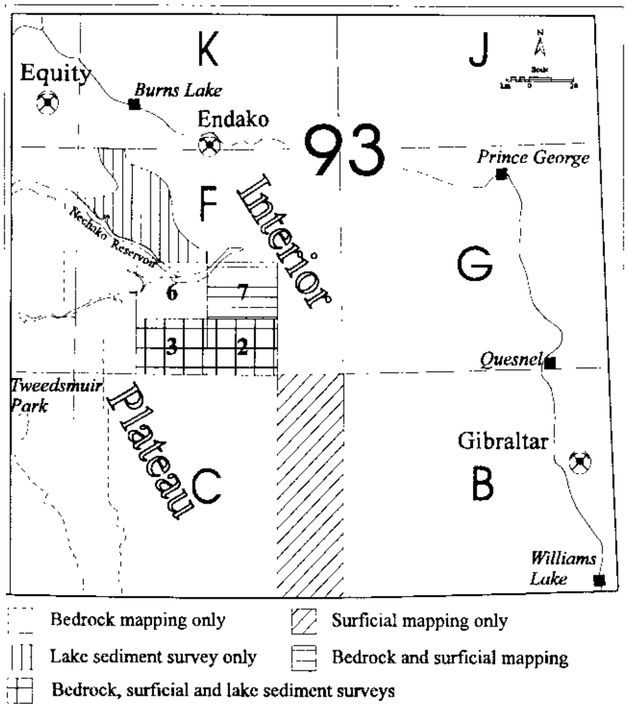

Figure 1. Location map of B.C. Geological Survey Branch studies conducted in the Nechako Plateau region as part of the Interior Plateau program.

LAKE SEDIMENT AND TILL GEOCHEMISTRY STUDIES

Regional lake sediment geochemical surveys have been completed over approximately one quarter of the Nechako River map area (Figure 1). The results of these surveys were provided by Cook and Jackaman (1994a, b). Lakes found to have elevated concentrations of gold and other elements during the regional survey were studied in more detail by Cook and Luscombe (1995). Detailed geochemical studies of lake sediments around a number of areas of known epithermal and porphyry style mineralization have also been conducted (Cook, 1993, 1995).

Regional till geochemistry surveys (Levson *et al.*, 1994) and drift prospecting potential studies (Giles and Levson, 1994a) have been completed in the Fawnie Creek map area. The results of detailed geochemical dispersal studies around known mineral prospects in the Interior Plateau region were compiled by Levson and Giles (1995) and Kerr and Levson (1995). New studies were conducted in the Fawnie Creek area in 1993 (Giles and Levson, 1994b) and this work was continued in 1994 (O'Brien *et al.*, this volume).

MINERAL DEPOSIT STUDIES

Mineral deposit studies in the Clisbako area in 1991 were discussed by Schroeter and Lane (1992). More recently, several mineral deposit studies were conducted in conjunction with regional bedrock mapping in the Nechako River area (Schroeter and Lane, 1994; Lane and Schroeter, 1995). Study areas include the following prospects with MINFILE identification numbers in paraentheses: Wolf (93F 045), Fawn (Gran; 93F 043), Fawn 5 (93F 053), CHU, C (CH; 93F 04), Blackwater-Davidson (PEM; 93F 037), Uduk Lake (93F 057), Tommy (Tsacha; 93F 055), Malaput (93F 056), April (93F 060), Ben (93F 059), Buck (93F 050), Paw (93F 052), Ned (93F 039), Yellow Moose (93F 058), Holy Cross (93F 029), Baez (Oboy; 93C 015) and Trout (93F 044).

INTEGRATED GEOLOGICAL STUDIES

An important focus of the Interior Plateau program has been the integration of geological studies in a number of different disciplines. One of the first products of these multi-disciplinary studies was the production of a combined bedrock and surficial geology map of the Fawnie Creek map area (Diakow *et al*, 1994). This was the first map of this type produced by the B.C. Geological Survey Branch in many years and, due to a positive reception given to it by mineral exploration companies working in the region, two more maps of this type were produced for the 1994 map areas (Diakow *et al*, 1995b, c). Other integrated studies include a detailed comparison of geochemical results from till and lake sediment surveys conducted in the Fawnie Creek map area (Cook *et al*, in press) and the identification of several new exploration targets in the same area using data from bedrock geology as well as till and lake sediment geochemical studies (Cook and Jackaman, 1994a, b; Cook *et al.*, 1994; Levson *et al.*, 1994). Further interdisciplinary work is planned for the Interior Plateau program and may lead to the identification of other areas with high mineral potential as well as the development of exploration techniques specifically suited to this part of British Columbia.

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British Columbia Geological Survey
Geological Fieldwork 1994

STRATIGRAPHIC HIGHLIGHTS OF BEDROCK MAPPING IN THE SOUTHERN NECHAKO PLATEAU, NORTHERN INTERIOR PLATEAU REGION (NTS 93 F/2 AND 7)

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KEYWORDS: Interior Plateau, Hazelton Group, Ootsa Lake Group, Chilcotin Group.

INTRODUCTION

The Blackwater River is a natural division in the central part of the British Columbia Interior Plateau that separates the Nechako Plateau to the north from the Fraser Plateau to the south. Bedrock mapping in the southernmost part of the Nechako Plateau began in 1992, and to date an area of 3500 square kilometres, centred on the Fawnie and Nechako ranges, has been mapped at 1:50 000 scale (Figure 1). This work provides a geological framework for surficial geological mapping, till and lake sediment geochemistry surveys and mineral deposit studies undertaken by the British Columbia Geological Survey Branch as part of a joint Federal-Provincial Mineral Development Agreement to provide geoscience data and assess mineral potential in the Interior Plateau region. The integrated approach of these programs in this underexplored region has successfully identified significant areas of anomalous till and lake sediment geochemistry and new mineralized epithermal showings. Since the inception of these studies, numerous maps and reports have been published; these are listed in Brown *et al.* (1995). Publication of a summary volume containing reports on the various projects in the Interior Plateau region conducted under the Mineral Development Agreement (1991-1995) is planned for early in 1996.

The purpose of this report is to highlight stratigraphic insights gleaned from the mapping program. The study area is part of a broad, structurally uplifted zone referred to as the Nechako uplift (Diakow and Webster, 1994). In the Nechako River map area (93F) and more specifically, in the Fawnie and Nechako ranges, the uplifted area is manifest as a topographically high-standing Lower and Middle Jurassic sequence, and a single exposure of Upper Triassic basement. These older rocks are unconformably overlain by isolated erosional remnants of Lower Cretaceous and Tertiary rocks. To the north and south, the uplifted area is flanked by an extensive blanket of mainly Eocene and younger volcanic rocks.

STRATIGRAPHY

BASEMENT AND JURASSIC ROCKS

Upper Triassic black siltstone, containing fossil shells tentatively identified as *Monotis* or *Halobia* is exposed at a single locality along the Red road, which hooks around the northern end of the Nechako Range. It is the oldest known rock unit in the study area, and a rare glimpse of presumed 'basement'. Jurassic volcanics interlayered with subordinate sediments comprise the most widespread map unit in the Fawnie and Nechako ranges. This unit, first mapped in the Natalkuz Lake area (93F/6) in 1992, and designated unit J(v,s) was described as a monotonous succession dominated by mainly basaltic flows characterized by fresh pyroxene phenocrysts and sparsely distributed feldspathic marine sediments that contained probable Middle Jurassic fossils (Green and Diakow, 1993; Diakow *et al.*, 1993).

The following year, mapping extended the distribution of these rocks to the south into the Fawnie Creek area (93F/3) where, in addition to the diagnostic lithologies of unit J(v s) an older, conformable volcanic sequence was recognized. These two lithostratigraphic divisions constitute the informal Naglico formation (Diakow and Webster, 1994). The lower division consists predominately of subaerial rhyolitic volcaniclastic rocks and minor flows, and in places, well layered maroon and green lapilli and finer tuffs (unit MJN1 of Diakow and Webster, 1994). In contrast, the upper division is a sequence of calcalkaline, augite-phyric flows of mafic to intermediate composition and volumetrically minor, intravolcanic fossiliferous sediments (units MJN2 and MJNs *of* Diakow and Webster, 1994). The sediments are composed mainly of volcanic detritus that includes angular plagioclase and lithic fragments in deposits of feldspathic greywacke, tuffaceous siltstone and sharpstone conglomerate. Fossils identified in these sediments by Dr. H.W. Tipper of the Geological Survey of Canada, loosely bracket deposition of the upper division between early Bajocian and early Callovian time. Three dates on single zircons from rhyolitic rocks in the lower division, analyzed by the Pb-Pb evaporation technique, are equivocal as they range in age from Permian to Middle Jurassic. Uranium-lead data on one sample suggests inheritance from older assimilated crust.

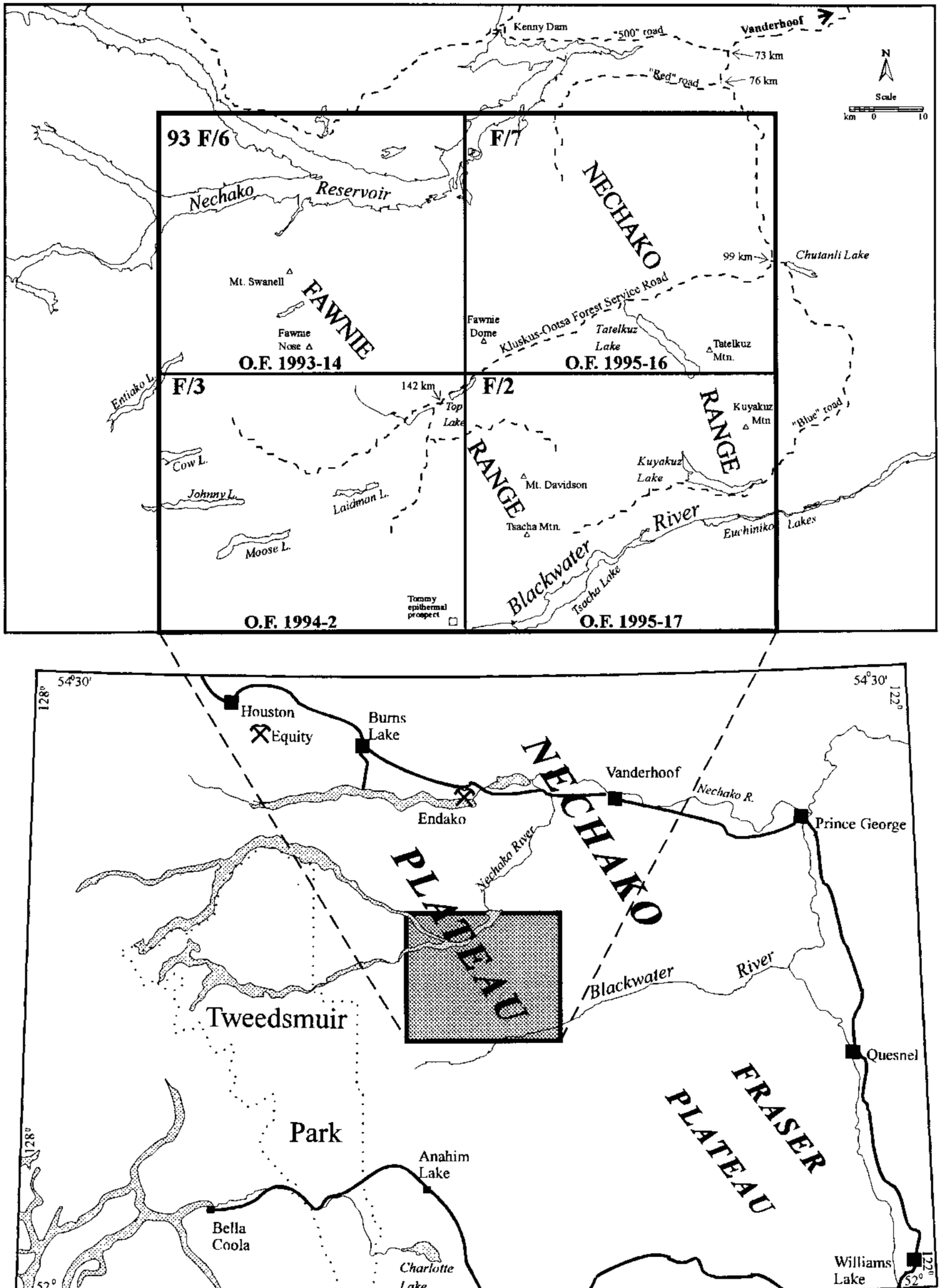

Figure 1. Location of published 1: 50 000-scale bedrock mapping on the Nechako Plateau.

During 1994, mapping was extended eastward into the Tsacha Lake (93F/2) and Chedakuz Creek (93F/7) areas. This work builds upon the twofold lithostratigraphic division of Jurassic strata established in the adjoining Fawnie Creek map area to the west. A major change in depositional environment is recognized in rocks of the lower division exposed in the Fawnie Range and those underlying the Nechako Range, 20 kilometres to the east. It is indicated by the change from subaerial felsic volcanics in the west to coeval intermixed felsic volcanic and marine sediments in the east. The marine sediments are further subdivided into two facies. A near-shore, sandy facies, that is traceable along part of the western flank of the Nechako Range, and a more distal, mudstone facies to the east and northeast. Both depositional facies exhibit felsic tuff interbeds and abundant lithic fragments thought to be derived from a nearby volcanic source.

Rhyolitic lapilli tuff and rare laminated flows assigned to the lower division crop out sporadically in the southern part of the Fawnie Range. They represent the eastward extension of a subaerial volcanic pile that is widespread in the Fawnie Creek area. Correlative epiclastic rocks to the east are exposed intermittently along the lower, southwest-facing slope of the Nechako Range between Kuyakuz Lake and Tatelkuz Mountain. They represent a near-shore facies composed primarily of sandstones and siltstones that are rich in angular feldspar detritus, and conglomeratic interbeds with subangular felsic lithic fragments. A particularly important outcrop is a roadcut near the 38-kilometre marker on the Blue road. Here reworked waterlain crystal tuff characterized by abundant quartz fragments is directly overlain by feldspathic siltstone containing the middle to late Toarcian ammonite, *Collina*. Because felsic volcanism appears to be contemporaneous with sedimentation, this fossil provides a minimum depositional age for rocks of the lower division. Moreover, in the absence of fossils it would be impossible to draw the direct correlation between these sediments and those representative of a deeper marine facies that lie to the north-northeast. This facies is also late Toarcian, determined from the small, but diagnostic bivalve, *Bositra*. The *Bositra* beds consist of recessive, black limy mudstone that commonly contain impure limestone concretions, lenses and discrete, white ash-tuff laminae. They are exposed in the low-lying area immediately adjacent to the northeast-facing slope of the Nechako Range between the Red road in the north and the latitude of Tatelkuz Lake in the south.

The Late Toarcian beds are found locally in close proximity but not in direct contact with lithologically similar, but older mudstone and siltstone. Several species of ammonites from this lower succession are early Toarcian, which suggests that a relatively quiet marine trough probably existed close to the same geographic location through most of Toarcian time. Field evidence also suggests that a middle to late Toarcian shoreline lay to the west, and beyond a subaerial volcanic field that periodically provided felsic airborne tephra and shed volcanogenic-epiclastic debris into the basin.

A distinctive, local stratigraphic marker composed mainly of lapilli tuff, minor accretionary lapilli and reworked waterlain crystal-rich tuff is exposed along the axis of the Nechako Range, southwest of Tatelkuz Mountain to the eastern end of Kuyakuz Lake. Its distinguishing lithological features are felsic potassium-bearing pyroclasts and angular quartz fragments. Although the lower contact was not observed, these deposits bear compositional and lithological resemblance to the underlying Toarcian rocks. Therefore, they are interpreted to represent a younger section that is stratigraphically continuous with the underlying Toarcian section. Epiclastic beds slightly lower stratigraphically than the volcanic marker unit yielded a fossil collection originally reported to contain the early Bajocian ammonite, *Witchellia* (Tipper, 1963, p. 28). This collection was recently re-examined by Dr. H.W. Tipper and re-assigned an Aalenian age. This new age assignment effectively extends the record of coeval felsic volcanism and marine sedimentation of the lower division of the Naglico formation from at least the middle Toarcian into the Aalenian.

Basaltic and andesitic flows, distinguished by the common occurrence of vitreous pyroxene phenocrysts, conformably overlie the Toarcian to Aalenian succession in the Nechako Range. In the northern part of the range these rocks appear to rest against a Lower Cretaceous clastic assemblage. The nature of the contact is uncertain; it may be either a fault or an unconformity. Fresh hornblende in the flows immediately adjacent to the sediments was sampled for an Ar-Ar date that should resolve the dilemma of possibly two lithologically similar mafic flow sequences - one Middle Jurassic and the other Early or Late Cretaceous. Similar flows, interlayered with maroon, fine-grained tuffs containing rare quartz phenocrysts, are found locally in the Fawnie Range on map sheets 93F/2 and 7. Based on corresponding lithologic characteristics, these rocks represent the eastern extension of strata comprising the upper division of the Naglico formation, which underlies much of the Fawnie Creek (93F/3) and Natalkuz Lake (93F/6) map areas.

Sedimentary units comprise relatively thin, recessive beds that are generally spatially associated with, but rarely in direct contact with volcanic rocks assigned to the upper division. This apparent relationship is noted at a number of localities, however, because the sediments are recessive, their contacts with bounding volcanic rocks are rarely exposed. The sediments are composed of immature feldspathic greywacke, black feldspathic mudstone, and scarce accumulations of granule and pebble conglomerate. Another unifying feature is a rich assortment of fossils that includes some ammonites, but mainly thick-shelled molluscs, indicative of a shallow-water marine depositional environment. Except for several fossil collections from the Fawnie Creek area that are questionably early Bajocian, most are early Callovian in age. Despite comparatively minor marine sedimentary interbeds, the depositional environment of the volcanic pile was mainly subaerial. Nowhere in this succession have pillowed lavas been found, and deposits interpreted as hyaloclastite are scantily distributed. It appears the volcanic pile was, at times, inundated by relatively warm, shallow marine water. The most significant of these transgressive(?) events in the study area appears to be marked by widespread early Callovian sedimentary rocks. Alternatively, the volcanic pile may have been slowly subsiding during quiet stages of volcanism, allowing marine conditions to encroach.

POST-JURASSIC ROCKS

Jurassic rocks in the study area are unconformably overlain by Lower Cretaceous sediments, and Tertiary volcanic sequences of Eocene and probable Miocene ages. The Cretaceous clastic assemblage is exposed semi-continuously along the axis of the Nechako Range; either it occupies a medial belt between flanking belts of lithologically similar pyroxene-bearing flows or, as described briefly above, is stratigraphically below or in fault contact with pyroxene-bearing flows. Correlative strata were previously mapped in the southwest corner of the Fawnie Creek map area where they are in fault contact with older Jurassic rocks (*cf.* unit MJNs; Diakow and Webster, 1994, p. 21). The hallmark of these rocks is abundant grey chert and black mudstone clasts in well sorted pebble-cobble conglomerates that are interlayered with light grey sandstone, and light green and black siltstone-mudstone beds. A rare ammonite from mudstone discovered by T. Richards prior to this project is tentatively identified as a Lower Cretaceous form. Other collections of shelly fauna are currently being examined by the Geological Survey of Canada.

Eocene and younger, subaerial volcanic rocks thin above the Nechako uplift; forming outliers that rest unconformably on Jurassic rocks. Eocene rocks of the Ootsa Lake Group apparently thicken north of the Natalkuz fault (Diakow *et al.*, 1993), a major northeast-trending structure that roughly demarcates the southern structural margin of a broad Tertiary volcanic field juxtaposed against older basement of the Nechako uplift. Eocene rocks in the western part of the study area are associated with a subvolcanic pluton and epithermal precious metal mineralization at the Wolf property. Based on similar lithologies, these rocks correlate with volcanic strata of the Ootsa Lake Group described in a section along the western flank of the Fawnie Range (Diakow and Webster, 1994, p. 22). Recent mapping has extended the distribution of this volcanic succession to the east-facing slope of the range, mainly between Top Lake and Mount Davidson. No Eocene rocks are recognized east of the Fawnie Range. Near Mount Davidson, the base of the Eocene section is marked by distinctive off-white and mauve, laminated rhyolite flows and related flow breccias. Another rhyolitic unit at the top of the section forms a massive sheet-like deposit capping Mount Davidson and other prominent knolls in the immediate area. The pyroclastic origin of these rocks is readily interpreted from lapilli-size lithic pyroclasts and abundant quartz fragments (up to 15%) supported by a well indurated groundmass. This pyroclastic deposit is both compositionally and texturally homogeneous, unusual features in light of its dimensions, locally as much as 250 metres thick, and an areal extent of about 20 square kilometres. The most plausible interpretation is that the deposit represents a uniformly welded ash-flow tuff resembling thick intra-caldera fill. The age of this unit is also in question. It contains scarce interbeds of flows, laharic breccia and minor volcanogenic siltstone that resemble lithologies in the upper division of the Naglico formation. The unit has been sampled for a U-Pb dating on zircon to determine the timing of crystallization.

Andesitic flows are exposed between conformably underlying and overlying rhyolitic rocks. The lithologic similarity of these rocks to those of the Naglico formation makes distinguishing the two successions difficult. By comparison, Eocene andesites in the area are relatively unaltered and contain slender plagioclase phenocrysts up to 5 millimetres long. Vitreous pyroxene is rarely observed in the Eocene rocks whereas it is often present in the Naglico formation (*cf.* unit MJN2; Diakow and Webster, 1994). In general, these andesite flows are very easy to confuse with older andesites unless they are very close to distinctive Eocene rhyolitic rocks.

A sequence of crudely layered, flat-lying flows that unconformably overlie Eocene rhyolitic volcanics, mainly north of the Nechako Reservoir, is assigned to the Endako Group (Diakow *et al.*, 1993). They have been mapped intermittently to the southern boundary of the Natalkuz Lake area and, in the east, to the northeastern corner of the Chedakuz Creek area where they overlie Jurassic flows. Despite the appearance of basalt, major elements from a representative suite of these rocks indicate they are andesitic in composition. They also contain modal clinopyroxene and orthopyroxene.

The youngest volcanic rocks in the study area are olivine basalt flows of the Chilcotin Group. Their distribution is most widespread in the southern part of the Fawnie Creek (93F/3) and Tsacha Lake (93F/2) areas where they underlie a relatively flat plain with pronounced escarpments at the erosional edge. In the study area, along the Nechako uplift, there appears to be only minor overlap of Endako and Chilcotin lavas. We suspect that the Nechako uplift may have acted as a topographic barrier to

Chilcotin lavas encroaching from the south and Endako lavas from the north. An overlap of these successions may occur along the southern boundary of the Natalkuz Lake area where Endako flows are exposed below topographically higher and more northerly exposures of Chilcotin lavas. Field evidence for a direct contact relationship was anticipated in the broad northwest-trending valley that lies between the Fawnie and Nechako ranges. Instead the lava sequences are widespread at the opposite ends of the valley, and Jurassic and Lower Cretaceous rocks are exposed in the central area. High on the western flank of the Nechako Range, at nearly 1350 metres elevation, an unexpected exposure of Chilcotin lava caps a granitic pluton. In this instance and another reported in the Naglico Hills (Diakow and Webster, 1994, p. 23) these young flows (*ca.* Miocene to Pliocene) occur well above exposures in valley bottoms at about 1150 metres elevation. This difference in elevation is believed to reflect block faulting.

MINERAL POTENTIAL

The Nechako Plateau is underlain by a prospective geological environment favourable for a variety of economic mineral deposit types. Porphyry deposits such as Endako, Fish Lake and Gibraltar occur peripherally as do epithermal precious metal deposits such as Blackdome and Silver Queen. Deposits that comprise a range of high-temperature polymetallic replacement lenses and disseminations, such as Equity Silver, also occur in the region.

These various mineral deposit types are repesented on the Nechako Plateau by the Wolf (MINFILE 93F 045) and the Tommy (MINFILE 93F 055) epithermal and the Capoose "transitional" prospects. The CH (MINFILE 93F 001, 004) and Ben (*see* Lane and Schroeter, 1995, this volume) porphyry prospects occur on 93F/7, in the Nechako Range, and the PEM (Blackwater-Davidson, MINFILE 93F 037), possibly transitional, prospect occurs in the Fawnie Range of 93F/2. Other occurrences include prospects on Tsacha and Kuyakuz mountains and a diatomite showing (MINFILE 093F 041) on the south side of Tsacha Lake.

There is good potential for a variety of deposit types, especially intrusion-related occurrences, to exist in the Jurassic Naglico formation that underlies the Fawnie and Nechako ranges. Lake sediment geochemical data (Cook and Jackaman, 1994a b) indicate numerous anomalous sites, plus, recently released areomagnetic data (Geophysical Data Centre, 1994) delineates potential near-surface intrusions in this area. These new data, including the surficial geology mapping (Giles and Levson, 1995 and Weary *et al.* 1995) and bedrock mapping (Diakow *et al.* 1995a, b) , could be instrumental in new discoveries.

TABLE 1. ANALYTICAL DATA FOR ASSAY SAMPLES COLLECTED ON NTS 93F/2 AND 7.

Field No.	UTM East	UTM North	Rock Description	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Th	Sr	Cd	Sb
			unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
IWE 13-2	397950	5912500	stratabound sulphides exposed in a trench	13	1193	81	51772	6.7	3	31	5850	17.17	19762	5	13	602	14
IWE 17-1	374650	5983450	disseminated and shear hosted pyrite in volcanic rock	4	89	146	2668	2.9	1	44	1689	5.58	41	4	8	7	2
IWE 22-9	399049	5889063	pyritic shears in basalt	19	171	2	534	0.1	37	36	809	5.31	6	2	44	1.5	2
IWE 24-3	384800	5922650	quartz veins in mudstones and siltstones	1	4	2	17	0.1	8	184	96	0.41	5	2	8	<0.2	2
IWE 24-5	383073	5921862	quartz veining and potassic alteration	4	2	4	17	0.1	1	48	223	0.27	191	5	3	<0.2	3
IWE 24-5	383073	5921862	quartz veining and potassic alteration	6	2	2	26	0.5	1	55	134	0.42	358	5	2	<0.2	5
IWE 24-5	383073	5921862	quartz veining and potassic alteration	7	1	2	15	0.2	2	63	47	0.4	172	5	2	<0.2	2
IWE 28-3	394350	5915650	pyritic laminated rhyolite	3	44	6	65	0.1	3	52	491	3.85	9	2	37	<0.2	2
JWH 7-4	395225	5913956	pyrite and chlorite bearing hornfels	2	52	2	83	0.1	2	31	598	4.29	7	3	47	<0.2	2
JWH 9-2	368750	5907050	pyrite and chalcopyrite in pyroxene porphyry	2	646	9	48	0.8	61	23	333	2.56	2	4	49	<0.2	2
JWH 9-3	369100	5906975	disseminated pyrite in maroon to green silicified rock	3	82	18	105	0.2	32	27	465	4.28	7	2	91	<0.3	2
JWH 16-1	375120	5985775	pervasively silicified zone with ~3% pyrite	5	88	6	1236	0.2	70	46	152	3.44	234	2	386	5.4	2
JWH 17-8	368214	5885863	gouge zone and quartz vein in intrusion	2	51	2	71	0.1	41	167	1655	10.84	13	4	10	<0.2	2
JWH 21-3	393050	5902080	quartz vein with malachite/pyrite at an intrusive contact	7	4611	59	41	18	21	21	331	2.81	7	2	94	<0.5	2
JWH 32-8	373604	5882916	altered maroon flows with quartz veining	2	7	11	24	0.1	1	21	305	1.12	4	5	4	<0.2	3
LDI 18-1	368121	5875599	quartz breccia with malachite in maroon flows	5	31647	16	8	51	1	23	304	0.76	29	2	167	<0.2	5

continued

Field No.		Bi	V	Ca	P	La	Cr	Mg	Ba	Ti	B	Al	Na	K	Au
	unit	ppm	ppm	%	%	ppm	ppm	%	ppm	%	ppm	%	%	%	ppb
IWE 13-2		8	25	0.56	0.023	2	8	0.21	14	0.01	2	0.5	0.01	0	##.#
IWE 17-14		5	20	0.33	0.058	15	4	0.28	53	0.08	5	1.4	0.04	<0.2	31
IWE 22-9		3	171	3.03	0.132	9	42	1.92	16	0.26	4	2.9	0.08	<0.1	13
IWE 24-3		2	5	0.05	0.004	2	11	0.11	16	0.01	10	0.2	0.01	0	5
IWE 24-5A		2	2	0.02	0.005	22	6	0.01	21	0.01	9	0.4	0.05	<0.2	23
IWE 24-5B		2	2	0.01	0.003	18	4	0.01	24	0.01	13	0.5	0.03	<0.3	65
IWE 24-5C	(see sample descriptions above)	2	2	0.03	0.006	22	5	0.01	25	0.01	12	0.5	0.02	<0.2	59
IWE 28-3		2	46	0.82	0.086	4	7	1.01	120	0.23	4	1.5	0.07	<0.3	9
JWH 7-4		3	140	0.78	0.095	3	3	1.61	92	0.38	2	1.9	0.19	1.6	1
JWH 9-2		2	94	4.27	0.127	9	55	1.98	61	0.16	10	3	0.07	<0.2	13
JWH 9-3		4	195	2.61	0.131	9	26	1.51	65	0.24	10	3	0.18	<0.3	4
JWH 16-10		4	15	5.31	0.107	3	12	0.12	48	0.11	4	7.2	1.05	0	19
JWH 17-8		5	163	0.33	0.130	2	34	3.1	12	0.03	3	3.7	0.02	0.1	3
JWH 21-3		321	62	1.9	0.117	7	42	1.08	15	0.17	4	1.2	0.05	0.1	57
JWH 32-8		2	3	0.06	0.010	22	2	0.01	165	0.01	4	0.3	0.01	0.3	1
LDI 18-1		19	10	3.44	0.002	3	1	0.02	100	0.01	5	0.2	0.01	0.1	1

Anatytical method: all elements by ICP from a 0.5 gram sample; Au by FA/ICP from a 20 gram sample.

Analytical results for grab samples collected during this bedrock mapping project are listed in Table 1. Samples 94IWE 24-5A, B and C of strongly bleached, potassically altered and quartz veined rock were collected from an approximately 25 by 25 metre, flat-lying outcrop. The three samples contain elevated gold abundance and interestingly high arsenic and manganese. There is potential for this alteration zone to extend, probably at shallow overburden depths, over a much larger area than is now exposed. Visible copper mineralization occuring at intrusive contacts was collected at stations JWH 17-8 and 21-3. Other samples, some of which are anomalous in copper, zinc and gold, are listed in Table 1: brief rock descriptions are included.

ACKNOWLEDGMENTS

We thank Dr. H.W.Tipper for his keen interest and geologic contributions to the project. He is responsible for identifying numerous fossil collections from this study, and re-assessing his own collections that date back to his original work in the Nechako River area during the early 1950s. Without this paleontological work, our attempts to subdivide and make sense of the Mesozoic rocks would have been significantly more difficult. It was a pleasure meeting Barry and Marian Mills and their entertaining family. We appreciated access to lodging and logistical support provided by the Mills family at their Tatelkuz Lake ranch. As usual Joyce, and Joe Meier of Northern Mountain Helicopters, kept the blades turning safely and on schedule. We also welcomed and benefited from discussions with prospectors and industry geologists working in the area.

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MINERAL OCCURRENCE INVESTIGATIONS AND EXPLORATION MONITORING IN THE NECHAKO PLATEAU (93F/2, 3, 7, 10, 11, 12, 14, 15 AND 93C/9 AND 16)

By R.A. Lane and T.G. Schroeter

KEYWORDS: economic geology, Nechako Plateau, epithermal, veins, silicification, structural control, breccia, bulk mineable, low sulphidation, quartz-adularia.

INTRODUCTION

This report summarizes preliminary investigations of eleven different mineral occurrences that were visited during the 1994 field season (Figure 1). Ten are located in the Nechako River map area (93F) and one in the Anahim Lake map area (93C). Metallogenic studies are part of a multidisiplinary project being carried out by the British Columbia Geological Survey Branch in the Nechako Plateau region of central British Columbia. The integrated project also includes regional-scale bedrock mapping, lake sediment sampling, surficial deposits mapping and till sampling. Since its inception, this project has raised the mining industry's awareness of the Nechako Plateau as an area that is underexplored. The potential of the region to host different styles of mineral deposits derives from its favourable geology, characterized by Jurassic Hazelton Group, Cretaceous Kasalka Group and Eocene Ootsa Lake Group stratigraphy, their genetically related intrusions and locally complex structural history. However, much of the geological record lies hidden beneath the low rolling, forested topography that is typical of the area, and a veneer of, locally, deceptively thin, glacial till.

In 1993, during the first full year of the project, many exploration targets were generated. Presentation of data and ideas to industry took place during the Cordilleran Roundup held in Vancouver in January, 1994. Included were bedrock gold anomalies discovered during the course of mapping the Fawnie Creek map sheet (93F/03; Diakow and Webster, 1994). The release of this information prompted an immediate response; staking of the occurrences began the following day. In June, 1994, the release of data from two regional surveys, lake sediment geochemistry (Cook and Jackaman, 1994) and till geochemistry (Levson and Giles, 1994), generated a wave of staking in the area. During the two months that followed the geochemistry releases, 708 claim units were recorded by eleven separate companies or individuals. Most of the new claims covered geochemical anomalies documented in the releases.

These contributions to the geoscience database for the Interior Plateau are, in part, responsible for the more than 1300 claim units staked in NTS 93F in 1994 (to mid-October), more than ten times the 1993 level, albeit a quiet year for staking in the area, and an increase of 35% over 1992 (Figure 2). Eight major companies, two junior companies and eight (or more?) prospectors and geologists were active in the region during the 1994 field season. The number of exploration projects in the area also increased, as did the level of exploration expenditures. Approximately 6500 metres of diamond drilling was completed during the summer, in fifty holes by four companies on six properties. Fall and/or winter drilling programs are planned for at least three more properties. Diamond drilling was not part of any exploration project in 1993.

Our understanding of the region continues to evolve as new information comes to light and refinements are made to existing databases. For example, the age of two intrusive bodies previously mapped as Upper Jurassic and/or Cretaceous, has been reinterpreted on the basis of new K-Ar data. One pluton, the Capoose batholith, has been confirmed as Jura-Cretaceous and the other, north of Tatelkuz Lake, has been assigned an Eocene age (L. J. Diakow, personal communication, 1994). These two periods of igneous activity are in addition to an event that occurred during the Late Cretaceous (Andrew, 1988) and may be related to alteration and mineralization at the Capoose prospect.

MINERAL OCCURRENCE DESCRIPTIONS

This year's work builds on information presented by the authors in 1992 and 1994 that described several different styles of mineralization (Schroeter and Lane, 1992; 1994). Several of those occurrences were re-visited in 1994. A brief description of each mineral occurrence investigated during the summer is presented below and summarized in Table 1. Included is a

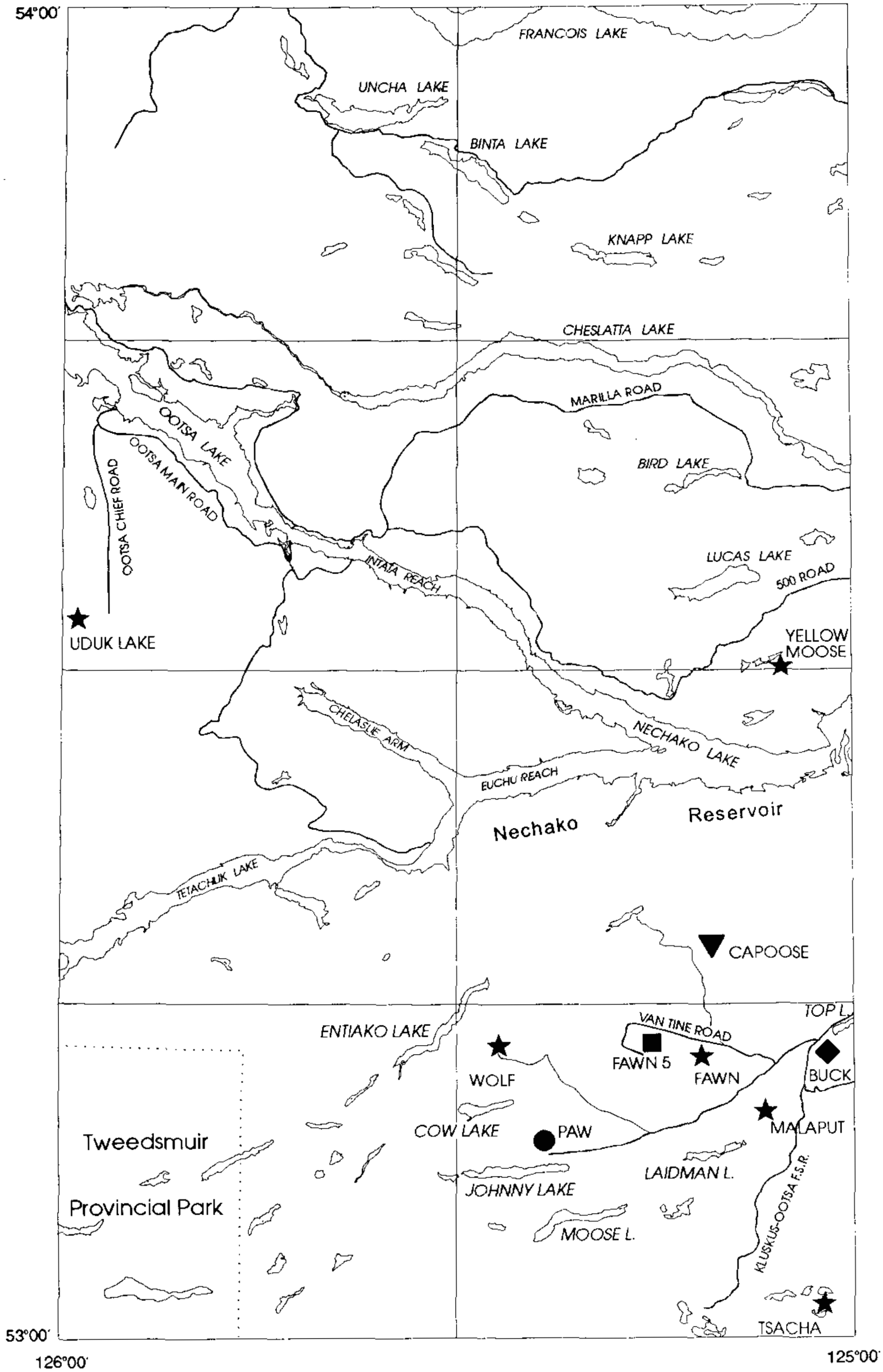


Figure 1. Location of metallic mineral occurrences on the Nechako Plateau visited in 1992, 1993 and 1994 (NTS 93F).

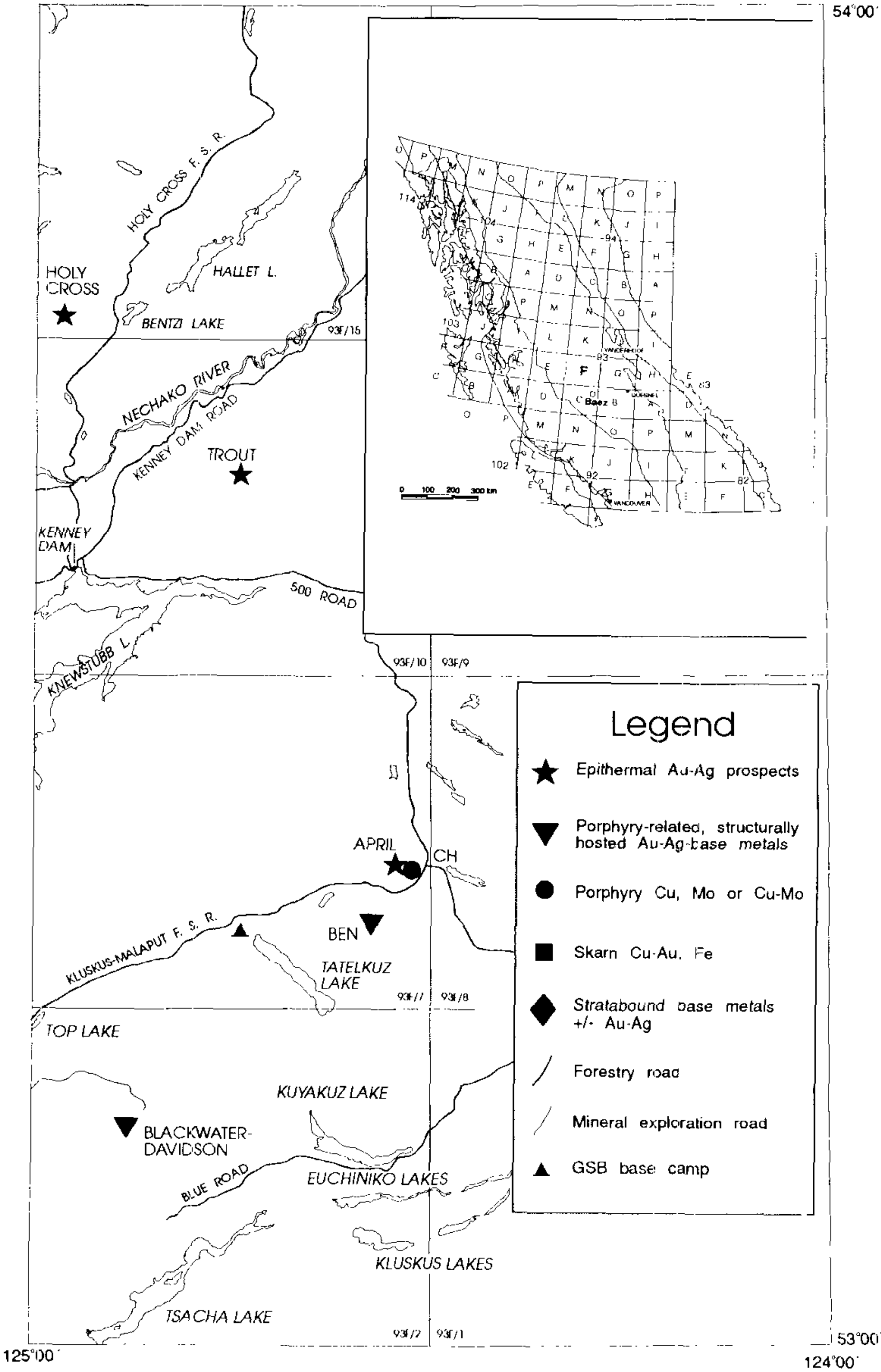

54°00'
HOLY CROSS F. S. R.
HALLET L.
HOLY CROSS
BENTZI LAKE
93F/15
NECHAKO RIVER
KENNEY DAM ROAD
TROUT
KENNEY DAM
500 ROAD
KNEWSTUBB L.
93F/10
93F/9
Legend
Epithermal Au-Ag prospects
Porphyry-related, structurally hosted Au-Ag-base metals
Porphyry Cu, Mo or Cu-Mo
Skarn Cu-Au, Fe
Stratabound base metals +/- Au-Ag
Forestry road
Mineral exploration road
GSB base camp
APRIL
CH
KLUSKUS-MALAPUT F. S. R.
BEN
TATELKUZ LAKE
93F/7
93F/8
TOP LAKE
KUYAKUZ LAKE
BLACKWATER-DAVIDSON
BLUE ROAD
EUCHINIKO LAKES
KLUSKUS LAKES
TSACHA LAKE
93F/2
93F/1
53°00'
125°00'
124°00'
0 100 200 300 km
VANCOUVER
Baez

TABLE 1. MINERAL OCCURRENCES INVESTIGATED IN 1994.

Property	Style of mineralization	Hostrock Age - Group	Map sheet	Operator
Tsacha (Tommy)	epithermal precious metal	Jurassic - Hazelton	93F/02	Teck Corporation
Buck	stratabound(?) or replacement precious-base metal	Jurassic - Hazelton	93F/03	Western Keltic Mines Inc.
Fawn	epithermal precious metal	Jurassic - Hazelton	93F/03	Western Keltic Mines Inc.
Malaput	epithermal precious and base metal	Jurassic - Hazelton	93F/03	Western Keltic Mines Inc.
April	epithermal precious and base metal	Jurassic - Hazelton	93F/07	Granges Inc.
Ben	struct.-hosted precious and base metal	Jurassic - Hazelton	93F/07	BHP Minerals Canada Ltd.
Trout	epithermal precious metal	Cretaceous - Kasalka	93F/10	Cogema Resources Inc.
Yellow Moose	epithermal precious metal	Eocene - Ootsa Lake	93F/11	Cogema Resources Inc.
Uduk Lake	epithermal precious metal	Eocene - Ootsa Lake	93F/12	Pioneer Metals Corporation
Holy Cross	epithermal precious metal	Eocene - Ootsa Lake	93F/15	Noranda Exploration Company, Limited
Baez (Oboy)	epithermal precious metal	Eocene - Ootsa Lake	93C/16	Phelps Dodge Corporation of Canada Ltd.

summary of a two-week, 1:15 000-scale preliminary bedrock mapping project in the Holy Cross Mountain to Bentzi Lake area (93F/14 and 15; including the Holy Cross mineral occurrence).

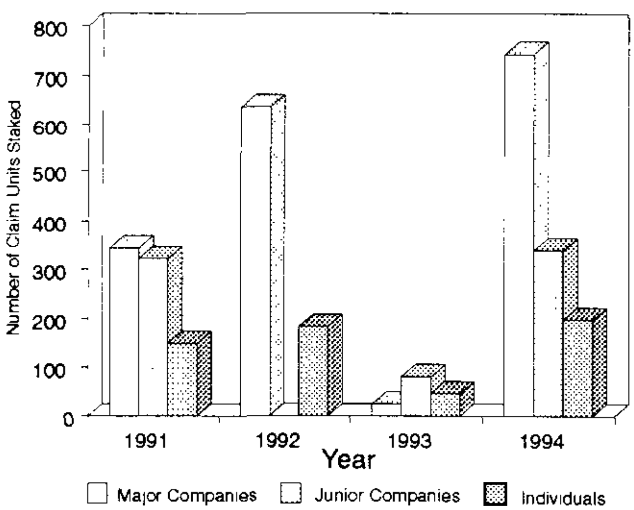


Figure 2. Histogram showing the number of mineral claims staked in the Nechako River map sheet (NTS 93F), by major companies, junior companies and individuals, from 1991 to 1994, inclusive.

More emphasis was placed on examining Tertiary Ootsa Lake Group acid volcanic hosted epithermal precious metal occurrences in 1994. Of the eleven occurrences visited, eight are epithermal in character and two more are possible epithermal settings. The remaining occurrence appears to be stratabound base metal target.

OOTSA LAKE GROUP EPITHERMAL PROSPECTS

HOLY CROSS (MINFILE: 093F 029) 93F/14E, 15W

The Holy Cross epithermal precious metal prospect was investigated as part of a property-scale (1:15 000) mapping project, undertaken by the senior author, between Holy Cross Mountain and Bentzi Lake (Figure 3). The project area is located approximately 33 kilometres south of Fraser Lake. The Holy Cross forest service road, which extends southward from Highway 16, 5 kilometres east of Fraser Lake, passes within 2 kilometres of the project area. Three secondary logging roads (the Holy Cross North, 37 and 40 roads) extend westward into the area mapped. A 4-wheel-drive road extends farther west from the end of the 37 road to an abandoned exploration camp and several trenches.

The area of interest includes a large part of the now lapsed HC claim group, an area that was the focus for exploration by Noranda Exploration Company, Limited during 1988 and 1989. The claims covered gold anomalies defined by rock chip samples of silica-flooded rhyolite (Donaldson, 1988). Exploration by Noranda included geochemical surveys, magnetometer and I.P. surveys, geological mapping and the excavation of 26 trenches (Donaldson, 1988; Barber, 1989). There is no record of exploration prior to Noranda's activity.

Topography consists mostly of gentle rolling to moderately steep slopes. Elevations in the area range from 850 to 1410 metres. Outcrop is concentrated mostly on ridge crests and steep south-facing slopes and covers 5 to 7% of the map area. Extensive logging has made outcrops in low-lying areas more obvious and accessible. Road building has generated additional exposures.

The oldest rocks exposed in the area are Middle Jurassic Hazelton Group intermediate volcanics. They occur along the north-facing slopes and low-lying areas in the northern part of the map area. Lithologies include reworked andesitic crystal tuffs and plagioclase-phyric flows. These rocks have been thermally metamorphosed to a fine-grained mottled pale pink and green rock with relict plagioclase phenocrysts where they are intruded by a biotite quartz monzonite plug.

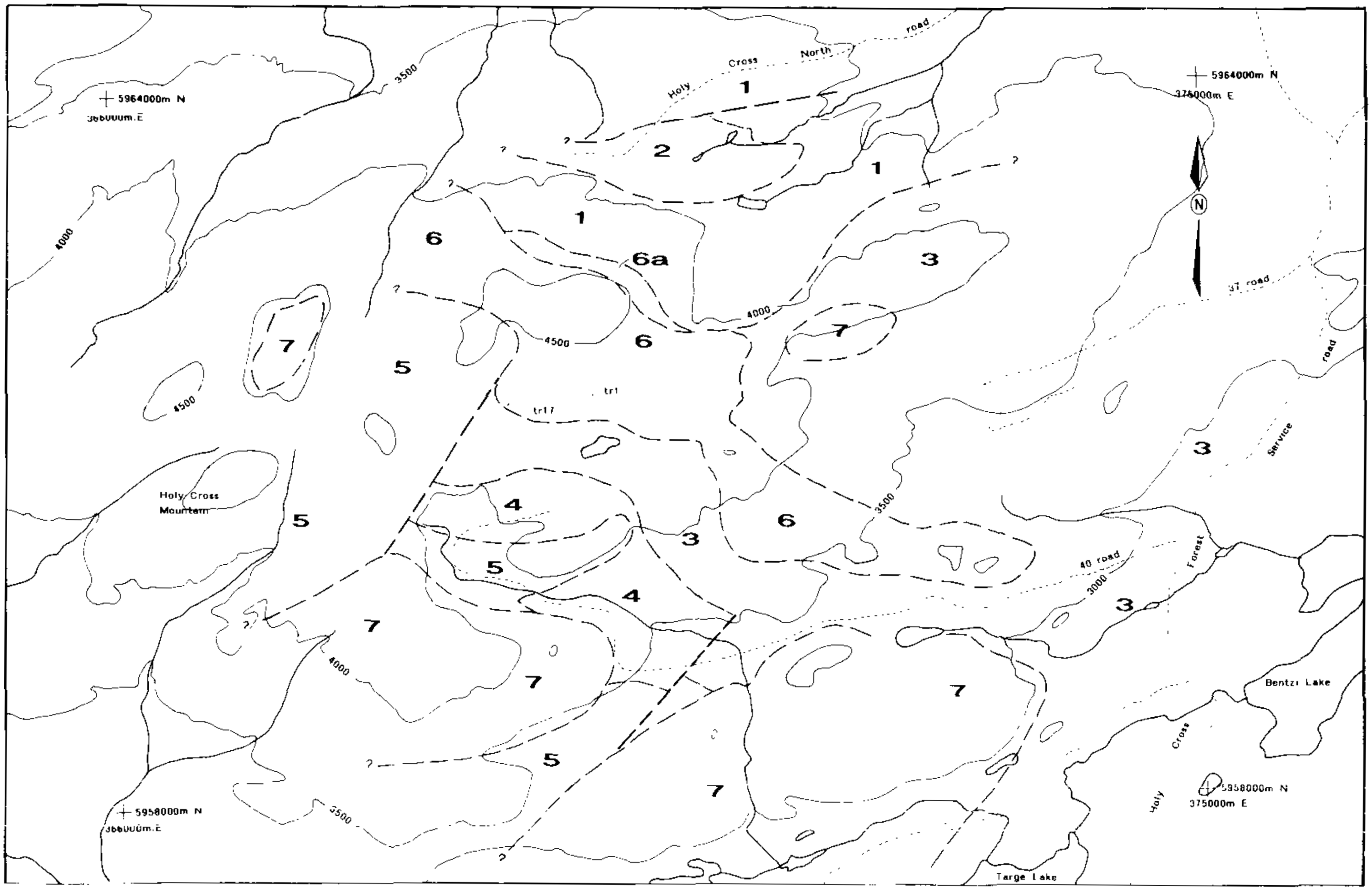
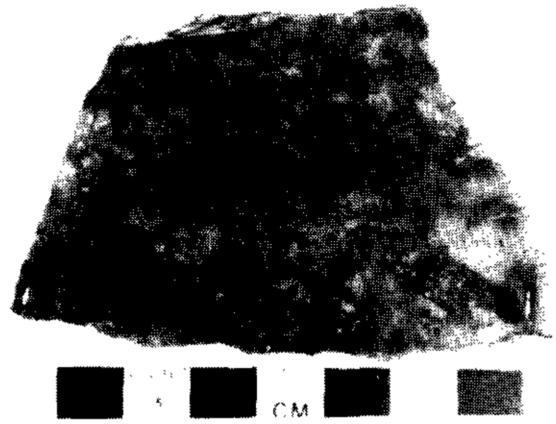


Figure 3. Preliminary bedrock geology map of the Holy Cross Mountain to Bentzi Lake area, southeast corner of NTS map sheet 93F/14E and southwest corner of 93F/15W. 1=Jurassic Hazelton Group; 2=Jura-Cretaceous biotite quartz monzonite; 3=Cretaceous Kasalka Group; 4=Cretaceous 'Skeena Group' equivalent; 5=unnamed Cretaceous(?) hornblende dacite; 6=Eocene Ootsa Lake Group; 7=Tertiary Endako Group. Heavy dashed lines=geologic contacts; fine stippled lines=roads; |···· |=locations of trenches referred to in text.



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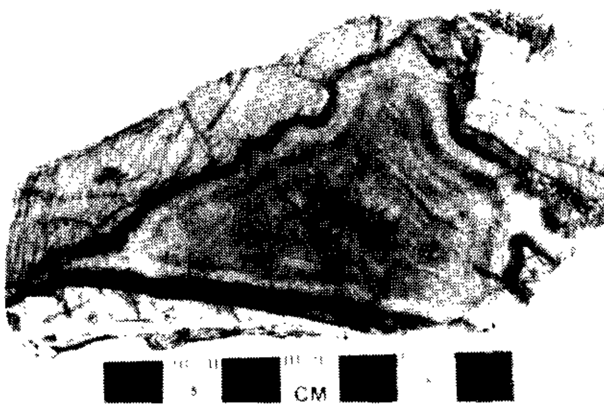

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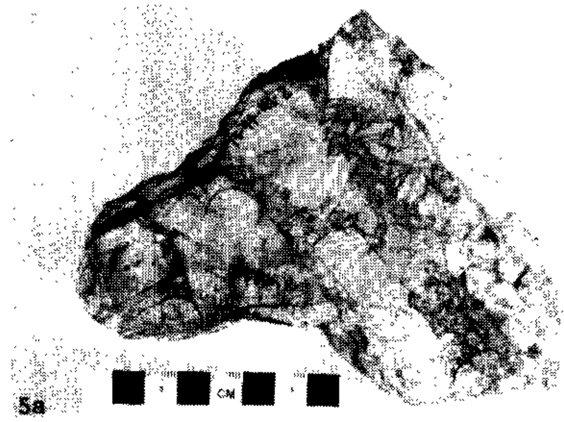

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Photo 1. Brecciated and intensely silicified rhyolite with traces of pyrite (py) from trench 1, Holy Cross epithermal gold-silver prospect.
Photo 2. Banded hematitic quartz vein cutting flow-banded rhyolite from trench 17, Holy Cross epithermal gold-silver prospect.
Photo 3. Slab of flow-banded rhyolite that shows early pervasive hematite flooding (dark grey areas). The formation of pyrite as disseminated cubic euhedra is evidence of sulphidization. Pyrite and fractures are enveloped by bleached, clay-altered hostrock.
Photo 4. Shallow trench exposing bleached, clay and silica-altered rhyolite at the Uduk Lake epithermal gold-silver prospect.
Photo 5. a) Brecciated rhyolite cemented by pyritic, chalcedonic and drusy quartz, and b) pyritic, dark grey chalcedonic quartz stockworks in brecciated rhyoite from trench 3, Uduk Lake epithermal gold-silver prospect.

The biotite quartz monzonite intrusion is salmon coloured, medium grained and contains from 3 to 4% weakly chloritized biotite. It may be correlative with the Jura-Cretaceous Francois Lake suite of intrusions that crops out predominantly to the north of the map area. Potassium-argon dating of a biotite separate from the intrusion is in progress.

Maroon to purple andesitic volcanic flows, probably part of the Late Cretaceous Kasalka Group, unconformably overly the Hazelton Group. They are overlain by apparent Skeena Group equivalent chert-pebble conglomerates. A hornblende dacite to andesite flow overlies the conglomerate. The hornblende phenocrysts are very weakly altered and are suitable for K-Ar dating; a sample has been submitted to the University of British Columbia for this purpose.

Maroon to pale-coloured flow-banded rhyolites and rhyolite breccias of the Eocene Ootsa Lake Group form a ridge that trends northwesterly across the map area (Figure 3). Andesite to basalt flows of the Tertiary Endako Group and related diorite to gabbro plugs and necks form resistant knobs to the south.

The Holy Cross mineral occurrence is an epithermal gold-silver prospect. The best gold values on the property were obtained from trench 1 where an 8.5-metre section of brecciated and intensely silicified rhyolite with 1 to 2% very fine grained, disseminated pyrite (Photo 1) averaged 0.51 g/t Au and 4.3 g/t Ag, including a 2-metre interval that graded 2.64 g/t Au and 9.7 g/t Ag (Donaldson, 1988). Manganese, limonite and hematite typically coat fracture surfaces in the massive grey crystalline silica. Other anomalous areas such as trench 17, contain banded hematitic quartz veins and stockwork zones hosted by flow-banded rhyolite (Photo 2). Barren or weakly anomalous quartz-stockwork zones are commonly associated with weakly to moderately argillically altered wallrock, reflecting a less intense, possibly more protracted event. Sulphide mineralization in these areas is very weak or absent. Pervasive hematitic alteration has stained andesites and rhyolites dark maroon or purple. Sulphidization appears to be a post-hematite event and has resulted in the development of up to 4% disseminated cubic pyrite euhedra (Photo 3). Pyrite cubes are commonly enveloped by bleached zones one to three times the size of the pyrite grain.

Sparse copper mineralization, consisting of trace to 1% chalcopyrite in quartz-carbonate veinlets, in Hazelton Group volcanic rocks may be genetically related to the biotite quartz monzonite intrusion. However, chalcopyrite also occurs in quartz-carbonate veins in younger rocks spatially unrelated to the quartz monzonite.

UDUK LAKE (MINFILE: 093F 057) NTS 93F/12W

The Uduk Lake epithermal gold-silver prospect, under exploration by Pioneer Metals Corporation, is located approximately 70 kilometres south-southwest of Burns Lake. Access to the property is along all-weather forestry roads that lead south from Burns Lake and Fraser Lake to Ootsa Lake. A ferry, run by West Fraser Sawmills Ltd., crosses the west end of Intata Reach and connects with the Ootsa Main and newly constructed Ootsa Chief logging roads that pass within 2 kilometres of the showings. A trail extends eastward to the occurrence from about the 34.5-kilometre point on the Ootsa Chief logging road (Figure 1).

The property was originally staked in 1981 by Amax Exploration Ltd. which carried out reconnaissance mapping and sampling but allowed the claims to lapse. Several junior companies explored the ground during the mid and late 1980s. Several modest diamond drilling programs tested silica stockwork zones with gold values in the range of 0.02 to 1.45 grams per tonne (Allen and MacQuarrie, 1985).

Pioneer Metals optioned the property from Pacific Comox Resources Ltd. in 1993 and carried out soil and rock geochemical surveys. Results outlined six gold-silver-arsenic anomalies that were trenched in 1994. Five of the six trenches sampled were anomalous in gold. Results included a 6-metre section grading 1.4 grams per tonne and an entire 42-metre trench averaging 0.41 gram per tonne (D. S. Dunn, personal communication, 1994).

The Duk claims cover a large (>2 km wide) area of hydrothermally altered rhyolitic to dacitic flows, tuffs and breccias of the Eocene Ootsa Lake Group (Dunn, 1993). Outcrop on the property is sparse, however, bedrock is commonly within 1 or 2 metres of the surface (Photo 4). A zone of clay and silica-altered rhyolite in angular float and outcrop, measuring about 600 by 200 metres, occurs in the southwestern part of the property. The 1994 trenches expose moderately to intensely clay-altered (kaolinite?) rhyolite flows, tuffs and lapilli tuffs. Weak silicification is accompanied by a quartz-chalcedony± sulphide stockwork that locally grades into a more sulphide-rich, black-matrix breccia with angular rhyolite clasts that are rimmed with a thin layer of chalcedony (Photo 5). Pyrite is the only sulphide mineral observed and occurs mainly in vein, stockwork and breccia zones and less commonly as weak disseminations in altered rhyolite. It is present in trace amounts ranging up to 5% locally. Grab samples typically grade over 1 g/t Au and have assayed as high as 5.7 g/t Au (D. S. Dunn, personal communication, 1994).

Exploration will continue in 1995 and plans include additional trenching and a follow-up diamond drilling program.

YELLOW MOOSE (MINFILE: 093F 058) NTS 93F/06, 11)

Cogema Resources Inc.'s Yellow Moose epithermal gold prospect was briefly investigated. The property is located south of Arrow Lake, about 20 kilometres west of the junction of the 500 road and Holy Cross road, approximately 110 kilometres southwest of Vanderhoof (Figure 1). The showings are accessible from the Knewstubb access road.

The Gus zone consists of diffuse silicification and minor quartz-chalcedony veining in brecciated rhyolite and crystal tuff to crystal lapilli tuff. Northeast-trending mineralized zones, consisting of narrow veins, stockworks and breccias carry 1 to 2% fine-grained disseminated arsenopyrite, stibnite and pyrite in intensely fractured rhyolite. Gold assays up to 0.8 g/t Au have been reported (Bohme, 1988). Clay alteration of hostrocks is pervasive. Fractures are coated with iron and manganese oxide.

The Arrow showing is on the southeast shore of the lake and was not examined. It is reported to consist of drusy quartz veins and chalcedonic quartz flooding in siliceous rhyolite and arkosic sandstone that contain coarse-grained stibnite, pyrite, marcasite and traces of cinnabar (Bohme, 1988). The showing carries negligible gold or silver values.

A third zone, an I.P. anomaly called the IPA zone, and the Gus showing, were evaluated by a six-hole, 626-metre diamond drilling program in 1994. Drilling outlined a northeasterly trending, weakly mineralized zone that dips moderately to the east (K. Schimann, personal communication, 1994).

BAEZ (OBOY - MINFILE: 093C 015) NTS 93C/9E, 16E

The Baez property (including the Oboy occurrence) is owned by Phelps Dodge Corporation of Canada Ltd. The claim group is located 125 kilometres west of Quesnel and covers more than 10 500 hectares (Figure 1). It adjoins the western boundary of the Clisbako property (Schroeter and Lane, 1992) owned by Eighty-Eight Resources Ltd.

The Baez claims were staked in 1992 and 1993 as a result of a reconnaissance stream sediment sampling program initiated in 1992 (Goodall, 1994). In 1993, reconnaissance soil sampling on four grids (A, B, C and D) produced several multi-element (Ag-As-Sb-Au-Hg) anomalies. In 1994 approximately 50 line-kilometres of soil sampling and about 50 line-kilometres of induced polarization survey were carried out on grid D. Prospecting, mapping and diamond drilling followed. The exploration target is a large, low-grade, heap leachable, epithermal gold deposit.

The property is underlain by a sequence of rhyolites, dacites, andesites and basalts of the Eocene Ootsa Lake Group. Outcrop on the property is sparse. Rhyolitic tuffs, flows and breccias that form the base of the Eocene succession on the property are the main hostrocks for mineralization (G. N. Goodall, personal communication, 1994). One of the targets is a north-trending multi-element soil geochemistry anomaly 800s metre wide by 1800s metre long. This anomaly is coincident with airborne EM and resistivity anomalies and a pronounced magnetic lineament.

Mineralized sections of core from the 1994 drilling program consist of bleached and clay-altered, fractured dacite to andesite. Fractures are filled with fine-grained silica and cored by fine-grained subhedral pyrite and/or marcasite. Pyrite also occurs disseminated throughout the wallrock as 2-millimetre and smaller euhedral cubes. Total pyrite content is estimated at 1 to 2%. Pervasive chlorite-calcite alteration, typical of the Baezeko River area, is widespread.

The Oboy epithermal gold prospect is about 8 kilometres west of the main target area on the Baez property. Outcrop is sparse in this area, but we examined core stored on the property from a 1987 drilling program by Lornex Mining Corporation Ltd., in joint venture with Canadian Nickel Company Ltd., on the Camp zone (Cann, 1987). Hostrock lithologies are pale green (bleached) flow-banded andesite and green and purple mottled felsic to intermediate pyroclastic breccia of the Eocene Ootsa Lake Group. Argillic alteration is moderate to intense and imparts a 'chalky' texture to the rocks. Mineralization consists of 2 to 5% fracture-controlled, fine-grained pyrite that occurs in a gangue of drusy quartz, calcite and chlorite. Disseminated, epigenetic pyrite cubes up to 2 millimetres across occur throughout the length of the holes. Several core samples were selected to compare mineralization and alteration styles with other prospects in the Interior Plateau region.

KASALKA GROUP EPITHERMAL PROSPECTS

TROUT (MINFILE: 093F 044) NTS 93F/10W

The Trout epithermal precious metal occurrence is located 90 kilometres southwest of Vanderhoof, on the Cutoff property, owned by Cogema Resources Inc. The property is accessible from the Kenney Dam road which extends to the southwest from Vanderhoof (Figure 1). Approximately 2 kilometres north of Cutoff Creek, at the River Ranch, an 8-kilometre, 4-wheel-drive road leads southward to the camp and main showing area.

The property is underlain by felsic to intermediate volcanic and sedimentary rocks of the Jurassic Hazelton

Group, Cretaceous Kasalka Group, Eocene Ootsa Lake Group and Tertiary Endako Group. Two prominent lineaments, a northeast-trending structure and a southeast-trending feature, intersect in the Swanson Creek valley near the main showing (Potter, 1985).

Epithermal quartz-adularia veins and gold-silver mineralization were discovered in 1984 during regional exploration for precious metals (Potter, 1985). Subsequent exploration of the property including drilling in 1985, 1987 and 1990, targeted mainly on the 'discovery' zone, failed to trace the mineralization. In 1992 Cogema Resources Inc. staked the ground and a multiparameter (VLF-EM, magnetics and resistivity) geophysical survey was flown in March, 1993. Eleven diamond-drill holes totalling 1221 metres were completed in 1994 (K. Schimann, personal communication, 1994).

The 'discovery' or 'main' zone crops out southwest of Swanson Creek, and south of the camp, in a swampy valley bottom. The exposure is a northeast-trending ridge of rock, 50 metres long, 12 metres across and about 4 metres high. It consists mainly of pyroclastic breccia and overlying polymictic conglomerate of the Kasalka Group. The shallow southwest-dipping contact between the breccia and conglomerate acted as a conduit channelling mineralizing hydrothermal fluids. The hangingwall is flooded with silica and the footwall is pervasively silicified for about a metre below the contact.

Pyroclastic breccia is mottled green and maroon. and consists mainly of locally derived Kasalka Group maroon volcanic material. Clasts tend to be subangular, feldspar phyric and range in size from 3 to 10 centimetres. The breccia contains quartz veins up to several centimetres wide that have an average orientation of 050/80°SE. Veins are banded and consist of several phases of pale brown to cream and clear chalcedonic quartz. Many veins also contain drusy cavities and bladed textures (quartz after calcite or possibly barite). Sulphide minerals were not identified in the veins, but there is 1 to 2% disseminated pyrite in the hostrock.

Polymictic conglomerate overlies the pyroclastic breccia with apparent conformity. Clasts in the conglomerate are pebble to cobble sized and well rounded, possibly milled, and consist of locally derived sedimentary, volcanic and intrusive lithologies. Clasts are rimmed and cemented by banded chalcedonic quartz-adularia veins up to 8 centimetres wide (Photo 6). Samples from a 5-metre trench across the outcrop averaged 19.5 g/t Au (Schmidt, 1987).

Visible mineralization consists of traces of very fine grained pyrite and a tarnished steel-grey mineral (possibly argentite) that comprise dark grey bands 0.5 to 2 millimetres wide, and rare disseminated pyrite grains, within the quartz-adularia veins. Dark grey features, 0.5 millimetres wide by 2 to 3 millimetres long and comprised of very fine grained pyrite and possibly other metallic minerals, are oriented oblique to the clast margin in bands of white translucent fine-grained quartz closest to the clasts. Micron-size native gold and argentite have been identified in thin section (Potter, 1985).

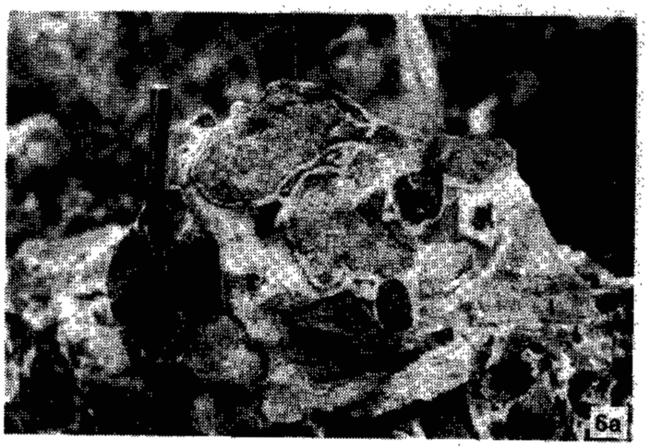
The textures and style of mineralization are similar to the Tertiary Cinola gold deposit, Queen Charlotte Islands that contains a resource of 40.7 million tonnes grading 1.65 g/t Au (Tolbert and Froc, 1988).

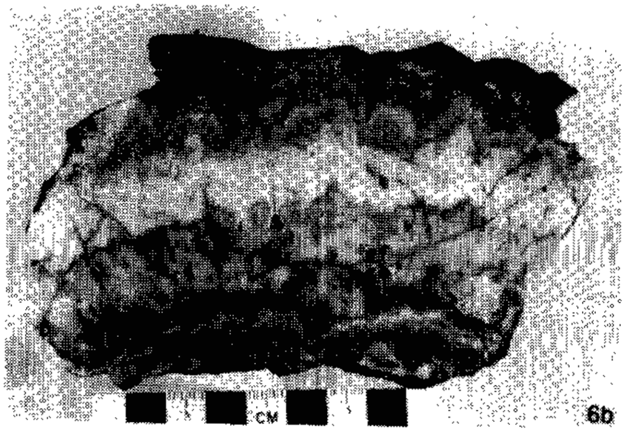
HAZELTON GROUP EPITHERMAL PROSPECTS

FAWN (MINFILE: 093F 043) NTS 93F/03E

The Fawn property is located approximately 120 kilometres southwest of Vanderhoof. It consists of seven claims totaling 140 units covering the east end of the Entiako Spur of the Fawnie Range. The claims are underlain mainly by Lower to Middle Jurassic Hazelton Group felsic to andesitic plagioclase-phyric flows, lapilli tuffs and minor argillaceous sedimentary rocks. The stratified rocks are weakly to moderately metasomatized and locally hornfelsed. Skarn mineral assemblages (diffusion skarn), consisting of garnet, pyroxene, biotite, quartz, epidote and chlorite, are locally developed in the thermal aureole of the Jura-Cretaceous Capoose batholith. Hazelton rocks may be a relatively thin cover overlying these intrusions that are exposed both north and south of Entiako Spur. A granodiorite to diorite stock, probably related to the batholith, and Eocene(?) felsic dikes, locally cut the stratified rocks.

In 1994, Western Keltic Mines Inc. conducted a six-hole, 617-metre drilling program to test Giver zone mineralization, and VLF-EM and arsenic-zinc-lead-silver soil anomalies that were outlined during exploration programs carried out in 1991 and 1993. Of particular interest was the Giver zone, where samples of clay and sericite-altered volcanic rocks, cut by quartz-sulphide breccia and stockwork zones (Photo 7), graded 0.6 g/t Au, 7.1 g/t Ag and 914 ppm As across 8.2 metres (Awmack, 1991). Two holes, drilled to intersect the Giver zone at depth, cored about 20 metres of pervasively clay and sericite-altered andesite. Significant widths of siliceous breccia and stockwork mineralization occur within the alteration; an 8.1-metre intercept in one hole assayed 2.02 g/t Au and 25.2 g/t Ag (Baknes and Awmack, 1994b). A third drill hole intersected similar alteration and mineralization 160 metres farther to the





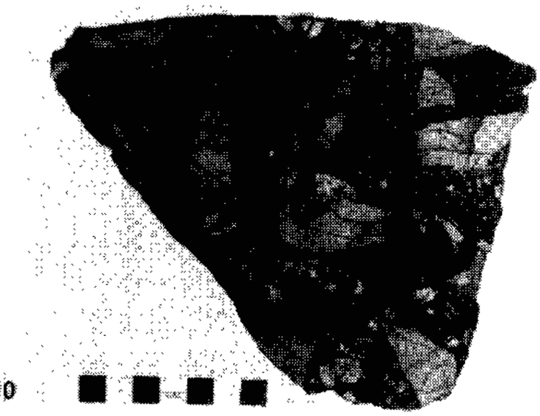


Photo 6. Two samples of epithermal-style mineralization from the 'discovery' outcrop, Trout property: a) Polymictic conglomerate showing well rounded pebbles and cobbles cemented by numerous phases of chalcedonic quartz and adularia; b) 8 centimetre wide banded quartz-adularia vein from the contact between polymictic conglomerate and pyroclastic breccia.

Photo 7. Cut and polished grab sample from the Giver zone surface exposure, Fawn epithermal gold-silver prospect. Bands of fine-grained sulphide, that rim silicified andesite clasts, are composed pyrite and arsenopyrite.

Photo 8. Diamond-drill core specimen from the Giver zone, Fawn epithermal gold-silver prospect. Chalcedonic and comb quartz, barite blades (ba) cement intensely silicified volcanic clasts. Dolomite rhombs (do) locally line drusy cavities.

Photo 9. Exposure of massive, fractured vein quartz on the Tsacha epithermal gold-silver property.

Photo 10. Rhyolite breccia from the Christmas Cake base metal silver showing, Buck property. Angular clasts of rhyolite are cemented by semimassive to massive sulphide intergrowths consisting of sphalerite, pyrrhotite, pyrite and galena.

west and helped outline the steeply north-dipping, east-trending zone of siliceous breccia.

Breccia zones consist of grey, intensely silicified and brecciated lapilli tuff. Sulphide content is about 1%, and consists mostly very fine grained pyrite that occurs as wispy coatings on angular clasts and as 2-millimetre and smaller irregular patches distributed throughout matrix and clasts. Traces of fine-grained acicular arsenopyrite partly replace clasts. Sphalerite and an unidentified steel-grey mineral occur in trace amounts. Chalcedonic quartz is the dominant gangue mineral and is cut by comb quartz and late calcite veinlets. Quartz-lined drusy cavities commonly contain rhombs of white dolomite, clusters of subhedral to euhedral barite and rare grains of sphalerite and possibly ruby silver (Photo 8).

MALAPUT (MINFILE 093F 056) NTS 93F/03E

The Malaput epithermal showing was discovered by a Geological Survey Branch regional mapping crew in 1993 (Diakow and Webster, 1994). Western Keltic Mines Inc. staked the ground shortly after information was released at the 1994 Cordilleran Roundup. The new claims adjoin the company's Fawn claims to the north (Figure 1).

The occurrence is a weakly mineralized, east-trending zone of quartz and sericite-altered felsic volcanic rock that crops out along an abandoned drainage channel that dissects the property. The rock is pale greenish white with locally well developed, delicate silica stockwork. Rare primary textures include lapilli-size lithic fragments, quartz eyes and an eastward-trending weakly developed fabric that may be relict flow banding. Fractures are coated with earthy hematite and/or pyrolusite.

The altered zone is weakly anomalous in gold, silver and base metals. Sulphide mineralization consists of traces of pyrite, sphalerite and galena associated with crosscutting calcite veinlets. The zone has been traced for over 300 metres along strike and a width of 25 to 30 metres.

TSACHA (TOMMY - MINFILE: 093F 055) NTS 93F/03E

A Geological Survey Branch regional mapping party discovered several epithermal quartz vein and stockwork zones in the Tommy Lakes area in 1993 (Figure 1). The veins crop out on hummocky, moss-covered knobs. The Tsacha 16-unit claim block was staked by Teck Corporation immediately following the release of information at the 1994 Cordilleran Roundup. The ground surrounding the discovery is now covered by claims owned by several different companies.

The Tommy Lakes area is underlain by Middle Jurassic Hazelton Group quartz and feldspar-phyric rhyolitic flows and minor ash-flow tuffs (Diakow and Webster, 1994).

In 1994 a program consisting of soil geochemistry, prospecting, trenching and rock chip sampling was conducted over the 'discovery' outcrops. The first of at least two massive white, crystalline quartz veins, crops out approximately 600 metres southwest of the easternmost Tommy Lake. This vein is 0.75 metre wide, sub-vertical and strikes approximately 020° (Photo 9). The second vein, at least 5 metres across including stringer zones, crops out farther to the southwest and has a similar orientation and a minimum strike length of 700 metres. Sulphide content of the veins is less than 1%. Traces of pyrite, chalcopyrite and tetrahedrite have been identified. Vague bands of earthy hematite and sparse malachite are minor vein constituents. Grab samples of typical vein material ranged in grade from 2.5 to 3.7 g/t Au and 1.4 to 41.8 g/t Ag (L. J. Diakow, personal communication, 1994).

In general the veins trend northerly and the system appears to plunge to the north. Evidence for this is a southward increase in brecciation, banding and drusy cavities, the presence of multistage brecciation, and an increase in the amount of quartz stringers outside the main vein and in the intensity of clay alteration in the wallrock.

Vein structures are open along strike to the north and south. Similar veins have been discovered on the Cogema Resources' Tam claims that cover ground along strike to the northeast. Teck plans to continue its trenching program into the fall of 1994. Potential for discovery of additional veins is considered to be excellent.

BEN (MINFILE: 093F 059) NTS 93F/07E

The Ben precious metal occurrence (Figure 4) is located approximately 5 kilometres north of Tatelkuz Mountain and is accessible from the Kluskus-Ootsa forest service road and Yellow secondary logging road. The property, owned by BHP Minerals Canada Ltd., comprises 50 claim units that were explored during 1991 and 1992.

Mineralized outcrops were discovered during reconnaissance exploration for volcanogenic massive sulphide deposits in 1991 (Wesa and St. Pierre, 1992). Exploration focused on quartz-sulphide zones that are hosted by intermediate flows, related pyroclastics and siltstones of the Hazelton Group. These rocks are intruded by plutons of at least two ages: an Eocene biotite hornblende granodiorite, and an older (Jura-Cretaceous?) monzonite. The east-trending body of Eocene granodiorite underlies the northern half of the property and truncates the older rocks. A northwesterly trending, steeply southwest dipping foliation cuts the older rocks. Hazelton Group rocks are commonly hornfelsed near contacts with the intrusions and contain up to several percent biotite, which gives the rock a brown to purplish cast.

Precious and base metal mineralization occurs along a north-facing slope within foliated rocks 200 to 300 metres south of the contact with Eocene granodiorite. Three showings, the Hooter, Shawn and Creek showings, crop out along a trend of approximately 150°, over a strike length of 80 metres within a zone of quartz-biotite-altered felsic tuff. Mineralization appears to parallel the foliation at 140°-150°. Disseminated to locally semimassive quartz-sulphide veins or seams contain arsenopyrite, pyrite and pyrrhotite, and traces of chalcopyrite, galena and sphalerite. A 3.0-metre chip sample across the Hooter showing assayed 0.7 g/t Au, 95 g/t Ag and 0.2% Pb; a 10-centimetre arsenopyrite-pyrite-quartz vein in biotite monzonite assayed 3.7 g/t Au and 5.2 g/t Ag (Wesa and St. Pierre, 1992). These zones are also anomalous in arsenic, zinc, antimony and bismuth. The highest gold value recorded on the property was from a polymetallic float boulder that assayed 12.4 g/t Au, more than 200 g/t Ag, over 1% arsenic and lead, and anomalous levels of zinc, antimony and copper (Wesa and St. Pierre, 1992).

Molybdenum occurs in trace amounts throughout the altered monzonite, as disseminations and coatings on fractures. It is commonly accompanied by traces of pyrite, pyrrhotite and arsenopyrite. The porphyry potential of the property has not been explored by the company, although occurrences several kilometres to the north (CH and Chu) have been investigated for porphyry molybdenum and copper deposits (Figure 4).

APRIL (MINFILE: 093F 060) NTS 93F/07E

The April precious and base metal showing is located 101 kilometres southwest of Vanderhoof. Access to the property is by the Kluskus-Ootsa forest service road that passes within 3 kilometres of the occurrence (Figure 1). A partly overgrown exploration road extends north-northwest the remaining few kilometres to the showing. Outcrop is sparse due to extensive glacial drift and forest cover.

The April showing is hosted by Jurassic Hazelton Group rocks about 1 kilometre north of an east-trending body of Eocene granodiorite (Figure 4). The hostrock is a grey-weathering, thinly bedded tuffaceous limestone that strikes 305° and dips steeply to the northeast.

The prospect is a lens or vein of massive to semi-massive sulphide that dips vertically and strikes at 320°. The vein is exposed discontinuously over a 15-metre strike length and varies in width up to a maximum of 1.8 metres. It pinches out abruptly to the north and is covered by overburden to the south. Subcrop of narrow quartz-pyrite-chalcopyrite veins occurs along strike to the south. Sulphide minerals present, in order of abundance, are: sphalerite, pyrrhotite, pyrite, galena, arsenopyrite and chalcopyrite.

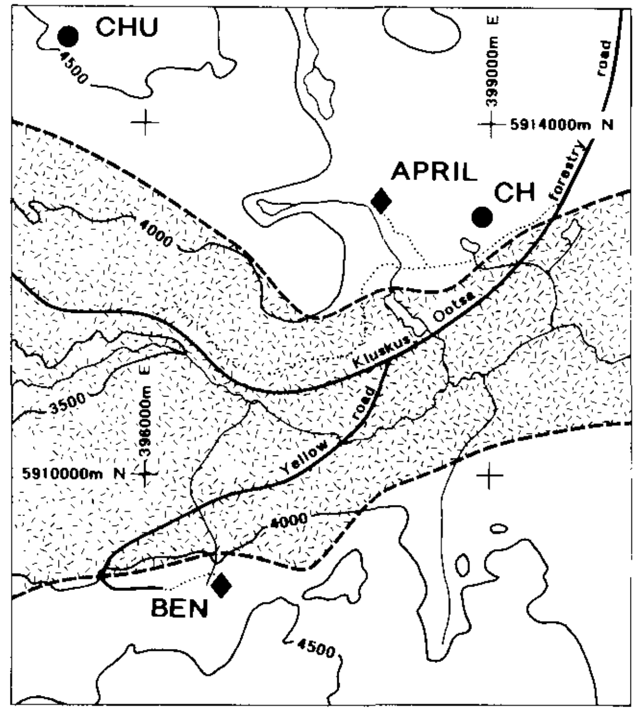


Figure 4. Location of April and Ben showings (diamonds) relative to an east-trending elongate body of Eocene granodiorite (stippled pattern with approximate contacts). Rocks to the north and south of the intrusion are Jurassic Hazelton Group intermediate volcanic and tuffaceous sedimentary rocks. Location of the Chu and CH molybdenum and coppper porphyry prospects (circles) are shown for reference.

The most recent work was a three-hole, 157-metre diamond drilling project conducted by Granges Exploration Ltd. in 1984 (Zbitnoff and Williams, 1985). The best assays from diamond drilling were 2.95 g/t Au, 4.0 g/t Ag and 0.77% Zn over 0.57 metre; and 1.4 g/t Au, 573.5 g/t Ag, 15.96% Zn and 15.83% Pb over 0.3 metre.

HAZELTON GROUP STRATABOUND (?) PROSPECTS

BUCK (MINFILE: 093F 050) NTS 93F/03E

The Buck property comprises 80 claim units that straddle Fawnie Creek and the Kluskus-Ootsa forest service road south of the junction of the Kluskus-Malaput and Kluskus-Ootsa forest service roads about 120 kilometres southwest of Vanderhoof (Figure 1). In early 1994, Western Keltic Mines Inc. completed a program that included soil sampling, mapping, prospecting, and magnetic and VLF surveys. This program followed exploration in 1992 that resulted in the discovery of stratabound pyrrhotite, pyrite and sphalerite mineralization called the Rutt zone (Caulfield, 1992).

The Buck claims are underlain by Lower to Middle Jurassic Hazelton Group felsic to intermediate flows and lapilli tuffs and fine to coarse-grained, locally fossilliferous volcaniclastics (Diakow and Webster, 1994). Regionally, these units are broadly folded. On the property, bedding typically strikes north-northeast and dips gently to the east. Post-Early Jurassic intrusions crop out in the south and northeast parts of the property.

The Rutt zone (Figure 5) crops out discontinuously and is exposed in several hand-excavated trenches along a northerly trend for about 450 metres (Caulfield, 1992). The true width of the zone has not been determined. Mineralization occurs in clay, sericite, chlorite and silica-altered lapilli tuffs, tuffaceous siltstones and argillites that overlie flow-banded rhyolite. One trench exposes rusty weathering, weakly mineralized argillaceous siltstones that contain 2% fine-grained disseminated pyrrhotite and pyrite, and 1% disseminated dark sphalerite. Float boulders, containing conformable bands of disseminated pyrrhotite and sphalerite, are exposed in a roadcut along the Kluskus-Ootsa forest service road (Baknes and Awmack, 1994a). They are presumably derived from the west-facing hill side west of the Rutt showing (West Slope) and expand the size of the exploration target.

The Christmas Cake showing, discovered during the 1994 exploration program, is approximately 300 metres southeast of the Rutt zone. It consists of stockwork and semimassive to massive sulphide mineralization in brecciated felsic tuffs that are exposed in two shallow trenches. Mineralization consists of intergrowths of sphalerite, pyrite, chalcopyrite, pyrrhotite and galena that are the matrix for angular clasts of rhyolite tuff (Photo 10). The same sulphides are disseminated throughout vuggy fine-grained milky white quartz-flooded zones. A grab sample from one of the trenches assayed 541 g/t Ag, 7.38% Zn and 2.25% Pb (Baknes and Awmack, 1994a). Outcrop exposure is poor in the area of the showing and the trend of the mineralization is not known. The Christmas Cake showing is less than 100 metres west of a quartz feldspar porphyry intrusion. Its genetic relationship to the intrusion and to the Rutt zone is unknown.

Galena lead isotope data from the Christmas Cake showing will be compared with data from the Blackwater-Davidson and Capoose prospects.

Western Keltic Mines Inc. has recently granted Brazos Pacific Corporation an option to acquire a 50% interest in the Buck property (McInnes, 1994). Plans are being finalized for a backhoe trenching program, for the fall of 1994 or winter of 1995, that will test the extent of the Christmas Cake and Rutt showings. A three-hole, 550-metre diamond drilling follow-up program is also planned.

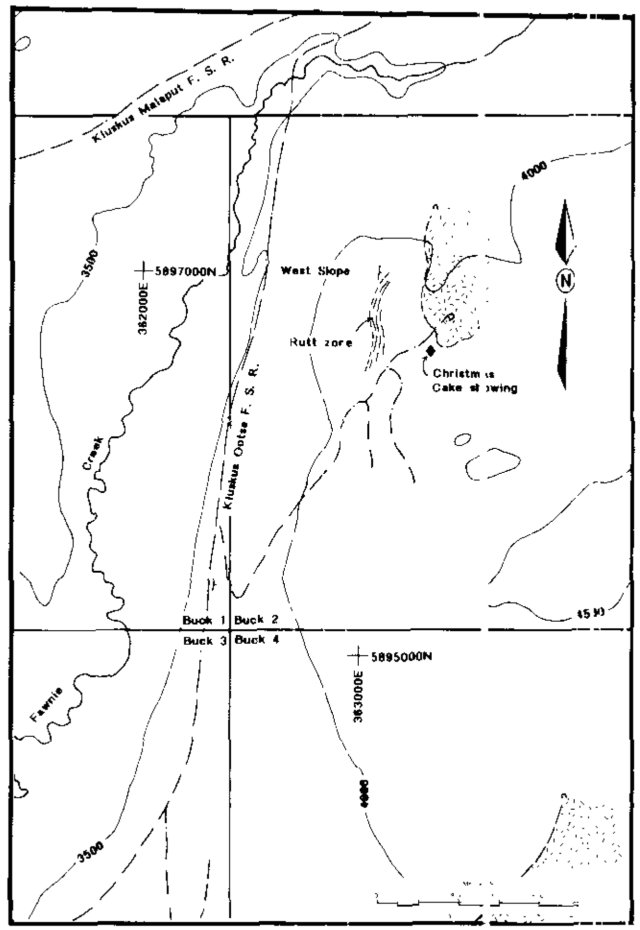


Figure 5. Location of the Rutt and Christmas Cake showings Buck claim group, map sheet 93F/2E. Note the spatial relationship to the quartz porphyry intrusion (stippled) in the northeast corner of the map area (modified after Baknes and Awmack, 1994a).

CONCLUSIONS

Epithermal precious metal occurrences in the Nechako Plateau region occur in three ages of hostrock: Eocene Ootsa Lake Group, Cretaceous Kasalka Group and Jurassic Hazelton Group. Ootsa Lake Group acid volcanic and associated sedimentary rocks host numerous low-grade gold-silver occurrences and may be the most prospective geology for heap leachable deposits. Discovery of bonanza vein systems is also a possibility. Cretaceous and Jurassic andesitic volcanic rocks host several epithermal precious metal prospects that are generally higher grade than the Eocene occurrences.

Precious metal bearing quartz-chalcedony(± adularia) veins, stockworks and breccia zones are typically low-sulphide and display classic epithermal textures such as banding and drusy cavities. Base metal content is generally low, suggesting that the systems are near surface (< 1 km deep). Hostrocks are typically intensely fractured and brecciated. Barren or weakly anomalous clay and sericite-altered wallrocks surround mineralized silica-rich and/or silicified zones.

The Ben and April precious and base metal vein prospects are high-sulphide systems and contain significant base metals. They may represent deeper level epithermal systems.

Stratabound base metal and silver mineralization is present in the Jurassic Hazelton Group interlayered sedimentary and volcanic rocks.

The porphyry copper and molybdenum potential of the region remains largely untested.

New information from regional mapping, regional and case study geochemical surveys and mineral deposit studies continue to spark exploration in the region. As a result the Nechako Plateau area is being evaluated more fully.

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NOTES

UPDATE ON 1994 LAKE SEDIMENT GEOCHEMISTRY STUDIES IN THE NORTHERN INTERIOR PLATEAU, CENTRAL BRITISH COLUMBIA (93F)

By Stephen J. Cook and Michelle E. Luscombe

KEYWORDS: Applied geochemistry, lake sediments, Nechako Plateau, gold, mineral deposits, limnology

INTRODUCTION

Most Canadian studies of lake sediment geochemistry have focused on Shield and Appalachian environments of eastern and northern Canada where there are considerable differences in climate, physiography and surficial geology relative to the Cordillera. Here, prospects such as the Wolf (Dawson, 1988) and Fawn (Hoffman and Smith, 1982) epithermal precious metal occurrences in the northern Interior Plateau were discovered by mineral industry regional lake sediment surveys, but there have been few detailed orientation studies and case histories from which to formulate exploration models for the area. These studies are important for successful application of lake sediment geochemistry surveys at both regional and property scales.

Interior Plateau field studies were first conducted in 1992 as part of the Canada - British Columbia Mineral Development Agreement (MDA). Their purpose is to investigate the effectiveness of lake sediment geochemistry in reflecting the presence of known mineral prospects, and to guide the design and implementation of provincial regional geochemical surveys (Cook, 1993). Results were applied to regional lake sediment surveys conducted the following year, which indicated the locations of most known prospects and delineated several new anomalous areas (Cook *et al.*, 1994). To date, regional coverage of approximately one-quarter of the Nechako River map area (NTS 93F) has been completed at an average sampling density of one site per 7.7 square kilometres (Cook, 1995; Cook and Jackaman, 1994a,b). In order to better interpret regional lake sediment data and to design more effective follow-up geochemical surveys, differences in metal distribution patterns in lakes with differing stream water and ground water flow patterns were investigated during 1994. This paper outlines the objectives of the study and describes fieldwork conducted. No results are reported here.

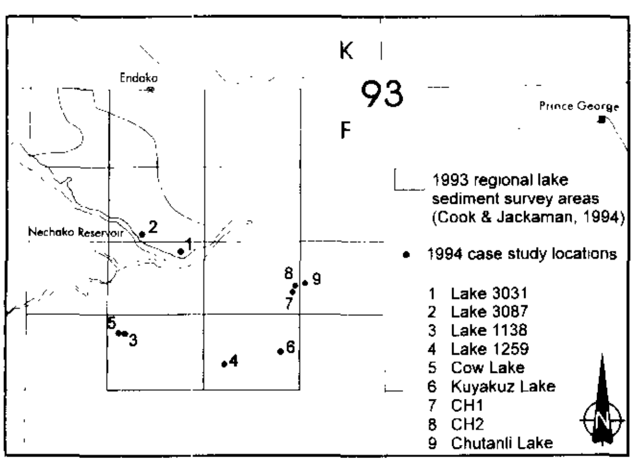

Figure 1. Location map of 1994 lake sediment survey areas in the Nechako Plateau, showing their relation to 1993 regional lake sediment survey areas of Cook and Jackaman (1994a).

OBJECTIVES OF THE INTERIOR PLATEAU LAKE SEDIMENT STUDY

Geochemical dispersion of gold and other metals into lake basins in the study area typically occurs in ground water, stream water, or a combination of the two. The metals subsequently accumulate in organic-rich sediments within diverse lake basins of varied size, depth, physiography and hydrology, among other factors. For example, while 60% of sites in the Fawnie regional survey area (Cook and Jackaman, 1994a) are in basins of pond size or smaller (<0.25 km²), 8% are located in large lakes (>5 km²). Little research has been conducted on the most appropriate methods of locating potential sources of elevated metal abundances within the often-extensive watersheds of different lake types. Whereas previous studies were designed to guide the design and implementation of regional geochemical surveys, this study examines interpretive and sampling techniques for optimal follow-up of regional anomalies.

The main objective of the 1994 lake sediment study was to characterize differences in sediment metal distribution patterns within lakes with differing ground water and stream water flow patterns. Results of earlier work (Cook, 1995) indicated that differences in metal distribution patterns and elevated geochemical signatures might be related to differences in metal input and accumulation between seepage lakes and drainage lakes. Differences in water income and loss in these two lake types are outlined by Wetzel (1983). *Seepage lakes* are those basins receiving predominantly ground water seepage or spring input below the lake surface, but lacking significant stream outflow. Water loss in these lakes, other than that due to evaporation, is restricted to seepage back into ground water. For the purpose of this study, lakes lacking significant stream inflows were included in this category. *Drainage lakes* lose water by stream flow from an outlet. In the context of this study, they include those lakes with relatively large watersheds receiving water from both surface influents and subsurface seepage. The influx of suspended particulate mineral and organic matter in stream waters is a major difference between these and seepage lakes. Ground waters play a major role in transporting metals to all lake basins (Hoffman and Fletcher, 1981) and there is a certain amount of overlap between the two lake types. For example, Boyle (1994) has further subdivided lakes into six varieties on the basis of relative ground water and surface water input. A useful discussion on variations in geochemical input to lake basins is provided by Earle (1993).

A series of case studies were conducted to document the geochemical differences between seepage and drainage lakes, and to provide data on which to base geochemical exploration recommendations for these and other areas in the northern Interior Plateau. Two main issues were considered:

- The existence of systematic differences in metal distribution patterns between drainage lakes and seepage lakes. Spatial relationship of these patterns with basin morphology, topography and stream inflows will influence geochemical data interpretation and subsequent exploration methods.
- The form of gold transport into drainage lake basins by stream waters: in solution, suspension or some combination of the two.

SCOPE OF 1994 FIELD STUDIES

Orientation studies of nine lakes were carried out during the period late July to late September, 1994 (Figure 1). A total of 362 sediment samples were collected at 266 sites (Table 1). The lakes included:

- Four small unnamed seepage lakes.
- Two large drainage lakes (Kuyakuz Lake; Cow Lake).
- Three lakes sampled to provide data complementary to prior case studies of lakes adjacent to porphyry prospects (Cook, 1993), and to ongoing glacial dispersal studies of the Geological Survey Branch (Giles and Levson, 1995; Giles *et al.*, 1995) and the University of New Brunswick (O'Brien *et al.*, 1995; Weary *et al.*, 1995).

Surveys of the six seepage and drainage lakes are the main focus of this paper. These were chosen on the basis of apparent flow type and regional lake sediment geochemistry results (Cook and Jackaman, 1994a). All six contain elevated concentrations of gold and associated elements such as arsenic, antimony and/or molybdenum in centre-lake or centre-basin sediments. The four seepage lakes span a range of physiographic environments, and include both eutrophic and unstratified variants. No attempt was made to choose lakes from among the limnological groupings of Gintautas (1984) or Earle (1993). The third group of lakes are in the vicinity of the CH porphyry copper-molybdenum prospect (MINFILE 093F 004), where prior

TABLE 1. SUMMARY LISTING OF LAKES SURVEYED: 1994.

	Lake Name	NTS	Trophic Status	Lake Size (km2)	Maximum Sample Depth (m)	Sediment Sites	Sediment Samples	Temperature and Oxygen Profiles
A)								
Drainage Lakes	Kuyakuz	93F02	Unstratified	> 5	16	69	94	3
	Cow	93F03	Unstratified*	1 to 5	15	50	68	-
Seepage Lakes	Lake 3031	93F06	Eutrophic	< 0.25	5.5	13	17	4
	Lake 3087	93F11	Eutrophic	< 0.25	7.5	24	32	5
	Lake 1138	93F03	Unstratified	< 0.25	3.5	15	21	1
	Lake 1259	93F02	Unstratified	< 0.25	3	17	23	1
					Subtotal:	*188*	*255*	*14*
B)								
CH Area	Chutanli	93F08	Unstratified	1 to 5	10	50	70	7
	CH-1	93F07	Unstratified	< 0.25	6	19	25	4
	CH-2	93F07	Unstratified	< 0.25	4	9	12	2
					Subtotal:	*78*	*107*	*13*
					Total:	**266**	**362**	**27**

Numbered lakes refer to regional site locations of Cook and Jackaman (1993a).
*After data of Coombes (1986).

lake sediment studies have been summarized by Earle (1993). These will be the subject of a future paper.

LOCATION AND GEOLOGY OF THE STUDY REGION

The study region (Figure 1) is located approximately 100 kilometres southwest of Vanderhoof on the Nechako Plateau, the northernmost subdivision of the Interior Plateau (Holland, 1976). The low and rolling terrain generally lies between 1000 to 1500 metres elevation. Bedrock is obscured by an extensive drift cover. Till and glaciofluvial outwash are the predominant surficial sediments (Levson and Giles, 1994; Giles and Levson, 1994, 1995). Within the study region, volcanic and sedimentary rocks of the Middle Jurassic Hazelton Group are intruded by Late Jurassic, Late Cretaceous and Tertiary felsic plutonic rocks (Tipper, 1963; Diakow *et al.*, 1994, 1995a,b,c). These are overlain by Eocene volcanics of the Ootsa Lake Group, Oligocene and Miocene volcanics of the Endako Group, and Miocene-Pliocene basalt flows. Metallogeny and mineral deposits in the area have been outlined by Schroeter and Lane (1994), and epithermal gold deposits are a prime target of recent exploration. Regional lake sediment and till geochemistry results (Cook and Jackaman, 1994a; Levson *et al.*, 1994) indicate that elevated concentrations of gold and associated elements occur in areas of Jurassic as well as Eocene bedrock, enlarging considerably the potential target areas for these deposits. For example, four of the six lakes discussed here are situated above units of the Middle Jurassic Hazelton Group.

FIELD AND LABORATORY METHODOLOGY

SAMPLE COLLECTION

Systematic collection of lake sediments and waters, and measurement of temperature and dissolved oxygen content of the water column was conducted at each lake (Table 1). Lake sediments were sampled from a zodiac or canoe with a Hornbrook-type torpedo sampler. Standard sampling procedures, as discussed by Friske (1991), were used. Samples were collected in kraft paper bags and sample depth, colour, composition and odour recorded at each site. Sites were located along profiles traversing deep and shallow-water parts of main basins and sub-basins, and at all stream inflows. The number of sites on each lake (Table 1) ranged from a minimum of nine in small ponds up to a maximum of 69 in large Kuyakuz Lake, in order to evaluate the relationship between trace element patterns and bathymetry, drainage inflow and outflow, organic matter content and sediment texture.

An unbalanced nested sampling design, similar to that described by Garrett (1979), was used to assess sampling and analytical variation. A modified version of the Regional Geochemical Survey sampling scheme used for this has been described by Cook (1993). Each block of twenty samples comprises twelve routine samples and five field duplicate samples to assess sampling variability, two blind duplicate samples to determine analytical precision, and one control reference standard to monitor analytical accuracy.

Two water samples, each comprising three 250-millilitre bottles, were obtained from the centre of each lake. One was taken near the surface at approximately 15 centimetres depth, the second was collected to 2 metres above the lake bottom using a Van Dorn sampler. The boat was anchored in place during both water sampling and temperature/oxygen profiling to prevent movement, and observations of water colour and suspended matter were recorded. Water samples were also collected from streams flowing into Kuyakuz and Cow lakes in order to determine if metals were transported in solution or suspension. To minimize potential contamination, polyethylene bottles were pre-rinsed in the laboratory with distilled water, carried to the field in sealed plastic bags, and rinsed again in the water to be sampled prior to actual collection. Samples were subsequently resealed in plastic bags and stored in a cooler and refrigerator prior to filtration and analysis.

DISSOLVED OXYGEN AND TEMPERATURE MEASUREMENTS

Oxygen and temperature measurements were conducted to verify pre-existing Fisheries Branch (B.C. Ministry of Environment, Lands and Parks) data (Burns 1978a,b; Coombes, 1986), to determine the trophic status of smaller lakes for which no data are otherwise available, and to investigate the variability of these measurements within separate sub basins of individual lakes. Water column profiles of dissolved oxygen content and temperature were measured at one to seven sites on each lake except Cow Lake, using a YSI Model 57 oxygen meter with cable probe. Measurements were generally made, at 1-metre intervals, in the centre of all major sub basins and at two near shore sites. A total of 27 profiles were measured (Table 1). The instrument was calibrated for lake elevation and air temperature prior to measurement at each lake, and data collected only during the afternoon period so as to standardize measurement conditions. Prevailing weather conditions were also recorded at the beginning of each profile.

SAMPLE PREPARATION AND ANALYSIS

Lake sediment samples were initially field dried and, when sufficiently dry to transport, shipped to Cantech Laboratories, Calgary, for final drying and sample preparation. The entire sample, to a maximum of 250 grams, was disaggregated and pulverized to approximately -150 mesh in a ceramic ring mill. Two analytical splits were taken from the pulverized material. The first 30-gram subsample was submitted to Activation Laboratories, Ancaster, Ontario for determination of gold and 34 additional elements by instrumental neutron activation analysis (INAA). The second was submitted to Acme Analytical Laboratories, Vancouver, for determination of zinc, copper, lead, silver, arsenic, molybdenum, iron, manganese and 22 additional elements, plus loss on ignition, by inductively coupled plasma - atomic emission spectrometry (ICP-AES) following an aqua regia digestion. Blind duplicates and appropriate ranges of copper and gold-bearing standards were inserted into each of the two sample suites to monitor analytical precision and accuracy.

Two of the three water samples from each site were filtered in the field through 0.45 micron filters. The filtered waters were analyzed for a suite of trace and major elements by inductively coupled plasma - mass spectrometry (ICP-MS) and inductively coupled plasma - atomic emission spectrometry (ICP-AES) techniques, respectively, at Activation Laboratories, Ancaster. The third sample from each site was left unfiltered and submitted to Chemex Labs, North Vancouver, for determination of the standard RGS analytical suite of elements in water (uranium, fluoride, sulphate and pH). Standards and distilled water blanks were included in the sample suites to monitor analytical accuracy. The filters were dried and retained in sealed containers for future analysis of the lake and stream water suspended fractions.

SUMMARY

No analytical results for lake sediments and waters from the 1994 field season are available at the time of writing. Future geochemistry work will concentrate on the continuation of regional lake sediment surveys, with priority given to the completion of the Nechako River map area (NTS 93F), and on the development and refinement of geochemical methods for both regional and detailed exploration. The development of exploration models for lake sediment geochemistry surveys in the northern Interior Plateau is an eventual goal of the project.

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NOTES

SURFICIAL GEOLOGY AND DRIFT EXPLORATION STUDIES IN THE TSACHA LAKE AND CHEDAKUZ CREEK AREAS (93F/2, 7), CENTRAL BRITISH COLUMBIA

By T.R. Giles, V.M. Levson and G.F. Weary

KEYWORDS: Surficial geology, drift prospecting potential, till, diamicton, glaciofluvial outwash, glaciolacustrine sediments, applied geochemistry, mineral dispersal, dispersal trains

INTRODUCTION

Quaternary geological investigations were undertaken in NTS areas 93F/2 (Tsacha Lake) and 93F/7 (Chedakuz Creek; Figure 1) in the Interior Plateau, funded in part by the Canada/British Columbia Mineral Development Agreement (1991-1995). The Interior Plateau project has three other components: bedrock geology, lake sediment geochemistry and mineral deposit studies (see Diakow *et al.*, Cook and Luscombe, and Lane and Schroeter, respectively, 1995, this volume). Previous surficial geology studies as part of this program include mapping and till geochemistry studies in 93F/3 (Fawnie Creek) in 1993 (Giles and Levson, 1994a,b; Levson and Giles, 1994; Levson *et al.*, 1994), 93C/1 and 8 (Chilanko Forks and Chezacut, respectively; Giles and Kerr, 1993, Kerr and Giles, 1993a,b) and 93C/9 and 16 (Clusko River and Toil Mountain, respectively; Proudfoot, 1993, Proudfoot and Allison, 1993a,b) in 1992.

A thick mantle of drift and widespread Neogene lava flows has hindered mineral exploration on the Interior Plateau. The geological, geochemical and geophysical databases in the region were until recently lacking in detail; the combined efforts of the Geological Survey of Canada and the British Columbia Geological Survey Branch, under the auspices of the MDA, have provided much new information. The lack of mineral exploration in this area is a measure of the difficulties involved and a perception of better chances elsewhere. Now, as the inventory of easily explorable lands decreases, new exploration methods are being developed in areas previously avoided.

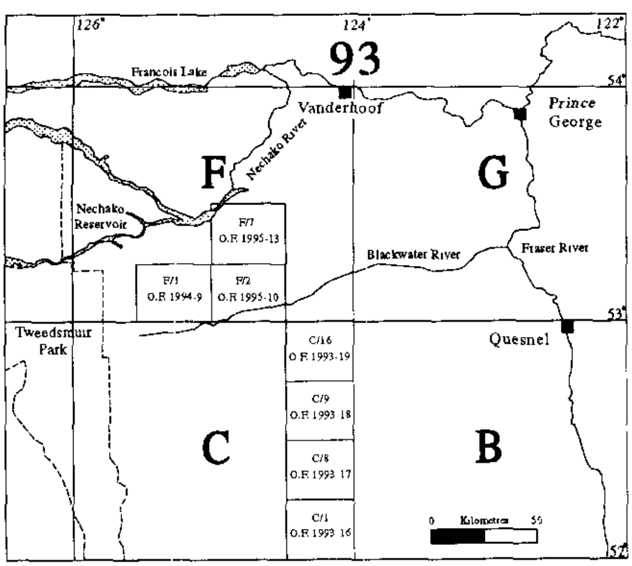

Figure 1: Location map of Tsacha Lake (93F/2) and Chedakuz Creek (93F/7) map sheets. The 1993 study area, 93F/3, and the 1992 study areas 93C/1, 8, 9, 16 are also shown.

Surficial geological mapping was completed on 93F/2 and 7 in order to understand the glacial history and aid in interpreting till geochemical data. Detailed case study work was conducted near known mineral prospects to help define models of glacial dispersal and evaluate the effects of surficial processes on geochemical distribution patterns (O'Brien *et al.*, 1995 this volume).

This years objectives are to:

- Compile 1:50 000 surficial geology maps of the Tsacha Lake (93F/2) and Chedakuz Creek (93F/7) areas, conduct stratigraphic and sedimentologic studies of Quaternary deposits in the area, and define the glacial history and ice-flow patterns.
- Complete a regional (1:50 000) till sampling program for 93F/2 and F/7 and produce a series of till geochemistry maps and reports for mineral exploration purposes.
- Develop and refine methods of drift exploration applicable to the Interior Plateau region by conducting detailed case studies around known mineral prospects.

STUDY AREA

The study area lies on the Nechako Plateau, in the west-central part of the Interior Plateau (Holland, 1975). The Fawnie Range trends south-southeast on the southwest side of the area and the Nechako Range parallels this on the northeast side (Figure 2). The highest peaks are Mount Davidson at an elevation of 1861 metres (6107 feet) in the Fawnie Range and Kuyakuz Mountain at 1781 metres (5842 feet) in the Nechako Range. The Fraser Plateau reaches as far north as the Blackwater River across the southern portion of the area. The Chedakuz valley extends through the centre of the area, from the Blackwater River northwest to the Nechako Reservoir and is flanked on either side by the Fawnie and Nechako ranges. Chedakuz Creek flows south from the east side of Kuyakuz Mountain,

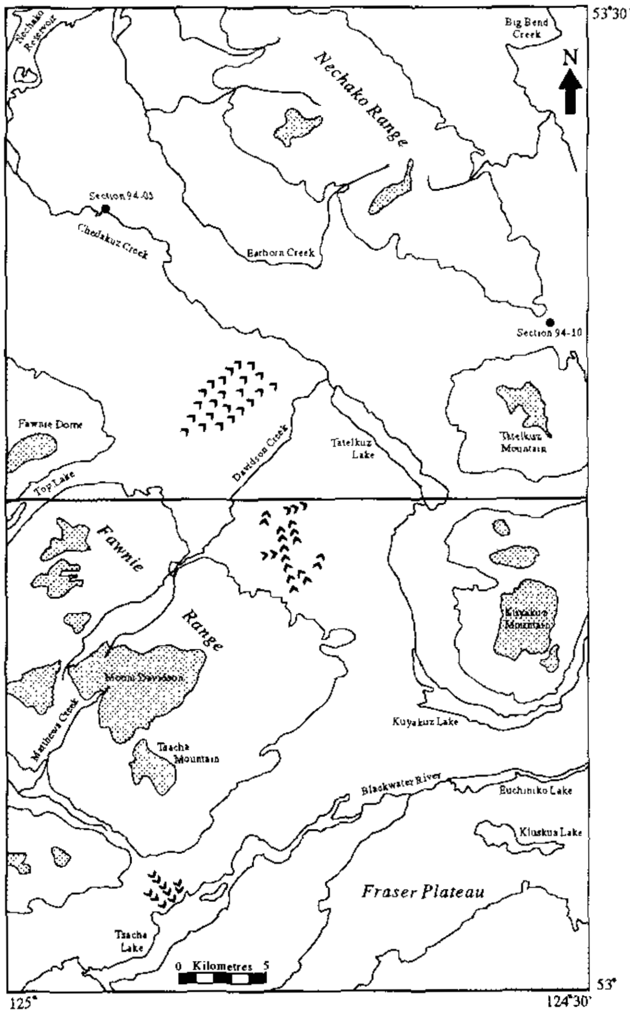

Figure 2: General physiography of the Tsacha Lake-Chedakuz Creek area. Light shading represents areas with elevations above 1220 metres (4000 feet) and darker shading areas in excess of 1520 metres (5000 feet). Major esker complexes and locations of sections noted in the text are also shown.

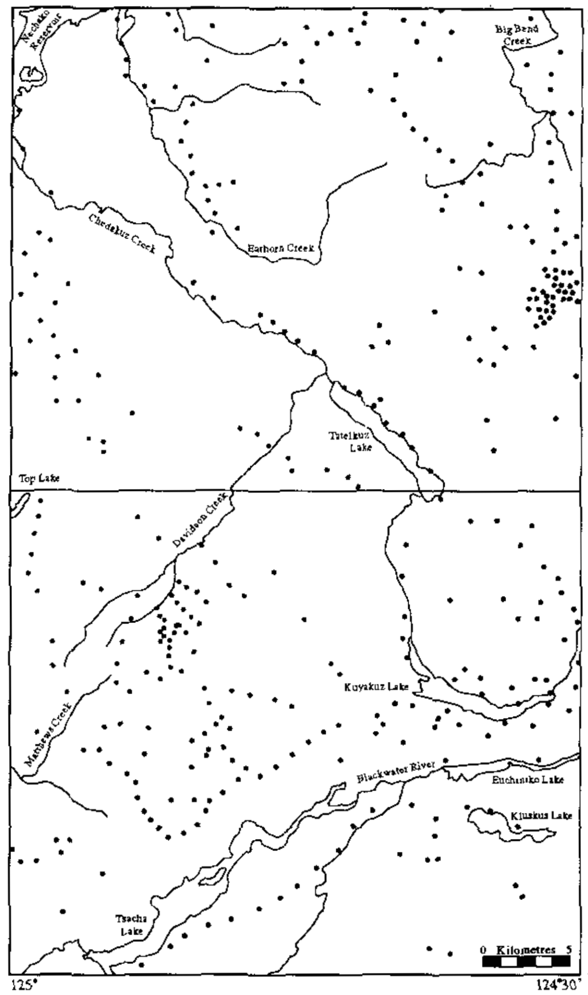

Figure 3: Location map of sample sites in the study area.

north through Kuyakuz Lake to Tatelkuz Lake and then northwest until it finally empties into the Nechako Reservoir. The Fraser Plateau and the southern flanks of the Fawnie Range drain into the Blackwater River which flows east into the Fraser River. The lowest elevation in the area is on the Nechako Reservoir, around 915 metres (3000 feet). Valleys in the area are broad with gently sloping sides reflecting glacial modification. During Late Wisconsinan glaciation, ice moved into the area from the Coast Mountains before flowing further north, northeast and east onto the Interior Plateau (Tipper, 1963,1971).

The study area is approximately 100 kilometres southwest of Vanderhoof and is accessed by the Kluskus-Ootsa forest service road. Logging road access is good for most of 93F/7 but much of 93F/2 is unlogged and accessible only on foot.

METHODS

Surficial geology mapping was completed by preliminary interpretation of air photographs (suites BC87050, BC88074 and BC88075), field checking and stratigraphic and sedimentologic investigations of Quaternary exposures in the study area. Ice-flow history was largely deciphered from the measurement of the orientation of crag-and-tail features, flutings, drumlins and striae.

Basal till samples (each 3-5 kg in weight) were collected for geochemical analysis in order to detect buried mineralization. Sampling was conducted mainly in truck accessible areas near logging roads and forest clear-cuts. Trail bikes, boats and helicopters were also used where feasible. Numerous foot traverses were completed in otherwise inaccessible regions. Sample locations were selected to obtain complete coverage of the map area, with the greatest density of samples along transects perpendicular to the established ice-flow direction (Figure 3). Where roads parallel the former ice flow direction, wide-spaced sampling was used, as closely spaced samples would repeatedly represent the same terrain directly up-ice and therefore duplicate each other. An intermediate sample spacing was used on transects oblique to flow.

Samples were collected from the C mineral soil horizon, which is comparatively unaffected by the pedogenic processes operative in the A and B-horizons (Agriculture Canada Expert Committee on Soil Survey, 1987; Gleeson *et al.*, 1989). Sample sites consist of natural and man-made exposures (roadcuts, streamcuts, lake shores, borrow pits, soil pits and trenches). Sample depths in soil pits vary from 50 to 150 centimetres, averaging about 1 metre and are almost always greater in roadcuts (up to 8 m). Locations of sample sites were plotted on a 1:50 000 topographic base map with the aid of air photographs. A total of 195 till samples were collected in 93F/2 and 206 in 93F/7, for a total of 401 samples throughout the study area (Figure 3). A density of approximately one sample per 5 square kilometres was achieved. Higher density sampling was conducted in areas of perceived higher mineral potential and around known mineral prospects to provide a clearer understanding of glacial dispersal processes. At each sample site, data collected included descriptions of sediment type, primary and secondary structures, matrix texture, presence of fissility or jointing, compactness, topographic position, slope and aspect, and sediment genesis and thickness. Further information was noted on surrounding vegetation, soil horizons, oxidation, bedrock striae and bedrock lithology.

Till samples were dried, split and sieved to -230 mesh (<62.5 μm). This fraction was analysed by instrumental neutron activation analysis (INA) and inductively coupled plasma analysis - atomic emission spectroscopy (ICP-AES) for a total of 47 elements. The -230 mesh fraction is frequently dominated by phyllosilicates which are generally enriched in metallic elements (Shilts, 1993) and for this reason is the preferred fraction to analyse. Half of each sample split was reserved for grain size or other follow-up analyses.

Detailed till and soil geochemical sampling was conducted at three mineral prospects: CH (MINFILE 93F 04), Uduk Lake (MINFILE 93F 057) and Pem (Blackwater-Davidson, MINFILE 93F 037, O'Brien *et al.* 1995, this volume). Follow-up studies based on results from the Fawnie Creek survey of 1993 (Levson *et al.* 1994) were also completed to document mineral dispersal processes. These include surveys on the Wolf (MINFILE 93F 045), Malaput (MINFILE 93F 056) and Buck (MINFILE 93F 050) prospects and the Van Tine and Cigar anomalies. Two further investigations were completed north of the Nechako Reservoir: on the Yellow Moose property (MINFILE 93F 058) and on the Stubb property. Eighty-five samples were collected along linear or fan-shaped traverses to document glacial dispersal and transport distance at these sites.

SAMPLE MEDIA

Sampling was restricted to basal tills rather than other types of surficial materials for several reasons (Giles and Levson, 1994a):

- Basal tills are deposited directly down-ice from their source and therefore mineralized materials dispersed within these tills can be more readily traced to their origin than can anomalies in other sediments. Processes of dispersal in ablation tills, glaciofluvial, and glaciolacustrine sediments are more complex and they are typically more distally derived than basal tills.
- Dominance of one regional ice-flow direction throughout much of the last glacial period has resulted in simple linear, down-ice transport of material. This makes tracing of basal till anomalies to source relatively easy compared to areas with more complex ice-flow histories.
- Due to the potential for development of large dispersal trains, mineral anomalies in basal tills may be readily detected in regional surveys.

ANALYSIS OF CLASTS IN TILLS

A new field procedure introduced this season included an evaluation of clasts in the till at each sample site. The objectives were to look for mineralized clasts, decipher patterns of glacial dispersal, determine the distances of glacial transport and rates of clast abrasion and rounding, and relate till-clast lithology to the bedrock lithology to aid in bedrock mapping. The procedure involved field identification of lithology, angularity and abrasion characteristics of each of five categories of clasts: 1) pebble-sized clasts of local origin in the basal tills (*e.g.* angular clasts lacking evidence of glacial transport; 2) cobble to boulder sized surface erratics of presumed supraglacial distal origin (*e.g.* rocks of Coast Mountain origin); 3) cobble to boulder-sized clasts showing abundant evidence of glacial abrasion (*e.g.* heavily striated and faceted Chilcotin basalts); 4) clasts of any size or shape showing evidence of potential mineralization (*e.g.* sulphides, heavy iron oxidation, drusy quartz); and 5) other rock types. A visual survey of a wide area around the sample sites was conducted to locate rocks of category 4, the main focus of the sampling program; these clasts were described and collected for assay. These data will be useful for tracing mineralized float to its source and to help determine bedrock lithology where exposure is limited due to drift cover.

SURFICIAL GEOLOGY

Different types of surficial sediments have distinctly different provenances based on their transportation and depositional histories. Six genetic categories of surficial sediment were defined and mapped in the study region: morainal, glaciofluvial, glaciolacustrine, fluvial, colluvial and organic sediments. Subdivisions within these categories were noted and mapped accordingly.

MORAINAL SEDIMENTS

Surficial geology mapping in the area shows that morainal sediments are the most widespread Quaternary deposits. They form a cover of variable thickness across much of the area and may occur as hummocky, kettled, fluted or relatively flat topography. In the Chedakuz valley, till thickness varies from a few to several metres in low-lying area to less than 2 metres in upland regions and along steep slopes. Morainal sediments are commonly overlain by glaciofluvial outwash or a glaciolacustrine veneer at lower elevations.

Two distinct facies of morainal sediments are recognized: a compact, fissile, matrix-supported, sandy silt diamicton and a loose, massive to stratified, sandy diamicton. The first is interpreted to be basal lodgement and/or melt-out till and the latter to be glacigenic debris-flows and resedimented deposits. Basal tills seldom occur at the surface, usually being overlain by glacigenic debris-flow deposits and, on slopes, by resedimented diamictons of colluvial origin.

Basal tills are moderately to well compacted but range from weakly consolidated to very compact or overconsolidated. Moderate to strong platy fissility exists in the majority of samples, although they are occasionally weakly fissile or nonfissile. Weak to very strong oxidation, characterized by red-brown staining, is common and can occur pervasively or along vertical joint planes and horizontal partings. Subhorizontal slickensided surfaces are sometimes present, especially in clay-rich till. Clasts in the basal tills range in size from small pebbles to large boulders with medium to large pebbles dominating most exposures. As much as 50% of the till may be comprised of clasts, but most exposures have between 10 and 30%. Striated, faceted and embedded clasts are common and typically up to about 20% of the clasts are striated. Striated clasts are commonly flat lying and bullet shaped, and may be aligned parallel to ice-flow. Crude bedding, locally visible in the diamicton, is indicated by higher percentages of small pebbles in some beds. Lower contacts of basal till units vary from sharp and planar to gradational and irregular. Where till overlies competent bedrock that was abraded slowly by sediment-rich basal ice, there is a clear and sharp contact.

Glacigenic debris-flow deposits are loose to weakly compacted and are either massive or interbedded with stratified silt, sand or gravel. Clasts vary in size from small pebbles to large boulders but are usually medium to large pebbles. These diamictons typically contain 20 to 50% clasts although up to 70% are present locally. Subangular to subrounded clasts are most common, but local angular clasts may also occur. Typically up to 10% of the clasts are striated. Lenses and beds of sorted silt, sand and gravel occur in many exposures and may be continuous for up to 5 metres, although they are most frequently 10 to 100 centimetres wide. Debris-flow deposits may exhibit weak to very strong, preferential oxidation along the more permeable sand and gravel beds. Debris-flow units have gradational to clear lower contacts and typically overlie basal till or occur within glaciolacustrine or glaciofluvial sequences, such as in the Chedakuz valley, at elevations below 1040 metres (3400 feet). At one exposure along Chedakuz Creek (Figure 2, section 94-05) a silty-sand diamicton, 2 to 3 metres thick, with a broad, trough-shaped, erosive lower contact, overlies ripple-bedded, fine sands. This diamicton is loosely to moderately consolidated, matrix supported and contains up to 40% subangular to subrounded clasts. A thin bed of gravel overlies the diamicton and fills in an incised channel, 2 metres deep by 5 metres wide. Low consolidation, sandy matrix texture, stratigraphic associations and channelized form of the diamicton suggest that it is a glacigenic debris-flow deposit. Similarly, on the east side of the Chedakuz valley north of Tatelkuz Lake (Figure 2, section 94-10), a unit of horizontally bedded sand is erosionally overlain by a poorly exposed bed of massive, matrix-supported, sandy diamicton, 0.5 to 1.5 metres thick. This diamicton contains up to 30% subangular to subrounded clasts, is moderately compact and contains lenses of coarse sand. A second sand bed, 3 to 5 metres thick, overlies the diamicton and the section is capped by a pebble-cobble gravel. The presence of sand lenses within the diamicton, sand beds above and below it, and its moderately compact nature suggest a glacigenic debris-flow origin.

GLACIOFLUVIAL SEDIMENTS

Glaciofluvial sediments are common in valley bottoms and along valley flanks, occurring as eskers, kames, terraces, outwash fans and plains. They consist mainly of poorly to well sorted, stratified, pebble and cobble gravel and sand in deposits up to 10 metres thick. Clasts are mainly rounded to well rounded and vary in size from small pebbles to cobbles with rare boulders. Structureless or crudely bedded, small-pebble to cobble, sandy gravel beds are common. Frequently these deposits are interbedded with glacigenic diamictons indicating that they are proximal outwash deposits. Hummocky topography, consisting of ridges or hills of sand and gravel with large intervening depressions (kettle holes), is commonly associated with these deposits and indicates the presence of ice blocks.

On the eastern flank of Mount Davidson, meltwater channels, deeply incised into the morainal blanket, extend northward into eskers formed under stagnant ice masses in the Chedakuz valley (Figure 2). A large esker complex also occurs on the western margin of Chedakuz valley where Top Lake valley cuts through the Fawnie Range. The eskers fan out into the Chedakuz valley, indicating that they were formed subglacially by waters flowing out of the Top Lake valley. As the glacier retreated up Top Lake valley, stagnant ice remained in the Chedakuz valley and impounded drainage in the Top Lake region (Giles and Levson 1994a).

GLACIOLACUSTRINE SEDIMENTS

Glaciolacustrine sediments are found throughout the Chedakuz valley up to an elevation of approximately 1070 metres (3500 feet). Glaciolacustrine sediments were also found in the Top Lake valley. They include horizontally to wavy bedded, fine to coarse sand and horizontally laminated fine sands, silts and clays.

At section 94-05 (Figure 2), 6 metres of sand occurs beneath a 1 to 3 metre thick diamicton. Up to 2 metres of subhorizontally laminated clayey silt, with numerous sand and pebble lenses as well as rip-up clasts, overlies the diamicton. The basal unit is interpreted to be advance phase fluvial and proximal lacustrine sand deposited as glaciers moved into the valley. The diamicton is inferred to be a glacigenic debris-flow deposit. The deposits capping the section are interpreted as glaciolacustrine sediments deposited in quiet water with interbedded glaciofluvial deposits. The sequence of deposits at this section and others in the region indicates ice damming in Chedakuz valley during both advance and retreat stages of the last glaciation.

POSTGLACIAL FLUVIAL AND ORGANIC SEDIMENTS

Fluvial sediments occur in valley bottoms throughout the area, especially in the Chedakuz, Blackwater and Top Lake valleys. Most modern creeks and rivers in the area are meandering streams with gravel channels. Floodplains are dominated by fine sands, silts and organics. In upland areas small gravelly creeks have reworked glacial, glaciofluvial and colluvial sediments and locally are incised into bedrock. The flat, open terrain of Chedakuz valley and the Fraser Plateau (Figure 2) is characterized by marshes and shallow lakes filled with organic sediment. The organic deposits consist of decayed marsh vegetation with minor sand, silt and clay. Organic deposits also occur in low areas in valley bottoms.

POSTGLACIAL COLLUVIAL SEDIMENTS

A thin veneer of weathered and broken bedrock clasts in a loose sandy matrix occurs on steep slopes throughout the area. These deposits grade downhill into a thicker cover of colluvial diamicton derived from both local bedrock and till. Colluvial veneers are commonly found over tills on slopes. Colluvial diamictons are differentiated from till by their loose, unconsolidated character, dominance of coarse, angular clasts of local bedrock, crude stratification and lenses of sorted sand and gravel.

ICE-FLOW HISTORY

Results of ice-flow studies in the area indicate that there was one dominant flow direction towards the east-northeast. Striation measurements from exposed bedrock sites typically indicate northeast to east flow, varying from 055° to 080°. Topographic control of ice flow during early glacial phases is indicated by valley-parallel striae on bedrock surfaces that are buried by thick till sequences. A more complex local ice-flow history is indicated by highly variable striae trends at one site east of Kuyakuz Lake. At the Late Wisconsinan glacial maximum, ice covered the highest peaks in the region and movement appears to have been unaffected by topography, suggesting the elevation of the ice surface to be in excess of 1750 metres. This is supported by northwest trending striae and flutings on top of Tsacha Mountain (Figure 2; elevation 1734 metres). Crag-and-tail features, drumlins and glacial flutings are present throughout the area and indicate flow towards the east and northeast during full glacial time.

SUMMARY OF GLACIAL HISTORY

The first lobes of Late Wisconsinan Fraser glaciation ice advancing from the southwest were probably confined to the major valleys of the Nechako Reservoir and Blackwater River. Ice in the former probably led to damming of the Chedakuz drainage and development of a large proglacial lake there. At the margins of the advancing ice, coarse-grained proglacial outwash was deposited locally in the valley bottoms. Massive, matrix-supported, compact lodgement and melt-out tills were subsequently deposited by the advancing ice. Drumlins, crag-and-tails, flutings and striations all indicate that when the glaciers were thick enough to be relatively unaffected by topography during full-glacial times, ice flow was east-northeasterly (Giles and Levson, 1995: Weary *et al.*, 1995). During deglaciation, loose, sandy gravelly diamictons were deposited on top of the tills by debris flows.

Top Lake valley was the main outlet through the Fawnie Range for meltwaters from ablating ice to the west. Stagnant ice masses in the Chedakuz valley dammed water and created a glacial lake in the Top Lake area (Giles and Levson, 1994a; Levson and Giles, 1994). A large esker complex is located at the eastern end of Top Lake valley where meltwaters flowed under stagnant ice masses into Chedakuz valley. Confined subglacial flow also created eskers on the eastern flank of Mount Davidson and on the northwest shore of Tsacha Lake. Deeply incised meltwater channels are also common in Tsacha Lake and Blackwater River areas. Gravelly outwash plains formed in main valley bottoms as water and sediment were transported away from glacial ice.

During deglaciation a large glacial lake formed in the Chedakuz valley. Lake waters deposited sediment as high up as 1070 metres (3500 feet) on the valley sides, approximately 160 metres (500 feet) above the present valley floor. This lake was probably confined to the Chedakuz valley by an ice mass to the north in the Nechako Reservoir valley and by stagnant ice and higher land to the south in the Chedakuz valley. Glacigenic debris-flow deposits and kettled topography in the valley and on the margins indicate that the lake was in contact with stagnant ice. Melting ice on the Fraser Plateau appears to have had free drainage eastward along the Blackwater River, away from the study area.

DRIFT PROSPECTING POTENTIAL

The ease with which a surficial sediment can be traced back to its original bedrock source using common methods of sampling near-surface sediments is referred

TABLE 1. DRIFT PROSPECTING POTENTIAL MATRIX IN THE STUDY AREA

Map symbol	Dominant surficial materials	Transport distance	Derivative phase	Traceability to bedrock source	Dispersal pattern	Applicable survey scale and type
VERY HIGH POTENTIAL						
R	bedrock	N/A	source	N/A	N/A	N/A
C	colluvial diamicton and rubbly talus deposits	< 100 m to 1 km	first	very good	downslope, linear to fan shaped	1:5000 (property-scale) S, C
HIGH POTENTIAL						
Mv	morainal diamicton, mostly basal tills < 1 m thick	< 2 km	first	good	down-ice, linear dispersal train	1:5000 to 1:50 000 S, C, T, HM
Mb	morainal diamicton, mostly basal tills > 1 m thick	< 5 km	first	good to moderate	down-ice, linear dispersal train, narrow, elongated	1:5000 to 1:100 000 S, C, T, HM
MODERATE POTENTIAL						
M : FG	sandy diamicton, often mantled by < 1 m of glaciofluvial deposits	> 1 km	second	moderate to poor	broad, down-ice, elongated fan	1:10 000 to 1:100 000 S, C, T, HM
LOW POTENTIAL						
F + FG	fluvial and glaciofluvial gravels and sands, > 1 m thick	> 5 km	second or third	generally poor	broad, down flow, fans, discontinuous	1:50 000 to 1:250 000 (regional scale) C, HM
VERY LOW POTENTIAL						
O	organics	> 5 km	third or fourth	generally poor	irregular, discontinuous	1:100 000 to 1:250 000 (regional scale); N
L + LG	lacustrine and glaciolacustrine sand, silt and clay	> 5 km	third or fourth	generally poor	irregular, discontinuous	1:100 000 to 1:250 000 (regional scale); N

to as drift prospecting 'potential'. It refers only to the relative usefulness of different surficial sediments for geochemical, lithological and heavy mineral sampling programs, particularly those conducted at property scales (~1:5000), and does not apply to other types of surveys including geophysical surveys, biogeochemistry, lake and stream sediment geochemistry and vapour geochemistry which are not strongly influenced by the nature of the surficial sediments at the sample site.

Drift prospecting potential categories are derived from surficial geology data. Five categories of potential are outlined in Table 1, with different surficial sediments being ranked by genesis, sediment thickness, transport distance, number of erosional and depositional phases (derivatives) and traceability to bedrock source. The probable dispersal pattern of mineralization and the applicable type and scale of survey to locate such mineralization are also indicated on Table 1. Transport distance is the expected distance of sediment travel, measured from the bedrock source to the place of deposition. One cycle of erosion, transport and deposition of bedrock material to form a sedimentary deposit is considered to be one derivative phase. If the sediment is then re-eroded, transported and redeposited then the sediment is a second derivative. Basal till, formed of comminuted bedrock material, transported and deposited directly by ice by lodgement or melt-out processes is a first derivative of bedrock. Glaciofluvial sediments, derived from till or from material within the ice, have undergone two episodes of transport and are viewed as second derivatives of bedrock. Resedimented glacial deposits, consisting of a mix glacigenic debris-flow deposits and minor glaciofluvial sediments, are for this work, considered to be second derivatives. Traceability to bedrock source is a reflection of the probable transport distance, the number of derivative phases, and the size, shape and continuity of the dispersal plumes.

CONCLUSIONS

To reflect mechanical dispersal processes, samples should be collected from within the C mineral soil horizon. Sedimentologic data should be collected at all sample sites in order to distinguish till from glacigenic debris-flow, colluvial, glaciofluvial or glaciolacustrine sediments. These sediments have different processes of transportation and deposition which must be recognized in order to understand associated mineral anomaly patterns. For example, local variations will be reflected in some sediments while regional trends may be evident in others. Analysis of these sediments will be useful only if their origin is understood.

A basic understanding of ice-flow direction, glacial dispersal patterns, and transportation distances is also required for successful drift exploration programs. Interpretation of data with respect to glaciation may provide the explorationist with new avenues to explore for bedrock sources of mineralized float or geochemically anomalous soil samples.

Till geochemical sampling combined with surficial geology mapping has proven to be a useful method for detecting mineralization elsewhere in the Interior Plateau region. This was demonstrated by the detection of all documented mineral occurrences in the 1993 map area (Levson *et al.*, 1994), including several sites not identified in the literature before the sampling program was conducted. In addition, several new multi-element till geochemical anomalies, with values comparable to those down-ice of advanced prospects in the area, were discovered. These data strongly suggest that geochemical surveys, using basal tills as a sampling medium, are an effective tool for regional exploration in the Interior Plateau region.

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NOTES

TILL GEOCHEMICAL SAMPLING: CH, BLACKWATER-DAVIDSON AND UDUK LAKE PROPERTIES, BRITISH COLUMBIA: REPORT OF ACTIVITIES

By E.K. O'Brien, B.E. Broster, T.R. Giles and V.M. Levson

KEYWORDS: Geochemistry, dispersal trains, glacial geology, mineralization, soils, till, Nechako

INTRODUCTION

This paper describes a till geochemical sampling program conducted in the 1994 field season by the authors on the CH, Blackwater-Davidson and Uduk Lake properties (Figure 1). A detailed sampling program was completed in conjunction with a regional till survey (Giles *et al.*, 1995, this volume) to better define areas of mineralization and to study glacial dispersal processes on three properties. This work follows on similar studies previously completed in the region (Giles and Levson, 1994a,b; Levson and Giles, 1994; Levson *et al.* 1994).

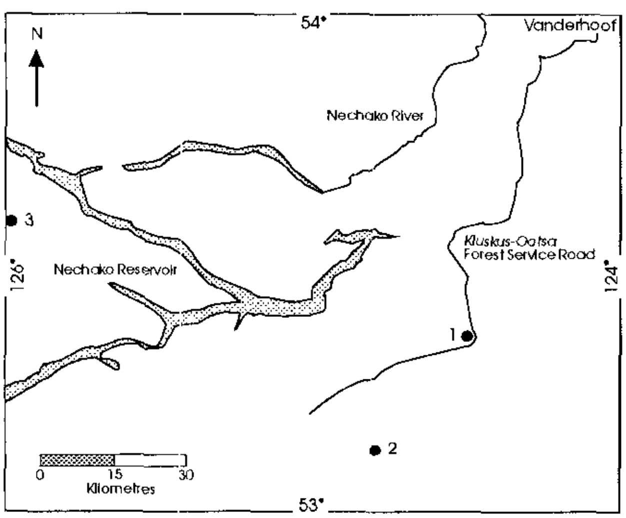

Figure 1. Location of areas sampled south and west of Vanderhoof; 1 CH, 2 Blackwater-Davidson and 3 Uduk Lake.

On the properties selected for this study, soil samples had been previously collected and these data were available for examination. The objectives of this project are to compare the geochemistry of till samples with samples previously collected from the A and B soil horizons, and to examine the effectiveness of till geochemical studies in locating zones of high mineral potential in areas of thick overburden.

Vertical profile sampling was completed in trenches on the Uduk Lake property. These samples will be used to assess geochemical variability in the A, B and C soil horizons derived from till.

BACKGROUND

Glaciers moving over mineralized bedrock erode bedrock and deposit the debris in till as dispersal trains (Shilts, 1976; Coker and DiLabio, 1989). Dispersal trains are fan or ribbon-shaped zones of anomalous mineral and geochemical concentrations located down-ice from mineral occurrences. They can be used to locate new occurrences, and can also contribute to an understanding of dynamics of glacier flow (Hornibrook *et al.*, 1993). The size of the dispersal train within the till is often many times larger than the original outcrop of mineralized bedrock because of debris mixing and dispersal within the glacier. As a result, till is an excellent medium for geochemical exploration.

Tills are 'first-derivative' products of bedrock, deposited by the linear movement of glaciers, and till dispersal trains are relatively easy to trace back to the point of origin (Shilts, 1993). Higher order derivatives, such as glaciofluvial or glaciolacustrine sediments, have a more complicated transport history, often with several episodes of transport; tracing them back to their source is more difficult and less accurate.

FIELD METHODS

Mapping of the surficial geology at each property has now been completed. During mapping (June - August, 1994), areas suitable for geochemical till sampling were identified and sampled. Local ice-flow directions were interpreted mainly from glaciated landforms identified on 1:60 000 aerial photographs, including crag-and-tail features, flutings and drumlins. These directions were confirmed on site by direct measurement of striae and landforms.

Sampling traverses down-ice from the mineralized zone on the Blackwater-Davidson property were oriented perpendicular to local ice-flow direction and form a fan shape. Some sample sites coincided with soil anomalies detected by previous sampling programs by the property owners. At all properties the sampling density was greatest slightly down-ice and around the area of highest mineral potential. Additional till samples were collected directly up-ice from the known showings to ensure that the source of the dispersal train is not further up-ice than inferred by the property owners.

With the exception of Uduk Lake, where eight trenches were available for study, sample sites typically consisted of roadcuts and hand-dug pits often exceeding 1 metre in depth. Lodgement till (*sensu stricto*, Dreimanis, 1976) was the preferred sample material. All sample sites were marked with a B.C.G.S. regional geochemistry aluminum tag indicating the sample number and with orange flagging tape. The sample locations were plotted on topographic maps with the aid of air photographs; where possible, sample locations were referenced to the property grids.

The geochemistry of the till samples will be analyzed using the -230 mesh (-62.5µm) fraction. A suite of 35 elements will be analyzed by instrumental neutron activation analysis (INAA) and 30 by inductively coupled plasma - atomic emission spectroscopy (ICP-AES). Vegetation samples consisted of bark from mature, healthy lodgepole pine trees, of roughly equal diameters. These samples will be analyzed by INAA and ICP-AES. All results will be made available in a 1995 Open File report.

REGIONAL BEDROCK GEOLOGY

The regional geology of the Nechacko River (93 F) map sheet was mapped by Tipper (1954, 1963) at 1:250 000 scale. Revised 1:50 000 bedrock geology maps will shortly be released for the Tsacha Lake (93F/2) and Chedukuz Creek (93F/7) areas (Diakow *et al.*, 1995a,b,c). The basic stratigraphy underlying all three properties consists of rhyolitic volcanics and sediments of the Lower to Middle Jurassic Hazelton Group. These rocks are intruded by Cretaceous to Eocene granitic to dioritic stocks. Overlying these units are Late Cretaceous to Eocene age Ootsa Lake Group felsic to intermediate volcanics. Oligocene to Miocene andesitic to basaltic flows of the Endako Group cap the section.

CH PROPERTY

DESCRIPTION OF SURVEY AREA

The CH property is currently owned by Placer Dome Inc. It is located approximately 90 kilometres south-southwest of Vanderhoof, British Columbia (53°21'N, 124°25'W). The claims straddle the boundary between 93F/7 and 93F/8 map sheets (Figure 2). Access to the property is by the Ootsa-Kluskus forestry service road to near kilometre 100. Access roads on the property are suitable for four-wheel-drive vehicles only.

The CH property lies on the north flank of a large meltwater channel which cuts through the Nechako Range. The area is characterized by a gently undulating topography, dissected by glacial meltwater channels and with several swamps and lakes. Local elevations are relatively low, ranging between 1100 metres (3600') to about 1340 metres (4400').

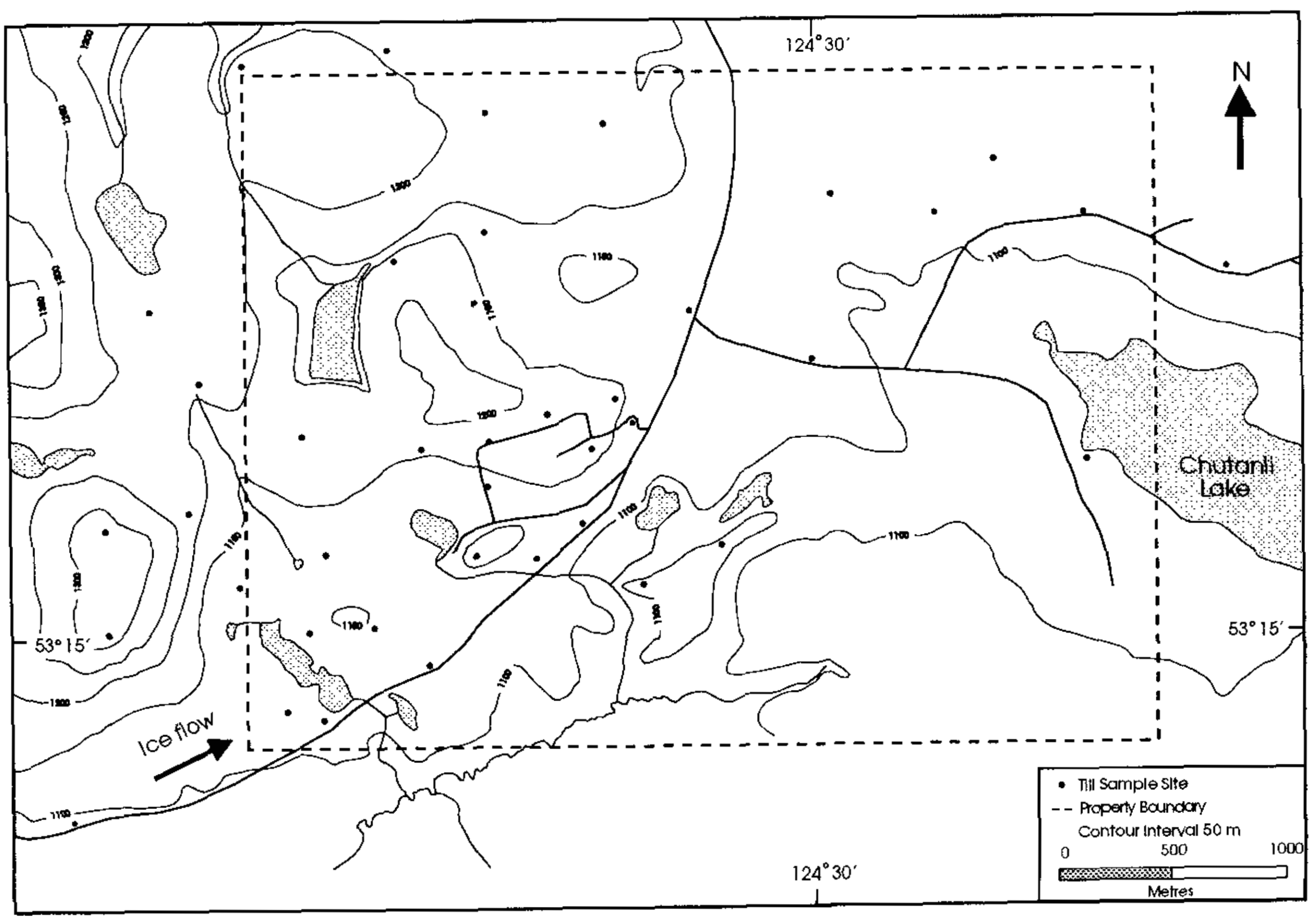

Figure 2. Site map for the CH property (dashed lines) with sample locations and glacial flow direction.

ALTERATION AND MINERALIZATION

Mineralization in the property is related to a hydrothermal system active during the emplacement of the Jurassic-Cretaceous Chutanli batholith (Warner and Cannon, 1992). Emplacement of the batholith led to hornfelsing of the country rocks, most intense in the northwest quadrant of the property and was accompanied by several types of alteration; propylitic, potassic, sericitic and siliceous (Edwards and Campbell, 1992).

Previous exploration programs uncovered sulphide veins containing lead, zinc, silver and gold in a trench located in the northwest portion of the claims. However, the primary exploration target is a porphyry-style quartz stockwork containing copper with minor gold mineralization (Edwards and Campbell, 1992).

SURFICIAL GEOLOGY

The area has been glaciated and covered with thick deposits of till and meltwater debris. The orientation of drumlins and flutings on the property indicates that the last major direction of ice flow was northeastward, towards 055°.

Deglaciation involved large-scale stagnation and frontal retreat. Large areas were inundated with meltwater and dissected by spillway channels. Extensive deposits of glaciofluvial sand and gravel occur in and adjacent to the spillway channels. A veneer of ablation till is common throughout the area.

WORK COMPLETED

Forty-five till samples were collected on the CH property (Figure 2), as well as ten additional samples, five collected down-ice and five collected up-ice. One area was chosen for detailed sedimentological profiles where twenty additional overburden samples were collected.

BLACKWATER-DAVIDSON PROPERTY

DESCRIPTION OF SURVEY AREA

The Blackwater-Davidson property, owned and actively explored by Granges Inc., is centred approximately 150 kilometres south-southwest of Vanderhoof, British Columbia at 53°11' north, 124°48' west. Access to the property is by the Kluskus-Ootsa forest service road to kilometre 146. An access road suitable for four-wheel-drive vehicles, continues eastward for approximately 18 kilometres to the property main grid. The claims are located on the north slope of Mount Davidson, in the Fawnie Range of the Nechako Plateau (Figure 3). Elevations range from about 1565 metres (4500') to 1861 metres (6107') at the peak.

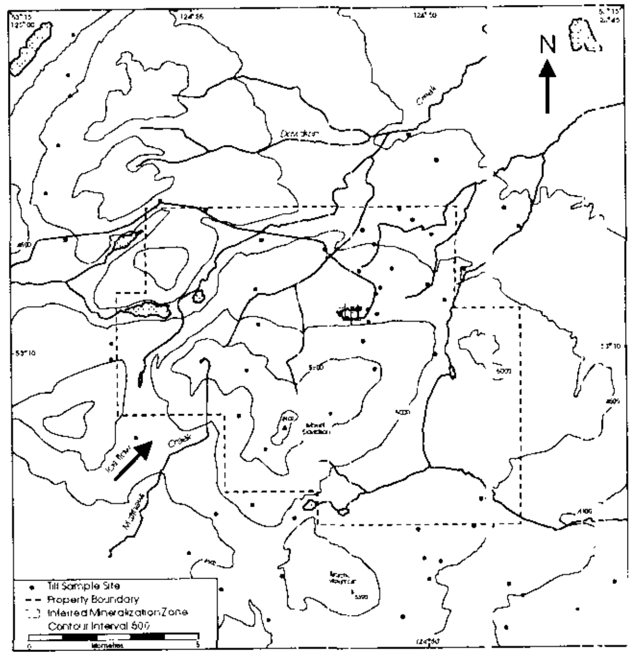

Figure 3. Site map for Blackwater-Davidson property (dashed lines) with sample locations and glacial flow direction.

MINERALIZATION

Sulphide mineralization on the property is associated with kaolinite and silicic alteration of felsic and intermediate volcanic rocks. A zone of gold and silver mineralization has been defined on a central grid. A strongly altered kaolinitized outcrop, in the southwest area of the claims, also contains sulphide minerals.

SURFICIAL GEOLOGY

This region has been glaciated, leaving little outcrop on the property. In the Mount Davidson area, ice-flow direction was determined from numerous glacial flutings oriented at approximately 045° (Figure 3). Slight deviations were recorded near the mountain peak.

Although the main direction of movement remained northeastward, the ice mass was forced around the mountain, rather than flowing directly over it. This type of interference with glacier flow often results in complex dispersal patterns (Hornibrook *et al.*, 1993).

WORK COMPLETED

The locations for 54 till samples on or close to the Blackwater-Davidson property are shown on Figure 3.

Glacial striae and landforms were examined and measured for evidence of multiple flow directions. These data indicate that the major flow direction was towards 045°.

UDUK LAKE

DESCRIPTION OF THE SURVEY AREA

The Uduk Lake property is presently owned and explored by Pioneer Metals Inc. It is centred 70 kilometres south-southwest of Burns Lake, British Columbia, at 53°38' north, 125°59' west, on the boundary between the 93E/9 and 93F/12 map sheets (Figure 4). A new forest service road off the Ootsa Main forest service road has been built southward to within 3 kilometres of the property. A proposed clear-cut would allow full road access to the site.

The property is situated in the Windfall Hills area of the Nechako Plateau. The claims lie just east of Uduk Lake, approximately 15 kilometres south of Ootsa Lake. Local topography is relatively subdued, at elevations ranging from about 1095 metres (3600') to 1220 metres (4000'), with abundant swampy and boggy areas.

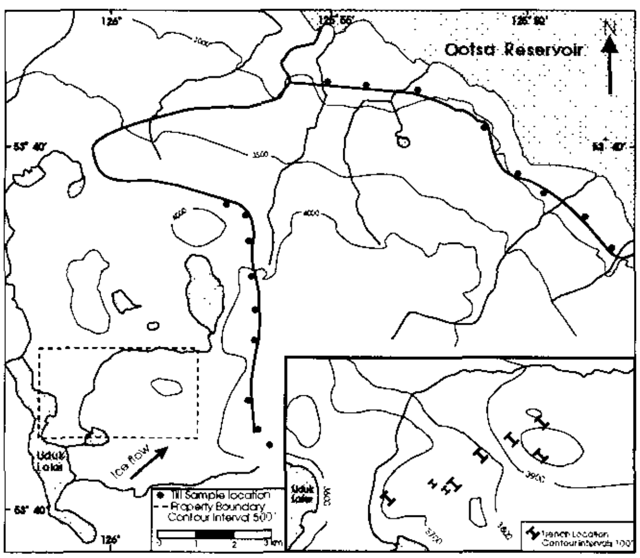

Figure 4. Site map for Uduk Lake with sample and approximate trench locations (insert) and glacial flow direction.

ALTERATION AND MINERALIZATION

The Ootsa Lake Group rhyolitic rocks at this property have undergone intense argillic alteration, transforming the volcanic rocks to a chalky clay. The rhyolites are characterized by intense silicification producing breccias and veins with drusy quartz. The age of mineralization is not well defined, but it is inferred to have occurred prior to the deposition of the Endako Group, as these rocks are unaltered (Taylor, 1989).

Nevadan-style epithermal deposits consist of stockwork veins in the altered rhyolitic rocks hosting low-grade concentrations, but often with high tonnages of gold and silver. The Uduk Lake claims have similar characteristics to this style of deposit (Taylor, 1989).

SURFICIAL GEOLOGY

The area has been intensely glaciated, with drumlins and flutings extensively developed. Outcrop is rare which has hampered exploration. Local ice-flow direction towards 050°, was interpreted from aerial photographs. The abundance of streamlined landforms suggests that the surface till sheet is probably a basal till, with an occasional thin veneer of ablation till and glaciofluvial sediment. Mineralized float has been found in till up to 15 kilometres down-ice (northeast) of the property.

WORK COMPLETED

Till samples were collected along the forest service roads which provide access to the property. Eighteen samples were taken several kilometres down-ice from the claims. These samples will help define the dispersal train.

Several areas on the claims were trenched by backhoe in the summer of 1994, as part of Pioneer Metals' exploration program. Areas designated for trenching had returned anomalous soil geochemical results. The trenches ranged from one to several metres deep, depending on the depth to bedrock, and 10 to 150 metres long.

The data from this study will be used to compare the element concentrations of the different soil horizons with that of basal till as well as the homogeneity of the till blanket (cf. Broster, 1986). In addition, the element concentrations from various sediment types and their relative usefulness for drift prospecting will also be assessed. A total of 40 soil and till samples were collected from the trenches. Ten vegetation samples were collected adjacent to the trenches, and twelve more southwest of the mineralized zone.

ACKNOWLEDGMENTS

Logistical and financial assistance for fieldwork was provided through a British Columbia Geological Survey Branch mapping project budget to Levson and Giles. Support for salary and travel was provided through a Natural Sciences and Engineering Research Council operating grant and a British Columbia Geological Survey Branch research grant to Broster. Additional field assistance was provided by Gordon Weary. John Newell is thanked for his constructive review of this paper.

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NOTES

NORTHERN SELKIRK PROJECT - GEOLOGY OF THE GOLDSTREAM RIVER MAP AREA (82M/9 AND PARTS OF 82M/10)

by J. M. Logan and M. Colpron

KEYWORDS: Goldstream River, French Creek, Goldstream mine, Montgomery, C-1, volcanogenic massive sulphides, Besshi, Lardeau Group, Badshot Formation, Hamill Group, Horsethief Creek Group.

INTRODUCTION

The Goldstream River area, in the northern Selkirk Mountains, contains numerous volcanogenic massive sulphide (VMS) occurrences, including the producing Goldstream mine, in addition to vein and placer gold deposits. The regional stratigraphic and structural settings of these mineral occurrences is, however, problematic. Previous workers have variously assigned rocks of the Goldstream area to the Horsethief Creek, Hamill, or Lardeau groups. The main objectives of the Northern Selkirk project are to establish the stratigraphic and structural framework of known VMS deposits in the northern Selkirk Mountains, and to assess the potential for similar deposits in correlative successions elsewhere.

This report complements the reconnaissance study of Logan and Drobe (1994). It presents the results of regional mapping of a 1150 square kilometre area completed during the summer of 1994. A 1:50 000-scale bedrock map will be published as Open File 1995-2.

REGIONAL GEOLOGY

The Goldstream River area straddles the boundary between rocks assigned to the North American miogeocline and the pericratonic Kootenay Terrane (Wheeler *et al.*, 1991; Wheeler and McFeely, 1991). It lies along the western flank of the Selkirk fan structure (Wheeler, 1963; 1966; Brown and Tippett, 1978; Price *et al.*, 1979; Price, 1986; Brown and Lane, 1988), a zone of structural divergence that follows the Omineca Belt, and the suture zone between North America and Intermontane Superterrane, from northeastern Washington to east-central Alaska (Eisbacher *et al.*, 1974; Price, 1986). The area is bounded to the west by the Columbia River fault, a major extensional fault of Eocene age along the east flank of the Monashee Complex (Figure 1).

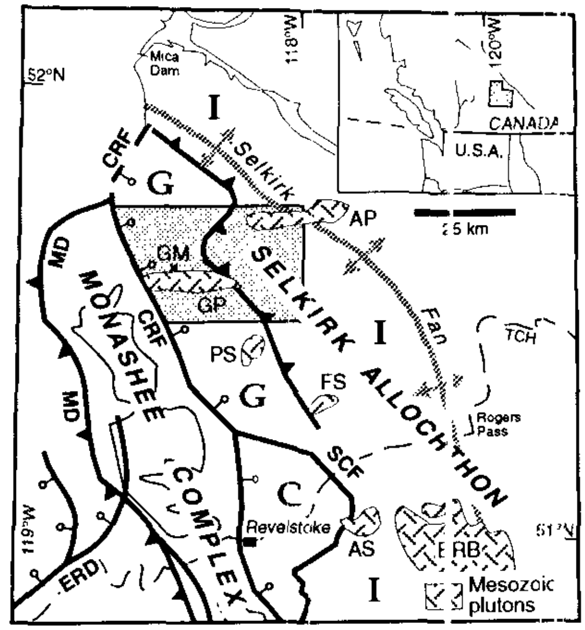


Figure 1: Location of the Goldstream River area along the western flank of the Selkirk fan structure, within the Selkirk allochthon; modified after Brown and Lane (1988). I = Illecillewaet slice, G = Goldstream slice, C = Clachnacudainn slice, CRF = Columbia River fault, DCF = Downie Creek fault, SCF = Standfast Creek fault, MD = Monashee décollement, ERD = Eagle River detachment BRB = Battle Range batholith, AS = Albert stock, FS = Fang stock, PS = Pass Creek stock, GP = Goldstream pluton, AP = Adamant pluton, GM = Goldstream mine, TCH = Trans-Canada Highway.

The northern Selkirk Mountains are underlain by a sequence of Neoproterozoic to lower Paleozoic metasedimentary and metavolcanic rocks that form part of the miogeoclinal wedge that accumulated along the western margin of ancestral North America. Wheeler (1963; 1965) has traced the stratigraphic successions defined by Walker (1926), Walker and Bancroft (1929), and Fyles and Eastwood (1962) in the Purcell anticlinorium and the Kootenay Arc, to the south, into the northern Selkirk Mountains. Wheeler assigned the various lithologic units of the northern Selkirk Mountains to the Neoproterozoic Horsethief Creek Group (Windermere Supergroup), the Eocambrian Hamill Group, the Lower Cambrian, *Archeocyathid*-bearing Badshot Formation, and the lower Paleozoic

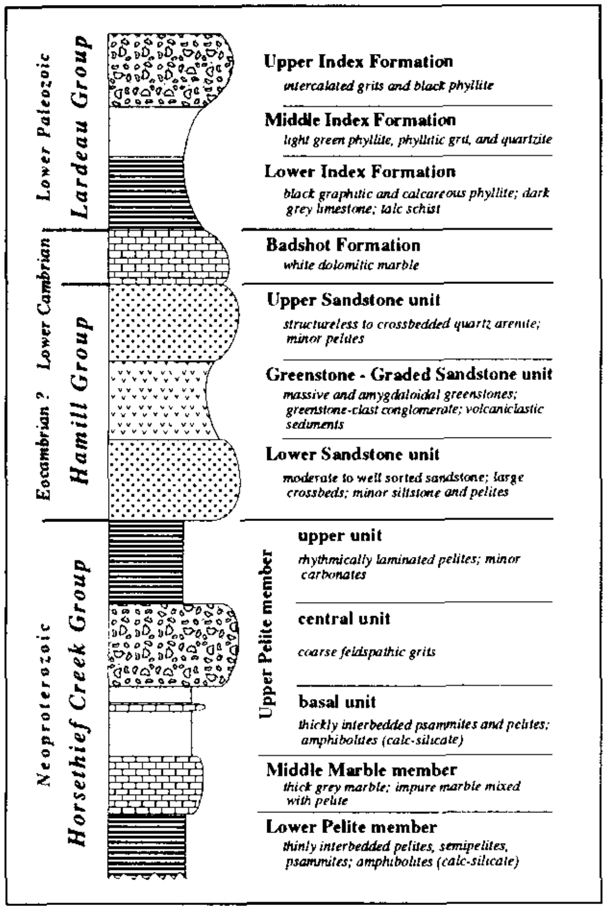


Figure 2: Schematic stratigraphic column for the northern Selkirk Mountains; compiled from data of Wheeler (1963), Brown *et al.* (1978), Devlin (1989), and Colpron and Price (1993). The lower pelite and middle marble members of the Horsethief Creek Group, and the upper sandstone unit of the Hamill Group are not exposed in the Goldstream River area.

Lardeau Group (Figure 2). To the north and east of Revelstoke, Wheeler also delineated an assemblage of higher grade gneissic and granitic rocks: the Clachnacudainn Complex (Figure 1). He suggested that rocks of the Clachnacudainn Complex form a salient of the Shuswap Metamorphic Complex into the northern Selkirk Mountains. Okulitch *et al.* (1975) and Parrish (1992) have shown that orthogneisses of the Clachnacudainn Complex are, in part, Devonian in age.

The northern Selkirk Mountains form part of a large allochthon that was displaced eastward some 200 to 300 kilometres along the Monashee décollement, between Late Jurassic and Paleocene time (Price, 1981; Brown *et al.*, 1986). As a result, the area is characterized by a complex pattern of superposed folding and faulting. The regional structural style is dominated by the northwest-trending Selkirk fan structure. The eastern flank of the fan structure is characterized by a northeast-verging imbricate thrust system which is part of the Rocky Mountain fold and thrust belt and is truncated by the Purcell thrust; a major northeast-verging out-of-sequence thrust fault (Simony and Wind, 1970). The western flank is dominated by southwest-verging fold-nappes and thrust faults (Wheeler, 1963; 1966; Raeside and Simony, 1983). Rocks along the western flank of the fan structure are generally metamorphosed to greenschist facies. Amphibolite facies rocks and migmatites occur along a west-northwest-trending metamorphic culmination that approximately follows the northwest trend of the Selkirk fan structure. It extends some 90 kilometres from near Mica dam to Rogers Pass (Figure 1).

The area has also been the locus of intermittent plutonism from Middle Jurassic to Late Cretaceous. Two main suites of granitic plutons intrude the western flank of the Selkirk fan (Gabrielse and Reesor, 1974; Armstrong, 1988): a Middle Jurassic (*ca.* 180-165 Ma) suite of granodiorite and quartz monzonite that generally cuts the regional structures, but is locally deformed by them; and a mid-Cretaceous (*ca.* 110-90 Ma) suite of quartz monzonite, diorite and two-mica granite that clearly truncates all regional structures. In addition, a less voluminous Late Cretaceous (*ca.* 70 Ma) suite of leucogranites has recently been recognized within the Clachnacudainn Complex (Parrish, 1992).

STRATIGRAPHY OF GOLDSTREAM RIVER AREA

The lithologic similarities between the Horsethief Creek, Hamill and Lardeau groups, and the intensity of deformation and metamorphism in the Goldstream River area, have complicated correlations with well established stratigraphic sequences to the south. In particular, the sequence of rocks exposed in the vicinity of the Goldstream mine have been interchangeably assigned to the Horsethief Creek, Hamill and Lardeau groups. Wheeler (1965) showed much of the area north of Goldstream River to be underlain by strata of the Horsethief Creek Group. He correlated rocks south of the river with the lower Paleozoic Lardeau Group. Brown *et al.* (1977), Lane (1977) and Höy (1979) correlated rocks of the Goldstream River area with the Horsethief Creek and Hamill groups. Brown *et al.* (1977; 1978) established a three-fold subdivision of the Horsethief Creek stratigraphy in the Goldstream area. More recently, Brown and Lane (1988) showed the western half of the area to be underlain by rocks of the lower Paleozoic Lardeau Group.

The results of our mapping show the Goldstream area to be underlain by four fault-bounded slices which comprise distinct stratigraphic assemblages (Figure 3). The structurally highest two slices underlie much of the map area. They roughly correspond with the Illecillewaet and Goldstream slices (Figure 1) defined by Brown and Lane (1988). In the Goldstream River area, the Illecillewaet slice is exclusively composed of rocks of the Horsethief Creek and Hamill groups. To the west, the Goldstream slice, which hosts the Goldstream orebody, is composed of strata correlative with the Badshot Formation and the Lardeau Group. The structurally lowest two slices are limited to the southwestern corner of the map area. They comprise higher grade metamorphic rocks which remain of uncertain correlation.

HORSETHIEF CREEK GROUP

The stratigraphy of the Horsethief Creek Group in the northern Selkirk Mountains has been subdivided into three members by Brown *et al.* (1977, 1978): the lower pelitic, middle marble, and upper pelitic members (Figure 2). Brown *et al.* (1978) further subdivided the upper pelitic member into three assemblages: a lower subdivision of thickly interbedded psammites and pelites; a central subdivision of coarse feldspathic grits with pelitic schist interbeds; and an upper subdivision of rhythmically laminated pelites (Figure 2). Brown *et al.* have suggested that the uppermost subdivision of the upper pelitic member grades westward into a sequence of calcareous pelitic schists with intercalations of marble, impure psammite and quartzite.

In the Goldstream area, the Horsethief Creek Group is predominantly exposed along two northwest-trending belts (Figure 3). The eastern belt includes exposures in the vicinity of Goldstream Mountain, between Goldstream River and the Adamant pluton. In this area, the Horsethief Creek Group can be subdivided into three mappable units, which we correlate with the three subdivisions of the upper pelitic member of Brown *et al.* (1978). The lower unit is composed of a sequence of intercalated fine-grained quartz grits, impure quartzites, garnet-biotite schist, and subordinate dolomitic marbles. Graded beds in this sequence are commonly displayed by an increase in the abundance and size of metamorphic index minerals toward the more pelitic layers. The schist layers commonly contain hornblende-rich horizons, attesting to the overall calcareous composition of this sequence. The upper part of the sequence is dominated by a package of light grey marble, dark grey argillaceous marble and limestone conglomerate. This marble sequence has a maximum thickness of about 200 metres and is overlain by more quartz grits and garnet-biotite schist.

The middle map unit of the Horsethief Creek Group consists of interbedded coarse-grained feldspathic grits and laminated phyllites. The grit beds range from 30 centimetres to 5 metres thick and are generally poorly sorted. Subangular quartz and feldspar clasts are up to 1 centimetre in size. Rip-up clasts are locally present near the base of grit beds. Phyllite interbeds are from a few centimetres to 1 to 2 metres thick and commonly display good graded beds of more silty material. This sequence grades upward into a distinct unit of light to medium grey, rhythmically laminated phyllites (upper map unit). Bedding is defined by graded siltstone and fine-grained sandstone layers. Crossbeds are locally present within the sandstone layers.

Coarse-grained amphibolites are found within the lower map unit of the Horsethief Creek Group north of Goldstream Mountain and near Hitchhike Peak (Figure 3). These amphibolites are generally concordant with layering in the grit - pelitic schist assemblage, although they locally exhibit crosscutting relationships indicating their intrusive origin. Similar amphibolites are also found within pelites of the upper map unit of the Horsethief Creek Group in upper Norman Wood Creek.

South of Goldstream River, phyllites of the upper map unit grade into an assemblage of light green phyllites, calcareous and micaceous quartzites, and white, buff and grey limestones. Coarse-grained calcareous grits and green calcareous phyllites mark the transition between the rhythmically laminated phyllite unit and this calcareous assemblage. Quartzites are progressively more mature (compositionally) toward the top of the section.

The western belt of the Horsethief Creek Group is best exposed in the alpine country between Norman Wood and French creeks, and between Goldstream River and Sorcerer Creek (Figure 3). Here, the Horsethief Creek Group consists dominantly of dark grey, green and tan calcareous phyllite and schist, intercalated with variable amounts of micaceous quartzite and grit. Light and dark grey marble horizons are present throughout the section, with the most prominent occurring near the top of the section. This marble horizon is easily identified by the presence of three beds of more resistant light grey marble within a more recessive micaceous marble. It has been traced from the headwaters of French Creek to the confluence of Sorcerer and Downie creeks (Figure 3)

Volcanogenic rocks are found locally within the western belt of Horsethief Creek Group. The most prominent exposure of volcanic rocks is along alpine ridges east of Downie Peak. Here, the rock consists primarily of a massive, dark green chlorite schist with variable amounts of epidote. Minor amounts of greenstone-clast conglomerate and light green siliceous phyllite are also associated with greenstone outcrops.

Brown *et al.* (1977) have correlated marble exposures along the flanks of Stitt Creek, and those east of French Creek, with the middle marble member of the Horsethief Creek Group. Our mapping in the Stitt Creek area shows that the marble sequence is bounded by quartzitic rocks on both sides. This association contrasts with the dominantly pelitic facies described by Brown *et al.* (1978) below the middle marble member. We suggest, therefore, that the marble sequence exposed

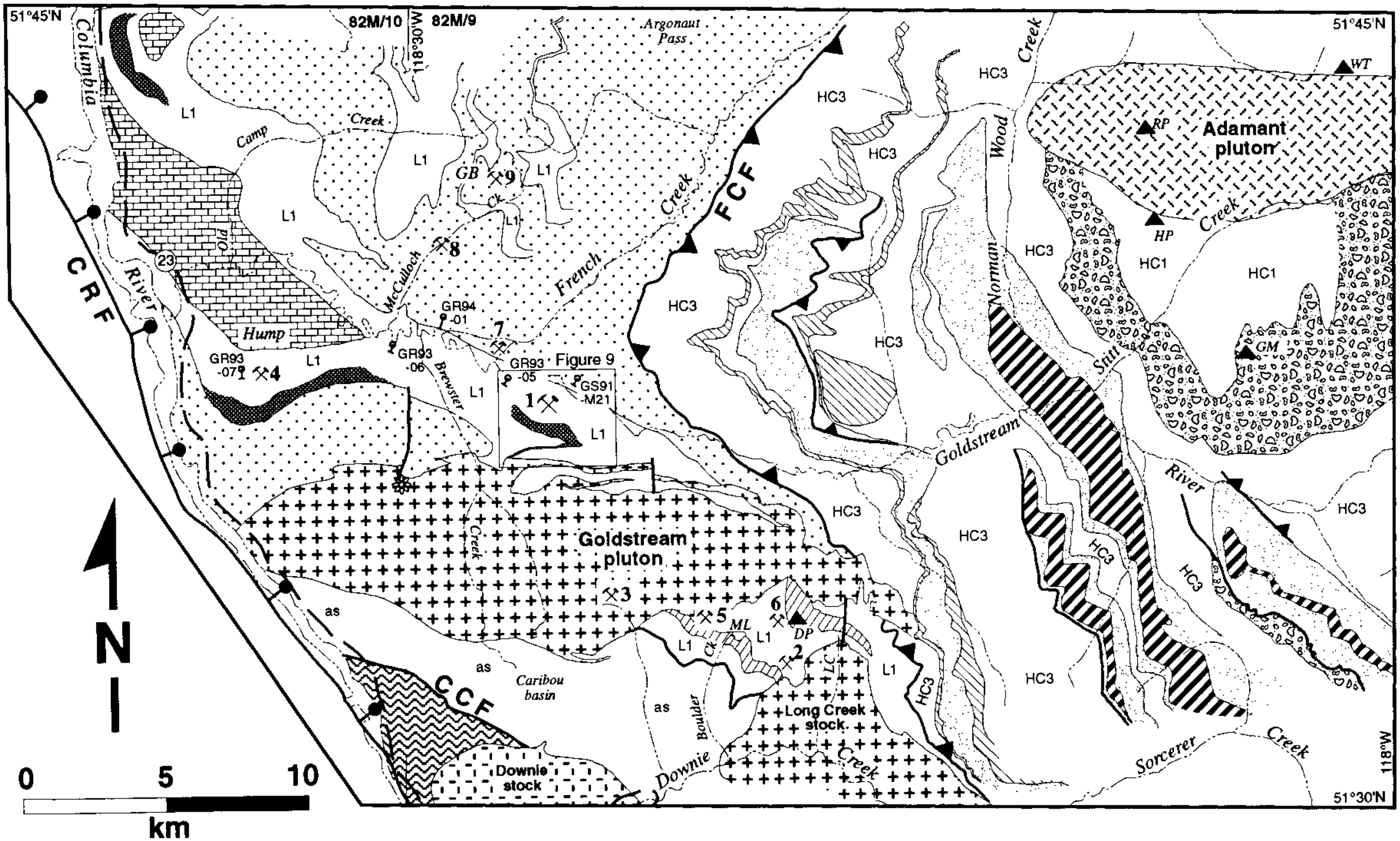
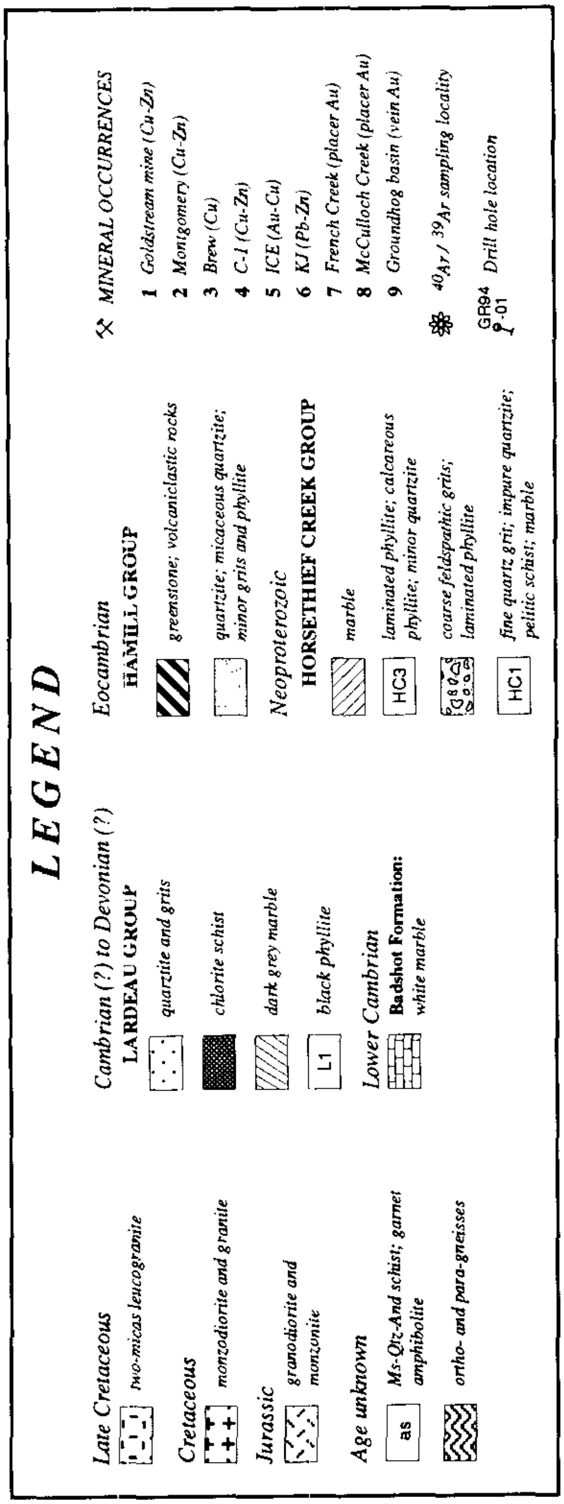


Figure 3: Geological map of the Goldstream River area compiled from our 1994 mapping and from Gibson (1982; 1989). DP = Downie Peak, ML = Montgomery Lake, LC = Long Creek, GM = Goldstream Mountain, HP = Hitchhiker Peak, RP = Remillard Peak, WT = Waldorf Towers, GB = Groundhog basin, CRF = Columbia River fault, FCF = French Creek fault, CCF = Caribou Creek fault.

along Stitt Creek corresponds to the carbonate facies described by Brown *et al.* near the top of the lower subdivision of the upper pelite member (Figure 2). Similarly, marble exposures east of French Creek occupy a higher stratigraphic level (near the contact with the Hamill Group) than the middle marble member of the Horsethief Creek Group. The main implication of these stratigraphic revisions is that only rocks of the upper pelitic member of the Horsethief Creek Group are exposed in the Goldstream River area.



HAMILL GROUP

Devlin (1989) recognizes three stratigraphic divisions within the Hamill Group in the northern Selkirk Mountains (Figure 2): a lower sandstone unit; a greenstone and graded sandstone unit; and an upper sandstone unit. Only the lower two divisions were mapped in the Goldstream River area. Rocks of the Hamill Group are exposed in the core of four southwest-verging synclines in the eastern half of the map area (Figure 3).

The basal Hamill Group corresponds to medium to coarse-grained quartzite and quartz grit, intercalated with minor grey phyllite. Quartz grains are generally well rounded and well sorted, and graded quartz grits are commonly present at the base of quartzite beds. The grits are composed almost exclusively of subangular quartz granules and pebbles (only rare feldspar clasts) in a matrix of well sorted medium sandstone. Trough crossbedding (0.3-0.5 m) is common in the basal quartzites.

The remainder of the lower sandstone unit corresponds to light grey, light green, or dark grey, fine-grained micaceous quartzites intercalated with green and/or grey phyllites. Metre-thick, clean quartzite beds are locally present within the micaceous quartzite assemblage.

The Goldstream River area comprises the largest volume of volcanic rocks within the Hamill Group. The volcanic sequence is composed, in approximately equal proportions, of massive and amygdaloidal greenstones, and volcaniclastic rocks. The greenstone is characterized by the presence of chlorite (or biotite) aggregates which are aligned along the dominant foliation. These chlorite aggregates are probably indicative of the original porphyritic texture of the basaltic flows.

Volcanic conglomerate, chloritic and feldspathic grits, mature quartzite, and lapilli tuff horizons are intercalated with the greenstone on a scale of a few metres to several decametres. The conglomerate comprises clasts of felsic volcanic rock, amygdaloidal and massive basalt, dolostone, quartzite and feldspathic grit. The clasts are subrounded to rounded (although flattened along the dominant foliation), 3 to 30 centimetres long, poorly sorted, and supported by a matrix of fine-grained chlorite schist. The grit horizons are medium to coarse grained, and are commonly graded and crossbedded. Tuffaceous rocks constitute the largest volume of material in the volcaniclastic sequence. They are differentiated from the greenstone by the widespread presence of muscovite in the matrix. Volcaniclastic horizons are locally well graded.

Felsic volcanic rocks are present at a few localities in the Goldstream River area. They occur in layers 2 to 3 metres thick which are conformable with layering in the enclosing mafic volcanic and volcaniclastic rocks. At one locality, south of Goldstream River, the felsic rocks are discordant with the underlying mafic volcanic rocks. This felsic dike may be a feeder to the overlying concordant felsic volcanics. The similarity of composition of the felsic flows (or sills) and the felsic clasts found within the volcanic conglomerate indicate that felsic and basaltic volcanism coeval.

CONTACT RELATIONS BETWEEN HORSETHIEF CREEK AND HAMILL GROUPS

The contact between the Horsethief Creek and Hamill Groups is traditionally considered to be a regional unconformity (Devlin and Bond, 1988; Devlin, 1989). Other workers have suggested that the Horsethief Creek and Hamill Groups are conformable with each other (Reesor, 1973; Warren and Price, 1993). In the Goldstream River area, (Figure 3) this contact is commonly sheared, and different levels of Horsethief Creek stratigraphy are juxtaposed against quartzites of the Hamill Group along the faulted contacts (Lane, 1977; Brown *et al.*, 1978; Devlin, 1989). In other places, the contact appears to be gradational. This gradation is marked by increasingly more mature quartzites in the upper Horsethief Creek and the presence of rhythmically laminated phyllite in the basal Hamill Group.

BADSHOT FORMATION

Massive white and grey marble, and buff dolostone exposed in the core of the Goldstream anticline, west of the Goldstream mine, are similiar to and possibly correlative with the late Lower Cambrian, *Archaeocyathid*-bearing Badshot Formation to the south (Wheeler, 1963; Read and Brown, 1979). The carbonate crops out along Highway 23 from the northern margin of the map, south to the Goldstream River. White and buff-weathering dolomite cliffs rise from the middle of the Goldstream valley at its western end and form a topographic culmination locally known as the "hump" (Figure 3). Along the highway, outcrops are brilliant white, massive and variably cut by two conjugate joint sets. Chemical analysis shows the carbonate to be a relatively pure dolomitic marble (Hurlburt *et al.*, 1988).

The unfossiliferous nature of all the limestones in the area make distinction between them difficult and correlations tenuous. Early workers mapped much of the carbonate in the Goldstream River and Downie Creek map areas as Badshot Formation, including the carbonate forming Downie Peak (*e.g.*, Wheeler, 1965). Stratigraphy and facing directions suggest that this carbonate is part of the Index Formation (Logan and Drobe, 1994).

LARDEAU GROUP

The Lardeau Group, as defined by Fyles and Eastwood (1962) in the Ferguson area, includes six formations. In ascending stratigraphic order these are: dark grey and green phyllite of the Index Formation; black siliceous argillite of the Triune Formation; grey quartzite of the Ajax Formation; grey siliceous argillite of the Sharon Creek Formation; volcanic rocks of the Jowett Formation; and grey and green quartz-feldspar grit and phyllite of the Broadview Formation. Farther north, in the Illecillewaet synclinorium, the Lardeau Group comprises a lower unit of black graphitic phyllite, a middle unit of green phyllite, quartzite and marble, and an upper unit of grit and black phyllite (Figure 2; Colpron and Price, 1993). Regional correlation of these units places them beneath the Jowett and Broadview formations and therefore within the Index Formation (Read and Wheeler, 1976; Sears, 1979; Colpron and Price, *in press*). A similiar three-fold subdivision of the Lardeau Group can be applied in the map area (Figure 4; Gibson and Höy, 1994; Logan and Drobe, 1994). Rocks of the Index Formation are exposed north of the Goldstream pluton, in the footwall (lower plate) of the French Creek fault. Similiar rocks flank the carbonate on Downie Peak at the east end of the Goldstream pluton (Figure 3).

The area extending from the mouth of the Goldstream River east to the Goldstream mine has been divided into three mappable units, each gradational one into the other and, therefore, conformable. The lower unit is predominantly a sequence of dark rocks which includes carbonaceous and calcareous phyllite and schist, dark grey carbonate and subordinate micaceous quartzite. It is correlated with the lower Index Formation and is host to the Goldstream orebody. The phyllites are strongly sheared phyllonites adjacent to marble of the Badshot Formation exposed along Highway 23. Farther east, at the mine, these rocks are referred to as the "dark banded phyllite" because of the pervasive cleavage which gives them a banded appearance. Lenticular pods of talc-magnesite schist and serpentine-antigorite schist occur near this lower contact with the Badshot Formation at the "hump". Coarsely crystalline fuchsite is associated with the talc-altered bodies which probably represent original mafic dikes and sills.

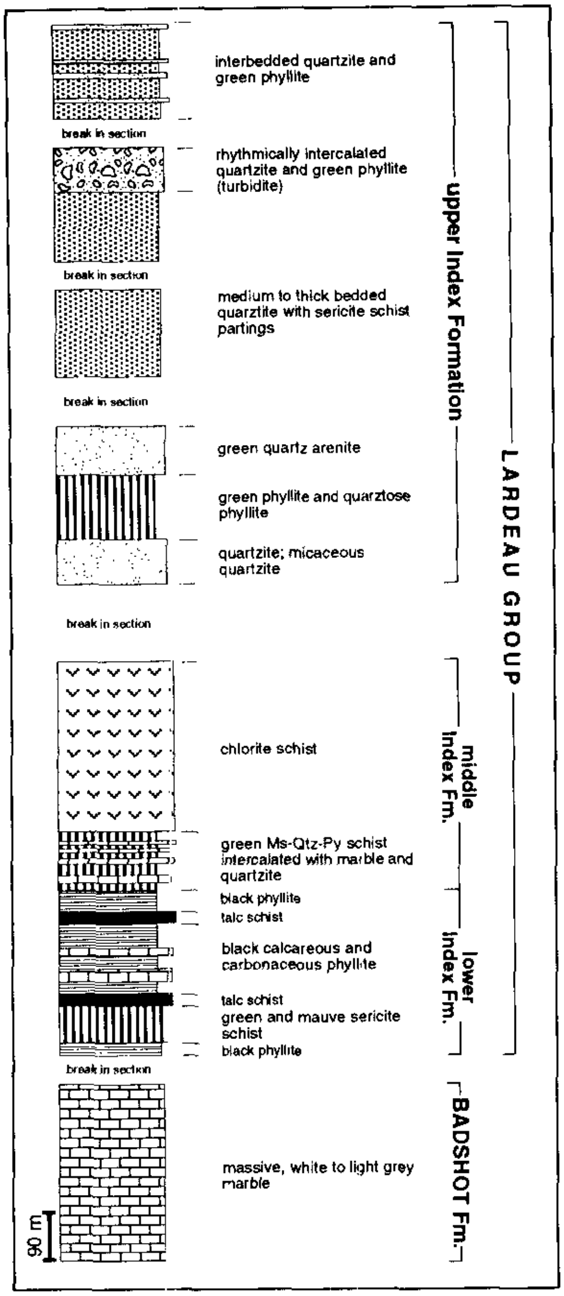


Figure 4: Schematic stratigraphic section of the Lardeau Group in the Goldstream River area (modified after Logan and Drobe, 1994). The section is a composite of measured sections along the overturned limb of the Goldstream anticline (see Logan and Drobe, 1994, for detailed description). Correlations with the Lardeau Group stratigraphy defined by Colpron and Price (1993; see Figure 2) in the Illecillewaet synclinorium, to the southeast, is shown on the right.

Green chlorite-actinolite schist, massive greenstone, thinly layered calcareous green phyllite and minor micaceous quartzite make up the middle member of the Index Formation. This sequence of volcanic rocks, subvolcanic intrusives and sedimentary rocks is the thinnest and least continuous of the three members in the Goldstream River area. The green schists are interlayered at various stratigraphic levels with the upper quartzite unit. Near the "hump" the chlorite schist is well foliated, contains white carbonate partings and several percent euhedral magnetite and pyrite crystals. Massive greenstone crops out south of the mine. Preliminary trace element chemistry indicates that the massive greenstone at the mine and the chlorite schist from the "hump" are tholeiitic basalts of mid-ocean ridge basalt (MORB) affinity, clearly different from the alkaline basalts of within-plate affinity reported for the Index and Jowett formations and possible correlatives within the Covada Group to the south (Smith and Gehrels, 1992c; M. T. Smith, personal communication, 1994). A swarm of thin mafic subvolcanic sills intrudes dark phyllites in the footwall sequence at the mine.

The upper member of the Index Formation consists of rhythmic beds of greenish micaceous quartzite, green sericite-chlorite phyllite and coarse-grained quartz grit. Micaceous quartzite predominates and the greenish hue is characteristic of this unit. The grit beds range from 10 centimetres to 3 metres thick, and are well sorted and commonly graded. Quartzites are planar bedded, ungraded and typically less than 2 metres thick. Locally the grits are interbedded with green phyllites on 2 to 5-centimetre scale.

Strata in the Groundhog basin have been divided into the lower dark phyllite and upper micaceous quartzite and grit packages (Figure 3). Calcareous, green chlorite schists of the middle member are present but do not constitute a mappable unit; they are included in the upper quartzite package. A fuchsite-bearing, talc-ankerite schist, known locally as the "spotted dog", is a characteristic unit of this area. It occurs near the contact between the quartzite and phyllite packages, usually within the latter. This rock type may represent a hydrothermal exhalation similiar to the sulphide-rich ferruginous talc sinters forming in the Guaymas Basin today (Lonsdale *et al.*, 1980). Black and brown carbonate units are interlayered with the phyllites; light grey carbonates are interlayered with the quartzites. Sections of pure, pink, pale grey and greenish quartzites occur within the predominantly micaceous quartzite package. These are planar bedded and well sorted. Graded bedding is very subtle and difficult to discern. Grey-green quartzose phyllite is interlayered with the quartz grit and quartzite.

The Lardeau Group rocks at the southeast end of the Goldstream pluton were mapped and stratigraphic sections were measured along two separate traverses; the southwest flank of Downie Peak and east of Long Creek (Logan and Drobe, 1994). The sequence west of Downie Peak is coarsening upward and includes: biotite and muscovite-quartz schists interlayered with marble (equivalent to the lower Index); and schist, quartzite and grit of the upper Index. This sequence is abruptly overlain by the white marble forming Downie Peak. The lower part of the sequence hosts the Montgomery volcanogenic massive sulphide deposit. East of Downie Peak, between the Goldstream pluton and Long Creek stock, are graphitic and sulphidic biotite hornfels, biotite and muscovite schist, marble/calcsilicate and micaceous quartzite. A siliceous spessartine-bearing graphitic phyllite within this sequence is correlated with the "garnet zone" in the Goldstream mine stratigraphy (see below). Mafic subvolcanic greenstone and green chlorite schist are interlayered with micaceous quartzites near the top of this section. These rocks are equivalent to the lower black phyllite and middle greenschist members of the Index Formation.

CONTACT RELATIONS BETWEEN BADSHOT FORMATION AND LARDEAU GROUP

Fyles and Eastwood (1962) interpreted the Lardeau Group to overlie limestones of the Badshot Formation conformably, but described the contact in the Ferguson area as strongly sheared and, therefore, of uncertain stratigraphic significance. Reinterpretation of stratigraphic relationships in the Trout Lake area and regional stratigraphic correlations with the lower Paleozoic rocks of the Covada Group, in northwestern Washington, has led Smith and Gehrels (1992a, b, c) to interpret the Lardeau Group as an inverted stratigraphic sequence that has been tectonically juxtaposed over the Badshot Formation. Alternatively, work in the Illecillewaet synclinorium (Colpron and Price, 1992; in press) indicates that the Index Formation of the Lardeau Group conformably overlies the Badshot Formation.

The contact between the Badshot Formation and the Lardeau Group is not exposed in the Goldstream River area. However, the stratigraphy intersected in drill holes west of the Goldstream mine shows that contacts between units are gradational. Despite the presence of localized shearing along main contacts, the sequence is interpreted to be conformable.

PISOLITIC DOLOSTONE

A buff-weathering, fine-grained and thinly foliated dolostone crops out east of Downie Peak along the north-trending ridge which caps Long Creek stock. Here, it is a pristine pisolitic dolostone which consists of concentric-layered, brown, ovoid pisoliths 5 millimetres in diameter, within a white to buff, cryptocrystalline dolomitic matrix (Logan and Drobe, 1994). The pisolitic dolostone is intruded along its base by a metadiorite sill. The excellent preservation of these primary sedimentary textures is uncommon for rocks of the area. This unit crops out in an area complicated by layer-parallel faulting and younger high-angle normal faults, and is not easily correlated with other marble units in the map area.

CARIBOU BASIN

The rocks exposed in the Caribou basin, south of the Goldstream pluton, were mapped by Höy (1979) as part of his "quartzite and schist" subdivision, which he correlated with the Hamill Group. Most of the area is underlain by a quartz-rich sequence of interlayered micaceous quartzite, pelitic schist and amphibolite. The micaceous quartzites form prominent ridges, whereas interlayered pelitic schists form recessive benchs. South of Downie Creek, Brown (1991) correlated similiar rocks with the Jowett and Broadview formations of the Lardeau Group.

Massive to thickly bedded quartzites predominate. They contain clean quartzite horizons interlayered with typically thinly foliated micaceous quartzite. Muscovite-andalusite-quartz schists, biotite-garnet-quartz schists, and lesser calcsilicate horizons are interlayered with the micaceous quartzites. Dark green amphibolite layers may represent primary igneous rocks, but are more likely derived from metamorphosed calcareous units. Contact metamorphism has produced garnet-biotite-actinolite-andalusite assemblages in the calcareous pelitic units. Coarse, 2 to 5-centimetre, elongate aggregates of fine-grained quartz and muscovite are interpreted as pseudomorphs of andalusite. These pseudomorphs are a major constituent of pelitic schists in the Caribou basin. Höy (1979) previously interpreted them as retrograded kyanite porphyroblasts.

GNEISSES NEAR DOWNIE CREEK

Garnet-grade paragneiss and orthogneiss crop out along Highway 23 south of the Goldstream pluton (Figure 3). Outcrop is sparse and the gneisses are intruded by leucogranite sills of the Downie Creek suite and by younger pegmatites. The gneisses include micaceous quartzite, interlayered pelitic horizons, coarse garnet amphibolite and foliated diorite. Micaceous quartzites and interlayered biotite gneisses exposed along the highway north of the Downie stock contain synkinematic garnet pophyroblasts. The garnets are commonly mantled by retrograde chlorite rims. These higher grade gneisses may be correlative with Devonian gneiss of the Clachnacudainn Complex to the south.

INTRUSIVE ROCKS

Four plutons intrude strata of the Goldstream River area. These are interpreted to represent three distinct episodes of plutonism: Middle Jurassic (Adamant pluton), mid-Cretaceous (Goldstream pluton, Long Creek stock) and Late Cretaceous (Downie Creek stock). All of the main igneous bodies have been sampled for major and trace element geochemistry, petrology and geochronology. The details of each suite follow.

ADAMANT PLUTON

The Adamant pluton is an elliptical, east-trending composite intrusion comprising hypersthene-augite monzonite cores surrounded by hornblende (± biotite) granodiorite (Fox, 1969). Only the western half of the pluton is exposed in the Goldstream River area. Our mapping was restricted to its margins.

In the Goldstream River area, exposures of the hypersthene-augite monzonite phase of the pluton are restricted to the glaciated terrain surrounding Remillard Peak, and to cirques south of Waldorf Towers (Figure 3). Here, the monzonite also contains variable amounts of hornblende and biotite (Fox, 1969). The remainder of the pluton consists of a homogeneous medium-grained hornblende granodiorite. The granodiorite locally has an orbicular texture. A narrow border of foliated biotite (± hornblende) granodiorite is present along the northeastern margin of the pluton.

Adamant pluton is discordant with the trend of regional structures to the south; along its northern margin, the regional foliation and several bands of marble strike parallel to the pluton contact. Fox (1969) and Shaw (1978) proposed that emplacement of the pluton predates the development of dominant regional structures in the area. Okulitch (*in* Stevens *et al.*, 1982) speculated that it may even be as old as Paleozoic. Fox and Shaw related the deflection of structures near the pluton to deformation around a rigid inclusion during the Middle Jurassic. Fox also proposed that the outer zone of granodiorite results from hydration of the original pyroxene monzonite during regional metamorphism. Zircon from the outer zone of the pluton yielded a concordant U-Pb age of 169±3.4 Ma (Shaw, 1980). Because of its occurrence within the hydrated outer zone, Shaw has interpreted this age to date the metamorphism of the pluton. We concur with Woodsworth *et al.* (1991) that this date may alternatively reflect a Middle Jurassic age for the pluton. The complete overprinting of regional tectonic fabrics in the contact aureole suggests that the thermal anomaly associated with emplacement of the pluton outlasted (at least in part) the development of regional structures.

GOLDSTREAM PLUTON

The Goldstream pluton is an elliptical, east-trending intrusive complex. It consists of monzodiorite and granite sills and pendants of layered country rock. The western end of the body consists of a mixture of schists, gneisses and more or less conformable sills of granitic rock (Wheeler, 1965). The pluton is a composite body consisting predominantly of an older hornblende biotite monzodiorite phase and a younger, more felsic, biotite quartz monzonite to granite phase. Textures in the felsic phase vary from equigranular to sparsely porphyritic, centimetre-scale potassium feldspar phenocrysts characterize the latter. The margins of the pluton are defined by east-trending pendants and inclusions of metamorphosed country rock inter-digitated with monzodiorite and granite sills. The abundance of inclusions and their structural continuity at the margins, as well as in the centre of the pluton, indicate passive emplacement and wallrock assimilaton, and suggest that the present erosion surface may be close to the roof of the intrusive body.

Interdigitations of concordant granitic and monzodioritic sills with pendants of country rock distinguishes the Goldstream pluton from other plutonic bodies in the northern Selkirk Mountains. This intrusive style and the presence of a foliation within the granitic rock has been interpreted to suggest that emplacement of the Goldstream pluton predates the dominant regional deformation and could be as old as Devonian (Höy, 1979).

Discordant contact relationships between the intrusive phases and the pendants, and the various degrees of assimilation of xenoliths within the Goldstream pluton indicate, however, that emplacement of the pluton postdated the development of the penetrative foliation in the xenoliths (Logan and Drobe, 1994). The biotite foliation, locally present within the granitic phase of the pluton, is interpreted as either a magmatic foliation, or a ghost foliation inherited from assimilated xenoliths.

Hornblende and biotite mineral separates from the monzodioritic phase of the Goldstream pluton both yielded $^{40}Ar/^{39}Ar$ plateau ages of 114±4.5 Ma and 100±1 Ma, respectively (Figure 5). Metamorphic mineral assemblages in the aureole of the Goldstream pluton (*cf.* Metamorphism below) indicate that it was emplaced at high level. The hornblende age of 114 Ma is therefore interpreted to be the best estimate of the crystallization age. The younger biotite age (100 Ma) suggests slow cooling. Such a slow cooling rate (~14 °C/Ma) is somewhat unexpected in a high-level intrusion. Further geochronological studies of the Goldstream pluton are required in order to elucidate its emplacement history.

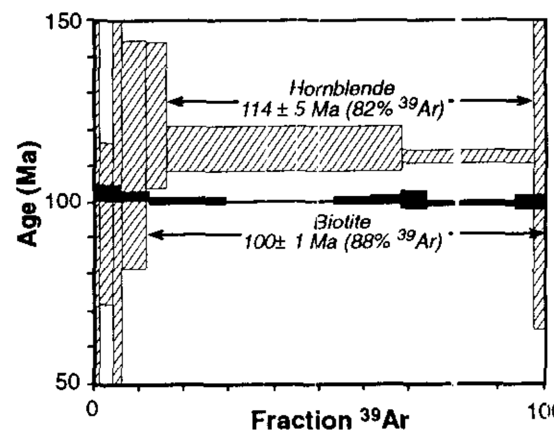


Figure 5: $^{40}Ar/^{39}Ar$ age spectra for monzodioritic phase of Goldstream pluton. Sampling locality is shown in Figure 3.

LONG CREEK STOCK

The Long Creek stock is a 5 by 8-kilometre body centred on Long Creek. It extends from south of Downie Peak across Downie Creek (Figure 3) and south of the map area to the mouth of Standard Creek (Brown, 1991). A 1370-metre vertical section of the stock, capped by marbles and phyllites of the Lardeau Group, can be viewed to the east, from the highway at Downie Creek. The eastern contact dips northeasterly and is subconcordant to strata. Along its western margin the stock clearly truncates regional structures. The stock consists of medium-grained biotite quartz monzonite similar to the felsic phase of the Goldstream pluton, but, in contrast, is generally free of inclusions of country rock. The margin of the intrusion is characterised by a zone of massive quartz and quartz-feldspar segregations, and sericite alteration 50 metres wide (Vanderpoll, 1982) and is associated with tungsten-bearing skarns developed in calcareous country rocks.

DOWNIE CREEK STOCK

The Downie Creek stock is a roughly circular body exposed north of Downie Creek at its confluence with the Columbia River. Fresh exposures of the stock are rare, but it forms a prominent talus slope along the north flank of Downie Creek. The stock is a medium to fine-grained, equigranular two-mica leucogranite, composed of plagioclase, potassium feldspar, quartz, biotite and muscovite in the proportions of a quartz monzonite to a granite. Fine-grained garnet is locally present. Country rocks are garnet-grade biotite-quartz paragneiss and dioritic orthogneiss of the lowest structural slice along Highway 23, and garnet-andalusite schist and micaceous quartzite in the Caribou basin to the northeast (Figure 3). The Downie Creek stock is interpreted to truncate the Caribou Creek fault (Figure 3). It is crosscut by brittle fault zones and chloritic breccias associated with the Columbia River fault at its western end.

ARGONAUT PEGMATITE COMPLEX

Abundant sills and dikes of pegmatite (1-5 m wide) intrude the psammitic schist exposed east of Argonaut Pass and along the flanks of French Creek (Figure 3). The sills are concordant with the north-trending, east-dipping attitude of the dominant foliation in the area. Dikes are subvertical and trend east-west; they are most abundant along the ridgetop east of Argonaut Pass and along the western flank of French Creek, where they comprise approximately 50% of the outcrops. The Argonaut pegmatites are composed of quartz, plagioclase and muscovite with minor amounts of biotite and garnet. A peculiarity is the presence of pods of sillimanite(?) 30 to 40 centimetres long.

STRUCTURE

The complex structure in the northern Selkirk Mountains is the result of polyphase folding and faulting associated with the Mesozoic accretion of allochthonous terranes at the western edge of the North American plate (Monger *et al.*, 1982, 1994). The earliest structures were postulated by Read and Wheeler (1976) to predate a middle to late Paleozoic erosional unconformity, but large-scale major folds and faults are generally accepted to be related to polyphase deformation during Mesozoic orogenesis (*e.g.*, Brown *et al.*, 1986; Price, 1986). These structures were transported eastward 200 to 300 kilometres together with the migrating deformational front above a diachronous décollement (Monashee décollement; Brown *et al.*, 1986, 1993), prior to Eocene extension (Brown and Journeay, 1987).

The Goldstream area is dominated by southwest-verging fold-nappes and thrust faults characteristic of the western flank of the Selkirk fan structure (Wheeler, 1963, 1966; Brown and Tippet, 1978; Raeside and Simony, 1983; Brown and Lane, 1988). The origin of the Selkirk fan has been ascribed to "the superposition of two distinct phases of deformation upon strata previously involved in nappe formation" (Brown and Tippett, 1978) or to "one protracted phase of deformation" (Price *et al.*, 1979). Earlier workers (Lane, 1977; Brown and Tippett, 1978; Höy, 1979; Brown and Lane, 1988) have suggested that dominant, southwest-verging folds in the area deform a previously inverted stratigraphic sequence and that strata of the Goldstream slice occupy the overturned limb of an early southwest-verging nappe (Carnes nappe; Brown *et al.*, 1983; Brown and Lane, 1988). Our stratigraphic revisions, and proposed correlations for rocks exposed in the western part of the Goldstream area, indicate that the stratigraphic sequence was not inverted prior to development of the regional southwest-verging folds.

Two generations of structures (and associated tectonic fabrics) are recognized throughout the Goldstream area. They correspond to the second and third phase structures of Lane (1977), Brown and Tippett (1978), and Höy (1979). The earlier generation of structures correspond to northwest-trending, southwest-verging folds and thrust faults which define the map pattern (Figure 6). These structures locally deform an older schistosity which is subparallel to bedding. They are also interpreted to deform a set of older contraction faults between Goldstream River and Sorcerer Creek. Regional relationships indicate a Middle Jurassic age for this generation of structures (*e.g.*, Parrish and Wheeler, 1983; Brown *et al.*, 1992;). The southwest-verging structures are deformed by younger, easterly trending, gently plunging folds. These structures predate the emplacement of the mid-Cretaceous intrusive suite. These two generations of structures are readily recognized by their overprinting relationships with respect to one another and to regional metamorphic events. North-trending fractures, normal faults and gentle open warps are the youngest structures and are interpreted to be associated with Eocene crustal extension along the Columbia River fault.

The Goldstream River area is subdivided into two structural domains bounded by the French Creek fault (Figure 6). In the eastern domain, dominant folds are tight isoclines with north-trending axial traces; in the western domain, the axial trace of dominant folds trend more northwesterly. Younger, east-trending cross-folds are present in both domains. The eastern and western domains correspond, respectively, to the Illecillewaet and the Goldstream slices of Brown and Lane (1988).

NORTHWEST-TRENDING STRUCTURES

The structural style of the Goldstream River area is dominated by north and northwesterly trending, southwest-verging structures. Folds are tight to isoclinal, overturned to recumbent, and characterized by axial plane schistosity which dips either east, northeast or, where refolded by later cross-folds, northerly. Fold axes plunge moderately to the northeast. The superposition of younger, easterly trending cross-folds has produced type 3 interference patterns (Ramsay, 1962).

In the eastern structural domain, the competent quartzites and volcanic rocks of the Hamill Group are deformed into a series of four west-verging synclines between Sorcerer Creek and the Goldstream River (Figure 6). These parallel folds are locally truncated by thrust faults (Photo 1).

The French Creek fault is the major north-trending thrust fault that separates the eastern and western structural domains (FCF; Figure 6). It places the older rocks of the Horsethief Creek and Hamill groups, to the east, over rocks of the Lardeau Group in the Goldstream slice. The French Creek fault is exposed in marbles along the French Creek road north of the Goldstream River. Shear sense indicators from a grey, thinly foliated marble mylonite in the footwall of the fault consistently show tops-to-the-west sense of motion. North of this exposure, the fault continues into the French Creek valley maintaning its east dip, but probably warped about the east-trending synclinal cross-fold. East of the Long Creek stock, the fault separates strongly foliated, mylonitic greenstones, dolostone and dark phyllite of the Horsethief Creek Group from Lardeau Group phyllite and carbonate (Figure 3). The fault is traced to the south into the Downie Creek fault (Brown, 1991), a major northwest-trending, southwest-verging thrust fault. At its southern end, the fault dies out in the core of a southwest-verging anticline which forms part of the Illecillewaet synclinorium (Colpron and Price, 1993).

The Goldstream anticline is a west-northwesterly trending structure cored by dolostone of the Badshot Formation in the western structural domain (Figure 6). Its axial trace follows the Goldstream River southeasterly, where it swings into near parallelism with the northern margin of the Goldstream pluton (Figure 6). Minor folds associated with the Goldstream anticline plunge to the east. Parasitic minor folds in green micaceous quartzites and grits of the upper Index Formation, north of the Goldstream River, are Z-shaped; minor folds in phyllite of the lower Index at the open pit, south of the Goldstream mine, are S-shaped. A north-trending anticline-syncline pair, cored by Badshot dolostone, occurs to the north, in the vicinity of Nicols Creek, and probably reflects the northward continuation of the Goldstream anticline. The strongly sheared nature of the enclosing phyllites has been interpreted by earlier workers (*e.g.*, Read and Brown, 1981; Gibson and Höy, 1994) to be associated with the Goldstream River fault: a major northwesterly trending structure linking the

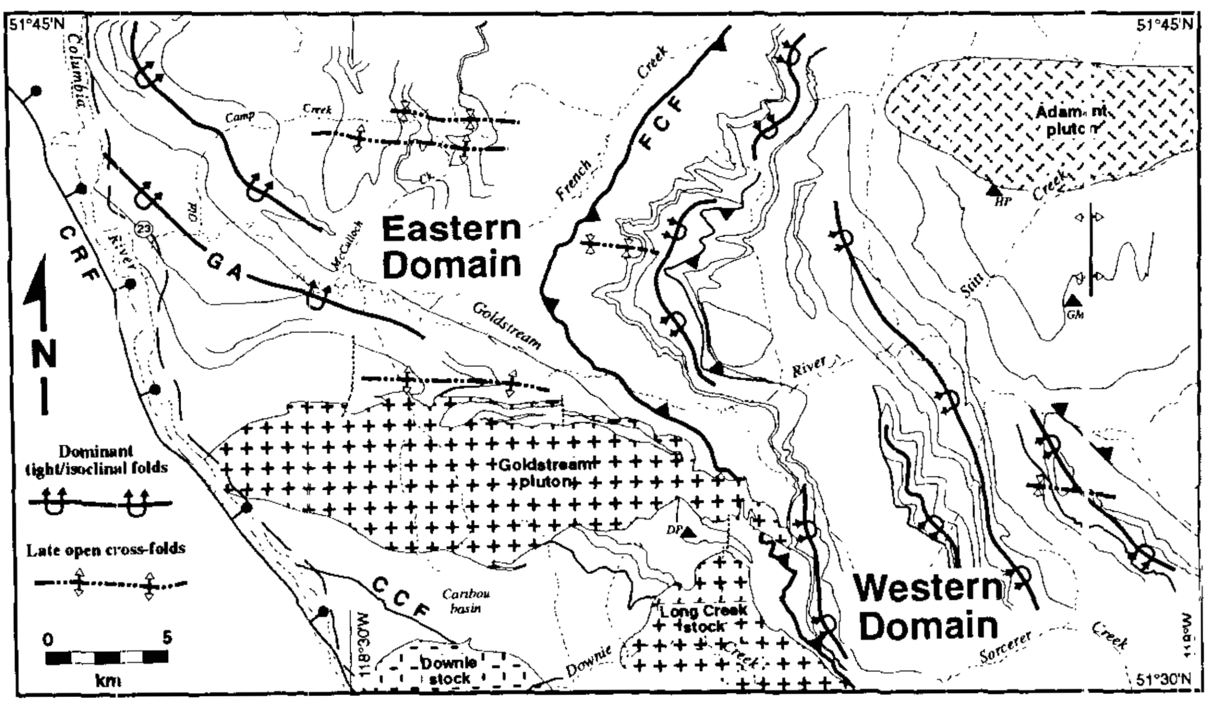


Figure 6: Structural map of the Goldstream River area showing the location of major folds. Major faults: CRF = Columbia River fault, CCF = Caribou Creek fault, FCF = French Creek fault; GA = Goldstream anticline.

Photo 1: Southwest-verging parallel folds and thrust faults in Hamill Group quartzites; view is towards the northwest. Outcrops are located between the headwaters of Sorcerer Creek and Goldstream River.

Photo 2: Early recumbent isoclinal folds (in centre) of micaceous quartzites of the Horsethief Creek Group refolded about open, upright east-trending cross-folds; view is to the east.

Downie Creek fault to the Columbia River fault zone. However, the stratigraphic continuity in drill holes both north and south of the Goldstream River does not support the existence of such a structure.

A poorly understood, northwesterly trending structure separates rocks of the Index Formation on the southwest flank of Downie Peak from the quartz-rich sequence of interlayered micaceous quartzite, pelitic schist and amphibolite of the Caribou basin. It is conformable with the dominant foliation and truncated by the Goldstream pluton at its northern end and the Long Creek stock at its southern end. This structure is probably correlative with the southwest-verging Standard thrust fault to the south (Brown, 1991).

The Caribou Creek fault (CCF; Figure 6) is northwest-trending structure that is inferred to separate higher grade metamorphic orthogneiss and paragneisses, possibly correlative with the Clachnacudainn gneiss, from the mixed package of micaceous quartzites, pelitic schist and amphibolites of the Caribou basin. It is truncated by the Downie Creek stock to the south.

EAST-TRENDING STRUCTURES

Young, east-trending, steeply dipping crenulation cleavage and open folds are superposed on the northwest-trending structures. Deformation of the earlier schistosity produced a pervasive crenulation cleavage in the phyllite and calcareous chlorite schist of the Index Formation. These cross structures are best developed north of the Goldstream River, in the Groundhog basin, and north of the Goldstream pluton. In the Groundhog basin the folds are upright, open chevron and kink folds. East of French Creek, rocks of the Horsethief Creek and Hamill groups are gently folded about an easterly trending synformal axis (Figure 6).

South of the Goldstream River, the Index Formation is folded into an upright antiform about an east-trending axis. The strata at the mine dip moderately north, on the north limb of this cross-fold; the south limb is intruded by the Goldstream pluton and offset by high-angle reverse faults (G. Gibson, personal communication, 1994).

EARLY CONTRACTION FAULTS

The earliest fault structures recognized in the Goldstream area are north-trending, east-dipping faults between Sorcerer Creek and Goldstream River (Figures 3 and 6). These structures are illustrated in Brown and Tippet (1978, Figure 3), who described the Hamill Group as "preserved in synclinal keels that are generally faulted against sheared limbs of anticlines in the Horsethief Creek Group". Fold vergence and bedding truncations indicate that these structures are east-verging imbricate contractional faults which placed the Horsethief Creek Group onto Hamill Group rocks. Continued deformation overturned these structures which now appear to have a normal sense of displacement. Similar overturned, east-verging thrust faults were recognized by Zwanzig (1973) in the Illecillewaet synclinorium to the south.

COLUMBIA RIVER FAULT

The Columbia River fault zone separates the hangingwall Selkirk allochthon from the footwall rocks of the Monashee Complex (Figure 1). The Columbia River fault is a normal fault which dips 20° to 30° to the east. Motion is dip slip and of sufficient magnitude to juxtapose greenschist facies rocks of the Goldstream slice against upper amphibolite facies rocks in the footwall (Read and Brown, 1981). The fault is responsible for the development of cataclasite and chloritic breccias in the Goldstream pluton and Downie Creek stock. Discreet brittle fault zones less than a metre wide, and characterised by anastomosing slip planes and angular centimetre-scale breccia fragments. are visible in weathered exposures of the Badshot Formation along Highway 23. The late-stage brittle-ductile deformation of the carbonates here overprints earlier ductile fabrics. Internal structures visible on weathered surfaces include anastamosing alternating dark and light wispy foliation which wraps around angular, rotated and stretched carbonate breccia fragments.

Additional late-stage, brittle deformation includes east-trending, north-side-down normal faults which are exposed in the Goldstream River valley and in the Goldstream mine workings. These are generally foliation-parallel shear zones.

RELATIONSHIPS BETWEEN PLUTON EMPLACEMENT AND DEFORMATION

The temporal relations of Middle Jurassic granitic intrusion to regional deformation in the northern Selkirk Mountains, and particularly the deflection of dominant structures around these bodies, has been addressed by various authors. The debate has mostly focused on the relationships around Fang stock, south of the Goldstream River area (Figure 1). Wheeler (1963) originally concluded that the deflection of structures reflects the forceful emplacement of the Fang stock after development of the regional structures. Reesor (1963) suggested that the pluton was emplaced early in the tectonic history and was subsequently deformed. Recent work by Brown *et al.* (1992) suggests that Fang and Pass Creek stocks were emplaced after the development of the regional southwest-verging structures and that the deflection of structures is related to later "rigid-body rotation of the plutons". Colpron and Price (1993) argue that emplacement, consolidation and rigid-body behaviour of the Fang stock all occurred during progressive development of the regional southwest-verging structures.

A similar deflection of the regional structures occurs around the Adamant pluton (Fox 1969; Shaw, 1978). Fox and Shaw concluded that this deflection of structures resulted from deformation around a pretectonic intrusion. However, relationships along the southern margin of the Adamant pluton suggest that the pluton was emplaced late in the defomation history.

In a detailed section across the aureole northwest of Hitchhiker Peak, the metamorphic assemblages overprint the dominant foliation in the wallrocks and granitic leucosomes are common within an 800-metre radius from the pluton. Porphyroblasts increase in size (up to several centimetres) as the pluton is approached. Within 500 metres of the contact, the country rocks are completely devoid of foliation, and dismembered calcsilicate and amphibolite boudins are "floating" within a quartzite matrix. Deformational features are limited to disharmonic, ptygmatic folds and boudinaged calcsilicate and amphibolite layers. Because the style and orientation of folding in the aureole of the Adamant pluton differ from that of regional structures in the area, we relate this deformation to the emplacement of the pluton rather than to regional deformation. These relationships imply that intrusion of the Middle Jurassic Adamant pluton occurred after the development of the dominant structures in this area. However, large-scale deflection of the regional structures to the north and east of the pluton suggests that deformation continued after its emplacement (Fox, 1969; Shaw, 1978). We therefore suggest that perhaps Adamant pluton had a similar emplacement history to Fang stock.

A chiefly retrograded, contact metamorphic aureole surrounds the Goldstream pluton. It overprints the dominant foliation and the younger east-trending cross-folds. This implies that emplacement of the mid-Cretaceous Goldstream pluton postdates the development of the east-trending cross-folds. Numerous zones of brittle-ductile deformation associated with the Columbia River fault crosscut the pluton at its western edge, along Highway 23. The eastern edge of the pluton truncates the French Creek fault (Figure 3).

METAMORPHISM

Rocks of the Goldstream River area contain mineral assemblages characteristic of greenschist to amphibolite facies metamorphism. Figure 7 shows the distribution of isograds as defined by first occurrence of index minerals mapped in the field. Assemblages characteristic of the chlorite zone are found within a west-northwest-trending metamorphic depression which approximately follows the Goldstream River (Figure 7). Chlorite-kgrade mineral assemblages define the dominant foliation throughout the Goldstream area. Synkinematic biotite-grade assemblages are present in the northern part of Groundhog basin.

The low-grade depression is flanked to the northeast and southwest by two metamorphic culminations (Figure 7). The southwest culmination surrounds the Goldstream, Downie and Long Creek intrusive bodies, and is ascribed, for the most part, to

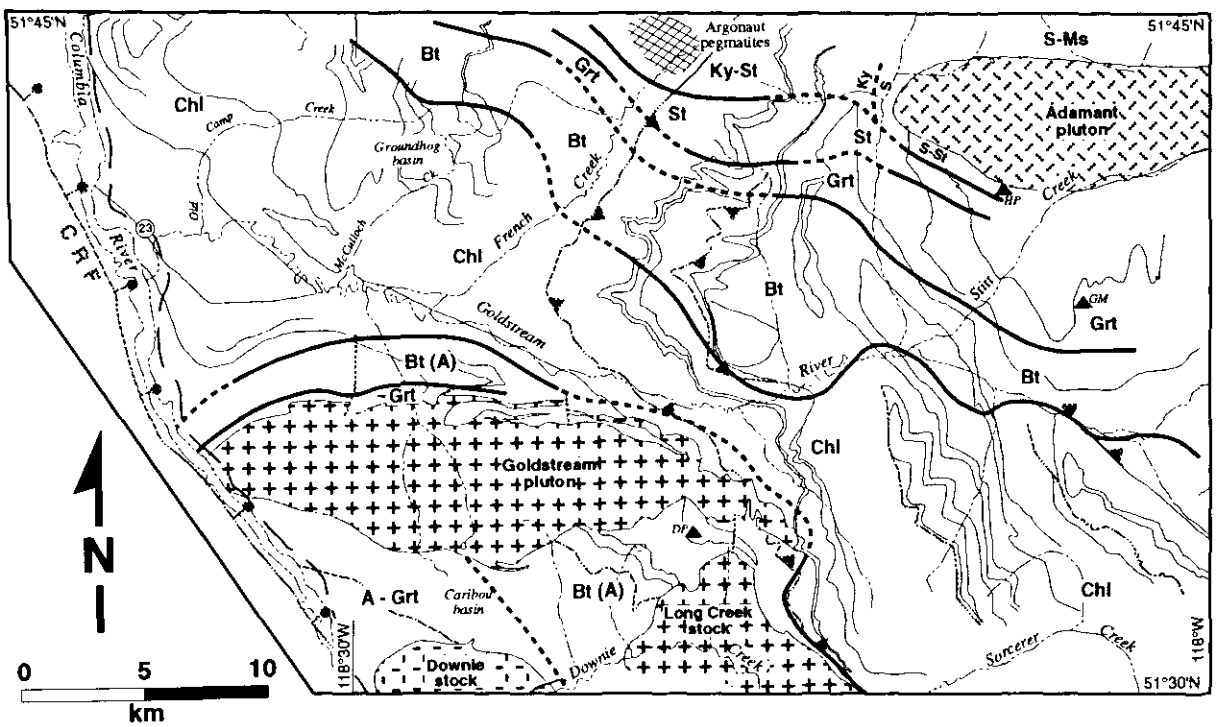


Figure 7: Metamorphic map of the Goldstream River area. Isograds are defined on basis of the first occurrence of index minerals mapped in the field. Metamorphic zones: Chl = chlorite, Bt = biotite, Grt = garnet, St = staurolite, Ky-St = kyanite-staurolite, S-St = sillimanite-staurolite, S-Ms = sillimanite-muscovite, A-Grt = garnet-andalusite. (A) denotes the presence of retrograded andalusite pseudomorphs. Cross-hatched pattern shows distribution of pegmatites. See Figure 3 for other abbreviations

contact metamorphism imposed by these plutons. Assemblages of the biotite and garnet zones define this metamorphic culmination (Figure 7). Psammitic and pelitic rocks in this culmination commonly contain andalusite pseudomorphs up to 5 centimetres long. Calcareous rocks along the northern flank of the Goldstream pluton contain fine radiating clusters of actinolite. Occurrences of fresh andalusite are restricted to the immediate vicinity of the Downie pluton. Coexisting biotite, garnet and andalusite constrain emplacement of the Downie pluton to bathozone 2 (or less) of Carmichael (1978), corresponding to a pressure of less than 350 MPa (3.5 kbar). Similarly, andalusite pseudomorphs in the aureole of the Goldstream pluton constrain its emplacement to bathozone 3 or less (less than 375 MPa (3.75 kbar)). The southwest metamorphic culmination is most likely a composite contact aureole of Cretaceous age. A notable exception is the presence of synkinematic garnet-grade assemblages in gneissic rocks exposed along Highway 23. We believe that these gneisses may preserve a pre-Cretaceous (?) garnet grade regional metamorphism.

The culmination in the northeastern part of the Goldstream area is a segment of a regional west-northwest-trending metamorphic culmination extending for more than 90 kilometres between Mica dam and Rogers Pass (Windy Range culmination; Read and Brown, *1981*; Greenwood *et al., 1991*; Read *et al.*, 1991). This culmination was first outlined by Wheeler (1965) and has subsequently been the subject of studies by Ghent (1975), Ghent *et al.* (1979) and Leatherbarrow (1981). Nathalie Marchildon (University of British Columbia) has recently initiated a detailed study of the southwest flank of the Windy Range culmination in the area northwest of French creek.

Regionally, the Windy Range culmination grades from biotite zone in the southwest, to sillimanite - potassium feldspar zone in the core of the culmination (Leatherbarrow, 1981; Read *et al.*, 1991). To the northeast, metamorphic grade decreases to kyanite-staurolite zone along the southwest flank of the Rocky Mountain Trench. In the Goldstream River area, assemblages characteristic of the biotite, garnet, staurolite and kyanite-staurolite zones are present along the southwest flank of the culmination. Sillimanite-staurolite grade assemblages in the contact aureole of the Adamant pluton may (or may not) be part of the culmination.

The west-northwest trend of the isograds is discordant with the more northerly trend of the regional structures north of Goldstream River (Figure 7). Porphyroblast growth in the Windy Range culmination appears to postdate the development of the dominant regional fabric. However, N. Marchildon (personal communication, 1994) reports synkinematic to post-kinematic prophyroblasts in the area northwest of French Creek. Locally, biotite porphyroblasts define a weak alignment which parallels the trend of late crenulations in the area. Calcareous psammites metamorphosed to garnet grade (and higher) commonly contain large aggregates of hornblende arranged in a characteristic "bow-tie" texture. Kyanite porphyroblasts, locally as large as 15 centimetres long, are randomly oriented along the surface of the dominant regional fabric. These relationships indicate that high-grade metamorphism along the Windy Range culmination is late to postkinematic with respect to the development of the dominant regional structures in the area (Brown and Tippett, 1978; Leatherbarrow, 1981). Mineral alignments which parallel the trend of late crenulations suggest that metamorphism was locally contemporaneous with the development of late open folds.

The assemblage biotite-garnet-kyanite constrains metamorphic conditions to at least bathozone 5 (pressures in excess of 500 MPa (5 kbar); Carmichael, 1978). Leatherbarrow (1981) reported pressures of about 500 MPa (5 kbar) and temperatures up to about 500°C for the southwest flank of the Windy Range culmination. West of Argonaut Pass, kyanite porphyroblasts are partially (to completely) replaced by andalusite. Kyanite is still preserved in the core of larger andalusite porphyroblasts. This relationship indicates decompression to bathozone 3-4 (*ca.* 375 MPa, (3.75 kbar)).

The contact aureole of the Adamant pluton contains assemblages of the garnet-staurolite sillimanite-staurolite, and sillimanite-muscovite zones (Figure 7). Sillimanite occurs in large bladed pseudomorphs after kyanite; relict kyanite is still present in thin sections. Coexisting sillimanite, staurolite, garnet, biotite, muscovite and kyanite constrain emplacement of the Adamant pluton to the transition between bathozones 4 and 5, corresponding to pressures of about 500 MPa (5 kbar; Carmichael, 1978). Similarities of mineral assemblages and pressures suggest that contact metamorphism in the aureole of the Adamant pluton may be related to the Windy Range metamorphic culmination. Replacement texture of kyanite by sillimanite may even indicate that the pluton is somewhat younger than the culmination, and is consistent with the indications of late decompression observed in the Argonaut Pass area.

MINERAL OCCURRENCES

MASSIVE SULPHIDE DEPOSITS

A number of volcanogenic massive sulphide deposits occur within the polydeformed, and metamorphosed terrigenous sediments and interlayered mafic volcanic flows and sills of the Lardeau Group. The Goldstream orebody and the Standard, Brew and Montgomery copper-zinc prospects have characteristics of Besshi-type deposits (Höy *et al.*, 1984). Zinc-lead±copper deposits at the Rift and C-1 prospects have characteristics of both distal volcanogenic massive sulphide deposits (Large, 1977) and clastic-hosted deposits. Besshi-type deposits occur within either mafic volcanic rocks or terriginous clastic rocks interlayered with mafic flows or sills. Clastic-hosted deposits occur within well layered successions of dominantly calcareous schists, carbonate and quartzite, generally free of volcanic influence.

Additional mineral deposits in the map area include lead-zinc carbonate replacements, tungsten-copper skarns, base and precious metal quartz veins and placer gold concentrations.

GOLDSTREAM MINE

In conjunction with the regional mapping, 4 weeks were spent studying the Goldstream deposit. Surface and underground mapping and sampling of hangingwall, massive sulphide and footwall lithologies of the mine sequence were completed. In addition, drill core from some of the 1991, 1993 and early 1994 diamond drilling programs was logged and sampled. Major and trace element analyses will be used to characterize the alteration assemblages, element mobility and possible vectors towards the ore horizon. The data from this alteration study form one aspect of a larger regional lithogeochemical study.

The Goldstream mine is located on the south side of the Goldstream valley, approximately 14 kilometres east of Highway 23 (Figure 3). Copper-zinc mineralization was discovered at Goldstream during construction of logging roads in 1972. Noranda Mines Ltd. acquired the property in 1975 and completed 8912 metres of diamond drilling, outlining 3.175 million tonnes of ore grading 4.49% Cu, 3.24% Zn and 20 g/t Ag. A production decision was made in 1980 and the mine opened in 1983. Depressed metal prices forced the mine to close less than a year later. Production during this period totalled 11 850 tonnes of copper and 505 tonnes of zinc from 428 000 tonnes milled.

Bethlehem Resources Corporation and Goldnev Resources Inc. acquired the Goldstream property from Noranda in 1989. Production resumed in May 1991. The mine is currently producing at a rate of 1150 tonnes per day. Production from May 1991 to Oct 1, 1994 totals 55 838 tonnes of copper and 39 343 tonnes of zinc from 1.35 million tonnes milled.

During the past year, exploration and development work at the Goldstream mine was supplemented by provincial funding provided under the Mineral Exploration Incentive and Accelerated Mine Exploration programs. Exploration work targeted the C-1 zone and the western strike extension of the mine horizon in the area between Brewster Creek and the C-1 zone (Figure 3). Development work tested the down-plunge extension, grade and thickness of the orebody below the 350-metre elevation. Eleven diamond-drill holes drilled from the north side of the Goldstream River have been completed totalling 5226.5 metres. The deepest exceeded 670 metres (Wild, 1994). Reserves as of October 1, 1994 include: drill indicated to the 150-metre level, 455,000 tonnes at 4.10% Cu and 3.24% Zn; and geologically inferred to the 0-metre level, 300,000 tonnes of 4.20% Cu and 3.24% Zn (C. J. Wild, personal communication, 1994). These are equivalent to two years of current production.

Goldstream is a Besshi-type volcanogenic massive sulphide deposit of early Paleozoic age. The orebody is hosted by a structurally complex, inverted package of fine-grained calcareous and carbonaceous clastic rocks, and mafic volcanic rocks of the Index Formation, which has been intruded and metamorphosed by the mid-Cretaceous Goldstream pluton. The mine sequence is best exposed along the east wall of the open pit (Figure 8). A detailed description of this section is given in Logan and Drobe (1994). In general, the mine sequence consists of a lower dark pelite, including an iron-silica-manganese-enriched unit (garnet zone), a massive sulphide layer enveloped by a micaceous and calcareous quartzite unit, a carbonate unit and an upper mafic metavolcanic unit (Figure 8). The mine sequence is distinguished from the lower Index Formation elsewhere by the presence of iron-manganese and boron-rich sedimentary units which are associated with the massive sulphide layer. These chemically distinctive units extend laterally beyond the sulphide horizon and provide better exploration targets than the smaller alteration envelope of chlorite-biotite-sericite schist that encloses the massive sulphide layer at the mine.

The garnet zone at the mine is a complex unit consisting of: graphitic phyllite with or without garnet; very thinly layered chert; siliceous iron carbonate and garnet-bearing horizons; and siliceous iron sulphide and garnet-bearing horizons. It extends laterally 1.5 kilometres northwest and 3 kilometres southeast from the mine. Drill hole GR93-5, northwest of the mine and apparently distant from the Goldstream pluton (Figure 3), intersected 15 metres of weak garnet zone, consisting of coarse garnets (1 cm) mantled by retrograde chlorite rims. Correlative horizons south of the mine are very siliceous, grey chert-like layers mineralized with several percent pyrrhotite. The garnet horizon occupies the stratigraphic footwall of the deposit (Figure 8). Typically, iron-manganese and silica-rich horizons are found in the stratigraphic hangingwall, and as distal facies to Besshi-type deposits. The garnet zone at Goldstream may reflect an early low-temperature hydrothermal exhalation unrelated to the deposit-forming event. Alternatively, it may have formed by selective replacement of permeable sediments in the upper part of the hydrothermal system (Slack *et al.*, 1993) at the same time the sulphide layer was forming. Ore consists of intermixed pyrrhotite, chalcopyrite and sphalerite and numerous rounded inclusions. The inclusions comprise various wallrock lithologies, several generations of metamorphic quartz and clasts of massive sulphide, floating in a matrix of swirled fine-grained sulphides (*durchbewegung texture)*, a texture common in metamorphosed massive sulphide deposits. Sulphides within the ore layer are fine grained, often folded, recrystallized gneissic bands; commonly, they are remobilized into discordant fracture fillings and pressure shadows. Disseminated sulphides extend into the hangingwall and, less often, the footwall rocks. The quartzite adjacent to the massive sulphide layer contains up to several percent disseminated pyrrhotite, chalcopyrite and sphalerite. The distribution of the sulphides appears to be related to replacement of calcite matrix cement in the quartzites.

Surface mapping on recent logging roads (Gibson, 1994; this study) has traced the mine stratigraphy around an east-trending cross-fold south of the open pit (Figure 9). Manganese-garnet units occur along the southern limb of this fold; siliceous/chert(?) horizons and massive sulphides (East Creek showing) occur structurally below it. Four drill holes (GR93-1 to 4) tested the extension of the mine horizon on the south limb of the fold. All holes were collared in rocks below the footwall marble and drilled south, ending in hangingwall rocks (Figure 9). No significant base metal mineralization was intersected. Up to five chert horizons were recognized in drill core; two are located below the footwall limestone and one of these, in hole GR93-3, contains 1.9 metres of semimassive pyrrhotite and chalcopyrite (G. Gibson, personal communication, 1994). This mineralized horizon is stratigraphically equivalent to the East Creek zone, discovered in 1974. Mineralization consists of coarsely crystalline, massive pyrrhotite, veined with chalcopyrite. This high-grade pod (20 centimetres by 1 metre) of recrystallized sulphides lies along the lower contact of the footwall marble and is interpreted to be skarn mineralization (G. Gibson, personal communication, 1994). The stratigraphy can be correlated between GR94-1 and

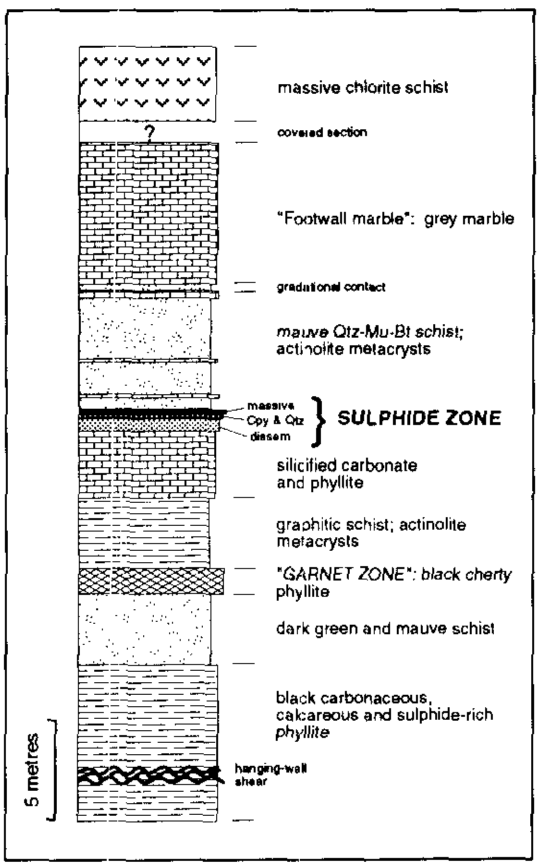


Figure 8: Measured stratigraphic section of the east wall of the Goldstream mine open pit. Modified after Logan and Drobe (1994).

GR94-3. However, in hole GR94-1 the chert-garnet zone is barren of sulphides. Strata at the collar of GR93-1 dip steeply south and are cut by a vertical fault zone. The three chert-garnet zones intersected in hole GR93-1 may reflect fold duplication on tight parasitic Z-shaped folds. The Goldstream pluton was intersected in the bottom of drill hole GR93-1 (Figure 10). The pluton leaves little room for continuation of the mine sequence around the south limb of the fold or for undiscovered orebodies, except possibly in inliers in the pluton, and current exploration (1994) is again focused on the north limb of the fold at its western end.

Preliminary conclusions from underground mapping and sampling follow those of earlier workers (Höy *et al.*, 1984) that sulphide textures and morphology of the orebody reflect Middle Jurassic deformation and metamorphism. The orebody is a northeast-plunging ruler-shaped body. The mineable section of ore is approximately 300 metres long and 1 to 3 metres thick with a down-plunge extension exceeding 2000 metres. The orebody is developed by sublevels spaced at 8 metre vertical intervals and mined by long hole stoping.

The southern boundary of the orebody crops out along the east wall of the open pit at 845 metres elevation. It is hosted by tight, isoclinally folded and sheared calcareous and quartzose pelitic rocks. The northeast plunge of the orebody parallels stretching lineations and fold axes of the dominant, northwest-trending structures. Structures along the length of the sulphide body vary from northwest to southeast and across it, from footwall to hangingwall. The generally competent footwall marbles and lesser phyllites exhibit moderate to tight northeast-plunging folds, but the micaceous carbonate and schists of the hangingwall, together with the sulphide body, are typically ptygmatically folded and faulted into southwesterly verging structures. The intensity of deformation increases northward towards the hangingwall.

The northwestern boundary of the orebody plunges northeasterly (Figure 9). It coincides with structural disruption along high-angle faults and tight upright folds. Low-angle, east-trending faults occur at the boundary. They generally follow the hangingwall, but locally cross to the footwall, faulting-out complete sections of the sulphide layer. Rocks at the northwestern end of the orebody are generally less competent, with relatively more biotite, sericite, chlorite and talc, and less silica alteration (C. J. Wild, personal communication, 1994). As the sulphide layer is traced to the east, the orebody tapers in thickness and copper grade drops off. Thick, white quartz sweats and large quartz augen are present in the massive ore along both footwall and hangingwall sections at the southeastern end of the orebody. A steep, northeast-trending, east-side-down, normal fault offsets the ore horizon along the east wall of the open pit; displacement is on the order of 10 metres.

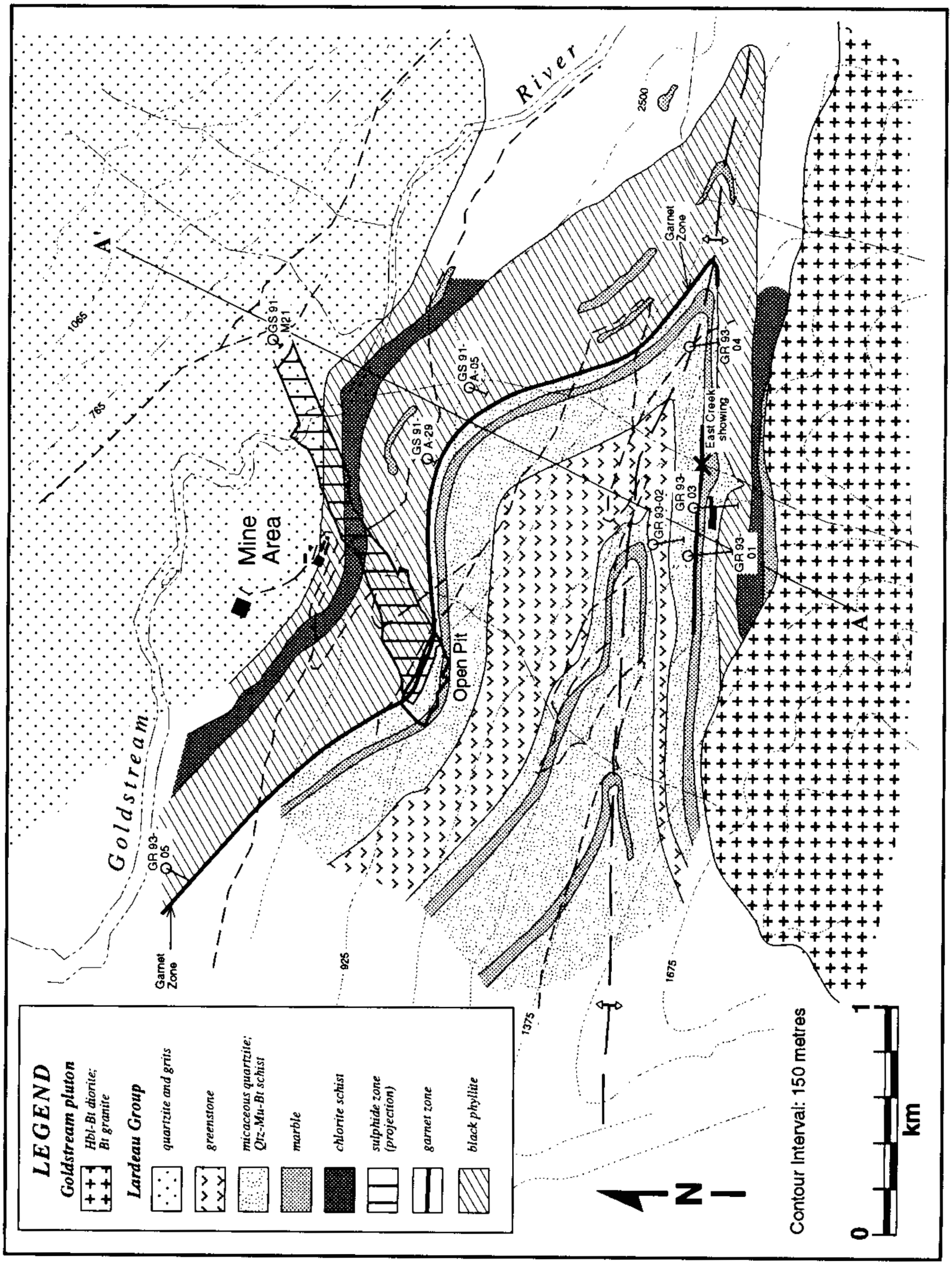


Figure 9: Detailed geological map of the Goldstream mine area compiled from our 1994 mapping and from Gibson (1994).

Foliation-parallel brittle fault zones follow incompetent layers in the footwall and hangingwall rocks. The footwall shear is a west-trending reverse fault, dipping 30° north. It follows the footwall of a narrow section of sulphidic phyllite and mafic sills within the footwall marble, approximately 60 metres below the orebody. The hangingwall shear is an anastamosing structure that in general follows the garnet zone. It comprises a number of foliation-parallel shears, dipping 30° or less to the north, resulting from the competency contrast between siliceous and carbonaceous units of the garnet zone. The hangingwall shear has a top-to-the-southwest sense of shear, similiar to the regional sense of motion.

The orebody varies in thickness along its length, where isoclinal folding and shearing have stacked fold hinges along low-angle faults. Locally, it consists of northeast-plunging rootless-fold hinges of massive sulphide ± disseminated layers. These flat fault structures are folded about younger east-trending folds. This configuration is overprinted by contact metamorphism of the mid-Cretaceous Goldstream pluton. The youngest deformation event has produced north-trending broad open folds and minor strike and dip deviations in the massive sulphide layer.

South of the mine, the lower greenschist facies rocks are overprinted by the contact aureole of the Goldstream pluton. Metamorphic assemblages include biotite, muscovite, garnet, andalusite, actinolite and cordierite(?). For the most part, the calcareous strata have been metamorphosed to a calcsilicate sequence. These minerals have been retrograded by late-stage fluids and in most cases only relict porphyroblasts of chlorite or sericite remain. Greenish-brown tourmaline, probably magnesium-rich dravite or schorl-dravite, is present in concentrations up to 10 modal percent in quartz-muscovite schists and impure carbonates of the footwall section. In the carbonates, coarse tourmaline crystals up to 3 centimetres long are intergrown with actinolite on foliation planes. Both minerals define a mineral lineation parallel to the elongation of the orebody.

Wallrocks adjacent to the massive sulphide layer include a pale silver weathering, thinly interlayered calcareous muscovite schist and quartzite. Very fine grained secondary biotite, and more rarely, actinolite occur in the hangingwall and immediate footwall. It has been suggested that this envelope to the massive sulphide layer is in part an exhalative unit (Höy, 1991). The rhythmic layering of quartzose units with calcareous and micaceous partings suggests to us that most of this unit is clastic in origin.

Black to dark green, lustrous chlorite zones are locally present, but rare. Most often they are associated with either disseminated chalcopyrite zones or inclusions in massive sulphide rocks. Chlorite alteration appears to be late stage and to be associated with crosscutting fractures and fault zones. Pale yellow quartz-muscovite-chlorite-andalusite-cordierite(?)-tourmaline schists are interlayered with calcsilicate assemblages and black phyllite south of the mine. The rocks outcrop close to the northern edge of the Goldstream pluton and, as a result, are retrograded to quartz, chlorite and muscovite. These coarse, porphyroblastic schists may be equivalent to the spotted cordierite-anthophyllite rocks (dalmatianite) which

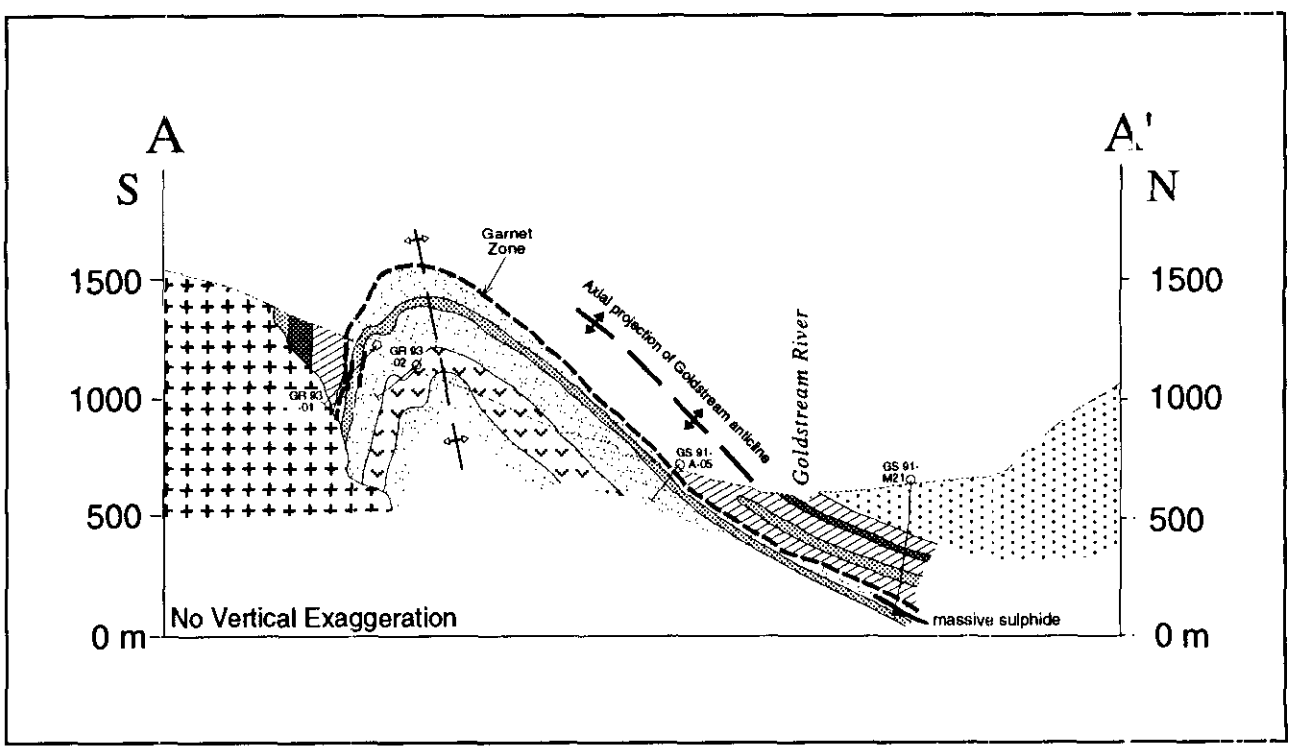


Figure 10: Cross-section of the Goldstream mine area. See Figure 9 for location of the line of section and for the legend.

surround Archean copper-zinc deposits in the Rouyn-Noranda district. At this stage, it is difficult to determine whether these assemblages are related to syndepositional alteration related to ore formation, the regional metamorphism or later contact metamorphism (prograde followed by retrograde metamorphism), or the combined affects of all these processes.

C-1

The C-1 zone was discovered in 1991 by diamond drilling coincident geochemical and geophysical anomalies on the south-facing slope of the 'hump', approximately 9 kilometres west of the Goldstream mine (Figure 3). The zone is comprised of one or more layers of disseminated and banded to locally semimassive pyrrhotite and sphalerite, with trace amounts of chalocopyrite and galena (McArthur *et al.*, 1991). Ten drill holes tested the zone over a strike length of 400 metres and down dip for up to 75 metres (McArthur *et al.*, 1991). The best intersection returned 3.94 % Zn, 1.54 % Pb, 0.04 % Cu and 31.19 g/t Ag over 2 metres. The sulphides are hosted by strongly fractured and faulted dark chlorite phyllite, carbonate and black graphitic phyllite, and minor quartz stockwork zones within these units. The thinly foliated calcareous green chlorite schists and carbonates are probably equivalent to the middle Index Formation, or the uppermost lower Index Formation, and are correlated with footwall rocks at the Goldstream mine. Talc-altered ultramafic rocks and dark graphitic phyllite crop out in a soapstone quarry 2 kilometres east of the C-1 zone. Drill hole stratigraphy (McArthur *et al.*, 1991) eastward towards the mine, shows an interlayered sequence of graphitic phyllites, chloritic phyllites, talc-altered ultramafic rocks and lesser carbonate as far east as the tailings pond (approximately 4 km east of the C-1 zone). Northwest of the C-1 showing, asbestos-bearing serpentinite occurs in graphitic schists of the lower Index Formation at the Monarch showing (Wheeler, 1965), now submerged by the Columbia River. Thinly foliated talc-altered greenschists and ankeritic talc schist may represent zones of hydrothermal exhalation (Fox, 1984) rather than altered ultramafic rock.

The mineralogy and host stratigraphy of the C-1 showing are similiar to the stratiform Rift lead-zinc deposit located approximately 22 kilometres north. The Rift consists of a number of layers of massive sphalerite, pyrite, pyrrhotite and galena, up to 2 metres thick. Sulphides are hosted by a predominantly schistose package of staurolite-grade quartz-garnet pelitic schist and layered calcsilicate with lesser psammite and marble (Gibson and Höy, 1985). A sheared and metamorphosed ultramafic body, 15 metres thick, intrudes the metasediments above the massive sulphide layer. It consists of magnesite, antigorite, talc and magnetite. Similiar ultramafic rocks occur in the Keystone area and are intimately associated with massive sulphides at the Standard deposit farther south.

MONTGOMERY

The Montgomery showings are located approximately 12 kilometres southeast of the Goldstream mine, below Downie Peak. They comprise a series of massive and disseminated sulphide lenses in micaceous quartzose schist, marble and carbonaceous sericite-chlorite phyllite. The hostrocks are similiar to those at the Goldstream mine, although metamorphosed to higher grade, and include siliceous garnetiferous hornfels, biotite and muscovite schist (± andalusite), and impure marble containing tremolite.

Sulphides have been traced intermittently by trenching for 770 metres along the Downie Creek slope (Schindler, 1982). This horizon extends across the divide between Long Creek and Boulder Creek at an elevation of about 1825 metres and then north along the Boulder Creek slope where it has been tested by open cuts and trenching for 250 metres. At its eastern end it has been tested by a short adit. The trace of the sulphide horizon corresponds with three zones of moderate to high airborne electromagnetic conductors (Bottomer and Dvorak, 1990) which trend westward, following topography for 3.6 kilometres from the western contact of the Long Creek stock. The extent of this horizon is apparent in the field and can be traced as discontinuous rusty zones exposed along cliff faces. Disseminated pyrrhotite is ubiquitous, but massive sulphides occur as discontinuous lenses along the horizon and base metal content, copper in particular, is low and erratic (Schindler, 1982). The width of the massive sulphide layers varies from 1 to 3.5 metres. Gunning (1929) reports a second zone of stratabound mineralization 215 metres vertically above and north of the adit. He describes disseminated pyrrhotite mineralization with low copper values, in a silicifed calcareous sediment. This zone was not visited during the 1994 field season, but it appears to have a similiar geophysical signature to that of the main horizon (see Bottomer and Dvorak, 1990), and a strike length of 500 metres.

Towards the eastern end of the sulphide zone, at the adit, hangingwall rocks are quartz-rich graphitic and rusty weathering biotite-sericite schists that contain chalcopyrite, pyrrhotite and traces of sphalerite. The sulphide zone contains mainly massive pyrrhotite with minor chalcopyrite and clear, rounded fragments of quartz, and dark green chlorite inclusions identical to the Goldstream ore. The footwall to the sulphides is mafic chlorite-biotite-quartz schist and calcsilicate. Felsite apophyses from the Long Creek stock crosscut the succession and skarns are developed in calcareous units. The sulphide layers have been folded about east-trending cross-folds and, at the portal, the sulphide layer dips south out of the hill. Limited sampling of the sulphide layer at the adit by Schindler (1982) showed a range of values between 0.3% to 0.7% Cu, and grades of 1% to 2% Cu where chalcopyrite is concentrated along the margins of the sulphide bed. Zinc averages approximately 0.5%. Analysis of a single grab sample from the adit returned values greater than 1 % Cu, 3120 ppm Zn, 116 ppm Pb, 37 ppb Au and 11.6 g/t Ag.

Two diamond-drill holes were completed in October of 1990 to test the down-dip extension of the massive sulphides exposed at the adit (Campbell and Lewis, 1991). The holes were collared approximately 85 metres northeast of the adit (B. Meyer, personal communication, 1994). Multiple, narrow massive sulphide horizons were intersected over 12 metres in thinly intercalated biotite schist and calcsilicate rocks structurally above the projected sulphide layer. The massive sulphide body that crops out at the adit was not intersected.

Along strike to the northwest, several sloughed trenchs expose deeply weathered iron oxide coated fine-grained massive pyrrhotite and silicified, sulphidized biotite-sericite schists. Two hundred metres northwest of the adit, sulphides are exposed in a vertical cut. Massive pyrrhotite, chalcopyrite and minor sphalerite occur in two layers, 0.3 and 3 metres thick, separated by 1 metre of sulphidic sericite schist. The thicker and lower layer has a hangingwall quartz zone containing coarse chalcopyrite and pyrrhotite filling crosscutting fractures in the quartz. A 3-metre chip sample across the massive sulphides returned in excess of 1% Cu, 3540 ppm Zn, 500 ppm Pb, 29 ppb Au and 12.6 g/t Ag. The massive ore has the same mineralogy, gangue inclusions and texture as ore at Goldstream.

Farther west, in the Boulder Creek watershed, the zone can be traced as a rusty stratabound horizon for at least 250 metres across cliff faces. Host stratigraphy is pale orange weathering, black phyllite and mica schist of the lower Index Formation. Structurally above the schist is a thick package of buff, grey and white, crystalline, calcareous and dolomitic impure marble. The massive sulphide layer and schistose country rocks are tightly folded about northeast-plunging east-verging structures.

The sulphide bodies are lensoidal, not exceeding 10 metres in length or 2 metres in thickness, and discontinuous along strike. Pyrrhotite is the dominant sulphide. Chalcopyrite is concentrated along siliceous margins of the lenses and occurs as disseminated blebs and streaks within the pyrrhotite groundmass, or as pressure shadows to clear, rounded quartz inclusions. Alteration of the enclosing metasediments is most obvious in the footwall rocks. They consist of thinly foliated, silicified and sericitized pink mafic volcanic rocks which pass downward into a chloritic, actinolite greenschist (mafic metavolcanic rock) and thinly foliated, rusty weathering biotite-chlorite-quartz schists. Hangingwall rocks are thin-layered, dark grey quartzose biotite schists with variable disseminated pyrrhotite. The sulphide zone and host stratigraphy were sampled as part of the regional alteration study.

UPPER MONTGOMERY

A disseminated sulphide bearing horizon crops out high above Montgomery Lake on the east-trending divide between Goldstream River and Downie Creek (Figure 3). The sulphide horizon is hosted by rusty weathering, thinly foliated actinolite schist and siliceous schist/metachert which form the hangingwall of a metadiorite sill 1 to 3 metres thick. The horizon can be traced for approximately 500 metres in a sequence of interlayered graphitic pelite, marble and micaceous quartzite which is coarsening upward. The sequence above the sulphide horizon consists of clean quartzite, mica schist and marble. The latter hosts the lead-zinc mineralization of the KJ showing.

The Upper Montgomery sulphide horizon has a prominent electromagnetic signature (Bottomer and Dvorak, 1990). It was sampled near its eastern and western ends and analyses returned low base and precious metal values, but elevated manganese.

Diamond drilling in 1994 tested the eastern end of this zone (Meyer, 1994). Drill hole 94-2 intersected two semimassive pyrrhotite zones separated by 26 metres of interlayered greenstone, dark graphitic pelite and carbonate units. The upper (3.8 metres) and the lower (3.2 metres) zones returned trace to insignificant copper values. Drill hole 94-3, collared 100 metres north-northwest of 94-2, intersected only the upper sulphide zone. Analysed samples returned trace amounts of copper.

ICE

The Ice showing was discovered in 1989 during a regional exploration program conducted by Bethlehem Resources Corporation and Goldnev Resources Inc. Numerous, subangular massive pyrrhotite boulders up to 0.5 metre square are dispersed along the north wall of a cirque at 2500 metres elevation (Figure 3). The southern margin of the Goldstream pluton crops out in the cliffs immediately to the north. A single grab sample consisting of chips from five of these boulders returned 6.23 g/t Au, 3.23 g/t Ag, 540 ppm Cu and 96 ppm Zn. These values compare well with those reported by Gibson (1989).

Polished thin section studies by J. Payne of Vancouver Petrographics Ltd., describe the sulphide sample as a fine-grained skarn dominated by pyrrhotite with interstial grains of diopside and lesser plagioclase. Chalcopyrite, minor bismuth minerals and traces of arsenopyrite and electrum occur mainly in patches and fractures in diopside (Gibson, 1989).

Massive pyrrhotite, with similiar gold grades to those reported here, has been discovered in place during the summer of 1994, in the cliffs above the boulder train. The massive pyrrhotite layer is 1 to 2 metres thick and exposed along strike for over 5 metres in a north-northeasterly direction. Analysed samples returned up to 7.5 g/t Au and elevated copper, bismuth and tungsten. The layer is hosted by a pelitic calcareous pendant in the Goldstream pluton (Meyer, 1994).

Boulders from the Ice showing have low base metal values, but their source is an interesting target due to the elevated gold values which are unknown in the other copper-zinc volcanogenic massive sulphide deposits of the area, except perhaps at the J&L about 25 kilometres to the south.

BREW

The Brew massive sulphide showing was discovered in 1989. It is located at the head of Granite Creek, approximately 6 kilometres northwest of, and on strike with the Montgomery showings. The showing is at the southern margin of the Goldstream pluton which is characterized by east-trending pendants and sill-like bodies.

Mineralization consists of at least two stratabound massive pyrrhotite lenses, each up to 0.7 metre thick, (Gibson, 1989) hosted by a pendant within the Goldstream pluton. Pendants in the vicinity of the showing are predominantly marble, micaceous quartzite and biotite-quartz-amphibolite gneiss. Foliation-parallel zones of coarse garnet-diopside-calcite skarn, 0.5 metre thick, are present in the marbles. Dikes of biotite-hornblende diorite cut the pendants, and locally envelop and digest the smaller country rock inclusions. Lithologies hosting the sulphides include rusty weathering micaceous calcsilicates and micaceous quartzite. These lithologies are similiar to the hostrocks at the Montgomery, which are correlated with the lower Index Formation and are equivalent to the Goldstream mine sequence.

Hornblende-biotite diorite of the Goldstream pluton is exposed where creeks have incised these pendants, suggesting that the main intrusive contact follows the steep south-facing slope and not the east-trending margins and main foliation of the pendants. Sketch maps by Gibson (1989) show hostrocks and massive sulphides at the Brew showing are folded into a south-closing anticline with a north-dipping axial plane. He projects the sulphide beds and strata downdip to the north. The apparent south-facing, dip-slope intrusive contact, may truncate the pendant relatively close to the present surface, limiting the potential for any down-dip continuity to the mineralization.

The sulphide zones are exposed along steep inaccessible cliffs that have inhibited assessment and sampling. The sulphide zone contains minor amounts of streaky disseminated chalcopyrite. Samples from the 1989 field program returned copper grades below 0.1 % (Gibson, 1989). Preliminary results from seven samples collected during the 1994 sampling were not higher than 650 ppm Cu (Brian Meyer, personal communication, 1994). The low copper content of the massive sulphide horizons, the small area of the pendant and its probable truncation by the pluton, limit its potential to host economic copper mineralization.

CARBONATE REPLACEMENT

The KJ prospect is a carbonate hosted lead-zinc sulphide occurrence. Small pods of coarse cubic galena with traces of sphalerite and pyrrhotite are localized in silicified breccia zones and quartz veins in grey, fine-grained dolomitic marble. The prospect has been described by Höy (1979) as stratabound within a pure to siliceous marble-calcsilicate gneiss layer several tens of metres thick.

Drilling on the carbonate unit (Ramani, 1975), shows the mineralized interval to be approximately 35 metres thick, with a down-dip continuity greater than 200 metres (Höy, 1979). Drilling in the fall of 1994 intersected approximately 47 metres of quartz flooding and veining. This includes a central 8-metre intercept of quartz stockwork with sporadic galena. Sulphide mineralization is weak, with 1 to 5 % pyrrhotite, traces of galena and very low precious metal values (Meyer, 1994).

GOLD-QUARTZ VEINS

The occurrence of gold-bearing quartz veins in the Groundhog basin was first reported shortly after the discovery of placer gold in adjacent creeks in 1865. The best known claims, Ole Bull and Orphan Boy, were explored in 1896 (Gunning, 1929; Wheeler, 1965). The Grounhog basin has been intermittently explored since 1900 (summarized in Schindler, 1984).

The mineralized veins trend north-northeast and are subvertical, cutting the gentle easterly dip of the dominant foliation at a high angle. At least two other sets of barren veins are identified in the Groundhog basin area (Schindler, 1984): veins that are concordant with the dominant foliation; and discordant veins 1 to 2 metres wide that trend east-southeast, parallel to the attitude of late crenulation cleavage in the area.

The mineralized veins average 25 to 30 centimetres wide (with a maximum width of about 4 metres) and are composed of milky quartz and pyrite, with trace amounts of pyrrhotite, scheelite, galena and free gold (Schindler, 1984). Pyrite cubes, 2 to 3 centimetres across, are locally observed in the veins. Ankeritic alteration is commonly developed in the wallrocks. Disseminated pyrite is also present in country rock adjacent to the veins. The veins locally have a limonitic alteration. Fuchsite is a common mineral in calcareous schist throughout the Groundhog basin. It shows no particular spatial or genetic relationship to the gold-quartz veins.

Schindler (1984) and Horne (1985) report that the best gold values are found in veins developed within graphitic schist of the Index Formation (Lardeau Group). However, Horne also mentions that the quartz veins are discontinuous and that the gold distribution is erratic.

PLACER GOLD

Placer gold deposits in French, McCulloch, Graham, and Old Camp creeks, and lower Goldstream River were discovered in 1865 (Gunning, 1929), and have been exploited intermittently since then. Production figures compiled by Holland (1980) show that the largest reported production originated from French Creek. Today, only a few small-scale operations on McCulloch Creek and Old Camp Creek are active. Thousand Hills Mining, has acquired a large block of ground and spent considerable time and money on exploration and production testing on its French Creek property. The gold occurs as coarse, angular nuggets close to bedrock, and as fine colours in gravels, and is commonly associated with galena (Gunning, 1929). The Groundhog basin area is the most likely source of placer gold.

EXPLORATION PARAMETERS

Periods of intermittent extensional tectonism are interpreted to have occurred along the western margin of North America throughout Late Proterozoic to early Paleozoic time (Gordey *et al.*, 1987, Turner *et al.*, 1989, Root, 1987). In the Selkirk Mountains, rocks of the Horsethief Creek and Hamill groups are interpreted to record Neoproterozoic and latest Proterozoic - Early Cambrian extensional tectonism (Bond *et al.*, 1985; Devlin, 1989; Ross, 1991), and the lower Paleozoic stratigraphy of the Lardeau Group may be explained in terms of extensional deformation (Colpron and Price, *in press*). Volcanogenic massive sulphide deposits of the Besshi-type form in various extensional environments (Slack, *in press*). The critical factors defining this deposit type include a spreading ridge to provide heat and basalt, and proximity to a land mass to provide clastic detritus. Interpretations of the geology of the northern Selkirk Mountains indicate that a rifted continental margin environment characterized the region at least three times during latest Proterozoic to Paleozoic.

All volcanogenic massive sulphide deposits in the region are hosted by the lower Lardeau Group. In the Goldstream River area, the Horsethief Creek Group contains only limited amounts of mafic volcanic rocks and, therefore, has limited potential to host Besshi-type deposits. The mafic volcanic rocks of the Hamill Group are chiefly barren and unaltered. Locally, strongly foliated Hamill greenstones have abundant malachite stain but no visible sulphides.,

The lower and middle members of the Index Formation in the Goldstream area consist of black carbonaceous phyllite and green calcareous phyllite that contain talc schist lenses and mafic to ultramafic volcanic rocks. This sequence of fine-grained euxinic clastic rocks, talc schist and mafic volcanic rocks may represent a sediment-sill complex similar to those forming at modern sediment-covered ocean spreading centres (Einsele *et al.*, 1980; Morton and Fox, 1993). Sulphide accumulation at these spreading centres (Escanaba Trough, Middle Valley and the Guaymas Basin) is similiar in its form, mineralogy and chemistry to Besshi-type volcanogenic massive sulphide deposits (Zierenberg *et al.*, 1993). The Index Formation, in the northern Selkirk Mountains, hosts numerous copper-zinc deposits that have characteristics similiar to the Besshi deposits in Japan (Höy et al., 1984). The Guaymas Basin, an ocean spreading centre at a rifted continental margin, is a possible modern analog of the tectonic environment that prevailed during deposition of the Lardeau Group. Trace element chemistry of the sill and dike complex in the Goldstream River area is compatible with this environment. Thus, the lower and middle members of the Index Formation are an important regional metallotect in the northern Selkirk mountains.

The Goldstream ore horizon, with or without its garnet zone, has been traced by drilling for approximately 3 kilometres northwest and 3 kilometres southeasterly, around the cross-fold south of the open pit and into the Goldstream pluton. Stratabound zinc-lead-silver mineralization occurs at the C-1 zone, approximately 8 kilometres farther west along strike and probably occupies a higher stratigraphic position (*i.e.*, lower in the hangingwall). A simliar sulphide-bearing horizon can be traced for over 3.5 kilometres on the south side of the Goldstream pluton from the Montgomery adit to possibly as far as the Brew showing. This horizon outcrops at high elevations along steep cliff faces, in dark phyllite correlative with the lower Index Formation. In addition, an isolated, fault-bounded occurrence of the garnet zone was discovered in 1993 east of Downie Peak (Logan and Drobe, 1994). It is unlikely that these horizons occur along a single stratigraphic level. They probably reflect active hydrothermal venting at various times during deposition and intrusion of the sediment-sill complex.

All of these horizons are extensive and capable of containing substantial massive sulphide inventories over restricted distances. The sulphide layer at the Goldstream mine averages 300 metres in strike length and 1 to 3 metres in thickness. The ore horizon has been drill tested for more than 6 kilometres without another substantial massive sulphide deposit being located. Besshi-type deposits occur as clusters of orebodies and, therefore, all prospective horizons require careful testing in order to evaluate their mineral potential.

There are several areas with high potential to host undiscovered volcanogenic massive sulphide deposits in the Goldstream River map area. The area west of the Goldstream mine is currently under exploration by Bethlehem Resources Corporation. North of the Goldstream River, between French Creek and the Columbia River, a large area underlain by rocks of the lower, middle and upper Index Formation probably contains rocks equivalent to the stratigraphy that hosts the Goldstream deposit. Rock types include dark graphitic and calcareous phyllite; chloritic schists (greenstones), phyllite and carbonates; and quartz and feldspathic grits and micaceous quartzites. This area has been prospected for gold-quartz veins but never fully assessed for its massive sulphide potential. Serpentine-talc bodies and abundant fuchsite are associated with mineral occurrences at the Rift showing, at the Goldstream mine and, to the south, at the Standard showing, and are ubiquitous in the rocks north of the Goldstream River, particularly in the Groundhog basin. This belt of rocks is under explored and warrants thorough assessment.

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NOTES

CALCITE IN COAL FROM THE QUINSAM MINE, BRITISH COLUMBIA, CANADA; ITS ORIGIN, DISTRIBUTION AND EFFECTS ON COAL UTILIZATION (92F/13,14)

Barry D. Ryan

KEYWORDS: Quinsam mine, cleats, calcium oxide, calcite, calcite liberation, coal combustion, slagging, fouling, electrostatic precipitator, coal blending.

BACKGROUND

The Quinsam mine on Vancouver Island exports an excellent thermal coal with good heat value and a low ash concentration. However, the ash carries with it a higher than normal concentration of calcium oxide (CaO). This project investigates the origin and distribution of the CaO in the coal and looks at some of the ways it can effect the behaviour of the ash when the coal is burnt in a boiler.

A preliminary look at existing data and at some coal samples indicated that much of the CaO is in the coal as calcite and possibly other carbonates which coat the surfaces of cleats. If the calcite is not removed by washing then it adds CaO to that already in the ash. If the ash concentration is low then this addition of CaO can cause the concentration in the ash to rise markedly. The mineralogy of the ash ensures that it also contains some CaO. The concentration of this component of the CaO probably remains fairly constant from sample to sample and will not vary as the ash content changes. It therefore cannot be reduced by washing. The component of CaO originating from calcite can be removed from the coal if the calcite is liberated during washing. If it is not removed, the CaO concentration of the ash of the washed coal may be high and variable.

High concentrations of CaO in thermal coals can cause a number of changes in behaviour of the ash in coal boilers, such as lowering the melting temperature of the ash, increasing the ash adhesion to boiler walls and increasing the resistivity of fly ash. These changes are not necessarily bad but should be documented. Blending provides a way of ameliorating the extremes in the ash chemistry.

At present most of the coal at Quinsam is mined from the basal No. 1 seam, either from the 2-N underground mine or a number of surface pits. Knowing the distribution of calcite in No. 1 seam, both geographically and within the seam from hangingwall to footwall, may provide options for run-of-mine blending to reduce the CaO content of the raw coal.

QUINSAM COAL MINE

The Quinsam coal mine is located 20 kilometres west of the town of Campbell River on Vancouver Island (Figure 1). The mine has been in operation since 1987, initially as a small surface mine and now is a combined surface and underground operation. Present annual raw-coal production is about 650 000 tonnes.

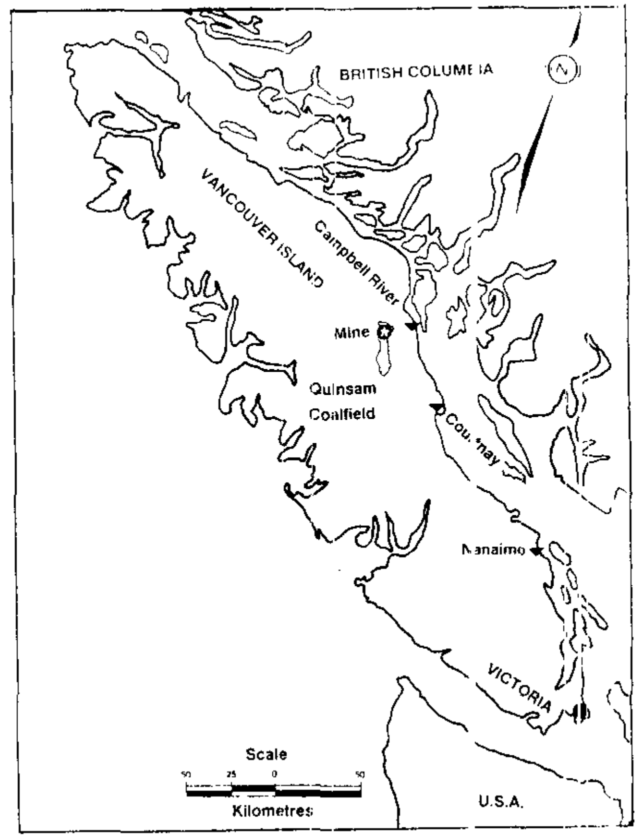


Figure 1. Location map of the Quinsam coal mine on Vancouver Island.

The coal seams at Quinsam are in the Comox Formation of the Upper Cretaceous Nanaimo Group (Kenyon *et al.*, 1991). The Comox Formation is divided into the basal conglomeratic Benson Member, which is overlain by the Cumberland and Dunsmuir members. Two seams outcrop in the Cumberland Member and two seams in the Dunsmuir Member. Most of the reserves are in the lowermost No. 1 seam in the Cumberland Member. This seam averages 2.3 metres in thickness and is sometimes overlain by a rider which averages 0.40 metre thick. It is mined underground and in surface pits. The overlying No. 2 seam averages 0.30 to 0.55 metre in thickness and is mined at surface in some pits. The No. 3 seam in the Dunsmuir Member averages 2.4 to 3.4 metres thick and is mined in surface pits. No. 4 seam is thin and is not mined. The stratigraphic separation from seam 1 to seam 3 is 30 to 60 metres.

CALCIUM OXIDE IN COAL

Calcium concentration is variously expressed as CaO% in the ash, CaO% in the total sample or as Ca in the total sample. If the calcium is mainly in mineral matter, its concentration on an ash basis will be independent of variations in the ash concentration. If it is mainly dispersed in the coal then its apparent concentration in the ash will increase as the amount of ash decreases.

Calcium oxide reported as a component of ash may actually be present in minerals that make up the mineral matter, as noncrystalline material associated with the coal or as minerals dispersed in the coal. Minerals found in the coal include carbonates such as calcite, dolomite, ankerite or siderite; minerals that make up the mineral matter include clays and feldspars. Minerals that may be associated with either mineral matter or coal include sulphates such as gypsum and phosphates such as apatite or gorceixite.

Calcium is introduced into the coal as part of the early coalification process, or later along cleats. Some calcium is initially extracted from sea water or ground water by the carboxylic acid groups (humic acid molecules). These molecules are destroyed by the coalification process and, at the same time, much of the interstitial water is expelled. Consequently as rank increases, CaO is released and moves through the coal with some of the interstitial water. During the early stages of coalification, siderite may form if conditions are anaerobic. This may be accompanied by dolomite if magnesium (indicating a marine influence) is present. Early forming carbonates may impregnate fusinite and semifusinite macerals because they have a structure and porosity which might not be present in vitrinite, which often does not have voids in its cell structure. During the second stage of coalification, calcite and ankerite crystallize, often on cleats (Stach *et al.*, 1975, p. 126). The CaO required to form these minerals comes in part from the coal but can be introduced from the surrounding rocks and penetrate the coal via the cleat system. Generally the reason for high concentrations of CaO in bituminous coals is the presence of calcite on cleats.

In general, the amount of CaO in coal decreases as the rank increases. Lindahl and Finkelman (1986) provide averages of 1.7% for lignites, 1.1% for sub-bituminous coals, 0.46% for bituminous coals and 0.1% CaO in total coal sample for anthracite. Raask (1985, p. 265) gives some data for low rank U.S. coals which show the same trend. Trends in British Columbia are similar. The Coal River lignite deposit has an average CaO content of 3.1%; the Hat Creek sub-bituminous deposit averages 0.29%; the Tuya River high-volatile B bituminous deposit averages 1.0 to 1.5%; the Telkwa high -volatile A bituminous deposit averages 1.0 to 1.5%; Kootenay medium-volatile deposits average 0.1 to 0.4% (with the exception of Byron Creek at 1.0%) and the Peace River medium-volatile deposits (Gates Formation) average 0.5 to 1.2% (Van der Flier-Keller and Goodarzi, 1992).

The exception to this trend is the Klappan anthracite deposit which averages about 1% CaO, noticably higher than the 0.1% average for anthracites. A plot of CaO in the total sample *versus* ash for Klappan data has a weak positive correlation, indicating that the CaO may, in part, be associated with fractures in the rock bands in the coal rather than with cleats. There is no correlation of CaO in the ash to ash content.

Whole-sample data for the Upper Cretaceous high-volatile bituminous coals on Vancouver Island average 1.65% CaO for 22 samples from the Comox Basin and 1.73% for 10 samples from the Nanaimo Basin to the south (Van der Flier-Keller and Dumais, 1988). The CaO content of the Wolf Mountain property (Perry, 1984) in the Nanaimo Basin is similar to the average for the basin. The average for the Chute Creek property in the Comox Basin is lower than the average for the Comox Basin.

The CaO content of 14 raw samples of No. 1 seam from the Quinsam mine averages 2.8% in the total sample (Matheson *et al.*, 1994) which is higher than the average for the Comox Basin. The averages for the No. 1 rider and overlying No. 2 seam are lower. The CaO contents in the ash do not correlate with the ash content or the amount of P_2O_5 in the ash (Table 1). In fact the CaO content does not have a positive correlation with any other oxide. Most of the CaO is therefore associated with a nonsilicate mineral, probably calcite, which is dispersed through the coal. In contrast, the medium-volatile bituminous coal seams in the lower part of the Mist Mountain Formation in southeast British Columbia generally have low concentrations of CaO, averaging 0.2% in the whole sample. Based on the correlations in Table 2, the CaO appears not to be associated with the ash and present in calcite, dolomite, siderite or phosphorus-bearing minerals that are dispersed thoughout the coal.

Whole samples of Upper Cretaceous coals on Vancouver Island have higher CaO contents than coals from southeast and northeast British Columbia. The higher concentrations are, in part, probably caused by calcite dispersed in the coal on cleats. The higher concentrations occur in both the Comox Formation in the Comox Basin and in the Extension and Protection formations in the Nanaimo Basin. In both basins it is the lowest seam which appears to have the highest CaO content (No. 1 seam in the Comox Basin and the Wellington seam in the Nanaimo Basin) and it is data from these seams that might be causing the high CaO% averages. In the Nanaimo Basin, data from seams other than the Wellington seam average 1% which is similar to the CaO concentration at Telkwa. The higher CaO in the lower seams may result from availability of CaO or because the seams have better cleat development.

TABLE 1
QUINSAM ASH OXIDE ANALYSES CORRELATION DIAGRAM

	ash	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5
ash	0.00	0.67	0.58	0.25	-0.78	0.12	0.71	0.76	-0.15
SiO_2		0.00	0.59	-0.10	-0.77	0.54	0.40	0.47	-0.09
Al_2O_3			0.00	-0.19	-0.52	-0.07	0.49	0.36	0.21
Fe_2O_3				0.00	-0.48	-0.21	0.27	0.66	0.12
CaO					0.00	-0.27	-0.59	-0.82	-0.15
MgO						0.00	0.16	-0.11	-0.11
Na_2O							0.00	0.56	-0.11
K_2O								0.00	0.06
P_2O_5									0.00

TABLE 2
SOUTHEAST BC ASH OXIDE ANALYSES CORRELATION DIAGRAM

	ash	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3
ash	0.00	0.77	0.20	-0.79	-0.74	-0.74	-0.13	-0.14	-0.62	-0.59
SiO_2		0.00	0.00	-0.96	-0.87	-0.94	-0.54	0.18	-0.24	-0.94
Al_2O_3			0.00	-0.19	-0.38	-0.19	0.49	-0.66	-0.75	0.00
Fe_2O_3				0.00	0.87	0.98	0.35	0.03	0.33	0.90
CaO					0.00	0.85	0.36	-0.04	0.57	0.88
MgO						0.00	0.31	0.10	0.27	0.90
Na_2O							0.00	-0.83	-0.34	0.58
K_2O								0.00	0.42	-0.26
P_2O_5									0.00	0.14

REGIONAL GEOLOGY, JOINTS AND ORIGIN OF CLEATS

Sediments often contain joints formed in response to regional tensional or compressive stress fields. Coal is also jointed but, because of its different rheology and maturation history, the joints generally have a different origin and are called cleats. Cleats usually form as orthogonal sets and are perpendicular to bedding. They are often parallel to, and sometimes connect with, regional joint sets in the surrounding sediments. The cleats are more closely spaced and generally do not exhibit the surface characteristics of shear joints. They probably form early in the maturation process, after the coal has become a fairly uniform, brittle solid (above a rank of sub-bituminous C) and while there is still a lot of compaction and water-loss induced shrinkage still to take place. Coal loses about 20% water by weight when the rank increases from sub-bituminous C to high-volatile B bituminous. This is equivalent to a 20% decrease in volume which is probably accompanied by additional compaction of the solid. Cleats form in the bright coal bands during coalification because bands which are ash poor and vitrinite rich are more brittle than the dull coal bands which are ash and inertinite rich (Gamson and Beamish, 1991).

The shrinkage often takes place in a subsiding basin which is experiencing regional stresses. These regional stresses, combined with shrinkage within the coal seam, produce two sets of tension cleats, one perpendicular to the basin axis and the other perpendicular to bedding and parallel the basin axis. The face cleats, which form first and are the through-going set are generally oriented at right angles to the basin axis, for example, the San Jaun Basin (Close and Mavor, 1991), the Mississippian and Pennsylvanian anthracite fields (Levine and Edmunds, 1993) and the Greater Green River Basin (Laubach *et al.*, 1993). Butt cleats, which terminate against the face cleats, are therefore generally oriented parallel the basin axis and often intersect bedding forming a line of intersection parallel the strike.

As the cleats are forming, water is being expelled from the coal and is channeled along the face cleats within the seams. Different lithotypes are more or less susceptible to shrinkage and water loss. At a rank of high-volatile bituminous, vitrinite can hold two to three times as much water as fusinite and therefore shrinks more during coalification. Water escaping from vitrain bands in the coal will tend to be trapped in the bands and move along face cleats, up the dip of the coal seam to the basin margins.

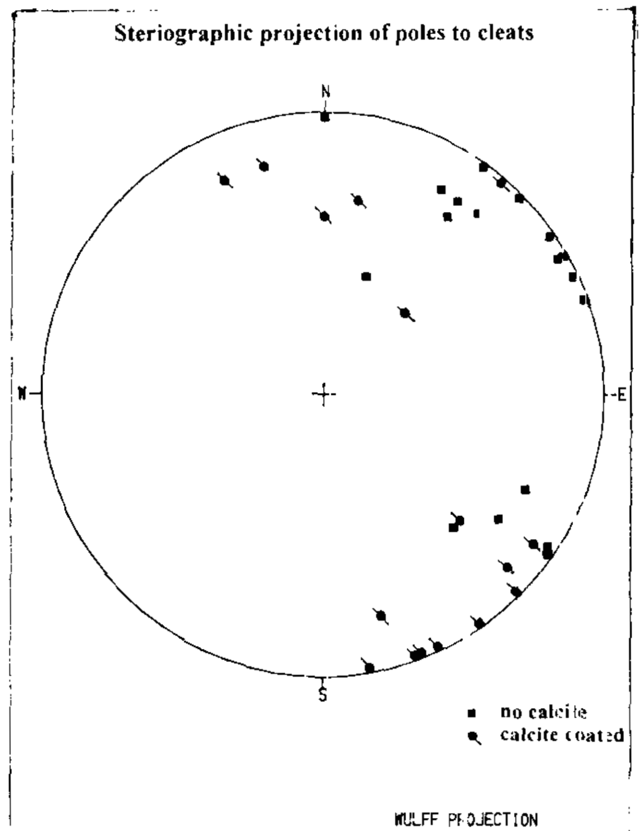


Figure 2. Sterionet plot of poles to cleats measured in this study.

Cleat orientations in No. 1 seam in the Quinsam mine were measured and the cleat coating, spacing and persistence noted. Generally the cleats are spaced between 0.5 to 10 centimetres apart and are persistent for up to 1 metre through the coal seams. Cleats are closer spaced and better developed in vitrain-rich coal. At most locations, two orthogonal set of cleats were measured, with, calcite coating often restricted to a single set. Cleat data are plotted as poles to surfaces (Figure 2). Calcite-coated cleats tend to strike east to southeast and cut across the trend of the bedding and basin axis. They appear to be the face cleats and are more dispersed than the second set of cleats that trend southeast and are parallel the basin axis.

The structure in the area has been discussed by Kenyon *et al.* (1991) and Gardner and Lehtinen (1992). Both papers describe early tensional faults trending easterly, which sometimes have calcite veins associated them. These faults are responsible for graben structures in the 2-N area and at surface are identified by low swampy ground. They also appear to act as channels for water into the underground mine. The calcite-coated cleat set is either related to these faults or to early stresses that formed the north to northwest-trending basin.

Gardner and Lehtinen (1992) identify a later period of pull-apart faulting that is largely restricted to the No. 1 seam zone. These faults parallel the strike of the beds and are down-dropped by a few metres on the down-dip side with respect to the regional bed-dip. The faults are gently dipping and consequently produce a barren zone up to 20 metres wide where they cut the coal seam. They probably represent ductile response of the incompetent No. 1 seam to buckling and down-warping of the sedimentary succession. A later period of northeast to southwest compression is described by Kenyon *et al.* (1991); it produced some folds and southwest-verging thrusts. They also identified a period of tear faulting that is probably post Late Eocene. These faults trend northeast to east and are assumed to be unrelated to any joints.

It is proposed that both sets of cleats formed early in the tectonic history, after the coal had reached a rank of more than sub-bituminous C. The east-trending face cleats formed first and remained open, but later east-west compression tended to close the southeast- trending butt cleats. Calcite could therefore have been introduced into face cleats at any time. Early calcite could originate from dewatering of the coal seam and late calcite from present day ground water movement.

CALCITE IN QUINSAM COALS

When visually estimating the amount of calcite in the coal it should be remembered that, because of the density difference between coal and calcite, the volume percent of calcite in the coal will be 53% less than the weight percent. The presence of calcite in Quinsam No. 1 seam was confirmed using simple field tests. The coating effervesces in cold dilute hydrochloric acid and is therefore probably mostly calcite and unlikely to contain much dolomite, siderite or ankerite. Analyses of sulphur in samples of fresh No. 1 seam indicate that there is very little sulphate and therefore very little calcium sulphate (gypsum) in the seam. Calcite was also stained using alizarin red S solution after etching with 10% hydrochloric acid. The stain confirmed the white joint-filling material was calcite. Calcite also fluoresces under short wave ultraviolet light. It was found that the calcite fluoresced a dull white when well exposed. This test was useful on individual samples and may be applicable in an open pit at night, unfortunately it could not be tested underground because of safety requirements and limestone dusting in the underground mine.

The calcite occurs in three general forms. Most is on the surfaces of cleats which are perpendicular to bedding (Photo 1); some occurs in desiccation fractures restricted to vitrain-rich bands1 to 5 centimetres thick (Photo 2).

Photo 1. Calcite on cleats in a sample of Quinsam coal.

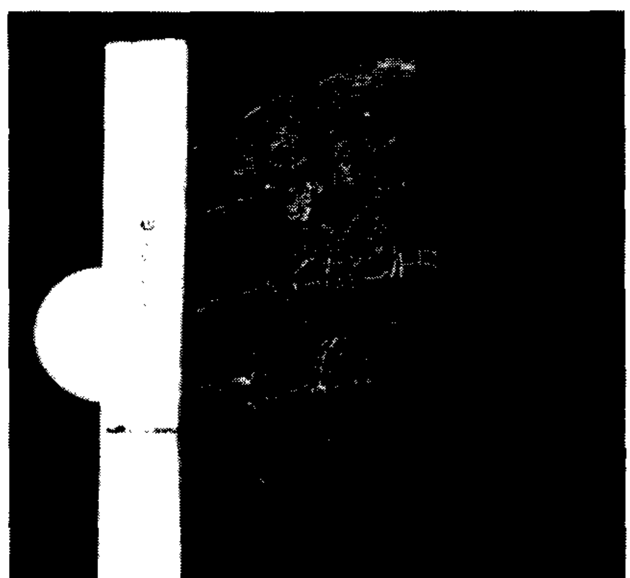


Photo 2. Calcite-filled crackle zone in a sample of Quinsam coal.

Calcite also occurs on crosscutting shear fractures with minor dilation (Photo 3). Calcite-coated cleats were observed in the coal underground in the 2-N area and at surface in the 4-S area (Figure 3). Calcite occurs on cleats as thin grey or white smears; it is discontinuous and does not form thicker veinlets. The cleats are perpendicular to bedding, 0.5 to 10 centimetres apart and usually terminate against high-ash or inertinite-rich bands. If the cleat traverses the ash band then that part of the surface tends not to be calcite coated. The calcite smearing is less than 1 millimetre thick, not striated, and under the microscope appears to be fractured into 1 millimere or smaller rectangular fragments. Because the calcite seems to be pervasive on at least one set of cleats, and the cleats generally do not connect with joints in the interburden, it appears that the calcite has moved parallel to bedding through the seam, at least in part. The calcite that fills discontinuous microfratures within thin vitrain bands may have been deposited earlier than the cleat calcite, and the calcite on crosscutting fractures was probably deposited last.

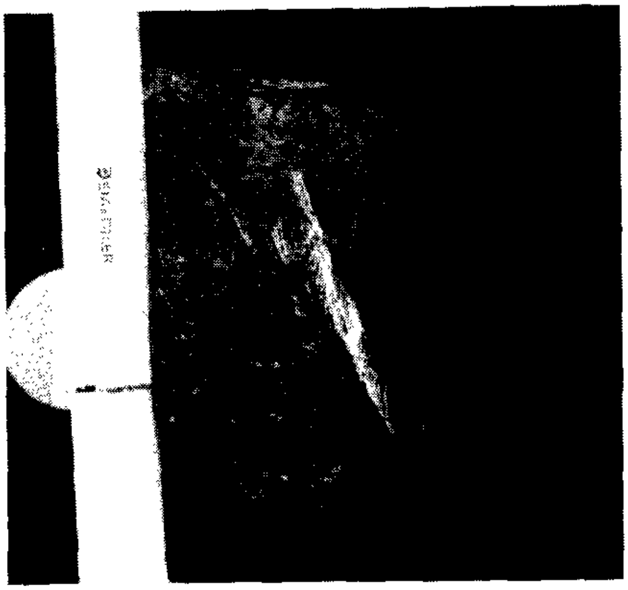


Photo 3. Calcite-filled fracture in a sample of Quinsam coal.

MEASUREMENT AND IDENTIFICATION TECHNIQUES FOR CaO AND CALCITE

The CaO content of a sample is measured as a component of the ash which is left after the coal is burnt off in the analysis process. The ashing process will not volatilize calcium in any form so that it remains in the ash residue. The calcium in the ash is usually measured by atomic adsorption spectroscopy and the results reported as CaO%.

For coals in which most of the CaO is from calcite, there might be a test that requires simpler equipment. The approach, used in this study, involves dissolving and removing the calcite from the sample with hydrochloric acid and then weighing either the leached sample or the precipitate retrieved after drying the acid leachate. A coal sample with 1% calcite contains 0.56% CaO and 0.44% CO_2. Forty grams of this sample contains 0.004 moles of CaO. This requires at least 0.008 moles of HCl or 8 millilitres of 1 molar HCl to convert the calcite to CO_2 and $CaCl_2$. Sufficient 1 molar HCl was added to samples to dissolve the calcite and the acid was then filtered off the coal sample and the sample dried. The sample weight after drying should indicate the amount of calcite removed. Unfortunately the drying process also removes water from the coal so that the leached sample has less water than the sample prior to leaching. This effect is particularly apparent for low rank coals that have variable and high as-received water contents. The HCl extracted from the leached sample was evaporated to dryness and the residue weighed. If the leaching only removes calcite and the precipitate is calcium chloride then it is possible to calculate the calcite concentration in the sample. Some uncertainty is introduced by the fact that the acid may dissolve some of the pyrite and other carbonates and iron and magnesium chlorides may also be precipitated.

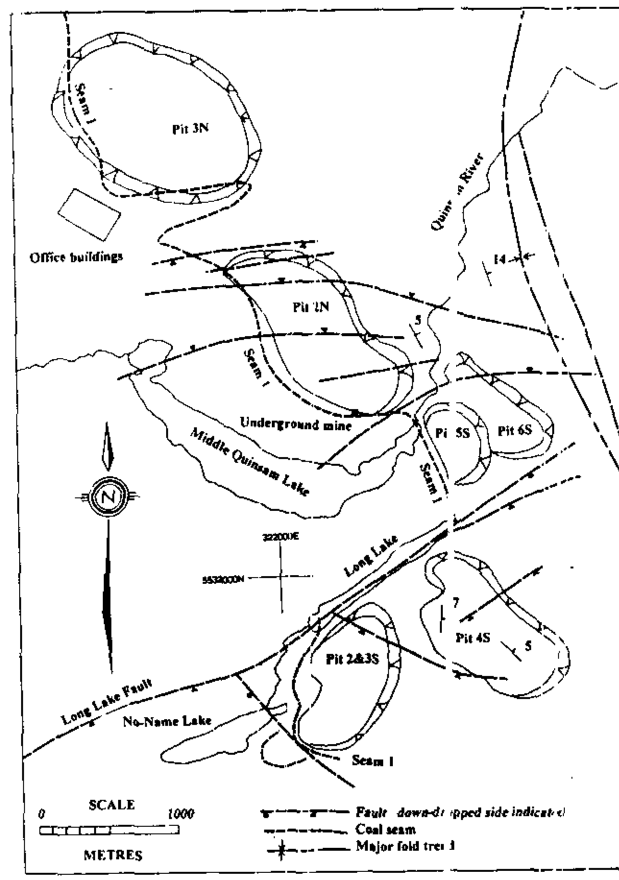


Figure 3. Mine geology and infrastructure showing location of pits and underground mine.

SAMPLING AND ANALYTICAL RESULTS

Thirteen locations were sampled in the underground mine, two locations in the No. 2 South surface pit and two drill holes from the 1992 exploration program (D10 and D13). In addition some drill-hole data from the 1992 Quinsam mine assessment report were used. All the data are in Table 3; sample sites with the exception of D21 and D25 are located on Figure 4 and coordinates are in Table 4. These two drill holes are collared to the east of the area covered by Figure 4. A total of 30 samples were analyzed in the study.

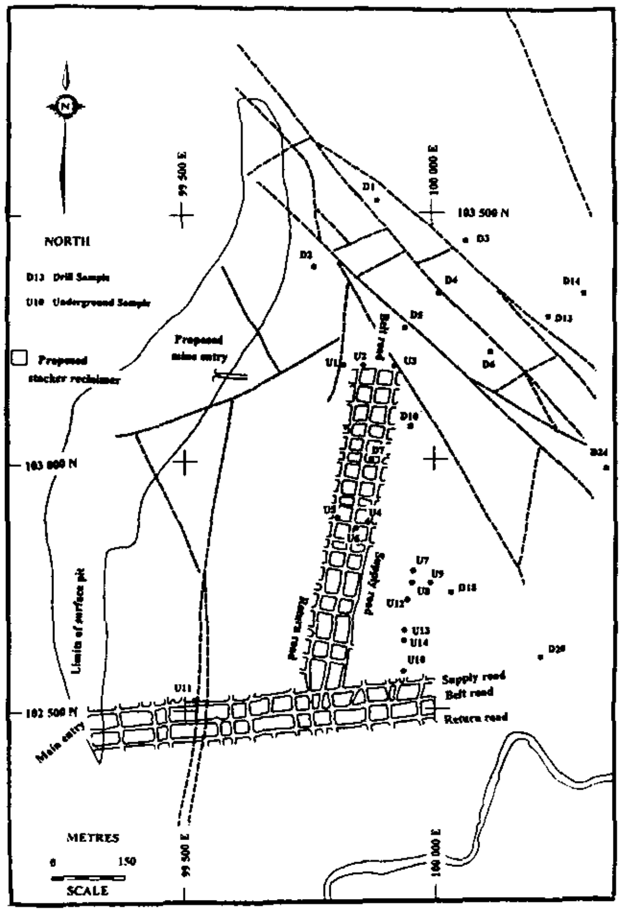


Figure 4. Location of underground samples in 2N underground mine.

The underground room-and-pillar mine extracts the top two thirds of the No. 1 seam and sometimes part of the overlying mudstone split and rider seam. The remaining footwall coal is sometimes recovered when the pillars are removed before sections of the mine are allowed to cave. Sampling is complicated by the fact that the coal is hard and not well cleated, and coal faces are dusted with limestone to reduce fire hazards. Generally about 1 metre of hangingwall coal was taken as the first sample, and as much of the remaining seam as was exposed as an additional sample. A vertical strip down the coal face, about 10 to 20 centimetres wide was cleaned off and samples collected as large fragments across the face. From 1 to 5 kilograms of coal was taken for each sample. Samples were washed at surface to remove any trace of the limestone dust.

Samples were crushed and split and some chemistry performed in the mine laboratory facility by the author, with the cooperation of Quinsam personnel. One of the splits was leached with hydrochloric acid. Splits of the raw sample, leached sample and dried precipitate from the leached sample were sent to a commercial laboratory for analysis. Raw and leached samples were analyzed for CaO% in the ash and total sulphur. Some samples of the calcium chloride precipitate were analyzed for CaO, Fe_2O_3 and MgO, and some of the coal samples were also analyzed for sulphur forms. The data are presented in Table 3.

The amount of CaO originating from calcite in the ash is calculated by subtracting the leached ash CaO% concentration from the initial ash CaO% concentration. Based on the amount of ash, this concentration can be expressed in terms of the whole sample or as a concentration in the coal-only part of the sample. The CaO% from calcite in the whole samples ranges from 1.6% to 4.22%. This is equivalent to a range of 2.3% to 7.2% mass of calcite or 1.2% to 4.1% volume of calcite in the whole sample.

The CaO content in the ash of the leached samples ranges from 1.17% to 16.44%. Two of the samples have distinctly higher concentrations of CaO than the rest (U1-1 and D13-1, Table 3). Either these samples contain a carbonate that is not leached by cold hydrochloric acid or some of the calcite was not removed. X-ray diffraction analyses of the sink ash from splits of these two samples indicated that the ash is composed of over 90% calcite with minor kaolinite and quartz. This indicates that some of the calcite was not leached. To check this, a plot of CaO in the ash before leaching *versus* CaO in the ash after leaching (Figure 5) was constructed. The data have a positive correlation factor and a best-fit line through the data indicates that the leached and unleached CaO values are the same at 0.4%. The unleached CaO value cannot be lower than the leached value, so 0.4% is probably the best estimate of the average CaO in the ash, not attributable to calcite. The increment of CaO in leached samples above 0.4% is probably calcite that was not dissolved by the acid.

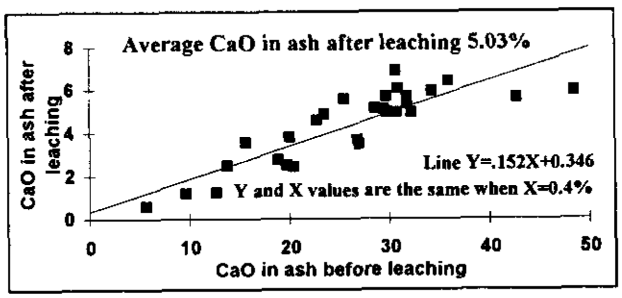


Figure 5. Effects of leaching CaO from ash.

It is also possible that the acid leach dissolved other carbonates. To check this, two precipitate samples with CaO contents of 29.5% and 38.9% were analyzed for MgO and Fe_2O_3. There was less than 0.3% Fe_2O_3 or MgO in the precipitates, indicating very little solution of dolomite, siderite or ankerite.

The possible solution of pyrite by the hydrochloric acid was checked by analyzing the total sulphur in the fresh and leached samples (Figure 6). The data plot close to a line with a slope of 1, indicating no loss of sulphur in the leached samples. A slope of less than 1 would indicate acid leaching of pyrite as pyritic sulphur makes up a component of the total sulphur. A plot of total sulphur *versus* pyritic sulphur (Figure 7) indicates that, for the underground data from this study, the amount of pyrite in a sample can be estimated using the linear relationship:

pyritic sulphur = 0.253 x total S% - 0.0465

The remaining sulphur is mostly organic. However surface data from Matheson *et al.* (1994), also in Figure

7, indicate that a larger proportion of the total sulphur is in pyrite. A plot of CaO from calcite in total sample *versus* pyritic sulphur (Figure 8) indicates a weak tendency for high pyritic samples to also have low calcite contents, but there is no clear relationship.

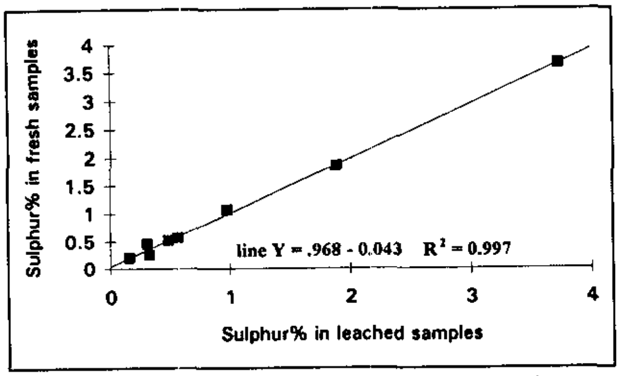


Figure 6. Total sulphur in fresh and leached samples.

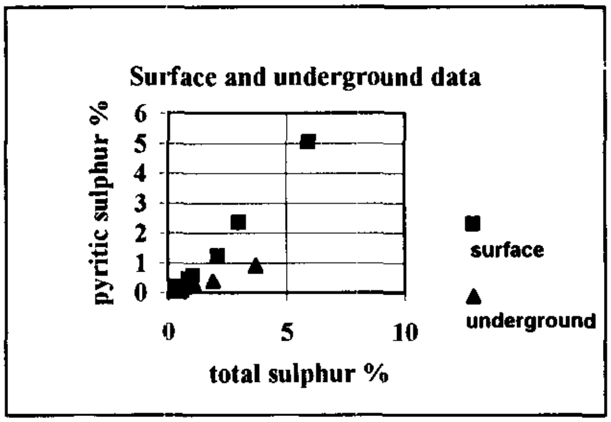


Figure 7. Relationship of total sulphur to pyritic sulphur.

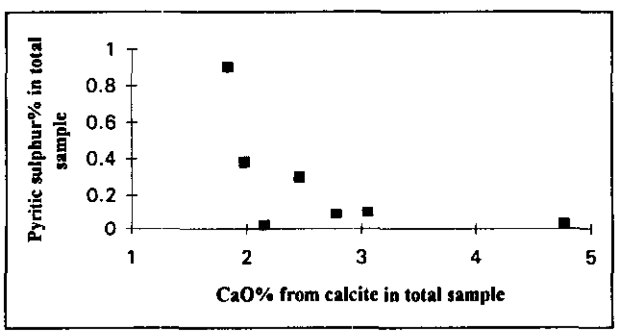


Figure 8. Pyritic sulphur *versus* CaO% from calcite in the total sample.

In most cases the acid-leach solution was rinsed off the coal sample through a filter and dried. The weight of precipitate divided by the sample weight should correlate with the amount of CaO derived from calcite in the total sample. In fact, if the precipitate is $CaCl_2$ then it is equivalent to 50.53% CaO. It should be possible to use the weight of precipitate to calculate the amount of calcite in the sample and, if there is a constant non-calcite-derived CaO concentration in the ash of 0.4%, it should also be possible to estimate CaO content of the total sample. A plot of weight of precipitate expressed as CaO in the total sample(X) *versus* CaO in the total sample minus 0.4%(Y) produces a line:

$Y = 0.869 + 0.585 \qquad R^2 = 0.89$ (Figure 9)

The line should have a slope of 1 and a zero intercept. It does not because not all the calcite was dissolved and so the precipitate weights are low by an amount dependent on the amount of calcite in the original sample.

The line in Figure 5 can be used to correct the precipitate weight and if this is done then the line:

$Y = 1.17\,X - 0.273 \qquad R^2 = 0.91$

is generated (Figure 10).

The data indicate that it might be possible to use the precipitate weight to estimate the total CaO in the sample. Based on the data in Figure 5 the average error in predicting total CaO using the corrected precipitate weight is 10% of the value and, at a one standard deviation, errors ranging form 2% to 16% can be expected. If the chemical procedure is improved so that all the calcite is dissolved, then better predictability could be achieved.

The mineral matter in No. 1 seam is somewhat unique in that it appears to have a very low content of free quartz. Because of the high carbonate content of some of the ash (up to 50% calcite), the mineral matter may lose up to 40% of its weight on ashing. This means that a sample with 16% mineral matter, containing a high calcite content, will report as about 10% ash and the coal will appear to have an unusually low heat value based on the 10% ash content.

REGIONAL DISTRIBUTION OF CALCITE WITHIN ONE SEAM

The data were analyzed to see if calcite distribution is systematic. Generally, more than one sample was collected from each site. The variation in CaO% for samples from a single site is almost as large as the variation between sample sites. A set of five channel samples, spaced 5 metres apart in the underground mine, also showed a wide variation of CaO content (S. Gardner, Quinsam mine, personel communication 1994). There does not seem to be a correlation of CaO% with position in the seam. Hangingwall samples do not consistently have higher CaO concentrations than mid-seam samples. All the samples at a single site were averaged to provide the best estimate of the CaO content for the full seam.

A variogram for total CaO% *versus* distance indicates poor if any significant spatial trends in the data. Despite this, simple contour maps were produced for total CaO% in the total sample (Figure 11) and CaO derived from calcite expressed as percent of the coal-only component of the total sample (Figure 12). Because the calcite is mostly on cleats that are restricted to the coal, it was felt that a contour map of CaO in the coal only might reveal regional trends. The CaO in the ash was corrected to CaO in coal-only using:

TABLE 3. ANALYTICAL DATA FOR UNDERGROUND SURFACE AND DRILL-HOLE SAMPLES

sample	thickness	wt smple	H_2O	Ash%	CaO_t%	CaO_r%	total S%	pyrtc S%	SO_4%	wt ppt
U1-1	HW-2.0M		1.53	6.81	40.45	16.44	0.52			
U2-1	HW-.70M	39.466	1.45	9.09	34.28	5.9	0.57			2.016
U2-2	.70-1.9M	40.006	1.35	9.6	31.77	5.65	0.29			1.725
U3-1	HW-1.0M	38.841	1.37	9.98	29.79	4.94	0.53			2.046
U3-2	1.0-1.9M	40.181	1.27	11.16	20.01	3.78	0.27			1.438
U4-1	HW-.80M	42.405	1.4	9.81	25.5	5.54	1.09	0.3	0.13	2.009
U4-2	.80-1.50M	47.553	1.52	7.86	23.5	4.84	0.26			1.562
U5-1	HW-.80M	43.705	1.41	9.75	22.8	4.56	0.36			1.513
U6-1	HW-.40M	43.141	1.35	9.97	29.74	5.65	0.57			2.456
U7-1	1.5M-FW	37.292	1.16	19	9.63	1.17	0.19			1.258
U8-1	HW-1.55M	38.561	0.89	7.89	28.56	5.1	0.33			1.612
U9-1	HW-.40M	40.677	0.91	13.06	19.68	2.48	0.43			2.333
U10-1	RDR .45M	41.265	1.42	14.82	13.77	2.46	1.88	0.38	0.21	1.419
U10-2	HW-.40M	43.783	1.43	9.14	30.87	6.01	0.52	0.09	0.03	2.461
U10-3	.40-1.20M	38.821	1.42	9.93	48.45	5.9	0.46	0.03	0.01	3.851
U11-1	HW-.60M	42.965	1.52	12.06	15.61	3.54	3.71	0.9	0.25	1.026
U12-1	HW-.50M	42.121	1.42	10.08	30.76	4.9	0.57	0.1	0.02	2.511
U12-2	.50-1.4M	47.872	1.43	7.12	30.67	6.86	0.25	0.02	<0.01	2.093
U13-1	HW-.60M	43.516	1.4	11.05	42.75	5.59	0.65			3.847
U13-2	.60-1.20M	49.195	1.37	7.92	35.92	6.38	0.28			1.918
U13-3	RDR .2-FW	41.285	0.92	31	12.7	1.21	2.17			2.652
D10-1	67.8-69.2M	41.502	0.96	11.4	29.5	5.05	0.25			2.301
D10-2	69.2-70.1M	46.275	0.92	10.6	18.82	2.73	0.22			1.496
D13-1	96.7-97.3M	41.056	1.02	5.06	38.86	13.88				1.219
D13-2	97.3-98.6M	43.194	1.03	9.28	32.2	4.9	0.29			2.299
D13-3	98.6-100.5M	41.377	1.01	9.42	31.81	5.33	0.27			1.975
S1-1	HW-1.2M	39.656	1.19	8.08	26.93	3.45	0.68			1.44
S1-2	1.20-1.5M	42.086	1.11	30.38	5.65	0.58	0.65			1.061
S1-3	1.55-2.55M	41.829	1.16	13.42	20.37	2.39	0.57			2.003
S2-1	HW-2.2M	40.704	1.28	9.84	26.85	3.65	0.98			1.886

CaO_t=total CaO in ash CaO_r=CaO in ash after leaching
S%= pyritic sulphur in total sample wt ppt= weight of precipitate from sample acid leach solution

CaO in coal = CaO in ash x ash /(100-mineral matter)

mineral matter =(ash x (1-(CaO-0.4) in ash/100) x1.08

An attempt is made to calculate the actual mineral matter, not a combination of mineral matter plus CaO reporting to the mineral matter. For this reason, the amount of CaO (minus 0.4%) is subtracted from the amount of ash and then the amount of ash multiplied by a constant to account for the loss of weight experienced when mineral matter composed of quartz and kaolinite is ashed.

The CaO content in coal varies from 2.4 to 4.4%. When the data are averaged on 100 by 100-metre blocks, and contoured, there is a tendency for CaO to increase to the northeast and southeast of the area covered by Figure 12.

Data were also provided by Quinsam staff for areas adjacent to the 2N underground mine and the same pattern of variability was observed. In the S5 area, 500 metres south of the 2N underground mine, two holes 200 metres apart have CaO contents of 6.15% and 1.87% in the coal. The 3N area, 1 kilometre north of the 2N underground mine, can be divided into a higher CaO area to the northeast and a lower CaO area to the southwest, based on five samples.

A preliminary correlation matrix was constructed using drill-core data and containing seam thickness, separation from rider seam, thickness of in-seam split and CaO content of coal. It was found that there is a weak correlation of CaO to in-seam split thickness. It would be interesting to continue this analysis with more data and more variables in the matrix. In a broad sense the CaO content does not seem to be related to distance from faults, although on a local scale, it may be. If CaO content is controlled by cleat development, then calcite content may be related to variable compaction effects caused by changes in the amount of sand in the lithological section above or below the coal seam.

SEPARATION OF CALCITE

A detailed study was undertaken by CANMET (Mikhail *et al.*, 1993) to investigate the washing characteristics of Quinsam coal, with particular reference to the CaO content of various fractions. Some of the data were made available to be used in the present study.

Before the content of calcite in the coal can be calculated, the amount of CaO originating from the ash must be known and subtracted from the total CaO content. If the CaO content is assumed to be constant for the ash in different sized fragments and in different

TABLE 4. SAMPLE LOCATIONS AND AVERAGE CaO% DATA

sample	easting	northing	CaO_cl%	CaO_tot%
U1	99816	103191	2.88	2.75
U2	99859	103186	3.3	3.07
U3	99916	103180	2.87	2.62
U4	99868	102872	2.38	2.2
U5	99806	102881	2.42	2.22
U6	99840	102866	3.21	2.97
U7	99954	102775	2.25	1.83
U8	99954	102760	2.4	2.25
U9	99992	102754	2.9	2.57
U10	99938	102581	4.4	3.95
U11	99522	102518	2.12	1.88
U12	99950	102718	2.68	2.51
U13	99942	102655	4.04	3.78
U14	99937	102640	ND	ND
D92-10	99954	103067	2.7	2.83
D92-13	100238	103296	2.32	2.84
D92-1	99883	103524	4.21	3.78
D92-2	99763	103396	3.27	2.96
D92-3	100062	103440	2.95	2.48
D92-4	100012	103344	3.17	2.65
D92-5	99940	103266	3.77	3.15
D92-6	100115	103215	3.34	2.79
D92-7	99868	102999	3.46	2.91
D92-14	100306	103336	3.17	2.65
D92-20	100216	102600	4.08	3.4
D92-21	100502	103032	3.08	2.53
D92-24	100356	102970	3.40	2.86
D92-18	100031	102738	4.12	3.09
D92-25	100507	103473	3.20	2.65
S1	97900	101650	2.65	2.34
S2	97700	101150	2.86	2.64

CaO tot% = total CaO in total sample
CaO cl% = CaO in coal part of sample only

specific gravity splits, then the calcite content of the total sample can be calculated.

If the calcite is associated with coal and, when liberated, forms small fragments, then the CaO contents of the 2.17 S.G. sinks for the coarse fragments will be mainly rock-split fragments with very little calcite. The CaO content of the 100-25, 25-10 and 10-0.5-millimetre-sized sinks (S.G. >2.17) are 0.81%, 0.51% and 1.36%. It is therefore safe to assume that the CaO content of the ash averages less than 1% and any CaO in excess of this amount is probably present as calcite. An ash-based CaO content of less than 1% for the single washability sample agrees with the 0.4% value determined from the 30 acid-leached samples.

The amount of calcite in the coal is calculated by subtracting 1% from the total CaO ash content and assigning the excess to calcite in the coal. The amount of calcite in the original sample can be determined by

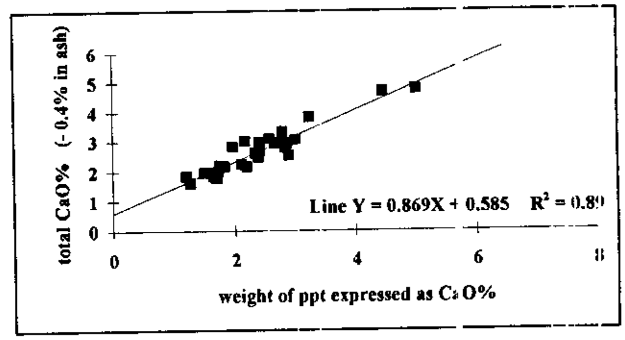


Figure 9. CaO% from calcite total sample *versus* CaO% in precipitate.

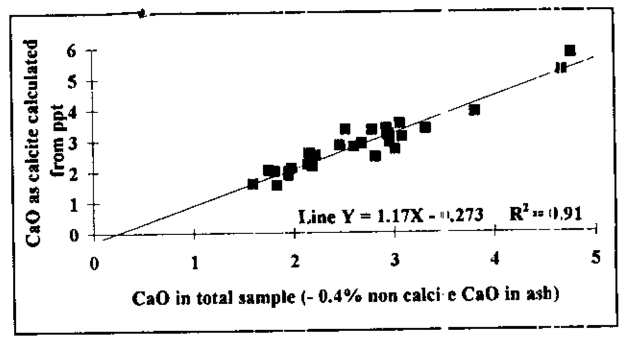


Figure 10. CaO% from calcite in total sample *versus* CaO% in precipitate, corrected for partial solution of calcite.

calculating the calcite in each size increment and weighting them together. This provides an average concentration of 3.6%, which is less than the calcite concentration in the 100-25-millimetre size fragments (4.57%). It is unlikely that these particles experienced any liberation of calcite and the calcite content of the other size fractions must average less than 3.6 % to ensure the overall average of 3.6%. A summary of calcite distribution by size and specific gravity, calculated assuming a constant 1% CaO from non-calcite sources, is presented in Table 5. The same information is displayed diagramatically in Figure 13

The amount of calcite liberated by crushing the raw coal can be estimated by subtracting the calcite content in the sizes 25-10 and 10-0.5-millimetres from an estimated average starting calcite content. This provides a minimum liberation of about 20%. The calcite content of the 0.5-0.15 and 0.15-0-millimetre sizes is increased by the addition of liberated and broken calcite fragments derived from the coarser sizes. The liberated calcite in the finer sizes may be all of the calcite in the size fractions or just that component above the average If all the calcite in the 0.15-0-millimetre size range is liberated together with half in the 0.5-.15-millimetre range then this provides an estimate of about 20% liberated calcite which agrees with the amount released from the coarser size fractions. It appears that the crushing process has liberated about 20% of the calcite in the raw sample. The 100-25-millimetres size fraction contains about 30% of the total calcite in the sample. The concentrations of calcite in the size ranges 25-10 and 10-0.5-millimetres are about two thirds the average indicating about a 30% liberation of calcite in these size fractions. Based on these numbers, crushing the whole sample to a 25-millimetre

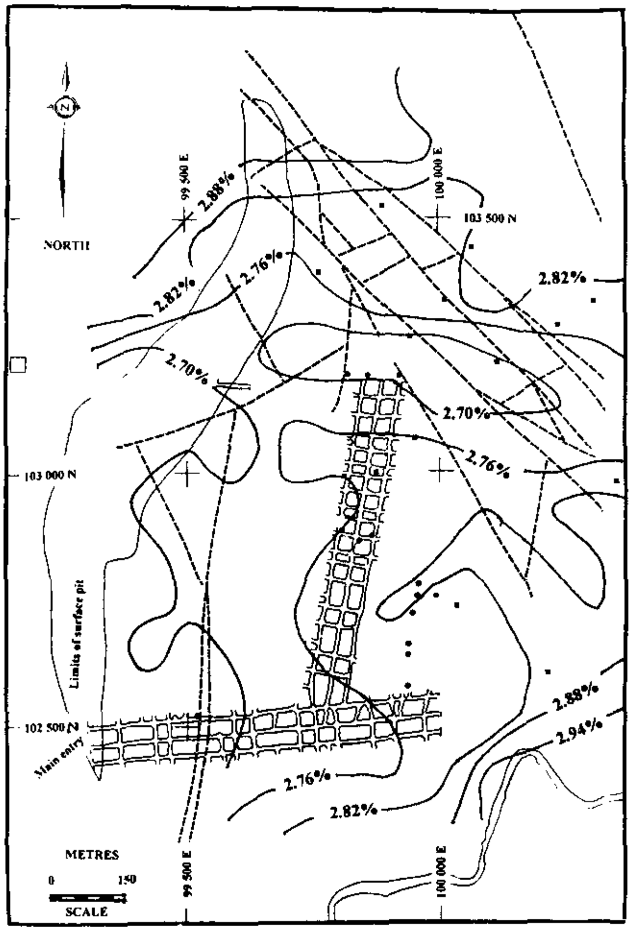


Figure 11. Map of 2N underground mine showing contours of total CaO% in total sample.

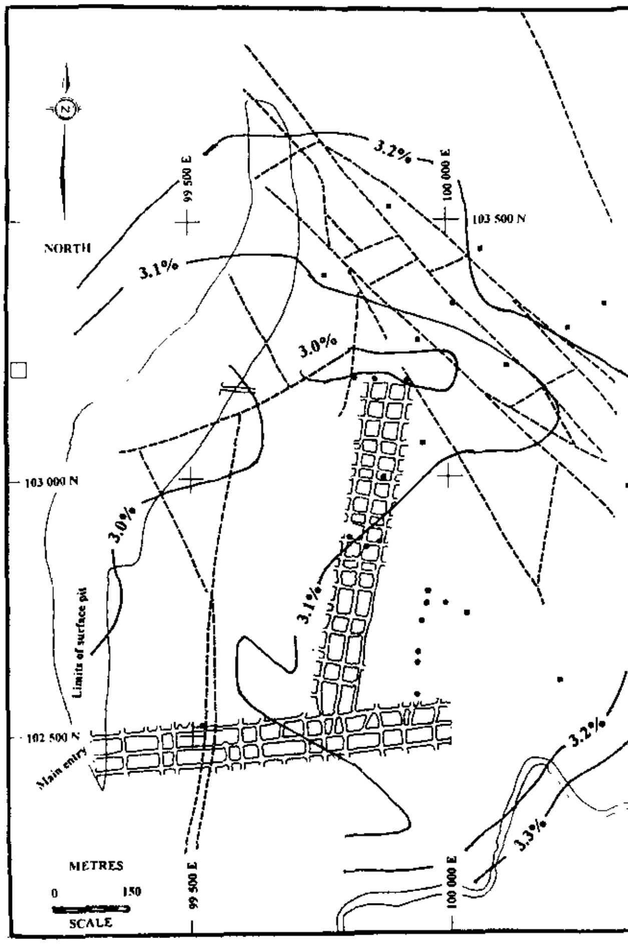


Figure 12. Map of 2N underground mine showing contours of calcite in coal-only part of sample.

top size would probably increase the calcite liberation from 20% to 30%.

It is possible to estimate the new particle-size distribution achieved by crushing the whole sample to a top size of 25 millimetres by plotting the existing size distribution on Rosin Rammler paper and then moving the line to the left to predict the new top size of 25-millimetres. This type of analysis indicates that the amount of minus 0.15-millimetre material will increase by at least 10%. An alternative approach in the plant, which would produce less -0.15-millimetre material, would be to screen and recrush only the 100-25-millimetre fraction. This should produce the same increase in calcite liberation without a large increase in the amount of fines.

Based on the above data, there is little if any liberated calcite in the 100-25, 25-10 and 10-.5-millimetre size fractions. Washing of these fractions will remove calcite as calcite-plus-coal particles, but will also reduce the ash and concentrate the remaining calcite in the remaining ash. The calculated calcite content of the >2.17 S.G. sinks in these sizes is low. This also indicates that there is very little liberated calcite. Most of the calcite is in the 1.5 to 1.7 S.G. splits and based on the amount of calcite and the specific gravity of the separating liquid, the specific gravity of the coal associated with the calcite has to be 1.35 in the 100-25 and 25-10-millimetre size fractions and 1.6 in the 10-0.5-millimetre size fraction. Obviously the calcite is associated with low ash coal in these size fractions. Most of the calcite liberated and fragmented from the coarse size fractions reports to the finest fraction where the >2.17 S.G. sinks contain 21% calcite.

The calcite is not easily liberated from coal particles but when it is, it breaks into particles less than 0.5 millimetres in size. Calcite can be removed as coal-plus-calcite particles from the size fractions greater than 0.5 millimetre by washing at specific gravity's ranging from 1.5 to 1.7. Calcite on cleats in hand samples appears to break off easily and it is surprising that it does not completely separate more easily from the coal. It is possible that it is not restricted to the cleats and some is dispersed through the coal.

ASH CHEMISTRY, CALCIUM OXIDE CONTENT AND THERMAL COAL UTILIZATION

Ideally an operator would like to burn ash-free coal in a power plant. In fact, with normal coal cleaning, about 5 to 15 % of the material introduced into the boiler

TABLE 5. CALCITE DISTRIBUTION BY SIZE AND SPECIFIC GRAVITY

Calcite calculated assuming 1% CaO not from calcite

RAW DATA

size mm	wt fraction	ash%	CaO% ash	wt calcite	volume calcite
100-25	23.49	32.75	8.82	4.57	2.41
25-10	24.25	32.63	4.87	2.25	1.17
10-0.5	40.21	31.28	5.88	2.72	1.42
0.5-0.15	4.51	21.37	15	5.36	2.84
0.15-0	7.54	42.29	12.6	8.79	4.74

Average calcite in sample =3.62% based on 1% CaO in ash minerals

WASH DATA

size in mm	100-25		25-10		10-0.5		0.5-0.15	
S.G.	ash%	wt calcite	ash%	wt calcite	ash%	wt calcite	ash%	wt calcite
1-1.3	6.04	0.9	3.98	0.95	4.78	13.8	4.22	0.495
1.3-1.35	6.39	2.63	5.72	2	5.45	13	6.15	0.604
1.35-1.4	10.52	6.5	9.87	5.6	9.92	15.9	7.74	0.86
1.4-1.45	14.43	9.7	15.03	6.4	14.32	18	10.36	1.02
1.45-1.5	17.66	12.7	18.73	10	18.4	22.6	15.12	1.49
1.5-1.6	21.8	16.3	24.16	13.9	23.43	23.6	19.43	2.13
1.6-1.7	30.75	9.7	33.7	10.5	30.72	20.4	28.15	3.13
1.7-1.8	44.44	9.9	45.25	5.8	38.91	20.3	36.79	5.42
1.8-2.0	51.18	3.3	53.85	1	51.83	11	47.89	8.12
2.0-2.17	65.85	0.5	66.84	2.7	61.46	10.6	58.93	11.9
2.17-2.5	80.46	0	80.94	-0.5	81.42	1	79.3	21.3

wt calcite = weight of calcite in sample

is ash. It must be collected either as small particles (fly ash), as dry-bottom deposits or as liquid slag, and removed. Many modern boilers use pulverized coal and are designed to handle ash as dry deposits most of which (80%) is collected as fly ash in electrostatic precipitators. The rest is removed as dry-bottom deposits via hoppers at the base of the combustion chamber. The operator is looking for an ash that will:

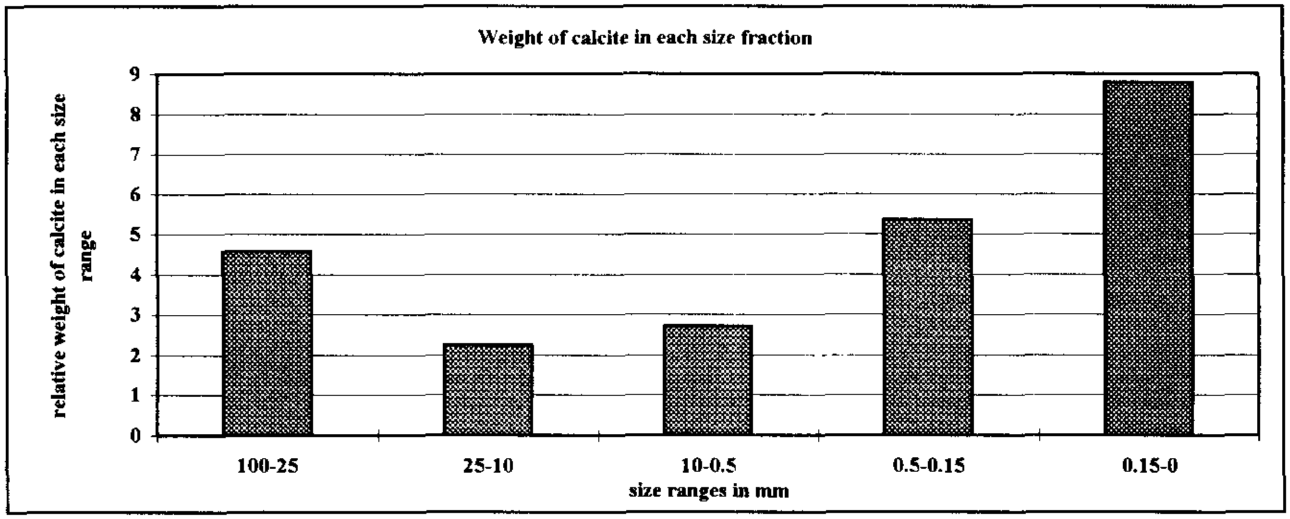
- Not produce a slag (melt at operating conditions; slagging problems).
- Not produce dry, sticky deposits in the boiler that may be difficult to dislodge and collect in the bottom hoppers (adhesion problems).
- Not produce deposits on the water tubes that corrode the metal (corrosion problems).
- Not contain refractory mineral fragments that will abrade metal surfaces (erosion problems).
- Be easy to collect as a fly ash in the electrostatic precipitators (favourable ash electrical resistivity)

In part, these properties are related to the size, segregation and form of the mineral fragments that enter the boiler with the coal. They can also be predicted, to some extent, using average ash chemistry.

The oxide chemistry of the inherent mineral matter in a particular seam is typically fairly constant. Variations are caused by variable additions of minerals associated with the coal, for example calcite, other carbonates, phosphates and pyrite. The amount of sulphur in the clean coal is closely monitored so that the main variations in clean-coal ash chemistry will be related to variations in CaO, Fe_2O_3 and MgO content. The main variant in the ash chemistry of Quinsam coal is CaO derived from calcite.

It is important to understand how variation in the content of these oxides changes the important ash properties of slagging, adhesion, corrosion, abrasion and ash resistivity, and effects the operation of the most commonly used pulverized-coal dry-bottom boilers. A number of characterization constants are used to predict ash properties. The most often used are base to acid ratio, silica ratio and dolomite ratio (Table 6). Equations using these constants are usually very sensitive to changes in the amount of alkalis in the ash.

Not all boilers are the pulverized-coal dry-bottom type and in some cases higher than normal CaO in the ash is an advantage. A high CaO concentration in the ash causes a lot of the sulphur to be trapped in the ash as $CaSO_4$ which reduces the amount of SO_2 entering the scrubbers. A high CaO ash may be an advantage in "integrated coal gasification combined cycle" plants (ICGCC) where coal is burned under pressure. A pilot facility in Japan uses a pressure of 2735 kilopascals. In this situation ash must be collected and removed as a fluid and a fluxing ash chemistry is required. Cement plants are not concerned about ash chemistry to the same extent as large power plants and an ash higher in CaO may actually be an advantage. Fluidized-bed boilers burn coal over a bed of granular limestone The coal and limestone particles are fluidized by passing air upward through the bed. The coal burns in association with the limestone and most of the SO_2 released is converted to gypsum. In this type of boiler any additional calcite introduced with the coal is of no consequence. The high CaO content may be an advantage for PCI use. The injection of a fluxing rather than a refractory ash into the bottom of the blast furnace may be preferred.



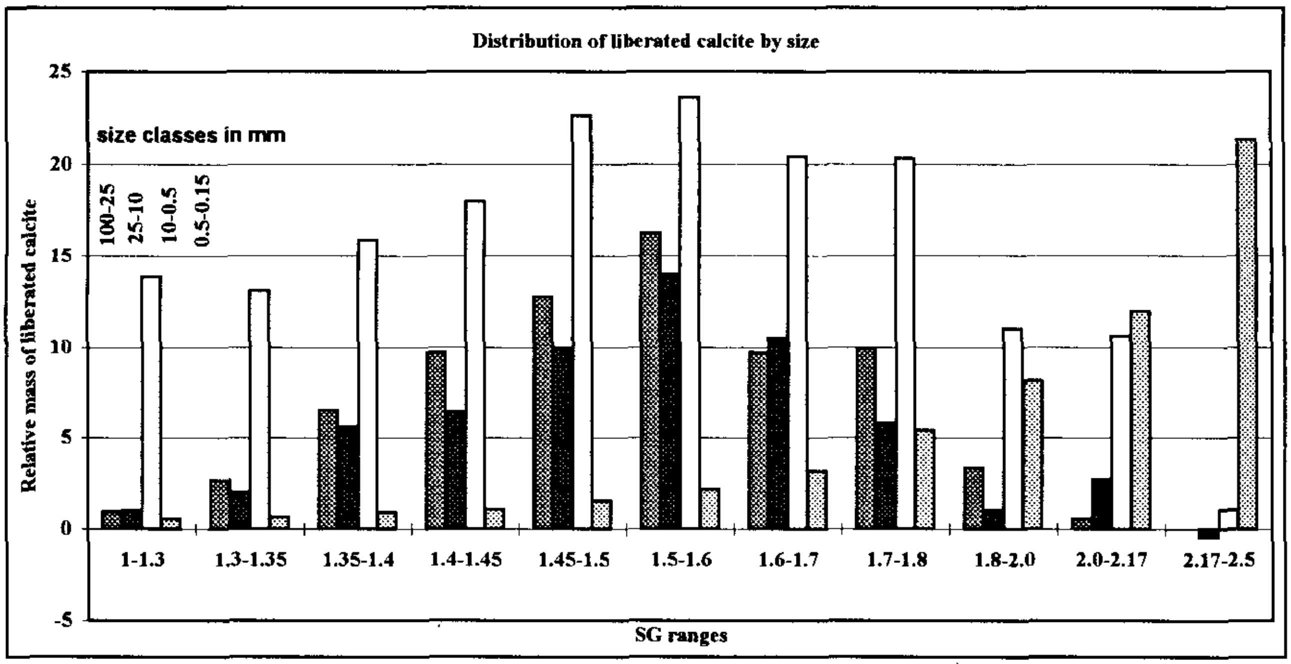


Figure 13. Calcite distributions in single bulk washability data.

Generally CaO, MgO and Fe_2O_3 act as mild fluxing agents in the ash, especially in the presence of excess SiO_2, whereas NaO and FeO act as strong fluxing agents. High and variable CaO in the ash effects a number of slagging and fouling parameters of the ash.

Dry-bottom boilers are not designed to handle much slag and it is important to be able to predict operating conditions that will not produce slag. Historically ash-fusion temperatures have been used as an indication of the slagging potential of the ash. Generally, temperatures measured under reducing conditions are used because they are lower than temperatures measured under oxidizing conditions and there are times when boilers operate at close to reducing conditions. Less emphasis is placed on ash-fusion temperatures today because it has been found that they are unreliable and are not easily correlated with other measures of slagging propensity.

Ash that melts completely over a small temperature range may coat the boiler walls with slag that is difficult to remove. A wider melting range will cause the deposit to solidify on the boiler walls and build up a thicker deposit that may be easier to remove with soot-blowers. The temperature difference between initial deformation and hemispherical deformation is a good measure of the melting range. The temperature range is in part related to the total CaO content. As the CaO content increases the temperature range decreases, and at high concentrations of CaO, the range is reduced, but is insensitive to additional increase in CaO concentration. The point at which the temperature range becomes insensitive to an increase in CaO is about 15%. If the CaO is in this range then increases may not make slagging problems much worse, but blending with a low CaO coal will produce major improvements in slagging properties.

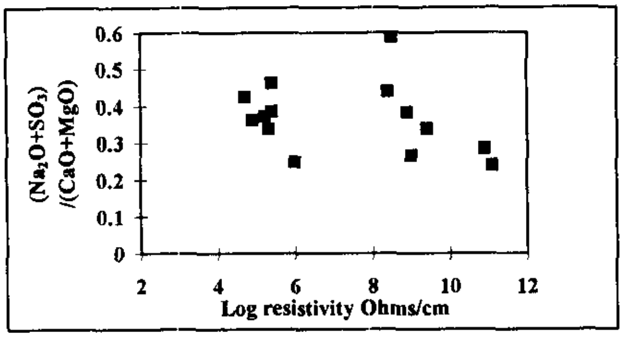


Figure 14. Relationsip of Selle *et al.* (1975) for ash chemistry *versus* ash resistivity using data from Tait *et al.* (1989).

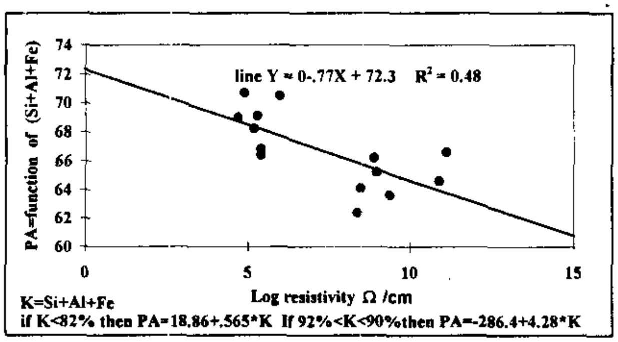


Figure 15. A plot of electrostatic precipitator efficiency as predicted by the relationship of Potter (1988) versus actual ash resistivity data from Tait *et al.* (1989).

The temperature at which the ash starts to melt is an important indication of its slagging propensity. Most boilers operate at temperatures in the range 700°C to 1400°C in the combustion area and therefore a non-slagging ash should melt at temperatures above 1400°C. There are number of empirical equations for predicting ash-melting temperatures (Table 6). The temperature at which slag tends to act as a liquid rather than a plastic solid is called the temperature of critical viscosity (Tcv) and the temperature at which it has a viscosity of 250 poise (liquid enough to be removed easily as a melt) is referred to as T250°C. Because the equations are empirical, there are often different versions in different references, with confusion as to the correct constants and units.

The equation used to predict Tcv values (Hoy *et al.*, 1965; Table 6) is probably only good to indicate relative trends and not too much emphasis should be put on absolute values. Vorres *et al.* (1986) studied the melting characteristics of synthetic ashes. Their data can be used to compare calculated Tcv temperatures with actual temperature break points in viscosity *versus* temperature plots. The predicted Tcv temperatures are generally within 100°C and higher than the expected value. Attempts by Vorres *et al.* to use the Watt and Fereday (1969) T250°C relationship (Table 6) to duplicate their experimental results were not successful and the equation consistently predicted T250°C temperatures that were too low. They also plotted the predicted temperature *versus* viscosity relationship derived by Hoy *et al.* (1965) with better results. In this study the Hoy *et al.* and Watt and Fereday equations for predicting T250°C provided similar results and the Watt and Fereday equation is used (Table 6).

The adhesion force is a measure of the tendency of the dry or semimolten ash to stick to the boiler walls. Idemitsu Kosan Co ltd. (1993) has published a relationship for adhesive force to silica ratio (Table 6). Idemitsu considers adhesion force to be one of the more useful ash parameters and it points out that it does not necessarily correlate with other factors such as ash-fusion temperature. It suggests that a value less than 100, preferably about 10, is required for a coal blend that will not produce fouling in the boiler. Work described by Raask (1985, p. 177) uses the amount of insoluble FeO in the slag to estimate an adhesion index (Table 6). When the FeO in the ash exceeds its solubility limit, the remainder is available to form a strong bond to the boiler walls.

Some alkali oxides form oxide metal compounds and effectively remove metal from the boiler walls. Calcium is a very effective anticorrosive agent when concentrations are above 8% (Skorupska, 1993). The abrasion effect of the minerals in fly ash is dependent on the amount of free quartz and pyrite in the coal.

For efficient operation, electrostatic precipitators require an ash resistivity in the range 10^7 to 10^{10} ohms per centimetre (Tait *et al.* 1989). If the resistivity of the ash particles is too low, they will not hold a charge and will not be attracted to the plates in the precipitator. If the resistivity is too high, the particles tend to insulate the plates and build up a back corona discharge. Generally the collection efficiency increases with increasing ash resistivity within the above range. Fly-ash resistivity decreases as the concentration of metal alkalis increases in the ash (Bickelhaupt, 1975). The presence of Fe_2O_3, K_2O and Na_2O reduces the ash resistivity; CaO, MgO, Al_2O_3 and SiO_2 increase ash resistivity. Some minerals survive the boiler temperatures and remain in the fly ash. Clays, if they retain OH, will have low resistivity. The resistivity increases if water is lost, but may remain low if the surviving mineral fragments contain iron. Quartz, on the other hand, has a high resistivity, in the order of 10^{12} ohms per centimetre.

SLAGGING ADHESION AND RESISTIVITY PROPERTIES OF QUINSAM ASH

Slag temperature, adhesion force and fly-ash resistivity are some of the more important ash characterization parameters for thermal coal. The effect of higher than normal and variable amounts of CaO on these and other parameters was investigated using the relationships in Table 6.

Data from Matheson *et al.* (1994) indicate that Quinsam coal has a moderate to low slagging propensity based on a relationship for the lignite-type ash (Table 6):

Slagging factor ≡ (hemispherical temperature + 4 x initial deformation temperature) /(5)

TABLE 6
SLAGGING AND FOULING RELATIONSHIPS

ASH CHARACTERIZATION

Base Acid Ratio = $(Fe_2O_3+CaO+MgO+Na_2O+K_2O)/(SiO_2+Al_2O_3+TiO_2)$

Silica Ratio = $SiO_2/(SiO_2+Fe_2O_3+CaO+MgO)$ Dolomite Ratio = $(CaO+Mg))/(Fe_2O_3+CaO+MgO+Na_2O+K_2O)$

Ash type = Bituminous $Fe_2O_3>(CaO+MgO)$ Lignite $Fe_2O_3<(CaO+MgO)$

TEMPERATURE VERSUS VISCOSITY RELATIONSHIPS

$T250°C = 10^7 x M/(\log_{10}(viscosity)-C)^{0.5} + 150$,

$C=.0415 x SiO_2 +.0192 x Al_2O_3 +.0276 x Fe_2O_3 + .0016 CaO - 4.92$ $M=0.00835 x SiO_2 + 0.00601 x Al_2O_3 - 0.109$

Viscosity in poise (Newtons/sec/m^2 =poise x 0.1) Relationship from Watt and Fereday (1969)

$\log_{10}(viscosity)=4.468$ (Silica ratio/100) + $1.265(10^4/T_k)-8.44$

Viscosity in Newtons/sec/m^2 T_k Temperature in °Kelvin. Relationship from Hoy *et al.* (1965)

CRITICAL TEMPERATURE

$Tcv = 2990 - 1470 x A +360 x A^2 - 14.7 x B + 0.15 x B^2$

$A = SiO_2/Al_2O_3$ $B = Fe_2O_3 + CaO + MgO$ Relationship from Hoy *et al.* (1965)

SLAG ADHESION

Slag adhesive force =23.15 - .28 x silica ratio Relationship derived from Idemitsu (1993)

Slag adhesion index $I_{ad}=FeO_{sol} - FeO_{pres}$

$FeO_{sol}=1.2(SiO_2-Al_2O_3)-0.6(CaO+MgO+Na_2O+K_2O+TiO_2)$ Relationship from Raask (1985)

ASH RESISTIVITY

$\log_{10}(resistivity) = D/(0.1632 x D - 0.00933)$ $D=(Na_2O+SO_3)/(CaO+MgO)$ Resistivity in ohms/metre

Relationship derived from data from Selle *et al.* (1972) for sub-bituminous coals in western USA

if $\sigma<82\%$ then $\sigma_m=18.86+0.565\sigma$ $82\%<\sigma<90\%$ then $\sigma_m=-286.4+4.28\sigma$

where σ = Si+Al+Fe relationship from Potter (1988)

σ_m=collecting area in mass units for a precipitator outlet concentration of 0.1 gm/m^3

ash resistivity log(ohms/cm) = (CaO+1.19)/.859 relationship derived from data in CANMET publication 89-4E

ash resistivity log(ohms/cm) = .7296 x A - 7.48 (R^2=.77)

where $A=-9.474 + .4249 x SiO_2 + 1.442 x CaO - .1758 x K_2O - .6026 x SO_3$

relationship derived by stepwise multiple regression of all oxides in ash analysis data from CANMET publication 89-4E

or using the relationship for a bituminous-type ash

Slagging factor ≡ (base acid ratio x sulphur)

A plot of ash-fusion temperatures *versus* various oxide contents indicates a weak positive correlation of ash-fusion temperatures with CaO content and base acid ratio and a weak negative correlation with SiO_2, Fe_2O_3 and MgO. The ash-fusion temperatures range from a low of 1265°C to a high of 1410°C (initial deformation temperatures), yet over this range there is no obvious correlation of temperatures with variation in the content of any of the major oxides. A study by Rimmer and Davis (1990) found a negative correlation of ash-fusion temperatures with Fe_2O_3 and a positive correlation with SiO_2, Al_2O_3, TiO_2, MgO and K_2O. Calcium oxide is not mentioned and in fact they state that calcite has little effect on ash-fusion temperatures.

Four Quinsam coal ash chemistries were used to check the effects of CaO on various ash properties. The first is an average of 14 analyses by Matheson *et al.* (1994) and the other three represent modified ash chemistries based on fixing the CaO content of the averaged analysis at 10%, 15%, 20% and 25%, while keeping all other oxides in their correct relative proportions (Table 7).

The results are presented in Table 8. In all cases the ash is defined as a lignite type, based on the definition in Table 6, with a moderate base acid ratio. The silica ratios are generally low, which leads to the prediction of high adhesive forces for the ash.

The predicted Tcv temperatures are generally high and vary from 1549°C at 25% CaO to 1625°C at 10% CaO. The predicted T250°C temperatures appear to be more reasonable and vary from 1135 to 1260°C. Based on the predicted T250°C temperatures, Quinsam coal has a medium slagging propensity (temperature range 1400-1150°C, Tait *et al.*, 1989). The adhesion force and adhesion index of the various Quinsam chemistries are all high (Table 8) because of the low silica index and apparently low solubility of FeO in the ash. All the ash chemistries indicate the potential for fouling in the boiler.

TABLE 7. AVERAGE QUINSAM ASH CHEMISTRY, MODIFIED CHEMISTRIES AND SOME POTENTIAL BLENDS

Sample	SiO_2	Al_2O_3	TiO_2	F_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	S%
Quin av	27.3	27.8	1.93	8.45	22.2	0.6	0.3	0.03	1.4	9.3	0.6
25CaO	26.3	26.8	1.9	8.1	25	0.6	0.3	0.03	1.3	9.0	0.86
20CaO	28.1	28.6	2.0	8.7	20	0.6	0.3	0.03	1.4	9.6	0.68
15CaO	29.8	30.4	2.1	9.2	15	0.7	0.3	0.04	1.5	10.2	0.68
10CaO	31.6	32.2	2.2	9.8	10	0.7	0.4	0.04	1.6	10.8	0.68
LCR	59.1	29.3	2	3	1.4	.3	.1	.5	1.2	.4	.6
BCC	48.2	33.5	2.2	2.5	5.7	1.2	1	.5	1	3.6	.5
FRC	58.4	27.6	1.6	4.7	1.8	.6	.1	1.2	1.1	1.1	.44
TELK	56.8	21.9	1.6	6.14	5.37	1.24	.61	.31	1.25	3	1

Quin av = average chemistry raw data from Matheson *et al.* (1994)
25CaO to 10CaO average chemistries adjusted for 25 to 10% CaO

LCR = Average chemistry Line Creek mine
BCC = Average chemistry Byron Creek Collieries
FRC = Average chemistry of some blends Fording River Collieries
TELK = Average chemistry upper seams
Data from Price and Gransden (1987)

TABLE 8. BLENDS OF QUINSAM COAL WITH OTHER B.C. COALS; EFFECTS ON VARIOUS SLAGGING AND FOULING PARAMETERS

QUINSAM COAL blended with other B.C. coals in 1 to 1 proportions									
Sample	Ash T	Ash	B/A ratio	Dol ratio	Si ratio	AD force	T250	TCV	Ash res
QAV+0	LIG	12	0.59	74.09	44.86	38215	1100	1552	H
Q25%+0	LIG	12	0.62	75.23	43.83	51046	1088	1549	H
Q20%+0	LIG	12	0.5	69.52	48.95	12119	1145	1567	1.70E-11
Q20%+LCR	LIG	12	0.23	63.84	71.95	19	1370	1363	1.90E-08
Q20%+BCC	LIG	12	0.28	67.85	66.35	92	1307	1473	1.40E-08
Q20%+FRC	LIG	12	0.26	60.48	70.38	30	1358	1343	1.50E+08
Q20%+T	LIG	12	0.31	62.84	66.88	79	1330	1272	2.90E-09
Q15%+0	LIG	12	0.41	62.2	54.48	2570	1202	1593	1.70E-06
Q15%+LCR	LIG	12	0.2	56.97	75.02	8	1398	1397	6.20E-06
Q15%+BCC	LIG	12	0.25	62.53	69.46	38	1334	1503	4.40E-05
Q15%+FRC	LIG	12	0.22	53.81	73.38	13	1386	1371	4.90E-05
Q15%+T	LIG	12	0.27	57.34	69.7	36	1356	1293	9.10E-06
Q10%+0	LIG	12	0.32	51.1	60.65	454	1260	1625	L
Q10%+LCR	LIG	12	0.17	47.26	78.26	3	1427	1427	L
Q10%+BCC	LIG	12	0.21	55.28	72.74	15	1363	1529	L
Q10%+FRC	LIG	12	0.19	44.65	76.53	5	1415	1401	L
Q10%+T	LIG	12	0.24	50.01	72.67	16	1386	1325	L
QUINSAM COAL AT 15%CaO blended with Telkwa coal in varying proportions									
15Q1.0	LIG	12	0.41	62.2	54.48	2570	1202	1593	1.70E-06
Q.9+T.1	LIG	12	0.38	61.42	57.84	999	1233	1517	2.40E-06
Q.8+T.2	LIG	12	0.35	60.55	61.04	408	1264	1443	3.30E-06
Q.7+T.3	LIG	12	0.32	59.59	64.07	174	1295	1387	4.70E+06
Q.6+T.4	LIG	12	0.30	58.53	66.95	77	1326	1335	6.50E+06

Q Quinsam
LCR Line Creek Resources
BCC Byron Creek Collieries
FRC Fording River Coal
T Telkwa
% numbers indicate % of CaO in Ash
.7 indicates mixing proportions
All samples assumed to be 12 % ash
Equation used for predicting relative ash resistivities
not applicable outside a range of 1E+5 TO 1E+12

Ash T LIG or BIT for lignite or bituminous
B/A base acid ratio
Dol dolomite ratio
Si silica ratio
AD adhesion force
T250 temperature at 250 poise
Tcv critical viscosty temperature
Ash Res ash resistivity in Ω /cm
H value above 1E+12 L value below 1E-5

The high CaO content of Quinsam coal will ensure that it will not cause corrosion. No estimates of erosion are made in Table 8, but because Quinsam ash appears to be low in free quartz and it is not expected to cause excessive ware of the pulverizers or erosion in the boiler. Pyrite can also cause erosion, but the raw samples analyzed in this study averaged about 0.68% total sulphur of which about 0.13% is probably pyrite. Consequently there will be very little pyrite in the washed coal available to cause problems.

Based on its high CaO content, Quinsam coal will have a high ash resistivity. The relationship suggested for sub-bituminous coals by Selle *et al.* (1972; Table 6) indicates that ash resistivity increases as the concentration of CaO increases. This relationship was tested using data from Tait *et al.* (1989; Figure 14) and does not appear to be useful for a broad range of Canadian coals. Potter (1988) uses the sum of Si, Al and Fe to predict electrostatic precipitator performance in terms of surface area required to collect a fixed amount of ash. This relationship was also tested and a weak inverse correlation of plate area to ash resistivity is apparent (Figure 15).

A correlation analysis of all the oxides in the ash *versus* ash resistivity, in Tait *et al.*, indicates that the best correlation with a single oxide is for CaO (Figure 16). The relationship is only approximate and is only substantiated over a range of CaO content from 4% to 15%. The R-squared value for the best-fit line is 0.7. A stepwise multiple regression analysis of the same data provided the best fit of the actual resistivity data to a function of ash chemistry (Figure 17, $R^2 = 0.77$). The analysis indicates that CaO, SiO_2, K_2O and SO_3 are the important oxides influencing ash resistivity. The data set from Tait *et al.* (1989) includes samples from the Elkview and Greenhills mines in southeast British Columbia. Measured ash resistivities for samples from these two mines were 7.9×10^4 and 2.0×10^5 ohms per centimetre, respectively, and these values can be compared to industrial results on the same well known coals to indicate whether the predicted resistivities should to be adjusted up or down. The present multiple regression equation which predicts resistivities over a range of 10^5 to 10^{12} ohms per centimetre is used to predict the resistivities for the Quinsam coals. If the predicted resistivity is outside these limits then it is designated simply as high or low in Table 8 because it is unlikely that there is a linear relationship outside the range of the data. The resistivities of Quinsam coal are high when the CaO content is above 20%. They are in the required range for CaO contents from 20% to 15% and are low for CaO contents of less than 10%.

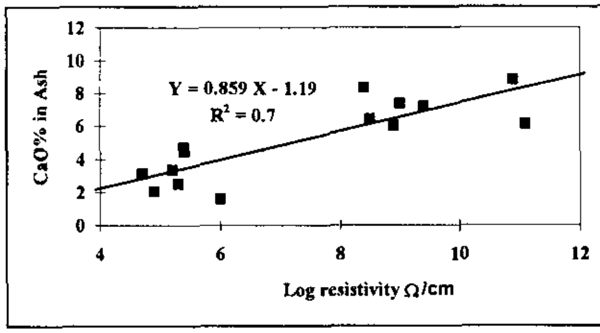


Figure 16. A plot of CaO% in ash *versus* actual ash resistivity data from Taite *et al.* (1989).

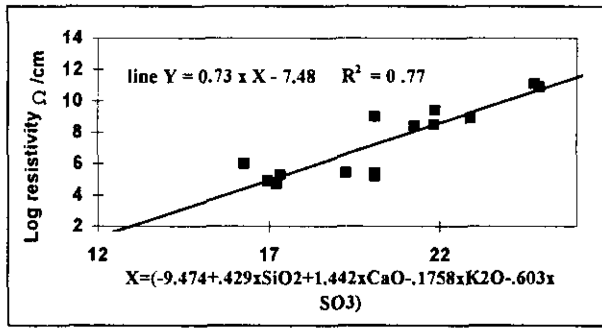


Figure 17. Plot of the results of multiple stepwise correlation analysis of ash oxide data and actual ash resistivity data, from Tait *et al.* (1989).

SLAGGING AND FOULING CHARACTERISTICS OF BLENDS OF BC THERMAL COALS

Most power plants burn a blend of pulverized coals so it is useful to investigate the effect on slagging and fouling parameters of blends of coals containing Quinsam coal. Because most slagging and fouling parameters have non-linear relationships to ash chemistry, it is often not apparent what the characteristics of a blend will be until the calculations are made. A computer program was used to calculate the blended ash chemistry of any number of coals, based on blend proportions and the amount of ash in each coal. The program then calculates the slagging and fouling parameters defined in Table 6.

A number of theoretical blends of ash oxide chemistry were created which mixed other British Columbia coals with varying proportions of Quinsam coal. The resulting ash chemistries are listed in Table 7 and the predicted slagging and fouling parameters are in Table 8. All coals were assumed to have 12% ash which is in the mid-range for acceptable thermal coals. The Quinsam coal was blended with average analyses reported in Price and Gransden (1987) for the lower seams in the Mist Mountain Formation at Line Creek mine (LCR), for upper Mist Mountain Formation seams from the Fording River Coal mine (FRC) and the basal Mist Mountain seam from the Byron Creek Collieries (BCC). An average analysis was also obtained for coal from the Telkwa exploration property which is a potential thermal coal mine. All the blends have lignite-type ash chemistry as defined in Table 6. All the slagging parameters based on T250°C values are improved when Quinsam coal is blended with coal from southeast British Columbia, except for Byron Creek coal which also tends to have moderate amounts of CaO in the ash. Most of the blends have low slagging propensity (T250°C > 1275°C) and some have T250°C values close to 1400°C, indicating no slagging propensity.

The adhesion force of the ash is greatly reduced in all cases and the 15% CaO Quinsam coal blends achieve adhesion forces close to the value of 10, which is considered to be an acceptably low value for minimal slagging problems.

Based on the relationship of CaO% to ash resistivity derived from the combustion data in Tait *et al.* (1989), ash resistivities of blends of Quinsam coal with other British Columbia coals decrease and are acceptable for most blends.

CONCLUSIONS

Some Upper Cretaceous coals on Vancouver Island have higher CaO contents than most high-volatile bituminous coals. Preliminary data indicate that seams higher in the coal-bearing sections may have more normal CaO contents.

The Quinsam mine is presently mining the lowest seam in the coal section in the Comox Formation and this seam has higher than normal CaO contents. The CaO originates in the coal as calcite which is on cleat surfaces and also may be dispersed in the coal. Because the calcite is associated with the coal and not the rock partings, washing the coal to remove the ash may result in higher concentrations of calcite in the wash ash. There is less than 1% CaO in the ash originating from minerals other than carbonates and there is from 0.0% to 7.5% CaO dispersed as calcite in the coal.

Because most of the CaO in the sample is present as calcite, a simple acid leach and weighing test can provide a moderately accurate way of estimating the total CaO in the sample.

The calcite does not liberate from the coal as easily as might be expected. This may be because some is dispersed through the coal and not coating the cleat surfaces. Crushing the coal to less than 100 millimetres top size produces complete liberation of about 20% of the calcite. Crushing to less than 25 millimetres top size would probably increase the calcite liberation from 20% to 30%. An alternative approach in the plant, which would produce less -0.15-millimetre material would be to screen and recrush only the 100-25-millimetre material. This should produce the same increase in calcite liberation without a large increase in the amount of fines.

The high CaO in the ash has a number of effects on its behaviour in a boiler. The melting temperature is reduced which may increase slagging. The stickiness of the ash, measured by adhesion force, increases and this can increase fouling propensity. The ash resistivity in the electrostatic precipitators increases. If the resistivity is sufficiently high then this may reduce the efficiency of the precipitators. High CaO content may aid in sulphur removal and help to limit metal corrosion in the boiler. The low content of free quartz in Quinsam coal helps reduce erosion in the boiler and wear on the pulverizer.

At Quinsam, the CaO content of the ash can be lowered at the expense of introducing more pyrite and sulphur. In terms of electrostatic precipitator performance this may be advantageous; the addition of iron and sulphur will lower ash resistivity and the extra sulphur is unlikely to overload the scrubbers because the CaO content will remain high and will remove much of the added sulphur as $CaSO_4$ in the bottom-ash deposits.

Blending Quinsam coal with other thermal coals can produce a thermal coal with acceptable ash properties, including slagging propensity, adhesion and ash resistivity.

ACKNOWLEDGMENTS

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GEOLOGY OF THE DRIFTPILE STRATIFORM, SEDIMENT-HOSTED Ba-Zn-Pb DEPOSIT, NORTHERN BRITISH COLUMBIA (94K/4)

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KEYWORDS: economic geology, stratiform Ba-Zn-Pb, Kechika Trough, Driftpile Creek, Earn Group, exhalites

INTRODUCTION

One of the world's largest concentrations of sediment-hosted stratiform zinc-lead-barite deposits is located in the Gataga area of northern British Columbia (Figure 1). The largest and most developed of these is the Cirque/South Cirque deposit, with estimated geological reserves of 38.5 million tonnes averaging 8.0% Zn, 2.2% Pb and 47.2 g/tonne Ag at Cirque and 15.5 million tonnes of 6.9% zinc, 1.4% lead and 32 g/tonne Ag at South Cirque (MacIntyre, 1992). The Driftpile deposit, located 80 kilometres north of Cirque, has been explored and drilled extensively in 1978-1982 by Archer, Cathro and Associates and from 1993 to the present by Teck Exploration Ltd. In spite of this considerable development, most information about the Driftpile deposit resides in private company reports. Notable exceptions are a Ph.D. thesis by Martin Insley (Insley, 1990) that includes a 1:5000 geologic map and cross-sections of the property and diamond drill hole logs; and a suite of conodont identifications based on Insley's collections, which appear in S.E.B. Irwin's M.Sc. thesis (Irwin, 1990).

This paper summarizes preliminary results of a one-month study on the detailed stratigraphy and mineralization of the Driftpile deposit, conducted in August 1994. Core from 25 holes drilled in 1993 and 1994 was logged and sampled for studies of conodont biostratigraphy and taxonomy by S.E.B Irwin and M.J. Orchard of the Geological Survey of Canada, and the area around Driftpile Creek was mapped at 1:2000 scale. This deposit study is a cooperative effort between the B.C. Geological Survey Branch and the Geological Survey of Canada (see companion paper, Paradis *et al.*, 1995). It forms part of a multidisciplinary program in the Gataga area which also includes regional mapping (Ferri *et al.*, 1995, this volume) and geochemical studies (Lett and Jackaman, 1995, this volume).

EXPLORATION HISTORY

The Driftpile Creek property was first staked in 1974 by Canex Placer Ltd. in joint venture with a syndicate, as a result of follow-up of anomalies from a stream sediment geochemical survey conducted by Geophoto Consultants Ltd in 1970. Encouraging additional results from sampling,, as well as the discovery of massive sulphide float boulders in Driftpile Creek in 1973 led to staking of 153 two-post claims in 1974, and a program of geological mapping, EM and hand trenching in 1974-75. The Gataga Joint Venture was formed in 1977 by Aquitaine Company of Canada, Chevron Canada Ltd., Getty Mining Pacific Ltd. and Welcome North Mines Ltd. Managed by Archer, Cathro and Associates, its aim was to investigate the potential of the Kechika Trough in terms of sedimentary exhalative deposits like those of the Selwyn Basin. The Gataga Joint Venture optioned the Driftpile property in 1978 and from then until 1982 conducted a major exploration program including 7560 metres of drilling in 54 diamond-drill holes, geological mapping, grid soil geochemistry, EM surveys, backhoe trenching and the construction of an airstrip. This program outlined an extensive series of northwest striking barite and sulphide-carbonate units, outcropping over an area 3 kilometres northwest-southeast by 1.5 kilometres northeast-southwest (Carne and Cathro, 1982a). Particularly favourable zones such as the Main, Camp, East, North Trench and Canyon zones, shown on Figure 2, were drill tested.

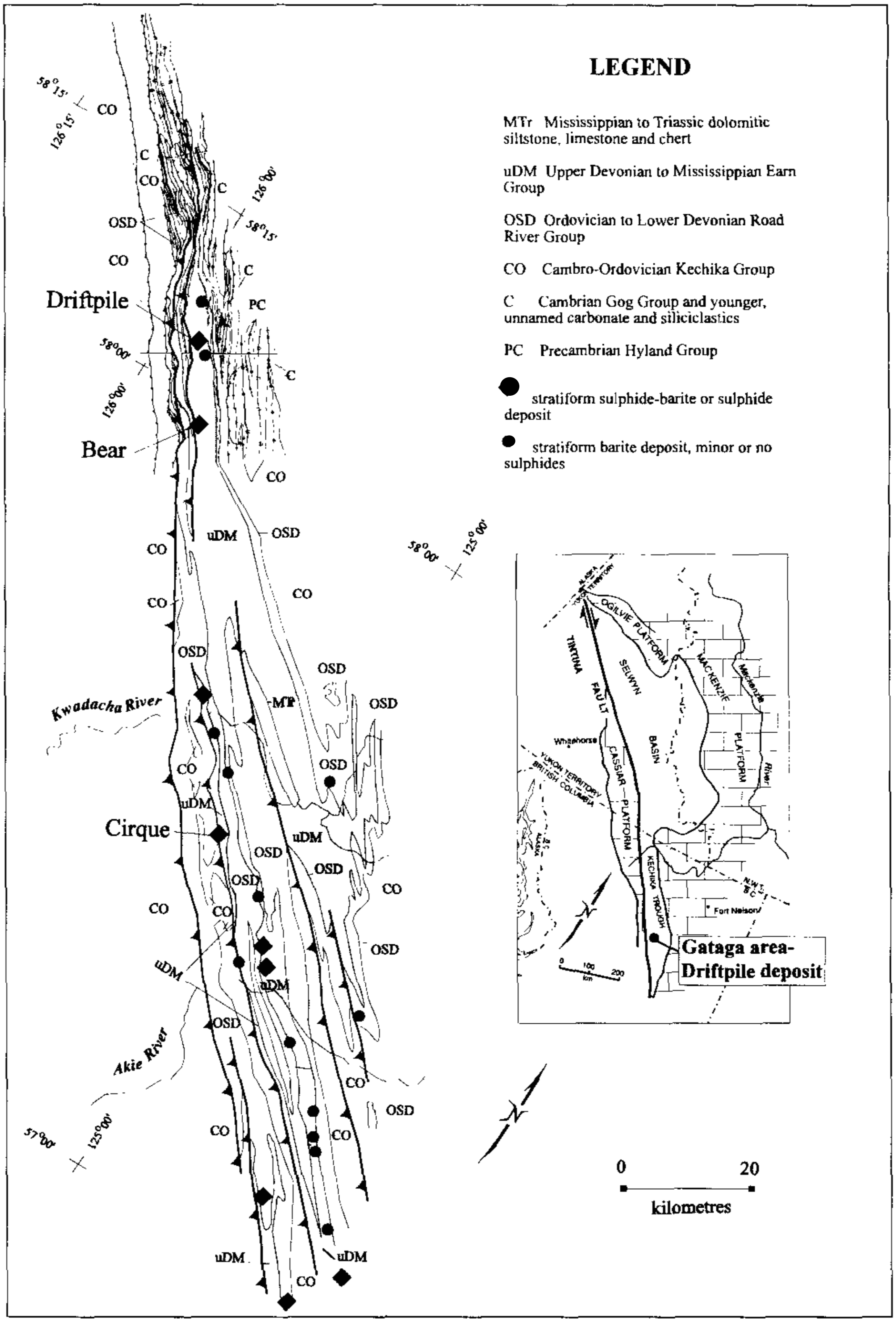

Figure 1. Regional geology of the central and southern Kechika Trough. Geology by MacIntyre (1992) and McClay *et al.*, (1989) for the area around the Driftpile deposit. Earn Group exposures shaded grey.

Following a ten-year hiatus in activity, Teck Exploration purchased the property in 1992. Teck drilled 4600 metres in thirteen holes in 1993, testing the Main zone. As a result of this work, a geological resource in the lower mineralized unit of the Main zone was estimated to be 2.44 million tonnes averaging 11.9% Zn, 3.1% Pb with a cutoff grade of 8% Zn (Farmer *et al.*, 1994). The 1994 program included drilling of 4400 metres in 26 holes on the East, Camp, Ridge and Canyon zones.

REGIONAL GEOLOGY

The Gataga area lies within the Muskwa Range of the northern Rocky Mountains, directly east of the Northern Rocky Mountain Trench - Tintina strike-slip fault system (Gabrielse, 1985). It includes part of the Kechika Trough or Kechika Basin, a southern continuation of the Selwyn Basin in Yukon. This feature has been variously interpreted as a two-sided trough (McClay *et al.*, 1989; MacIntyre, 1992) or west-facing open continental slope (Gabrielse, 1985; personal communication, 1994) during early Paleozoic time. Upper Cambrian through Lower Devonian strata are thin and of deep water facies, in contrast to the carbonate-dominated section exposed to the east. They are included within the Cambro-Ordovician Kechika Group and Ordovician to Lower Devonian Road River Group (Figure 1). The regional geology is more thoroughly described in the companion paper by Ferri *et al.* (this volume).

Although stratiform, sediment-hosted deposits of Middle Ordovician and Early Silurian age are present within the Kechika Trough, the major pulse of exhalative activity was in the Late Devonian. The Earn Group, a basinal siliciclastic package of Middle Devonian to early Mississippian age, hosts regionally extensive stratiform barite and many stratiform sulphide (-barite; -carbonate) occurrences, including Driftpile and the Cirque deposit (Figure 1). Correlative strata are exposed throughout the Selwyn Basin, where they host significant sedex deposits such as Tom and Jason, and on the Cassiar Terrane, where similar deposits are small and rare. The Earn Group represents a dramatic change in basin history. In it, easterly to southeasterly prograding coarse clastic wedges interfinger with black shales, siliceous shales, cherts and mudstones. The latter facies has been informally termed the Gunsteel formation from its silvery-blue appearance in outcrop. It hosts the stratiform barite and sulphide (-barite; -carbonate), which in the Kechika Trough are of Famennian age (Irwin, 1990). In the vicinity of the Cirque deposit, clastic rocks overlie the Gunsteel formation and its contained exhalite unit (Pigage, 1981); but at the Bear claims, 10 kilometres south of Driftpile, coarse clastic rocks occur at the base of the Earn Group in a panel west of the Mount Waldemar fault (McClay *et al.*, 1989). The relative stratigraphic position of exhalites and siliciclastics is an important issue, because it shows temporal relationships between regional tectonic activity and exhalative pulses.

Jura-Cretaceous crustal shortening of the ancestral North America continental margin deformed the Paleozoic to Triassic strata of the Kechika Trough into a complex, mainly northeast-verging fold and thrust belt. McClay *et al.* (1989) recognize five major thrust panels, defined by rocks of strongly contrasting stratigraphic levels and, in some cases, contrasting facies as well. The thrust faults that bound the major panels may be reactivated Paleozoic growth faults. Within each major panel, the strata are folded and stacked in duplexes. The Devonian exhalite occurrences are found in the central thrust panel. A stack of upper Road River and Earn Group horses is exposed within this panel, bounded by décollements at the base of the upper Road River Group and within the Earn Group. The Driftpile deposit is truncated to the west by the major thrust fault that bounds this panel, informally termed the Mount Waldemar fault. Graptolitic black shale of the lower Road River Group forms the immediate hangingwall of the fault. More regionally, the Mount Waldemar fault underlies a duplex of Road River and Earn Group strata including very coarse Earn clastics not seen in its footwall. It has been interpreted as a reactivated basin-bounding fault; and its position as the southwestern boundary of the Driftpile deposit suggests that this early structure may have channelled fluids that gave rise to the exhalative mineralization (McClay *et al.*, 1989; R. Carne, personal communication 1994).

GEOLOGY OF THE DRIFTPILE DEPOSIT

STRATIGRAPHIC SETTING OF THE DRIFTPILE DEPOSIT

The Driftpile deposit consists of several separate stratiform sulphide-carbonate and barite bodies, each folded and bounded by thrust faults (Figures 2, 3). They are hosted by the lower Earn Group, a sequence of black to dark grey shale, mudstone, argillite, siliceous mudstone and shale, and lesser chert. Conodont collections from in and stratigraphically near mineralization are all of roughly middle Famennian age; most precise dating indicates conodont fauna of the lower rhomboidea, lower marginifera and upper marginifera zones (Irwin, 1990). Archer, Cathro geologists recognized three distinct sulphide and/or barite units, designated in ascending order UH, NH and TH (Carne and Cathro, 1982a, b). Insley (1990) recognized one sulphide-carbonate unit M1, which passes laterally into a barite facies, and four overlying barite units, M2 through M4. The monotony of the hangingwall and footwall rocks, and the intense folding and faulting, make the distinction, correlation and extension of sulphide and barite units a matter of guesswork. The presently existing conodont data have not resolved the problem.

Diamond-drill hole 93-55 (Figure 4) provides one of the more complete stratigraphic sections in the Main zone area a few hundred metres west of the barite kill zone on surface (Figure 4). The lowest unit, from 310 metres depth to the bottom of the hole at 367 metres, is a black, sooty, somewhat siliceous shale. It contains sparse, wispy beds of quartz siltstone, and a few trains of oval pyrite-carbonate nodules. The base of the sulphide-carbonate unit is sharp, but apparently conformable. Its bottom few centimetres are interbedded with black siliceous shale with discontinuous radiolarian chert beds. Radiolarian chert is a characteristic component of the footwall of the sulphide-carbonate unit throughout the deposit, and is commonly interbedded with its base.

The sulphide-carbonate unit itself is dominated by laminated pyrite. Individual laminae range from 0.1 millimetre to nearly a centimetre in thickness, and may coalesce to form almost massive pyrite. They wrap around coarse-grained grey calcite concretions, which constitute up to 30% of the rock. Upwards, the sulphide zone is increasingly diluted with thin beds of mudstone and black shale. This hangingwall contact may be transitional over tens of metres. In the transition zone, the thin, black shale interbeds contain abundant sulphide laminae, but are separated by increasingly abundant grey, graded mudstone beds. These mudstones are interpreted as distal turbidites. Higher in the hole, the intervening black shales lose their pyrite content. In terms of event stratigraphy, it seems that an initial pulse of sulphide-rich exhalite was first diluted by very fine grained clastic influx before it began to wane.

The hangingwall unit is a turbidite sequence composed of interbedded grey mudstone and black shale. The average thickness of individual mudstone beds increases stratigraphically upwards. Immediately above the sulphide-carbonate unit they may be very thin, giving the rock a well-laminated appearance. Hundreds of metres above the unit they range up to metres thick. In thin section the mudstones are well graded and contain silt-sized quartz, chert and a few muscovite clasts.

A number of textural features are characteristic of the hangingwall unit. Coarse grained calcite concretions

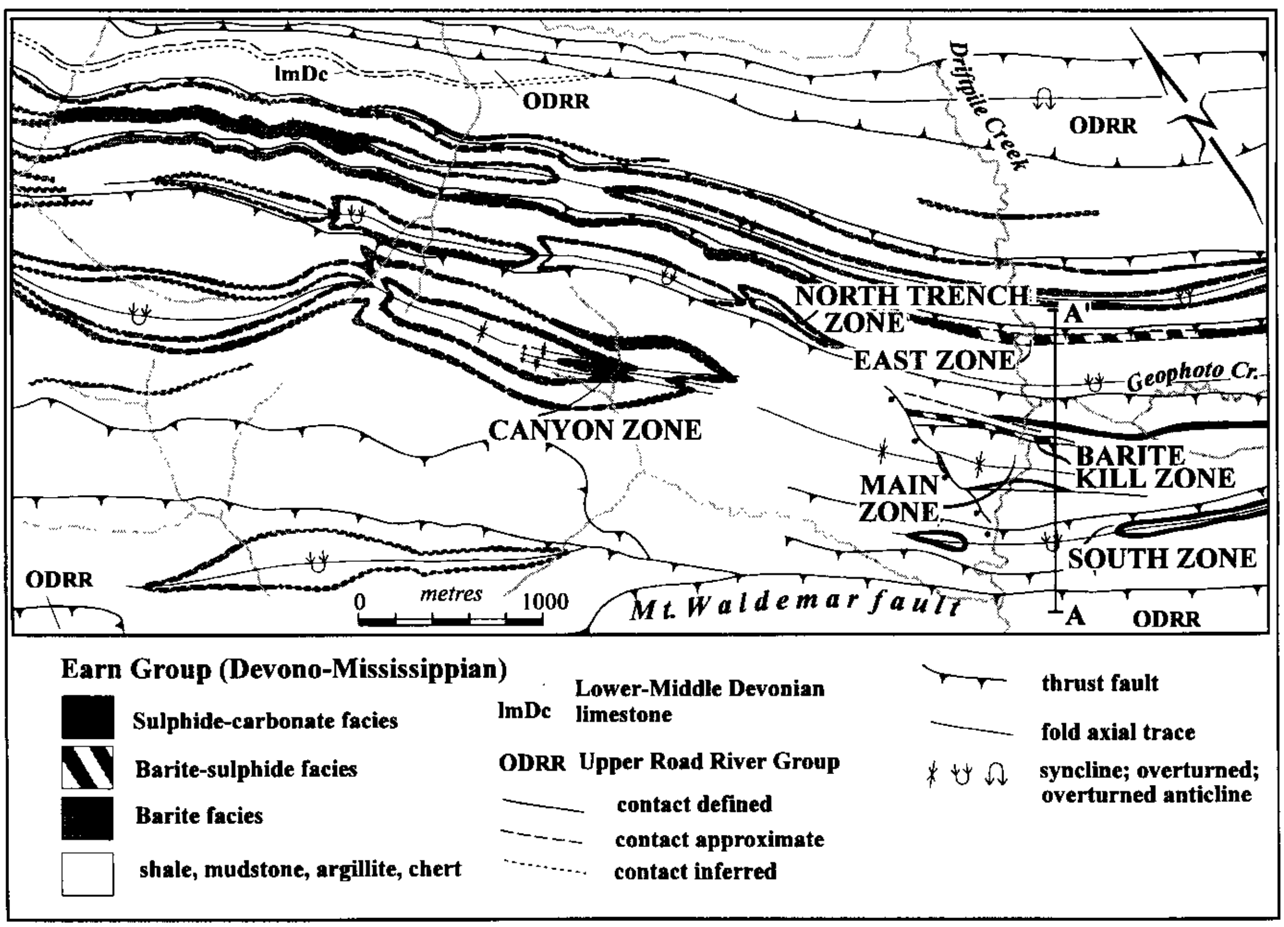

Figure 2. Detailed geology of the Driftpile Creek area. After Insley (1990), with modifications in the southeast corner from drilling and mapping by Teck Exploration in 1993 and 1994. The exploration camp is located at the prominent U-bend in Driftpile Creek, just north of the Mt. Waldemar fault. Cross-section A-A' is Figure 3.

range in abundance from 5 to 10% immediately above the sulphide-carbonate unit, to one every few metres higher in the hole. These concretions are much larger that those in the sulphide unit, from a few up to 30 centimetres across. They are consist of one, or of several overlapping spheres. In outcrop, amalgamations of concretions also form apparently stratiform bodies. Strings of pyrite-carbonate and barite nodules, each a few millimetres in diameter, parallel bedding. They tend to higher concentratations in the upper parts of the mudstone beds, although they also occur in the black shale interbeds. They increase somewhat in abundance upwards. Where calcite concretions occur with the barite or pyrite-carbonate beads, they surround them. Wispy beds of tan siltstone are rare but persistent. They are made up of many fine laminae. Their edges are irregular, concavo-convex in outline. Interestingly, these fine, distal clastic units show no correlation with the graded mudstones that make up most of this unit. They occur in equal abundance in the other units, such as the footwall black shale or even the sulphide units themselves.

Most Main zone drill holes were collared in the hangingwall unit. However, in hole 93-55, the uppermost thick grey mudstone of the hangingwall unit is overlain along a sharp depositional contact by sooty black carbonaceous, siliceous shale with abundant radiolarian chert interbeds. This unit bears a close resemblance to the footwall of the sulphide-carbonate unit. It is overlain conformably by black mudstone, finely striped with thin pyrite laminae. Teck geologists refer to this texture as the cryptic pyrite-laminated mudstone. It is interpreted as a distal equivalent of a sulphide unit. In hole 93-55 its upper contact is a faulted section many metres across. This fault is thought to have reverse motion; above the hangingwall unit of interbedded grey mudstone and black shales repeated.

THE SULPHIDE-CARBONATE AND BARITE-SULPHIDE UNITS

Detailed mapping and logging of 1993 and 1994 core allowed the construction of an east-west cross section at 13N, about 200 metres south of Driftpile Creek (Figure 3). The stratigraphic sequence in hole 93-55 is also intersected in the lower part of hole 93-58, shown on Figure 3. This sequence provides clear evidence for two separate pyrite-rich units, the lower Main zone and an upper, much weaker unit that consists only of fine pyrite laminations in mudstone. On Figure 3, the Main zone projects into the near surface between the barite kill zone and Geophoto Creek, where it is intersected by hole 78-06. The upper unit projects to surface at the barite kill zone. By this construction, massive to laminated barite is characteristic of the upper unit in addition to laminated pyrite.

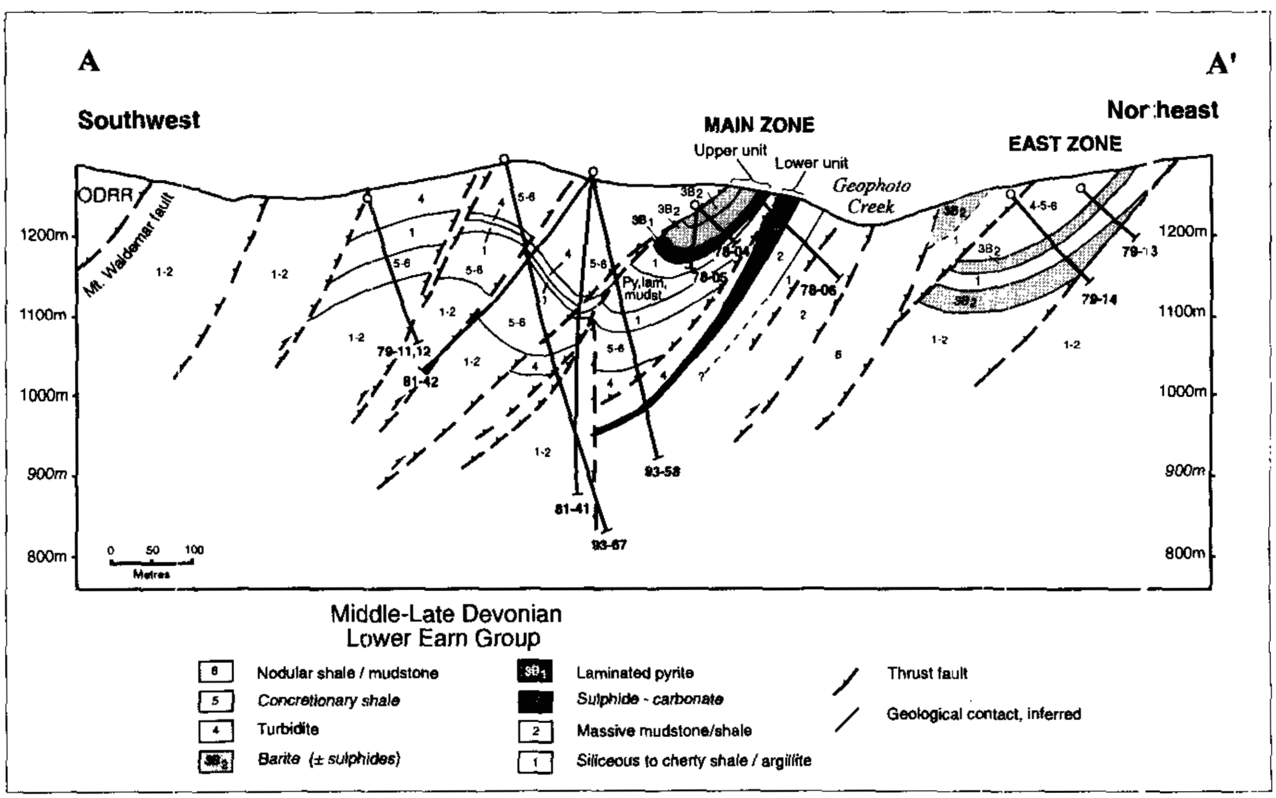

Figure 3. Detailed cross-section of the Main and East zones along grid 13+00 North, showing 1993 and earlier drill holes. Some outcrop data has been projected from the banks of Driftpile Creek (approximately line 15+00 North).

Of all the economically interesting units on the property, the lower, sulphide-carbonate unit in the Main zone is best understood at present. Drilling by Teck Exploration in 1993 delineated it for 800 metres along strike and 300 metres down dip across the upright, faulted syncline shown in Figure 3. This section is near the southern limit of the lower unit. Although it is intersected in hole 93-58, there is no equivalent in either hole 81-41 or 93-67. Teck geologists postulate an east-trending growth fault that limits the sulphide unit to the south. This inferred fault approximately parallels the axes of maximum thickness and of grade for the unit (Farmer *et al.*, 1994). The estimated true thickness of the sulphide-carbonate unit varies from 20 to 70 metres. It is variably diluted by mudstone turbidites and black shale. In some areas, massive sulphide with visible sphalerite and galena occurs near its base. Most of this unit, however, consists of laminated spheroidal and framboidal pyrite with subordinate amounts of sphalerite and galena. Sphalerite occurs as intergrowths and interstitial grains within the pyrite framboids.

As shown on Figure 3, the East zone is in a separate thrust panel from the Main zone, and therefore their relative stratigraphic positions are not known. The East zone sulphide-carbonate-barite unit is well exposed on the south bank of Driftpile Creek. It is roughly 50 metres thick, with interbedded pyrite-carbonate and black siliceous shale with radiolarian chert near its base, a central pyrite-barite(-carbonate) section in which pyrite and barite occur as sets of coarse laminations with lesser argillite interbeds, and an upper section in which blebby, bedded barite becomes more prominent

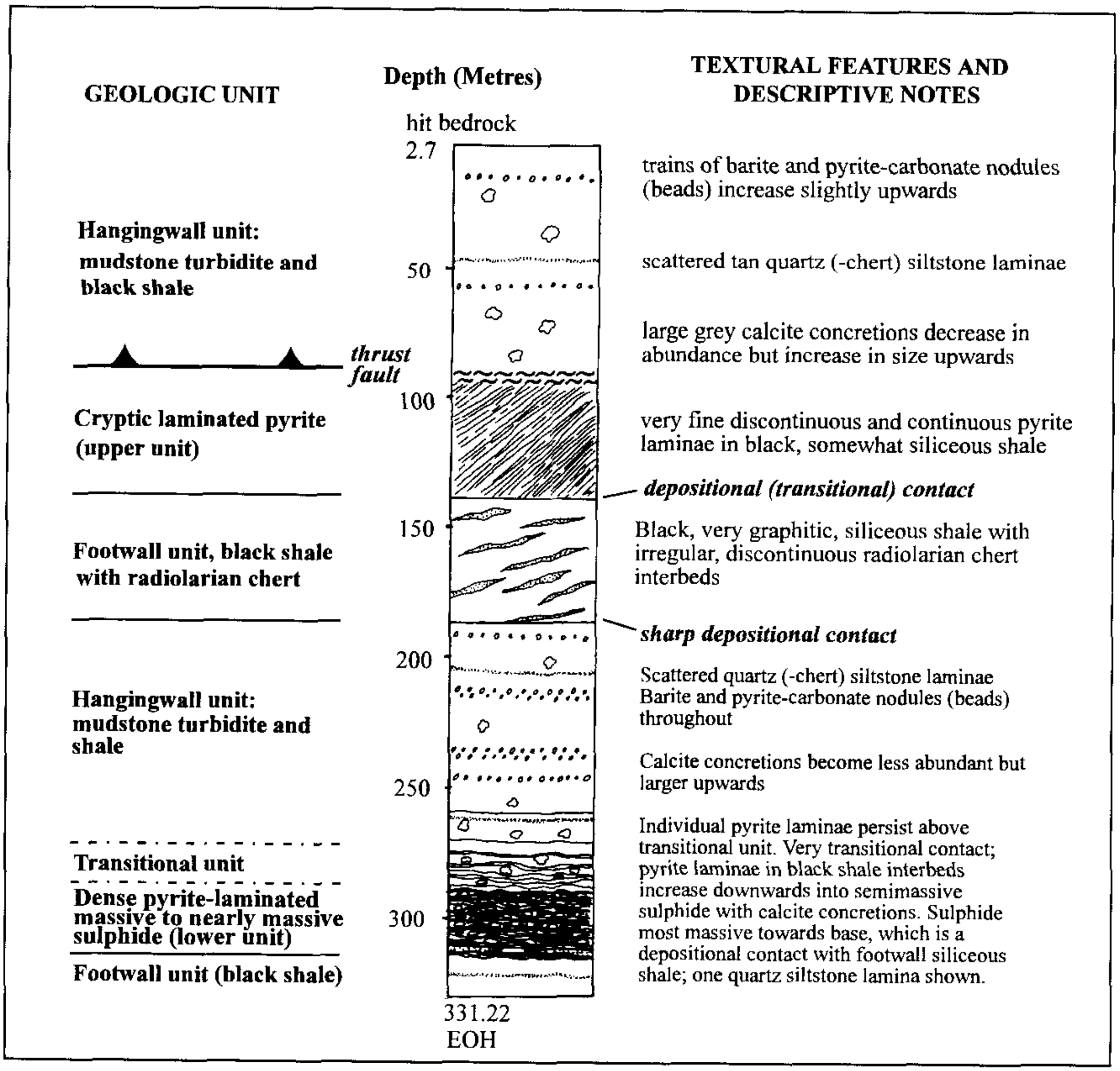

Figure 4. Stratigraphic log of Teck diamond-drill hole 93-55, from the Main zone.

upwards. Although in most respects this unit resembles the lower unit of the Main zone, the abundance of barite towards its top suggests a correlation with the barite kill (upper) zone. It is hoped that conodont data will settle this issue.

STRUCTURE

The lower Earn Group in the vicinity of the Driftpile deposit is broken into northwest-striking thrust panels parallel to the Mount Waldemar fault (Figures 2, 3). The thrust faults dip moderately southwest. Within the panels, strata are folded into open folds with moderately to steeply southwest-dipping axial planes and gently northwest-plunging (10-20°) fold axes. The cores of larger folds are occupied by broad zones of intense, disharmonic chevron folding - "M" and "W" folds. This feature renders vergence data from the sparse outcrops in the Driftpile Creek valley of equivocal value in large-scale structural interpretations. Most of the major folds are upright, except for the south zone near the Mount Waldemar fault, where a tight syncline is overturned to the northeast. In the Main zone, a southwest-dipping reverse fault offsets the western limb of a syncline (Figure 3). In core, this fault and others with demonstrable offsets are expressed as crush zones several metres wide. Such obvious correlation between offset and mechanical expression casts some doubt on the existence of cryptic, unrecognizable bedding-parallel thrust faults in core, although they cannot be ruled out.

Although several cleavages are observed in outcrop and in core, one is clearly dominant. It strikes northwesterly and is steeply dipping to vertical. It is axial planar to the major folds. Teck geologists, with caution, used the general consistency of this cleavage as an aid in establishing core orientation. This technique proved useful, except in very steeply inclined holes and those collared near major thrust faults. In the argillites, cleavage-bedding angles are typically moderate to large, in keeping with the open nature of the folds. As the sulphide-carbonate zones are approached, however, bedding is transposed into cleavage and mesoscopic folds are abundant. It is likely that the more ductile sulphides folded disharmonically and were thickened in fold hinges to a greater extent than their host argillites.

DISCUSSION

Core logging, detailed mapping and construction of an east-west cross-section along Driftpile Creek have established a preliminary stratigraphic and structural framework for understanding the stratiform mineralization The stratigraphy of the Earn Group at the Driftpile deposit shows at least two cycles of exhalative activity. Each is preceded by extremely euxinic, starved sedimentation as evidenced by the footwall siliceous shale and radiolarian chert. Each is succeeded directly by an influx of distal mud turbidites. This event stratigraphy may represent an interplay of tectonics and mineralization, in which discrete episodes of faulting triggered, first the release of metal-bearing brines and then, shortly afterwards, sediment transport down newly steepened slopes, perhaps accompanied by convective overturn of the water column. Ideally, conodont data may resolve the relative passage of time represented in the footwall, mineralized units and hangingwall units.

Diamond drilling in 1993 and 1994 has established two pyrite units in the Main zone: but correlation of these zones with others such as the East and Canyon zones depends on precise faunal ages. Only when the relative stratigraphic position of these is well established can property-scale facies variation within zones be addressed, and any reliable basin reconstruction be attempted.

ACKNOWLEDGEMENTS

We are indebted to Teck Exploration and to Fred Daley personally for generous sharing of information and access to new diamond-drill core. Rob Carne of Archer, Cathro and Associates (1981) Ltd. provided words of wisdom about the Driftpile property and the Gataga district. Graham Evans, Hugh Stewart and Jim Oliver of Teck are thanked for lively exchange of ideas. George Haselton and Carole Augereau gave valuable assistance in the field. This program is a cooperative effort by the B.C. Geological Survey Branch and the Geological Survey of Canada, funded in part by the Mineral Development Agreement 1991-1995.

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APPLICATION OF SPRING-WATER CHEMISTRY TO EXPLORATION IN THE DRIFTPILE CREEK AREA, NORTHEASTERN B.C. (94K/4, 94L/1)

By Raymond E. Lett and Wayne Jackaman

KEYWORDS: Applied geochemistry, Kechika Trough, Driftpile Creek, exploration, sedex Pb-Zn-Ag deposits, groundwater, spring-water, iron oxide precipitates.

INTRODUCTION

In the Kechika Trough of northeastern British Columbia, secondary iron oxide precipitates and ferricrete deposits are commonly associated with springs draining Paleozoic basinal-facies clastic rocks. These rocks host the Stronsay (Cirque), Bear and Driftpile Creek lead-zinc-silver-barite sedex deposits (MacIntyre, 1992). Depending on the pH and Eh of the near-surface environment secondary goethite in gossans can accumulate up to several thousand parts per million of As, Ba, Cu, Pb and Zn (Hassen and Bourezg, 1990). Carne (1983) also found that limonite spring deposits in an area immediately north of the Driftpile Creek deposit typically contain over 1% Zn and up to 463 ppm Pb, 200 ppm As and 158 ppm Mo. High (>0.5) Co/Ni ratios, detected in a number of the limonite precipitates, were explained by a possible massive sulphide source for the cobalt. Carne observed that the metals were most concentrated in the spring deposits where the discharging ground water was close to neutral. Fletcher and Doyle (1974) found high Co, Cu, Mn, Ni and Zn levels in acid stream-waters draining Paleozoic shales in Macmillan Pass, Yukon Territory. The shales are similar to those in the Kechika Trough. The absence of appreciable metal enrichment by secondary iron oxides in stream sediments was explained by the suppressed absorption of trace metals at low pH.

The enrichment of many metals by secondary iron oxides suggests a close relationship between the oxide mineral chemistry and the ground water chemistry. Previous studies have shown that ground water chemistry alone can be a valuable guide to buried metal sulphides. For example, Hoag and Webber (1976) distinguished between subsurface oxidation, inorganic surface oxidation and bacterial oxidation of sulphides as the processes responsible for liberating SO_4 into ground water. Using geochemical data for drill hole and spring-water samples collected around the Eustice, Quebec massive sulphide deposit, Hoag and Webber determined that sulphate levels below 160 ppm were principally due to non-bacterial oxidation whereas higher sulphate reflected extensive bacterial surface oxidation of sulphides. In the Jilin region, northeast China, Jiang *et al.* (1994) demonstrated a spatial relationship between SO_4-Mo enriched spring waters and copper-molybdenum skarn deposits concealed under Cenozoic plateau basalts. Sequential analysis of spring-sediment samples from the area revealed that molybdenum is predominantly present as sulphides and residual minerals, but that over 40% of the lead and zinc is bound to non-crystalline and crystalline iron oxides.

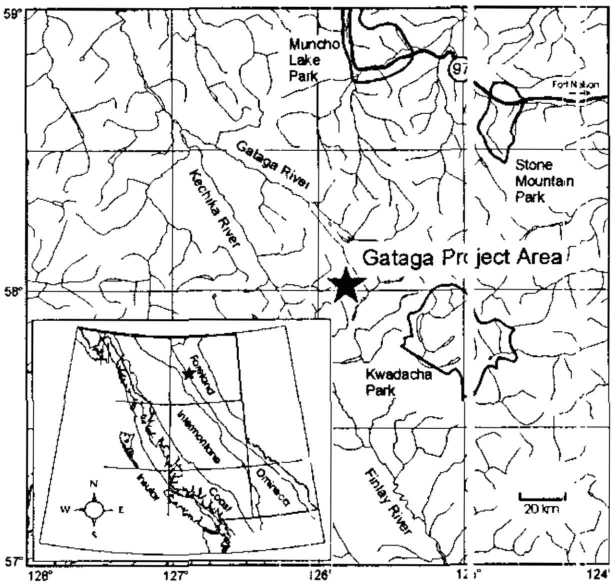

Figure 1. Location map of the Gataga Project.

Orientation surveys were carried out in the Driftpile Creek area (Figure 1) during the 1994 field season to investigate the relationship between spring-water and spring-sediment chemistry. The surveys were also designed to study other geochemical exploration problems, typical of the Kechika Trough, such as the effect of high zinc and silver backgrounds in soils and stream sediments. Preliminary geochemical data for the spring-water samples are discussed in this paper.

DESCRIPTION OF STUDY AREAS

LOCATION AND TOPOGRAPHY

Six sites neighboring the Driftpile Creek area were selected for detailed geochemical sampling and study (Figure 2). The region, situated east of the Rocky Mountain Trench in the Muskwa Range of the northern Rocky Mountains is characterized by northwest-trending

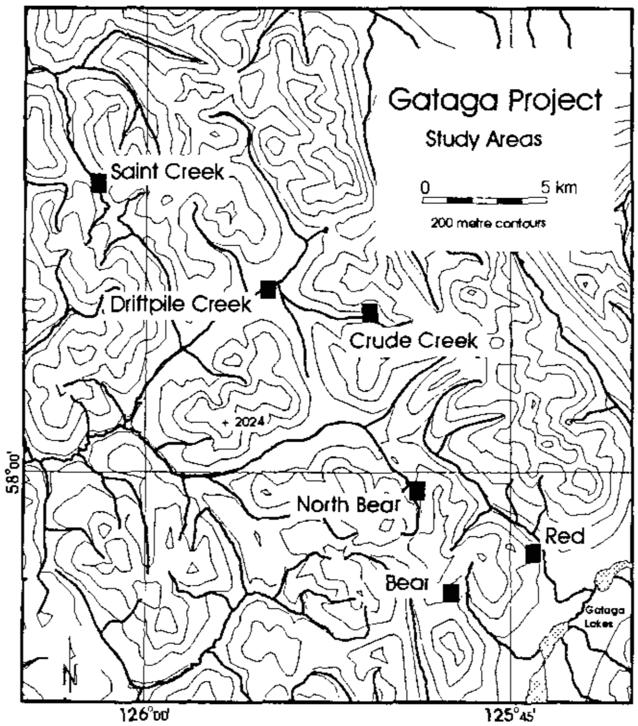

Figure 2. Location map of study areas.

mountain ridges which are 1000 metres to over 2000 metres in elevation. Evidence of glacial erosion and alpine glaciation can be found throughout the area. The rugged topography reflects rapid physical erosion of the Paleozoic sedimentary rocks. Streams flow in a predominantly trellised drainage pattern. Steep sided, narrow northwest-trending valleys are intersected by larger, subsequent, east to west-trending valleys. The tree line reaches up to 1500 metres with mixed woodland and grassland in the valley bottoms and alpine fir, black spruce and alder extending up the valley sides. Surface flora above 1500 metres consists of scattered alpine fir, willow and heather. Irregular patches characterized by an absence of vegetation and surface soil horizons, plus an abundance of ferruginous material are common throughout the area. Many of these vegetation 'kill zones' are associated with springs and seepages; others reflect high levels of elements such as Pb, Ba, Zn and Cd in the near-surface environment.

GEOLOGICAL SETTING

Geology, mineralization and structure of the Driftpile Creek area have been previously described by Carne (1983), McClay and Insley (1985) and MacIntyre, (1992) and currently, geological mapping of the region is being conducted by Ferri *et al.* (1995, this volume) as well as various mining companies. Principal geological elements of the Driftpile Creek area can be summarized as follows:

- A northwest-trending belt of tightly folded, predominately black, fine-grained siliciclastic Paleozoic rocks typical of euxinic basinal sediments filling the Kechika Trough.
- A stratigraphic sequence of Ordovician carbonaceous black argillites, cherts and thin limestone beds succeeded by orange-weathering Silurian dolomitic micaceous siltstone. The siltstone is overlain by Lower Devonian recessive silver-grey weathering black argillite, chert and, locally, crinoidal limestone. Ordovician to Lower Devonian strata form the Road River Group. Above this group is a conformable sequence of laminated siltstone succeeded by recessive, silver-weathering black argillites, cherty argillite, thin-bedded chert and, locally, chert-pebble conglomerate. These Middle to Upper Devonian strata form the lower Earn Group, locally identified as the Gunsteel formation in the Gataga district. The Gunsteel formation is host for several stratiform barite-pyrite-galena-sphalerite deposits such as the Bear and Driftpile Creek.
- Massive to laminated barite, laminated fine-grained pyrite with varying amounts of sphalerite and galena are interbedded with chert and black cherty argillite. Sedimentation and sulphide deposition demonstrate a rhythmic pattern characterized by pyrite-laminated siliceous argillite at the base of the sequence succeeded by laminated pyrite-sphalerite-galena; massive barite and carbonate nodules and blebby barite at the top.
- Geological structure is dominated by northwest-striking, steeply dipping chevron folds and west-dipping thrusts. The Mount Waldemar thrust is a major structure which separates older strata in the west from the lower Earn Group rocks.

SURFICIAL DEPOSITS

Glaciogenic landforms typical of the region around Driftpile Creek include long, U-shaped valleys, hanging tributaries and proglacial lake strandlines. A prominent terrace at the 1350-metre elevation along both sides of Driftpile Creek marks a transition from the steeper valley side to the more subdued upland topography. The terrace is marked by sandy textured deposits containing locally derived pebbles. Sorted, gravel-textured deposits also occur at the 1600-metre elevation on a steep, south-facing hill slope close to the Bear occurrence and these may represent sand deposits of a proglacial lake. Immediately south of Driftpile Creek, at a similar elevation to the 1350-metre strand line along a flat valley floor, is an area of irregular mounds and short ridges which may represent ice-stagnation deposits. Valley floor and lower hill slopes are mantled by an unknown thickness of drift and colluvium. Above tree line, ridge crests and steeper hill slopes are covered with rock talus and felsenmeer. A typical soil caterna consists of regosols, alpine dystric brunisols above tree line, orthic dystric brunisols on moderate hill slopes, gleysols and organic soils along the margins of streams.

SPRING-RELATED DEPOSITS

A total of 86 samples were collected from ground water springs and seepages. Most of the sample sites are surrounded by secondary mineral deposits which have a varying morphology. The most common deposits are:

- Small (10-20 cm high) mounds surrounding the actual spring discharge. The 'cold-spring' mounds consist of laminated red to dark brown iron oxide terracettes.
- Surface crusts of laminated iron oxide which are probably derived from the physical erosion of the cold spring deposits. The surface crusts also consist of variegated, friable ferruginous sinter which can form slabs scattered over the surface of vegetation kill zones. In the Red Gossan area, ferruginous sinter is associated with kill zones of 1 square kilometre in area, with no related ground water discharge.
- Ferricrete deposits consisting of rounded Paleozoic pebbles and cobbles cemented with sandy textured ferruginous material. These deposits may be several metres thick and may extend for several hundred metres along the side of creeks. No active springs are associated with them.
- White, laminated precipitate coating clastic sediment and vegetation debris in stream channels. This type of precipitate is less common than the ferruginous deposits and is most likely to consist of aluminum hydroxide. The precipitate is not generally found surrounding springs, but is most evident in the channel several metres downstream from the discharge. White precipitates occur in streams draining the Bear occurrence and the streams draining into the north Bear valley.
- White, laminated travertine forming the bank of a small pool surrounding a spring in the upper reaches of Crude Creek.

SAMPLING AND FIELD METHODS

At each of the study sites samples of the following media were collected:

- Water samples from seepages, spring and surface streams. At the sample site, water pH and temperature were measured with a Corning Checkmate meter, dissolved solids (conductivity) was measured with a Hanna Model 3ATC meter and dissolved oxygen was measured with a Hanna 8543 oxymeter. Sufficient water was collected to enable preparation of a filtered (0.45 μm), acidified (ultrapure nitric acid to pH 2) sample in the field. The sulphate content and alkalinity were also measured in the field with Hach analytical kits.
- Spring precipitate and ferruginous sinter samples.
- Soil and drift samples from areas surrounding selected spring deposits. Two soil-drift traverses were also sampled across the strike of the Bear sulphide horizon at the 1600 and 1650-metre elevations.
- Rock and ferricrete samples.
- Stream sediment and moss-mat samples.

LABORATORY ANALYSIS

Filtered, acidified water samples were analysed for a suite of 66 elements (Li, Be, Na, Mg, Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ru, Pd, Ag, Cd, In, Sn, Sb, Te, I, Cs, Ba, La, Ce, Pt, Nd, Sm, Eu, Gd, Tb, Dy, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Pt, Au, Hg, Tl, Pb, Bi, Th and U) by inductively coupled plasma mass spectroscopy and inductively coupled plasma emission spectroscopy at Activation Laboratories Ltd., Ancaster, Ontario. Results for several of the elements were excluded from the interpretation because of known inter-element interference (Ti), probable significant loss of element during the interval between sampling and analysis (Hg) and absence of any detectable element concentration in the samples (Au, Pt). Quality of the water geochemical data and possible sample contamination were monitored by analysis of filtered, acidified distilled water blanks, blind sample replicates and standards prepared by spiking bulk-filtered water from Crude and Driftpile Creeks with Cu, As, Co, Ni, Zn an Cd. Sulphate and fluoride in water were measured by ion chromatography and specific ion electrode by Chemex Laboratories, Vancouver.

Spring deposit, soil and drift samples were air dried and sieved to -63-micron size and were analysed by Acme Analytical (Vancouver) for 29 elements (Mo, Cu, Pb, Zn, Ag, Ni, Co, Mn, Fe, As, U, Th, Sr, Cd, Sb, Bi, V, Ca, P, La, Cr, Mg, Ba, Ti, B, Al, Na, K and W) by aqua regia digestion and inductively coupled plasma emission spectroscopy. Mercury was analysed by cold vapour atomic absorption spectrometry. Thirty-five additional elements (Au, Ag, As, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Hg, Ir, Mo, Na, Ni, Rb, Sb, Sc, Se, Sn, Sr, Ta, Th, U, W, Zn, La, Ce, Nd, Sm, Eu, Tb, Yb and Lu) were determined by thermal neutron activation analysis.

Ferricrete samples were broken up and the sandy matrix sieved to -180 microns. Rock samples were crushed and ground in a tungsten carbide mill to -75 microns. The prepared samples were analysed for the 29-element suite by hydrofluoric-nitric-perchloric-hydrochloric acid digestion and inductively coupled plasma emission spectroscopy. Mercury was analysed by cold vapour atomic absorption spectrometry and the 35-element suite by thermal neutron activation analysis.

RESULTS AND DISCUSSION

Mean concentrations for selected elements in spring-water samples from the study areas are shown in Table 1. A number of the elements originally determined were excluded because most values were below instrumental detection limits. The mean values reveal differences in spring-water chemistry between the areas. Saint and Red spring waters are neutral to weakly alkaline and have

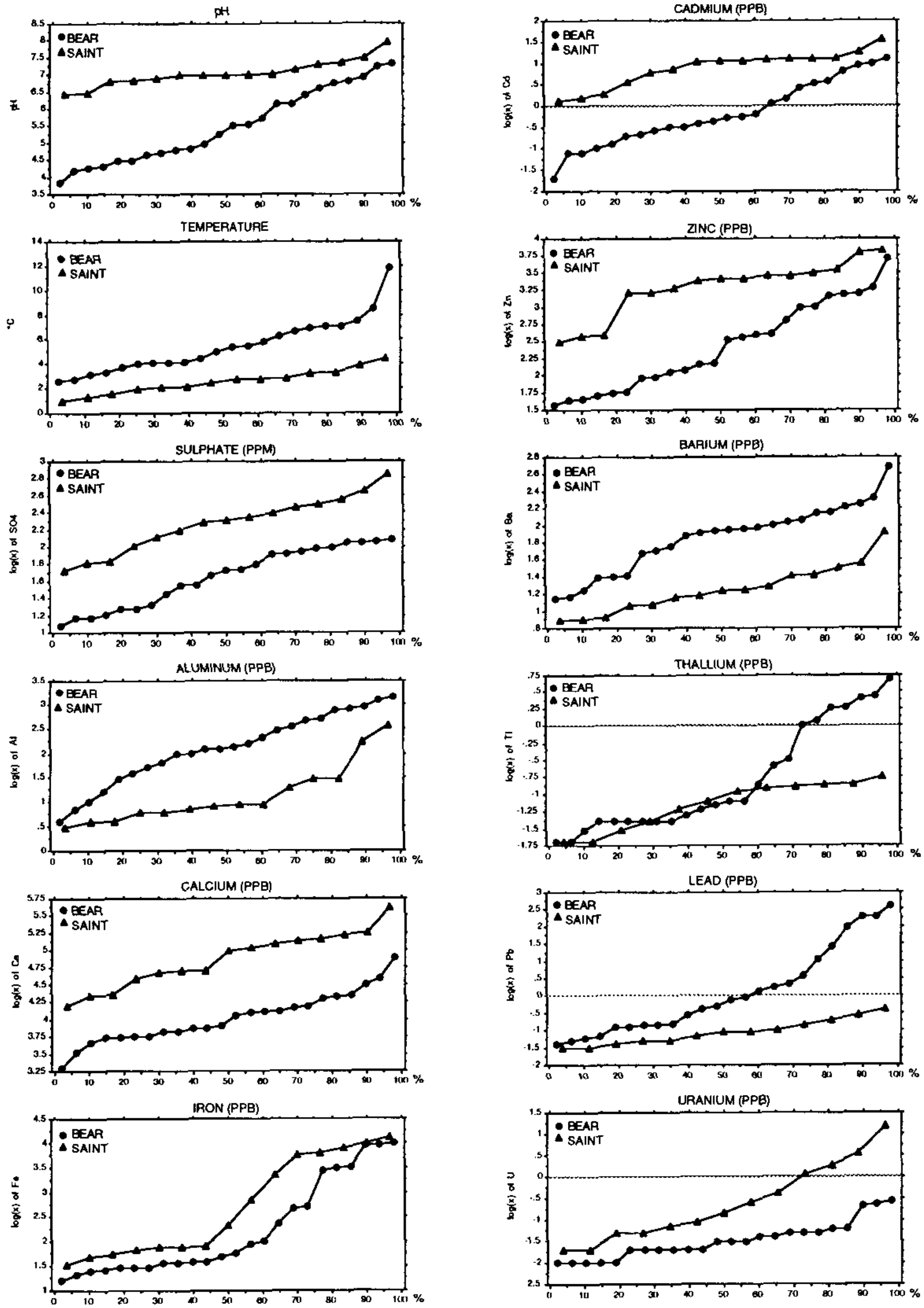

Figure 3. Comparison of Bear and Saint spring-water percentiles for pH, temperature, sulphate, aluminum, calcium, iron, cadmium, zinc, barium, thallium, lead and uranium.

TABLE 1
MEAN CONCENTRATION OF SELECTED ELEMENTS IN SPRING WATER

	Unit	Bear	N.Bear	Drift	Saint	Red	Crude
N		23	21	12	15	9	5
F	ppb	242	269	250	482	336	316
SO_4	ppm	58	174	74	236	264	321
pH		5.5	6.4	7.5	7.0	7.5	7.3
T	°C	5.4	4.4	6.7	2.5	4.9	3.7
Con	uS	78	225	286	404	436	498
O_2	ppm	7.00	5.50	9.40	4.67	4.50	5.04
Alk	ppm	1.40	2.10	4.36	5.50	10.20	7.60
Li	ppb	5.60	24.00	36.00	5.79	8.60	6.56
Na	ppb	133	982	9320	1540	799	1971
Mg	ppb	2138	11016	6072	15676	15688	21997
Al	ppb	321.0	719.0	159.0	44.0	8.7	18.0
Si	ppb	3395	3465	4037	3517	4189	5200
K	ppb	676	487	594	1067	2379	1133
Ca	ppb	14991	48367	41356	107577	149606	122726
Mn	ppb	142	848	530	327	174	285
Fe	ppb	1651	3578	449	3122	2065	6567
Co	ppb	4.25	30.00	2.84	13.94	11.98	16.30
Ni	ppb	38	155	48	382	284	225
Cu	ppb	2.04	5.50	1.70	1.08	0.80	0.88
Zn	ppb	698	560	3470	2610	2057	1262
Ga	ppb	0.06	0.15	0.23	0.12	0.07	0.11
Ge	ppb	0.04	0.07	0.14	0.09	0.08	0.09
As	ppb	0.13	0.56	0.14	0.99	4.50	1.24
Rb	ppb	1.69	0.87	1.61	1.90	4.70	1.89
Sr	ppb	75	345	270	513	1052	641
Y	ppb	0.67	4.55	0.45	0.76	0.60	0.93
Zr	ppb	0.94	1.50	1.41	1.53	1.54	1.55
Mo	ppb	0.16	0.29	4.94	1.74	2.84	3.52
Cd	ppb	2.23	1.57	7.54	10.67	20.09	5.07
Cs	ppb	0.21	0.12	1.00	0.24	0.62	0.12
Ba	ppb	102	32	141	23	49	22
Tl	ppb	0.73	0.06	0.79	0.07	0.38	0.09
Pb	ppb	38.52	0.74	0.95	0.12	0.09	0.51
U	ppb	0.06	0.17	1.23	1.71	5.87	0.42

greatest SO_4, F, Mg, Ca, Ni, Sr, Cd, and U contents. Bear and North Bear waters are weakly acid and have higher dissolved oxygen, Al, Ba and Pb. The neutral to weakly alkaline Drift spring waters are enhanced in Mo, Zn and Ba, but have lower SO_4 than the other areas. Element associations were identified by correlation coefficients calculated from untransformed data for all of the areas combined. Among the strongest, sympathetic associations (correlation coefficient >+0.9) are Pb with Zn and Cs with Tl. The correlations may reflect a common association of the metals in more mineralized water samples. A strong negative correlation between pH-Pb-Mn can be explained by the greater solubility of Pb and Mn minerals in more acid waters.

Differences between the Bear and Saint spring-water chemistry are highlighted by a comparison of percentile plots for spring-water pH, temperature, SO_4, Al, Ca, Fe, Cd, Zn, Ba, Tl, Pb and U (Figure 3). The shape of the Ca, Ba and SO_4 plots for the two areas suggests that values are drawn from one population and have a similar source. The higher Ca and SO_4 means for the Saint area may reflect a longer residence time for the ground water in geological structures, enabling a greater contribution of the more soluble elements from bedrock. The Zn, Pb, Tl, pH and U distributions have different moment statistics and, in the case of Pb and Zn for the Bear waters, are bimodel. The higher range of values are clearly related to a second source for these metals which is most probably a weathering sulphide body. The Fe distribution is bimodel and may reflect two distinct sources for the dissolved iron in both areas. Similar Cd and Zn percentile plots can be explained by common mineral association of these metals such as cadmium-rich sphalerite.

Oxidation of pyrite-bearing shales, generation of sulphuric acid and release of metals from the shale into groundwater is a probable source for the higher Fe, Co, Ni, Zn, Cd and U in Saint spring water. Very acid (pH<4) streams draining sulphide-bearing volcanics on northern Vancouver Island have more than 200 ppm SO_4, 23.3 ppm Ca, 0.55 ppm Fe and 15.49 ppm Al (Koyanagi and Panteleyev, 1992). The Saint spring waters have similar Ca, Fe and SO_4 levels, but have very low Al content and are also neutral to weakly alkaline. In situ neutralization of the acid water by carbonate rocks, interbedded with the shale, may explain the neutral pH of surface waters. Subsurface precipitation of $Al(OH)_3$ in the pH range 6 to 7 may also be the reason for the low Al content of the Saint spring water.

In contrast to the Saint area, the more acid, Bear spring waters have much higher Al, Ba, Pb and Tl, but lower Zn, Cd and SO_4. The Bear spring-water chemistry may reflect shorter residence time for the ground water in geological structures and solution of Pb-Zn-Fe sulphides

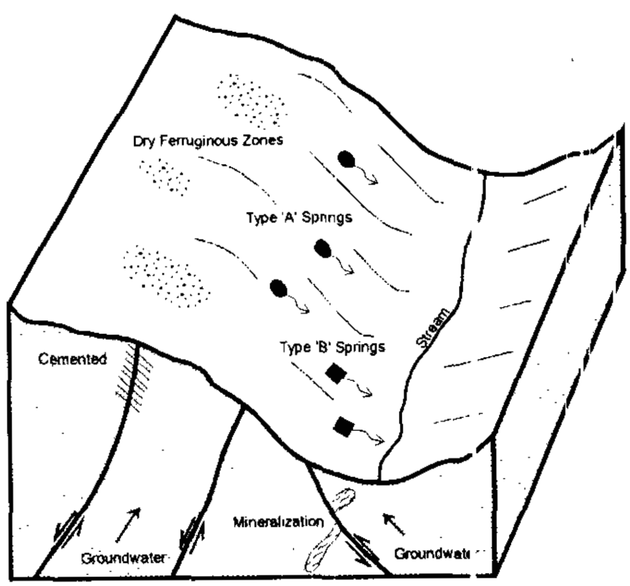

Figure 4. Generalized model for dry ferruginous zones, type 'A' and type 'B' springs.

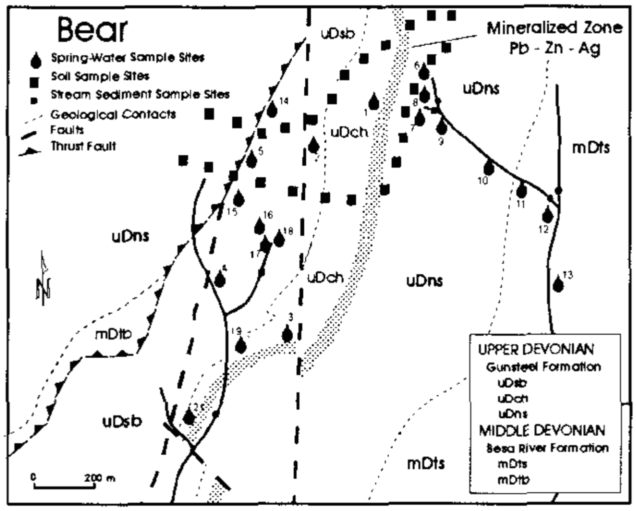

Figure 5. Bear water, soil and stream sediment sample sites.

in contact with the water. The low pH and the higher Al and Ba are characteristic of massive pyrite oxidation, release of sulphuric acid into the groundwater and partial dissolution of baritic shale. Galena and sphalerite will also dissolve in acid groundwater producing high dissolved Pb and Zn. The average Ba content of the Bear spring waters is close to the maximum concentration allowed by the barite solubility product, water temperature and SO_4 content (Steele and Wagner, 1983). As Ba mobility is less susceptible than Pb and Zn to pH changes, higher dissolved Ba levels may persist in the groundwater for a greater distance from the barite-sulphide source. Elevated Tl levels up to 100 ppm have been found in Cu-Pb-Zn massive sulphide ore and in minerals from Pb-Zn veins (Murao and Itoh, 1992). Hence, the association of dissolved Tl with the dissolved Pb can be an especially useful guide for galena mineralization because the thallium ion is stable over a wider pH range than lead (Fergusson 1990).

In summary, there are two distinctive types of spring-water chemistry. Type A waters are neutral to weakly alkaline, low in dissolved O_2, cool (2-4 °C) and have high SO_4, Zn, F, Ca, Mg, Ni, Co Sr, Cd, and U. Copious secondary iron precipitates surround most springs. Type B waters are acid to neutral, generally have higher dissolved O_2, are warmer (2-8 °C) and commonly have high Ba, Al, Pb, Tl. Secondary iron oxide precipitates are less abundant. Acid springs may have a copious white precipitate.

The different geological structures assumed to channel ground water and to be responsible for the two types of spring water are shown in a conceptual model (Figure 4). Also illustrated in Figure 4 is the spatial relationship between dry, ferruginous surface kill zones and active type A springs. This relationship is most evident in the Red area and can be explained by precipitation of secondary iron oxides around springs, later subsurface cementation of the ground water conduit with calcite or gypsum and subsequent displacement of the vertical ground water flow to other structures, producing a second spring line.

The very high Pb levels and associated Tl, typical of acid spring-waters discharging close to mineralization, are highlighted by the results in Table 2 and Figure 5. High Pb levels with elevated Ag, Co, Ni, Zn and As occur in the secondary iron oxide precipitates and moss-mat sediments at Bear sites 1, 6 and 9. The large enrichment of metals in precipitates associated with almost neutral spring-waters can be explained by the powerful sorption characteristics of iron oxides in the pH range 4 to 8. Analysis is in progress to determine if metals bound to specific minerals in the precipitates from the Bear and other areas can be used to discriminate between different source rocks.

CONCLUSIONS

Preliminary results of spring-water sample analysis reveal:

- Two distinct types of spring water occur. Type A waters, typical of the Saint and Red areas, are neutral to weakly alkaline and have elevated SO_4, Zn, F, Ca, Mg, Ca, Ni, Co Sr, Cd, and U. Type B waters associated with known Pb-Zn-Ag mineralization at the Bear deposit are more acid and have high Ba, Al, Pb, Tl.

TABLE 2.
WATER CHEMISTRY OF SELECTED BEAR SPRING-WATER SITES

Site (Sample ID)	pH	SO_4 ppm	O_2 ppm	Al ppb	Ca ppb	Fe ppb	Co ppb	Ni ppb	Zn ppb	Cd ppb	Ba ppb	As ppb	Tl ppb	Pb ppb
Bear 1 (943002)	7.2	80	1.3	4	38633	2700	15.0	75	1452	1.1	25	0.2	0.14	0.8
Bear 6 (943009)	6.1	88	7.4	7	31584	9245	12.7	114	5208	12.5	15	0.1	1.18	0.1
Bear 7 (943014)	6.9	112	7.0	16	21749	29	0.5	36	994	2.6	91	0.1	1.82	192.3
Bear 8 (943015)	4.3	114	7.4	97	15119	36	1.9	42	1551	8.5	77	0.1	2.54	392.1
Bear 9 (943016)	6.8	119	0.7	10	78235	3328	5.1	40	1509	0.1	14	0.2	2.73	1.4
Bear 10 (943017)	4.7	46	7.4	125	11350	58	1.2	23	1028	6.2	93	0.1	1.82	196.1
Bear 11 (943018)	4.7	36	7.2	126	6664	29	1.0	16	641	3.7	87	0.1	1.02	93.8

- The differences in water chemistry reflect the residence time for groundwater in bedrock and geological structures, oxidation of pyrite, weathering of shale, solution of lead-zinc sulphides, and in situ neutralization of acid groundwater.

FUTURE WORK

Further interpretive work involving results from the analysis of spring-waters, secondary iron oxides, soils and stream sediments will include :

- Distinguishing between barren, pyritic shale and lead-zinc sulphides as the potential source for the secondary iron oxide precipitates.
- Distinguishing between high geochemical background in stream sediments and soils due to the influence of metal-rich black shale and the contribution of anomalous metal from oxidizing base metal sulphides.

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NOTES

GEOLOGY AND MINERALIZATION OF THE GATAGA RIVER AREA, NORTHERN ROCKY MOUNTAINS. (94L/7, 8, 9 AND 10)

Filippo Ferri, JoAnne Nelson and Chris Rees

(Contribution to the Canada - British Columbia Mineral Development Agreement 1991-1995)

KEYWORDS: Northern Rocky Mountains, Gataga River, Kechika Trough, Hyland Group, Gog Group, Middle Cambrian, Kechika Group, Road River Group, Earn Group, sedimentary exhalatives, barite, lead, zinc.

INTRODUCTION

Cambrian to Mississippian rocks, deposited in a northwest trending depression called the Kechika Trough or Basin, are exposed along the western margin of the northern Rocky Mountains. The basin is host to numerous sedimentary exhalative barite-lead-zinc deposits of various ages, although the most numerous and economically important are Late Devonian, such as the Cirque (Stronsay) and Driftpile deposits.

The British Columbia Ministry of Energy, Mines and Petroleum Resources began a multi-disciplinary examination of this basin during the summer of 1994. This is a cooperative project with the Geological Survey of Canada and is funded, in part, by the second Mineral Development Agreement between the governments of British Columbia and Canada. This program included a detailed study of the Driftpile deposits (Nelson *et al.*, 1995, this volume; Paradis *et al.*, in press), a characterization of the geochemical signature of these occurrences (Lett and Jackaman, 1995, this volume) and a regional mapping project along the central part of the basin, north of Gataga River. This paper describes preliminary results of the regional mapping component.

The Gataga mapping project covers part of the western Muskwa Ranges of the northern Rocky Mountains, east and southeast of the confluence of the Gataga and Kechika rivers. The area is remote and primary access is by air (Figure 1). The centre of the map area is approximately 200 kilometres from both Dease Lake to the west and Watson Lake to the northwest. The larger communities of Mackenzie and Fort St. John are 400 kilometres to the southeast. The map area is bounded to the southwest by the Northern Rocky Mountain Trench, to the northeast by the Netson Creek - Netson Lake valley, by Forsberg Ridge to the southeast and by a northeast - trending line approximately 6 kilometres southwest of Gataga Mountain.

The southern third of the map area, between Gataga River and Forsberg Ridge, is characterized by subdued, glaciated terrain and the amount of exposure is less than 5%. Exposure increases dramatically northwest of the Gataga River with nearly 100% outcrop along ridges underlain by Cambrian carbonate rocks.

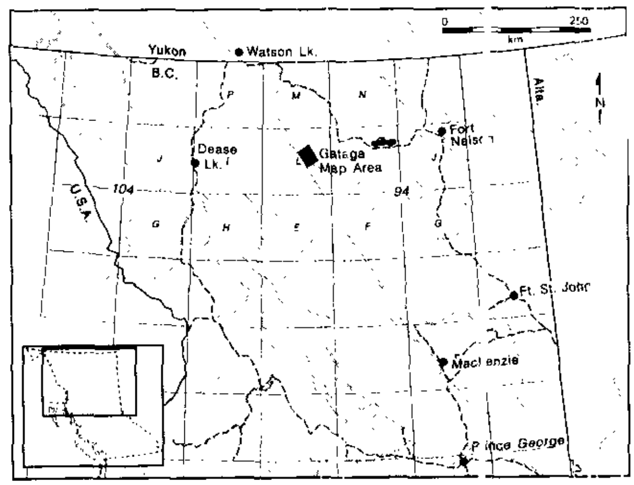

Figure 1. Northeastern British Columbia showing the location of the project area together with main physiographic and cultural features.

REGIONAL SETTING

The study area lies along the western margin of the Rocky Mountain subprovince of the Canadian Cordilleran Foreland Belt. The western boundary of the area follows the Northern Rocky Mountain Trench fault zone which separates displaced continental rocks of the Omineca Belt from ancestral North American strata of the Rocky Mountains (Figure 2). The Omineca Belt is represented by rocks of the Cassiar Terrane which bear similarities to those of the Northern Rocky Mountains although direct correlation is precluded by 450 to 750 kilometres of right-lateral displacement along the Northern Rocky Mountain Trench (Tempelman-Kluit, 1977; Gabrielse, 1985).

The Rocky Mountain subprovince is characterized by northeasterly folded and thrusted rocks of mainly Paleozoic and older strata (McMechan and Thompson, 1991). Strata within the map area range in age from Late Proterozoic to early Mississippian and record several depositional settings along the ancestral North American margin. The main depositional element in the map area is

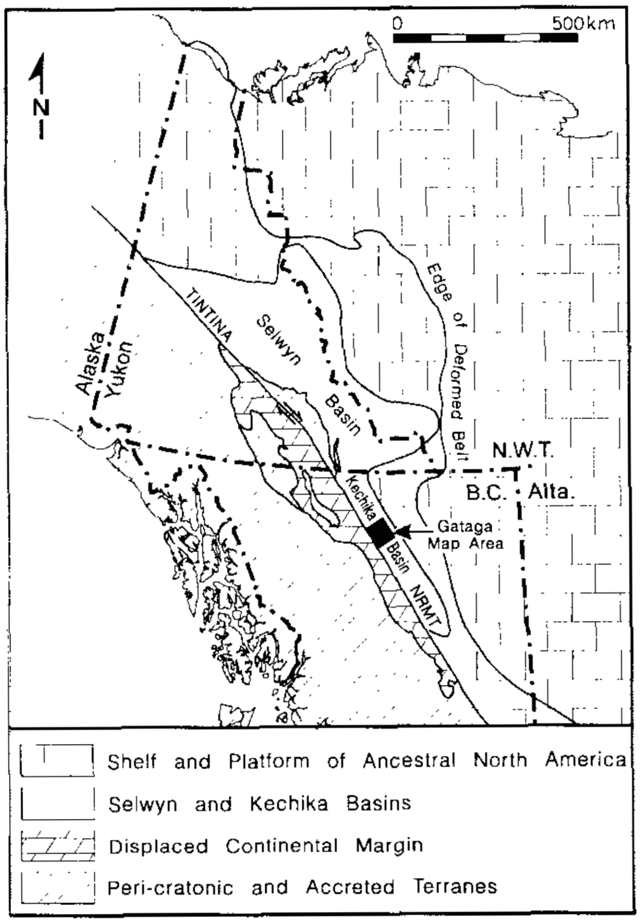

Figure 2. Simplified map of the northern part of the Canadian Cordillera showing the shelf-off-shelf boundary during Ordovician to Silurian time (modified from Cecile and Norford, 1991). NRMT - Northern Rocky Mountain Trench.

the northwest-trending, Paleozoic Kechika Basin which connects to the northwest with the Selwyn Basin in Yukon Territory (Figure 2). These basins are filled with finer grained, deeper water equivalents of coeval shelf and platform strata to the east. The geometry of the Kechika Basin is interpreted as either a westward-deepening basin (H. Gabrielse, personal communication, 1994) or as a narrow trough or embayment surrounded on three sides by shallower water facies (MacIntyre, 1992, McClay *et al.*, 1988). Rocks of the Kechika Basin were deposited on rift-related clastics of Late Proterozoic age which record the establishment of a passive continental margin by the end of the Precambrian. The basin was best developed during Ordovician to Devonian time when thick carbonate shelf sequences shaled out abruptly westward into off-shelf, fine-grained siliciclastic and carbonate rocks of the Road River Group (Cecile and Norford, 1979; Thompson, 1989). A much broader westward carbonate-to-shale transition is also present in Cambro-Ordovician strata of the Kechika Group (Cecile and Norford, 1979). Middle to Upper Cambrian carbonates also show a westward shale-out, although this transition is complicated by linear, north-trending reefal buildups in the western part of the basin (Fritz, 1979, 1980a, 1991; Gabrielse and Yorath, 1991). Similar carbonate buildups are found at the Middle Devonian level within the centre of the basin (Akie reefs; MacIntyre, 1992).

Fine-grained siliciclastics and minor limestone of the Upper Devonian Earn Group, and its eastern equivalent the Besa River Formation, represent a fundamental change in deposition across the western miogeocline. These rocks record the abrupt end of shallow-water carbonate deposition within the eastern miogeocline and the subsequent laying down of deeper water, fine-grained clastics. This widespread marine transgression has been attributed to rifting along the westernmost part of the miogeocline (Gordey *et al.*, 1987) or to contractional deformation (*i e.*, Antler orogeny; Smith *et al.*, 1993) with both models being supported by thick tongues of westerly derived coarse sediments in western Earn exposures.

Sedimentary exhalative barite±sulphide deposits of Middle Ordovician, Early Silurian and Late Devonian ages are present within the Kechika Basin (MacIntyre, 1992). The last are the most economically significant and are hosted by shales and siliceous shales of the lower Earn Group; the most important deposits are the Cirque (Stronsay), Driftpile Creek, Bear and Mount Alcock deposits. All are believed to have formed within sub-basins developed in response to either a Devono-Mississippian rifting event (Gordey *et al.,* 1987) or as a result of flexural extension related to westward foreland loading and deformation (Smith *et al.,* 1993).

PREVIOUS WORK

Reconnaissance - scale mapping along the northern part of Kechika Basin was first carried out by Gabrielse (1962a, b, and 1981), Gabrielse *et al.*, (1977) and Taylor (1979). Gabrielse examined the Kechika (94L), Rabbit River (94M) and Ware (94F, west half) areas, while Taylor mapped the Ware (94F, east half) and the Trutch (94G) map sheets. The southern parts of the basin have been mapped by Gabrielse (1975) in the Mesilinka River area (west half) and by Thompson (1989) in the Halfway River (94B) area. Taylor and Stott (1973) describe the shelf sequence immediately east of the study area.

More detailed regional mapping was conducted by MacIntyre (1980a, 1981a, b, 1982a) in the Akie River area and by McClay and Insley (1986) and McClay *et al.* (1987, 1988) between Driftpile Creek and Gataga River.

Early studies describing Ordovician and Silurian stratigraphy along the western part of the Kechika Basin include Jackson *et al.* (1965) and Norford *et al.* (1966). Taylor *et al.* (1979) elucidated the stratigraphy in the Ware (east half) map area. Fritz (1979, 1980a, 1991) details stratigraphic sections and relationships within Cambrian rocks of the Kechika Basin and the adjacent shelf sequence. Cecile and Norford (1979) describe the stratigraphic relationships along the transition between shelf and off-shelf facies in Ordovician and Silurian strata. Norford (1979) discusses Early Devonian graptolites within uppermost Road River strata between the Kwadacha and Akie rivers.

Published accounts of the economic potential of this area began in the early 1980s after nearly a decade of exploration within the Selwyn and Kechika basins. Early descriptions of the resource potential and exploration models for the Kechika Basin are provided by Carne and Cathro (1982) and MacIntyre (1982a, 1983). MacIntyre (1980b), Jefferson *et al.* (1983) and Pigage (1986) describe the geologic setting of the Cirque deposit. MacIntyre and Diakow (1982) give a brief account of the Kwadacha mineral occurrence and Irwin and Orchard (1989) refine the timing of mineralization in the Kechika and Selwyn basins.

STRATIGRAPHY

Rocks in the map area are preserved in a series of steep, southwest-dipping, northeasterly-verging thrust panels. Strata are represented by the Upper Proterozoic Hyland Group, the Lower Cambrian Gog Group, an unnamed Middle to Upper Cambrian sequence of carbonates and siliciclastics, the Upper Cambrian to Lower Ordovician Kechika Group, the Lower Ordovician to Lower Devonian Road River Group and the Middle Devonian to lower Mississippian Earn Group (Figures 3 and 4).

HYLAND GROUP (UPPER PROTEROZOIC)

Upper Proterozoic strata exposed in the map area are part of the Windermere Supergroup which forms a thick clastic wedge along the entire length of the Canadian Cordillera. These can be traced into similar Proterozoic rocks in the Nahanni map area which recently have been named the Hyland Group (Gabrielse and Campbell, 1991; Gordey and Anderson, 1993). The Hyland Group is subdivided into lower quartz-rich clastics of the Yusezyu Formation and overlying maroon to grey shales called the Narchilla Formation (Gordey and Anderson, 1993).

Rocks of probable Proterozoic age were observed in a handful of outcrops along the southwest slopes of the broad valley containing Netson Lake. These exposures consist predominantly of grey to green, greasy phyllite with minor thin-bedded, very fine grained sandstone. Lesser interlayered light to dark grey and cream-coloured slate, siltstone (calcareous) and very fine sandstone also occur. The predominantly phyllitic rocks outcrop immediately below Gog Group lithologies, suggesting they belong to the Narchilla Formation, whereas the grittier outcrops are stratigraphically lower than phyllites indicating they may be part of the Yusezyu Formation. The paucity of data does not allow differentiation between the two formations, all rocks of possible Proterozoic affinities are placed within undivided Hyland Group.

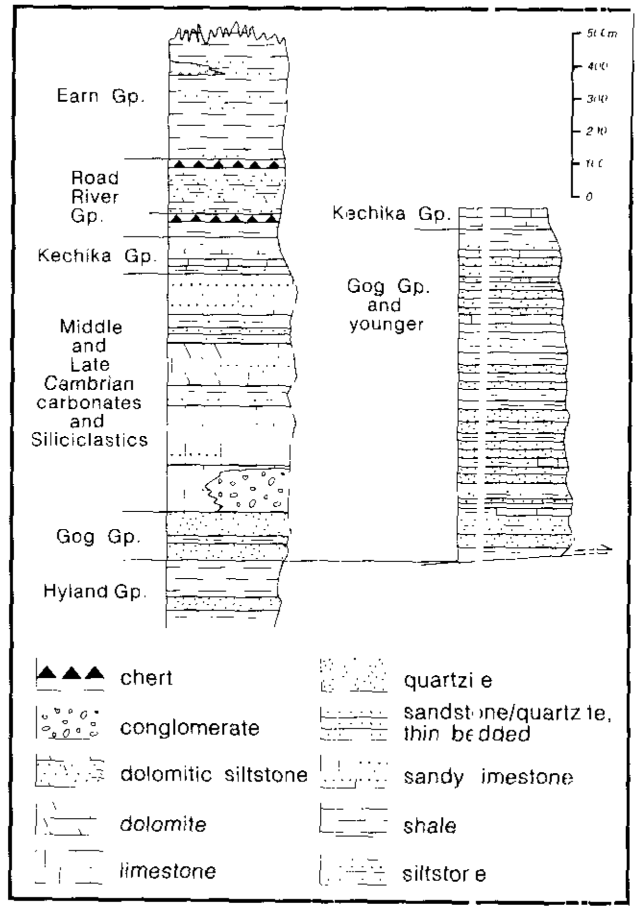

Figure 3. Simplified stratigraphic column of units within the project area. (a) Generalized column for the entire area. (b) Generalized column for the Gog and younger clastics found east and north of Split Top Mountain. See under *Gog and Younger Rocks*.

LOWER TO UPPER CAMBRIAN STRATA

Stratigraphically above the Hyland Group are thick sections of quartzose sandstone, siltstone, shale, carbonate and conglomerate of the Lower Cambrian Gog Group and an unnamed Middle to Upper Cambrian sequence of carbonate with lesser siliciclastics (Fritz, 1991). Rocks presently assigned to the Gog Group were previously called the Atan Group (Gabrielse *et al.*, 1977; Taylor and Stott, 1973) based on broad similarities between this quartzite-carbonate package and the type locality of the Lower Cambrian Atan Group in the Cassiar Mountains. The two-fold subdivision of Lower Cambrian strata, as exemplified by the Atan Group in the Cassiar Terrane, is not well developed in rocks of the Kechika Basin. The thick, Lower Cambrian carbonate is missing in the Gataga area. Instead, siliciclastics predominate with only thin

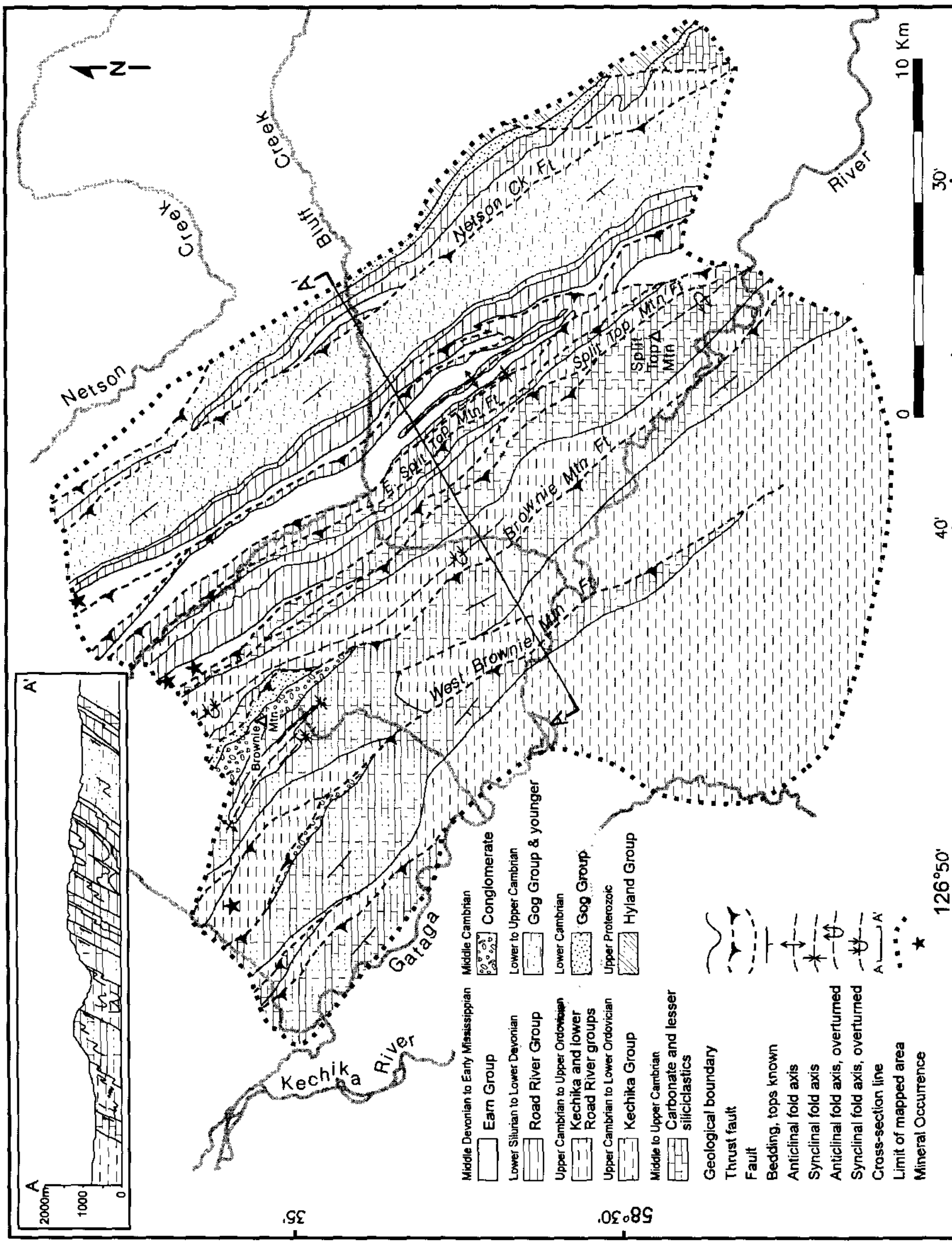

Figure 4. Generalized geological map of the study area. Inset shows stylized cross-section.

layers and lenses of archaeocyathid-bearing limestone. This led Fritz (1980b) to suggest that the term 'Atan Group' not be used east of the Northern Rocky Mountain Trench. The Lower Cambrian siliciclastic and lesser carbonate succession has broad similarities with the Gog Group as defined in the southern Canadian Cordillera, and that term is used here.

The top of the Gog Group is placed at the base of a thick carbonate succession which locally has been shown to be uppermost Lower Cambrian (Fritz, 1979, 1980a). In the map area, this carbonate succession, of mainly Middle and Late Cambrian age, shows rapid facies variations such that in some thrust panels carbonate is virtually absent. It is replaced by siliciclastic lithologies similar to the Gog Group, and which occur right up to the conformably overlying Kechika Group. This is particularly evident in the thrust panel east of Split Top Mountain where only a few metres of limestone and sandy limestone sit below Kechika Group rocks. Farther northwest, along strike, even these thin carbonates are missing. Similarly, in the far northeastern corner of the map area, the Cambrian carbonate south of Netson Lake passes northwestward into siliciclastics. The gradual northwestward disappearance of these thick Middle and Upper Cambrian carbonates is regionally significant. Nowhere north of Gataga Mountain do these carbonates reappear (Gabrielse 1962a, b).

Similar regional facies variations in Middle and Upper Cambrian successions have been documented elsewhere to the south and east (Gabrielse, 1981; Fritz, 1979; Taylor *et al.* 1979). These authors describe north to northwest-trending linear reefs separated by clastic facies. The rapid facies variations may reflect significant vertical fault motion resulting in the juxtaposition or interchange of shallow and deep-water environments. This theory is supported by the presence of thick uplift-related Middle Cambrian fanglomerates within the project area and to the east and southeast. These rocks grade laterally into typical Middle Cambrian lithologies (Taylor and Stott, 1973; Taylor *et al.*, 1979).

Where the Middle and Upper Cambrian carbonates are absent, Kechika Group rocks appear to rest conformably on top of slates and siltstones, which in turn lie conformably above coarser quartzose lithologies typical of the Gog Group. In the absence of a Middle Cambrian carbonate marker, it is not possible to precisely locate the top of the Lower Cambrian Gog Group within this thick succession. Assigning all these rocks to the Gog Group would be erroneous as, in its type locality it is restricted to the Lower Cambrian. Therefore, in areas where these dominantly siliciclastic Lower to Upper Cambrian rocks occur, we have assigned them to a composite unit designated *Gog Group and Younger Rocks*. Elsewhere, Cambrian rocks can be divided into Gog Group, the Middle Cambrian conglomerate unit, Middle and Upper Cambrian carbonates, and their siliciclastic equivalents, as follows.

GOG GROUP (LOWER CAMBRIAN)

As explained above, Gog Group rocks can be differentiated only in thrust panels containing thick Middle Cambrian carbonates. Poorly exposed sections of Gog siliciclastics and carbonates are exposed in thrust panels below the Netson Creek fault. In the far southeastern corner of the map area, thick to massively bedded, brown-weathering, brown to beige quartzite and quartz sandstone are found in sections up to 15 metres thick below the Middle Cambrian carbonate sequence. These quartzites and sandstones are sometimes calcareous and commonly show cross-stratification and bioturbation (*Cruziana*).

A well exposed, but strongly folded and faulted sequence of Gog quartzites is exposed on the east face of Brownie Mountain. Here the unit comprises thick to massively bedded grey and brown impure quartzite, quartz sandstone and white quartzite with lesser grey siltstone and sandy siltstone. The exact thickness of this Gog section is difficult to determine as it is in the core of an overturned northeast-verging fold which is cut by a thrust fault. A rough estimate is in the order of 100 metres. Sections of quartzite to impure quartzite from 10 to 30 metres thick are separated by 10 to 20-metre sections of thin to thick-bedded quartz sandstone and siltstone. The massive to thick-bedded quartzite horizons show cross-stratification and rare bioturbation in the form of bedding-perpendicular *Skolithus* burrows. The thinner bedded sandstone and siltstone sections commonly contain current ripples and bedding-parallel worm burrows. Less common but conspicuous orange-weathering, cross-stratified limestone to sandy limestone which may contain thin interbeds of calcareous sandstone, is found in sections up to several metres thick.

GOG GROUP AND YOUNGER ROCKS (LOWER, MIDDLE AND UPPER CAMBRIAN)

The thickest and most continuous section of this unit is exposed along the eastern side of the map area, extending from the Gataga River to the northern map boundary. Structural sections indicate thicknesses of approximately 1200 metres in the north and 1500 metres in the south, assuming no thrust faults have repeated this rather monotonous package. The section consists predominantly of flaggy, thinly interlayered brown to beige fine-grained quartz sandstone, siltstone and grey-green to dark grey slate. Some sections are dominated by slate and siltstone and others by thin planar-bedded sandstone. Slate and siltstone sections commonly have a grey to dark grey striped or banded pattern and contain layer - parallel worm burrows or other trace fossils. The basal part of the sequence contains 10 to 30-metre sections of thick-bedded, tan to white quartzite interlayered with lesser, thin-bedded grey to brown siltstone and green to grey phyllite. Some of the thicker sandstone sections exhibit cross-stratification and wave ripples on bedding surfaces.

In the southern part of this panel of Cambrian clastics, approximately 50 to 150 metres of striped or uniform, grey, grey-blue to dark grey to black slate and siltstone is exposed at the top of the section, immediately below the Kechika Group. In the northern part of the panel, thin to moderately bedded, grey to orange-weathering grey limestone to sandy limestone, siltstone and black chert layers or nodules are present in the upper part of this package.

Although limestones form a minor part of this map unit, they are important. The lower half of the succession locally contains discontinuous layers or lenses of brown-grey weathering, grey fossiliferous limestone, 10 centimetres to over 2 metres thick. These limestone horizons contain abundant archaeocyathid remains which, together with their lensoidal shape, suggest biohermal buildups (Photo 1). As archaeocyathids in North America are restricted to the Lower Cambrian, at least this part of the succession is known to be equivalent to the Gog Group. In the upper half of the succession, two types of limestone are seen: a grey-weathering limestone breccia 1 to 5 metres thick, and a grey, buff to brown or tan-weathering interlayered limestone, sandy limestone to calcareous sandstone and quartzite sequence 1 to 50 metres thick. No archaeocyathids were observed in either of these higher limestones.

The limestone breccia is composed of subrounded and rounded clasts of oolitic and massive limestone, up to 5 centimetres in diameter, and lesser shale clasts in a sandy limestone matrix. Limestone breccia beds grade upward into laminar limestone overlain by calcareous sandstone and quartzite which rarely contain flute casts and scour marks when succeeded by another breccia horizon. These features suggests a debris-flow origin for these deposits.

The limestone and sandy limestone are moderately to thickly bedded with the latter exhibiting cross-stratification. Pure to sandy limestone (up to 30% quartz grains) may contain thin interlayers of quartz sandstone or quartzite, giving the rock a distinctive ribbed appearance. Carbonate breccia horizons as well as grey to green slate layers are present locally.

These carbonate facies are prevalent in the top part of the map unit, very near its upper contact, and it is possible that they are distal equivalents of the thick Middle and Upper Cambrian carbonates found in other thrust panels. This is supported by the local presence of carbonate debris - flows which may be derived from nearby coeval, thick carbonate buildups. The amount of carbonate in the upper part of this clastic panel decreases to the northwest which mimics the northwestward disappearance of the Middle to Upper Cambrian carbonates in other panels.

Clastic rocks of Early and probably Middle and Late Cambrian age are exposed along the northeast-facing slopes immediately south of Netson Lake. Grey and rusty weathering, greenish grey and silvery, banded micaceous slate and siltstone, together with thinly bedded, very fine grained quartz sandstone are found immediately northwest of the Middle to Upper Cambrian carbonate shale-out in the extreme northeastern part of the map area. This area definitely contains Gog Group equivalent rocks, evident from several archaeocyathid-rich limestone lenses within the slates and sandstones.

Photo 1. 10 - metre - long archaeocyathid - bearing bioherm (outlined in white) within Gog Group clastics located 5 kilometres east-northeast of Split Top Mountain. The isolated nature of these buildups is clearly illustrated by the enclosing thick sequence of shale, siltstones and fine sandstones. Scale is shown by geologist to the right of bioherm.

CONGLOMERATE (MIDDLE CAMBRIAN)

Up to 250 metres of distinctive massive, polymict granule to boulder conglomerate is exposed along the top of Brownie Mountain. It is brown weathering, brown to grey or green and occupies a stratigraphic position between the Gog Group and Middle Cambrian carbonates. Similar, but much thinner conglomerate is exposed in the hangingwall of the West Brownie Mountain thrust. The lower contact of this unit was not observed at Brownie Mountain but its top appears to

Photo 2. General view of Middle Cambrian fanglomerates along the ridge containing Brownie Mountain. Note the poorly developed bedding and the wide range in clast size.

grade upwards into the thick section of limestones and dolomites. The conglomerate is matrix supported with 30 to 70% subangular to rounded clasts. Clast types include brown to white quartzite (70%), orange, grey or maroon-weathering limestone (10%), dark grey, grey or green slate and siltstone (10%) and green basalt(?), diorite or gabbro (10%). Grey to brown slate, siltstone and sandstone horizons up to several metres thick are locally present (Photo 2).

This conglomerate bears remarkable similarities to a fanglomerate in a similar stratigraphic position in the Tuchodi Lakes and Ware map areas (Taylor and Stott, 1973; Taylor *et al.*, 1979). This is one of numerous Middle Cambrian facies and is known as the 'Roosevelt facies' due to its excellent exposure near Mount Roosevelt in the Tuchodi Lake map area (Fritz, 1991). This unit is up to 1500 metres thick and related to growth faults which exhumed Proterozoic strata (Taylor and Stott, 1973; Taylor *et al.*, 1979; Fritz, 1991). Similar amounts of uplift are inferred in the map area from the presence of green slate, siltstone, basalt and gabbro clasts which must have been derived from underlying Proterozoic units. Fritz (1979) collected early Middle Cambrian faunas near the base of this unit east of the map area and has placed it entirely within the Middle Cambrian.

CARBONATE (UPPERMOST LOWER TO UPPER CAMBRIAN)

Most of the spectacular peaks in the Gataga River area are composed of steeply dipping panels of thick-bedded limestone and dolomite (Photo 3). Excellent exposures are found along the ridge northeast of the Gataga River in the extreme southeast part of the map sheet. This carbonate can be traced to the northwest where it thins and finally disappears into shales and siltstones. Split Top Mountain represents the next westerly belt of this carbonate package. Several ridges of carbonate that trend northwest from this area delineate splays off the main thrust at the base of Split Top Mountain. These carbonates also thin northwestward and the last carbonate associated with this fault zone shales out at the northern edge of the map area. These carbonates are cut obliquely by the thrust at the base of Brownie Mountain. Impressive exposures of these rocks are also found on the ridge west of Brownie Mountain.

Thicknesses and lithologic character of these rocks change dramatically across the map sheet. Approximately 1500 metres of carbonate are inferred from structural sections through the rugged ridge west of Brownie Mountain, whereas only 600 metres of carbonate are exposed on the ridge along the southeastern boundary of

Photo 3. Looking southwest towards Split Top Mountain. This mountain is composed of Middle to Upper Cambrian carbonates which make up most of the other rugged peaks in the area. The Gataga River valley is immediately to the west and Forseberg Ridge is in the middle ground. The Northern Rocky Mountain Trench is between Forseberg Ridge and the high peaks in the distance.

the map area. The northward thinning and disappearance of these carbonates is illustrated by the section along the eastern boundary of the map area which progressively thins from an initial 700 metres.

The dominant lithology is massive to thickly bedded, grey to tan-weathering, grey to white micritic to finely recrystallized limestone. Thin, discontinuous horizons of more resistant, lighter coloured dolomite and dolomitic limestone are locally present. Carbonate breccia and conglomerate are less common but were mapped along the easternmost limestone body. Fenestral dolomite was also seen towards the base of this limestone panel. Large sections of this limestone sequence have been variably dolomitized, forming massive buff to orange-weathering sections in the Split Top Mountain area, at Brownie Mountain and along the ridge west of Brownie Mountain. Limestone or dolomite may contain up to 30% well-rounded quartz grains and may be interlayered with thin to thick beds or sections (up to 5 m thick) of white to tan-weathering quartzite which give the succession a distinctive ribbed appearance. Planar to cross-stratified quartzite and quartz sandstone become dominant toward the base of the carbonate panel northwest of the mouth of Bluff Creek. This section is characterized by rare, but distinct layers of quartz-pebble conglomerate 10 to 20 centimetres thick. Sandy dolomite stratigraphically near the top of these conglomerate horizons may contain isolated quartzite cobbles up to 5 centimetres in diameter.

Late Early, Middle and Late Cambrian faunas have been recovered from these thick packages of carbonate south and east of the map area (Fritz, 1979, 1980a). Fritz collected late Early Cambrian trilobites from the base of these carbonates south of the Gataga River.

SILICICLASTICS (MIDDLE TO UPPER CAMBRIAN)

Middle to Upper Cambrian siliciclastics and lesser carbonates form lenticular sequences between 30 and 350 metres thick, within the main carbonate succession. They consist of thin to moderately bedded, grey and brown to tan-weathering, grey siltstone, slate and quartz sandstone, interlayered with lesser grey to buff-weathering sandy limestone, sandy dolomite, dolomite and dark grey argillaceous limestone. Sandstone is wavy to planar bedded whereas siltstone and slate sections have colour banding or striping and frequently worm burrows on bedding planes. Several of these horizons are found within the limestone sequence in the southeastern part of the map area and northwest of Split Top Mountain, but are traceable for only a few kilometres.

These rocks are remarkably similar to finer clastics described under Gog Group and younger strata. These tongues of clastic material within the carbonate units reflect, on a smaller scale, the rapid facies variation within Middle and Upper Cambrian strata in the map area.

Photo 4. Basal Kechika Group slates, calcareous slates and interlayers of grey to orange - weathering limestone. These thin limestone beds are a distinctive feature of the lower Kechika Group within the map area.

KECHIKA GROUP (UPPER CAMBRIAN TO LOWER ORDOVICIAN)

The name Kechika Group was first used by Gabrielse (1963) in the Cassiar Mountains and was later used to describe Upper Cambrian to Upper Ordovician strata in the Trutch and Ware map areas by Jackson *et al.*, (1965) and in the Tuchodi map area by Taylor and Stott (1973). The present application of this name to argillaceous carbonates and shales of Late Cambrian to Early Ordovician age was first used by Gabrielse *et al.*, (1977) in the Ware map area.

The Kechika Group, as with the underlying Middle to Upper Cambrian sediments, shows considerable thickness and lithologic variation. Sections of Kechika Group are approximately 500 metres thick along the southeastern margin of the map area, but decrease northwestward along strike to less than 200 metres. A maximum of only 200 metres of Kechika rocks is found in the central part of the next thrust panel to the west where Middle and Upper Cambrian carbonates are missing. This thickness decreases to less than 50 metres northwestward along strike and the unit appears to be absent to the southeast. East of Split Top Mountain, Silurian rocks of the Road River Group are found less than 50 metres above Cambrian clastics with only black slates of possible Ordovician Road River affinity between the two. This suggests either removal of Kechika rocks by a pre-Road River unconformity as seen by Gabrielse (1981) in the Ware area or lateral transition into lithologies similar to the Road River Group. Rocks assigned to the Kechika Group farther west occupy the cores of tight, northeasterly overturned synclines and although thicknesses have been exaggerated tectonically, original sections must have approached 500 metres in thickness. The predominance of Kechika lithologies in areas of poor exposure between massifs of Middle to Upper Cambrian carbonate south of the Gataga River suggests thicknesses of this magnitude or greater.

In the eastern part of the map area, the basal part of the Kechika Group comprises grey to dark grey, cleaved slate and silty slate, with discontinuous beds and lenses of grey and orange-weathering limestone to calcareous slate up to 10 centimetres thick that constitute up to 30% of the section (Photo 4). Generally, the thickness and percentage of limestone decreases up-section and only slate is present at the upper contact. Locally, grey to orange-weathering, planar-laminated dolomitic siltstone and silty slate up to 10 metres thick are found above Cambrian limestone. Light to medium grey weathering, dark grey micritic limestone up to 1 metre in thickness is locally found in the upper part of the Kechika Group along the northeastern edge of the project area. Upwards of 20 metres of orange-weathering, cleaved, bioturbated dolomitic slate to silty slate is present in the upper part of the Kechika Group east and northeast of Split Top Mountain. Generally, the carbonate content decreases northward in eastern exposures of the Kechika Group.

Green slate up to 5 metres thick, with distinctive crystals of barite up to 1 centimetre long, is found at the base of the Kechika Group, above Cambrian siliciclastics east of Split Top Mountain. Barite crystals were also observed in basal calcareous horizons of the Kechika Group in the northernmost part of this thrust panel.

Grey, buff and orange-weathering, grey and silvery slate, calcareous slate and silty slate with lesser thin beds or lenses of grey limestone characterize most of the Kechika Group immediately east and southwest of Brownie Mountain, and south of the Gataga River. Typically the carbonate content decreases up-section. Thin interlayers of grey limestone, from 0.5 to 10 centimetres thick, are abundant in the lower 50 metres. The Kechika Group is lighter coloured and more calcareous south and southwest of the Gataga River. In this area Kechika slate has characteristic light and dark grey colour laminations resulting from increased silt and/or carbonate content within lighter coloured horizons. This feature is very useful in differentiating these rocks from similar dark slates of the Road River Group, however, in some places Kechika slate is also dark in colour. This creates mapping problems in that the boundary between the two units is obscure, and the local absence of Kechika rocks is easy to overlook.

The Kechika Group rests unconformably above Cambrian carbonates in several localities. In the southeastern part of the map area, basal Kechika slates contain blocks of the underlying Cambrian carbonate. Similar relationships are seen at the eastern base of Brownie Mountain where carbonate clasts are found in Kechika slates at their contact with Middle to Upper Cambrian carbonates. West of Brownie Mountain various lithologies of the underlying Cambrian succession (carbonate, siliciclastics) are found below the Kechika Group, again suggesting an unconformable relationship.

This relationship is equivocal where the thick Middle and Upper Cambrian carbonates are lacking in the panel east of Split Top Mountain. The first orange-weathering limestone beds of the Kechika Group sit above approximately 25 metres of dark grey to black slate which grades downward into Cambrian siliciclastics east of Split Top Mountain. These dark slates appear similar to those interlayered with the overlying orange and grey limestones of the Kechika Group. There may be an unconformity between the similar shales, but it is impossible to distinguish. In the northeastern part of the map area Middle or Upper Cambrian limestones appear to be interlayered with Kechika slates near where these carbonates shale out. Limestone beds up to 1 metre thick and of similar appearance to the Cambrian carbonates are found at the base of the Kechika Group at this locality.

Graptolite collections from the Kechika Group have returned Early Ordovician ages. These are consistent with the highest beds of the group being Arenigian (late Early Ordovician; B.S. Norford, personal communication, 1994).

ROAD RIVER GROUP (LOWER ORDOVICIAN TO LOWER DEVONIAN)

The name Road River Group was extended into the Northern Rocky Mountains from its type locality in the Yukon by Gabrielse *et al.*, (1977). It is divided into two unnamed formations; an Ordovician sequence of black graptolitic slate and chert, and Silurian to Lower Devonian siltstone, graptolitic slate and minor chert.

BLACK SLATE/CHERT (LOWER TO UPPER ORDOVICIAN)

Complete sections of Ordovician Road River strata are confined to the eastern part of the project area. Approximately 125 metres of this unit is exposed along the banks of a creek in the southeastern part of the map area, below the thrust carrying the thick package of Cambrian siliciclastics. Upwards of 160 metres of Ordovician black slates are reasonably well exposed in the southern part of the next major thrust panel to the west. This sequence thins to 115 metres immediately south of Bluff Creek and only 50 metres are well exposed on the ridge to the north of the creek. Poor exposures farther north along this thrust panel suggest a thickness of only 50 metres.

Road River black slates crop out within the core of the northeast-verging syncline east of Brownie Mountain. A thick section of these rocks is also exposed west of Brownie Mountain and appears to rest directly on Cambrian clastics and carbonates. Assignment of black slates to either the basal Road River Group or Kechika Group becomes problematic in the Brownie Mountain area and in other areas to the east. Differentiating between the two units is virtually impossible in some localities and they have been grouped together. The difficulty in separating the two units may reflect a facies transition whereby Kechika rocks become more shaly and appear similar to the basal Road River strata. Furthermore, it is sometimes extremely difficult to differentiate between slates of the basal Road River Group and those of the Earn Group, especially where intervening, stratigraphically younger Road River rocks are poorly exposed. Biserial graptolites, which are restricted to the Road River slates, are helpful in resolving this problem.

Photo 5. View to the northwest showing resistive Road River Group dolomitic siltstones showing a thrust fault (arrow) with small displacement. Gataga Mountain is highest snow capped peak in the distance with Brownie Mountain immediately to the left. Although these rocks are quite argillaceous, they form resistive ridges due to their location between less competent lithologies of the Kechika and Earn groups.

The basal part of the Road River Group is composed of graptolitic dark grey, blue-grey and black graphitic slate and siliceous slate. Grey - brown and orange-weathering siltstone, up to 2 metres thick, and thin, grey, tan to orange-weathering, thin planar-laminated limestone beds are less common lithologies within this slate succession. Resistant layers of dark grey to black graphitic chert and siliceous argillite, 1 to 5 - centimetres thick, are found interlayered with the slaty rocks in the upper 5 to 10 metres of this unit.

Pale grey to greenish baritic tuff up to a metre thick is traceable for over 1.5 kilometres northwest of Brownie Mountain. A thin 'greenstone' horizon has also been mapped within basal Road River rocks near Gataga Mountain (B.S. Norford, personal communication, 1994). Volcanic rocks are reported elsewhere near the base of the Road River Group and are referred to as the Ospika volcanics (MacIntyre, 1992; Gabrielse, 1981). Thick volcanics underlying Gataga Mountain immediately to the north were originally believed to be Devono-Mississippian but are now thought to be part of this suite (H. Gabrielse, personal communication, 1994).

Graptolites recovered near the base of the Road River Group north of Bluff Creek are Middle Ordovician (Caradoc). Elsewhere the range of the basal Road River Group has been shown to be Early to Late Ordovician (Cecile and Norford, 1979).

SILTSTONE/SLATE (LOWER SILURIAN TO LOWER DEVONIAN)

Resistant, buff-orange weathering, grey to greenish grey, bioturbated dolomitic siltstone is the dominant member of the upper Road River Group (Photo 5). This unit is commonly referred to as the 'Silurian siltstone', although McClay *et al.* (1988) recovered Early Devonian conodonts from it. Bedding is difficult to discern in bioturbated sections except in thick - bedded shale and siltstone intervals. The rocks are thinly layered and planar laminated where bioturbation is lacking; and have a distinctive flaggy parting. Monoserial graptolites are typically preserved within these flaggy, non-bioturbated successions. Slates of the basal Road River are gradational with overlying Silurian siltstones over an interval ranging to tens of metres. The basal part of the Silurian siltstone may contain sections of grey, nondescript slate and silty slate more than 100 metres thick. Grey slates and siltstones in the footwall of the Split Top Mountain thrust fault have been assigned to the upper Road River Group as they are on strike with typical Road River lithologies farther to the northwest. Thin-bedded orange-weathering planar-laminated, flaggy limestone to silty limestone is locally developed.

The upper 10 to 15 metres of the Road River Group contains a distinctive chert-limestone succession which is locally an excellent marker (Photo 6). Dark grey-brown, grey and white, thin to thickly bedded chert with interlayers of dark grey cherty argillite comprises the basal 2 to 3 metres of this sequence. Approximately 1 to 2 metres of thin to moderately bedded, cream to light grey weathering, grey, silty to argillaceous micritic limestone interlayered with thin beds of typical Silurian siltstone are exposed 1 to 2 metres above the chert sequence. Several metres of orange-weathering, bioturbated siltstone succeed this limestone sequence and grade into overlying

Photo 6. View of the uppermost Road River Group showing the chert-limestone unit. Grey to brown chert can be seen beneath the hammer and this is followed by thinly interlayered limestone. Earn Group lithologies begin a few metres to the right of the photograph.

lithologies of the Earn Group across a stratigraphic thickness of 50 centimetres.

This chert-limestone couplet is recognized only along the well exposed ridges east of the Split Top Mountain thrust. Poor exposure may limit its expression elsewhere in the map area.

The main belt of upper Road River rocks is a thrusted and folded sequence east of the Split Top Mountain thrust and west of the thick package of Cambrian clastics. Silurian siltstone is also recognized in several thrust panels in the northeastern part of the map area and in the core of the northeasterly overturned syncline east of Brownie Mountain. Structural thicknesses are quite variable, ranging from 200 to 300 metres in the southern part of the main outcrop belt to 400 metres in the centre and approximately 250 metres in the northern part. Thicknesses ranging from 550 to 700 metres were deduced for the poorly exposed section east of Brownie Mountain. Stratigraphic thicknesses for the Siluro-Devonian part of the Road River immediately southwest of the map area are in the order of 75 to 200 metres (Gabrielse, 1981; McClay *et al.*, 1988) whereas 250 to 600 metres of this unit are reported near the edge of the Kechika Basin in the Ware and Trutch map areas (Cecile and Norford, 1979; Gabrielse, 1981). These sections suggest that the greater thicknesses of Siluro-Devonian Road River calculated within the present map area, especially in the poorly exposed regions, have resulted from structural thickening.

Only one macrofossil collection was recovered from the upper Road River within the map area during the 1994 field season. Lower Silurian (Wenlock to possibly late Llandovery) monograptids were collected from the lower part of the siltstone section east of Split Top Mountain. These graptolites occur close to the Cambrian contact with little or no Kechika or basal Road River below. Elsewhere, the orange-weathering dolomitic siltstone package has been shown to be Silurian (Cecile and Norford, 1979; Gabrielse, 1981). McClay *et al.* (1988) recovered Lower Devonian conodonts from limestones within the siltstone sequence. The chert-limestone sequence is very similar to Upper Silurian to Lower Devonian chert and limestone at the top of the Silurian siltstone in the Akie River area (MacIntyre, 1992). Lower Devonian basinal lithologies are up to 200 metres thick in the Akie River area near the edge of the paleocontinental shelf, but thin markedly to the west, within the basin (MacIntyre, 1992; Norford, 1979; Gabrielse, 1975).

EARN GROUP (MIDDLE DEVONIAN TO LOWER MISSISSIPPIAN)

Black slate, siltstone, chert and sandstone of late Middle Devonian to early Mississippian age in the map area belong to the Earn Group. The name Earn Group was extended southward from its type locality in the Yukon by early workers in the Gataga district who noted the striking similarity between Devono-Mississippian strata of the Kechika and Selwyn basins (Jefferson *et al.*, 1983; Pigage, 1986; MacIntyre, 1992; Gordey *et al.*, 1982).

The Earn Group has been subdivided into three informal units in the southern Kechika Basin; blue-grey weathering siliceous argillite of the Middle to Upper Devonian Gunsteel formation; rusty weathering, soft grey shale of the Akie formation; which grades laterally into chert-quartz siltstone, sandstone and conglomerate of the Warneford formation (MacIntyre, 1992; Pigage, 1986; Jefferson *et al.*, 1983). Although these three lithological variations of the Earn Group were recognized in the map area, it was not possible to map out the individual facies. This was due not only to the poor exposure of this succession, but also to the apparent interfingering of the various lithologies.

A structurally thickened section of Earn and Road River rocks extends from the Gataga River, immediately east of Split Top Mountain, northwestward to the north edge of the map sheet. The unit is well exposed along ridges in the southern part of this belt, whereas to the north topography becomes more subdued and the best exposures are found in creek valleys. Another important panel of Earn rocks is an apparently northwestward-thickening wedge in the footwall of a thrust carrying Middle Cambrian carbonates northeast of Brownie Mountain. Smaller occurrences of the Earn Group are mapped along the lower parts of Bluff Creek, on the northeast-facing slopes immediately south of Netson Lake and as isolated occurrences in the low ground east of the Kechika River. A minimum of 600 metres of this unit is inferred along poorly exposed slopes in the northern part of the map area as no upper contact is present.

The Earn Group is composed of grey to blue or silvery blue-grey weathering, dark grey to black, carbonaceous fissile shale, slate to siliceous shale. Sequences of blocky grey to dark grey sooty argillite to siltstone, siliceous argillite or chert are found within this shaly succession. Blocky argillaceous to silty sections contain 1 to 10-centimetre beds with thin interlayers of shale and display light to dark grey colour banding higher in the sequence. Less siliceous shale or slate sections can be recessive and appear to be present throughout the sequence. Sections of grey to dark grey to rusty weathering sooty slate with lustrous cleavage planes crop out along the middle part of Bluff Creek.

One of the characteristic features of the Earn Group in the Gataga district is the presence of red to orange limonitic seeps which locally cement glacial and soil material forming a ferricrete deposit or pavement. These deposits are numerous and easily seen from the air in the high alpine country south of the map area, but are more difficult to locate in the more subdued and wooded terrain covered by our mapping. Several are well exposed on the south side of Bluff Creek and numerous other occurrences were found in creek valleys and slopes underlain by the Earn Group.

Limestone, although rare in this fine clastic sequence, forms conspicuous sections when present. Grey, fine to coarsely recrystallized limestone with local barite replacement is found as isolated layers from 10 to 50 centimetres thick. A 2 to 3-metre section of grey-weathering, grey to dark grey, slightly argillaceous limestone with 1 to 10-centimetre argillaceous partings is exposed several kilometres north of Bluff Creek.

Dark grey to rusty weathering, dark grey, granule to pebble - conglomerate was noted in one locality towards the top of the Earn succession south of Bluff Creek. Clasts consists predominantly of subrounded to well rounded, light to dark grey chert and mono- to polycrystalline quartz with lesser sandstone, quartz wacke, slate, siltstone and feldspar fragments. This bed is 1.5 metres thick and approximately 15 metres long. Coarse to fine clastics of similar composition are quite common in the upper and western parts of the Earn Group. Regionally, these clastics contain paleoflow indicators giving westerly to northerly source areas (Gordey *et al.*, 1991).

The basal part of the Earn is dominated by shale, siliceous shale and slate which regionally hosts significant deposits of bedded barite±pyrite±sphalerite±galena. Several occurrences of stratiform or nodular barite and pyrite were encountered within the lower part of the Earn Group within the project area.

STRUCTURE

The structural fabric of the map area is controlled by northeasterly directed thrust faults. The thrust sheets are internally folded, have moderate to steep southwest dips and contain a pervasive, penetrative cleavage within argillaceous lithologies. Cambrian clastics and carbonates form the most competent stratigraphic sequence and tend to form rigid thrust panels (Photo 7). Kechika and Ordovician Road River shales comprise the most important zone of detachment in the map area. This is primarily the result of the low structural competency of these lithologies and their location between more rigid siltstones of the Road River Group (Photo 5) and carbonates and quartzitic rocks of the Cambrian succession. Earn lithologies are also relatively incompetent.

Major thrust faults in the map area carry Cambrian or uppermost Proterozoic strata in their immediate hangingwall (Photo 7). Five large thrust sheets have been delineated and the bounding thrust faults are informally referred to (from west to east) as: West Brownie Mountain, Brownie Mountain, Split Top Mountain, East Split Top Mountain and Netson Creek faults (Figure 4). These subdivisions roughly correspond to the four thrust packages mapped by McClay *et al.* (1988) to the southwest.

Displacement on these major thrusts is substantially larger than on individual thrust faults found higher in the stratigraphy of each thrust sheet. Some of the displacement on the larger faults must have been transferred into a series of smaller scale thrusts and associated folds in their footwalls. This is well displayed below Split Top Mountain and East Split Top Mountain thrust faults where Earn and Road River strata are repeated by small-scale folding and faulting. Thrusts within Earn and Road River rocks probably extended downward into the Kechika Group and this displacement must feed into the larger thrusts carrying Cambrian

Photo 7. View to the southeast from Brownie Mountain. Split Top Mountain is the isolated peak at the right of the skyline. Several thrust slices of Middle to Upper Cambrian carbonate can be seen in this photograph and have been outlined. These extend northwestward from Split Top Mountain and continue past the northern limit of the project area.

stratigraphy. McClay *et al.* (1988) have demonstrated similar features to the south which are part of duplex structures between major thrust faults.

Very large, northeasterly overturned folds can be recognized in the map area. The best example is the large syncline immediately east of Brownie Mountain. To the west of this is an anticline which has been cut by the Brownie Mountain fault (Photo 8). The thick Middle to Upper Cambrian carbonate successions commonly delineate northeasterly overturned anticlines at the leading edge of thrust panels. Excellent examples of this are along the southwest side of Split Top Mountain and on the carbonate knoll east-northeast of Brownie Mountain (Photo 9). Smaller scale folds with nearly horizontal axial planes are exposed on the west flank of Split Top Mountain . These folds were probably formed quite early in the deformation history and were then rotated into their present position by movement on the Split Top Mountain thrust. Apparently thick sections of Kechika and Ordovician shales in the south and southwestern part of the map area are probably the result of tectonic thickening within the cores of these larger scale folds.

The near linear nature of the lower Gataga River suggests it is a major fault. The relationship of this apparent structure to the right-lateral Northern Rocky Mountain Trench fault further suggests that it is a splay of this large structure with the same relative motion. Mapping of thick Middle and Upper Cambrian carbonate units across the Gataga River does not indicate any substantial fault displacement along the river. Right-lateral displacements of up to 200 metres can be inferred along the lower part of the Gataga River by the extrapolation of carbonate units across it. This implied displacement is difficult to substantiate considering the scale of mapping and lack of outcrop along the south side of the river.

ECONOMIC GEOLOGY

The highest potential for economic mineral deposits within the map area occurs in Devonian rocks of the Earn Group. This unit is known to host numerous economically significant sedimentary exhalative barite-sulphide deposits elsewhere in the Kechika and Selwyn basins. Barite-sulphide mineralization found within the lower part of the Earn Group over the course of the 1994 field season reflects this high mineral potential and suggests the possibility for other occurrences. Barite mineralization was also discovered in Ordovician shales of the Road River Group and basal rocks of the Kechika Group. Although no Silurian mineralization is known in the map area, the presence of barite and barite-sulphide occurrences in Ware and Trutch map areas (Cecile and Norford, 1979; MacIntyre, 1992), together with the enormous Early Silurian Howards Pass deposit of the Selwyn Basin, suggests that the potential of Silurian rocks should not be overlooked. Anomalous nickel-zinc values in some areas underlain by Earn rocks suggest the possible presence of stratiform nickel-zinc-platinum

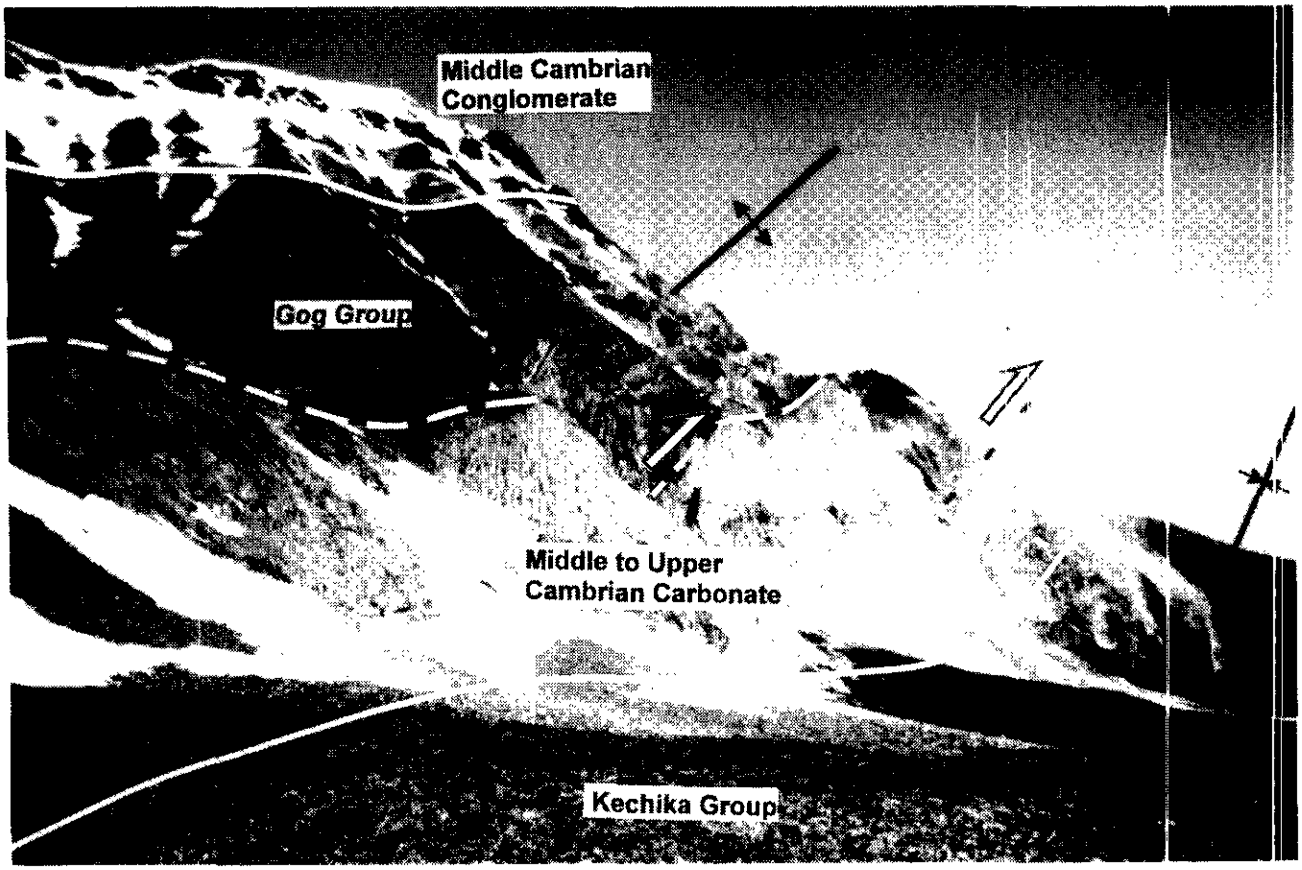

Photo 8. Scene along the east face of Brownie Mountain showing overturned rocks of the Kechika Group and Middle to Upper Cambrian carbonates. These are on the west limb of a northeasterly overturned syncline. Thrust above these are Gog Group siliciclastics within the core of a northeast - verging anticline, and Middle Cambrian conglomerate along the top of the ridge.

group element (PGE) deposits similar to those in the Selwyn Basin (Carne and Parry, 1990; Carne 1991). Several sulphide-bearing veins were also found in Middle Cambrian and Earn rocks. The following section gives a brief account of each occurrence within the map area. A detailed description of the deposit types is beyond the scope of this paper and the reader is referred to MacIntyre (1992) for a synopsis of Devonian and older mineralization within the Gataga district, and to Paradis *et al.* (in press) and Nelson *et al.* (1995, this volume) for a detailed account of the Driftpile Creek occurrence. Nickel-zinc-PGE mineralization is characterized by Hulbert *et al.* (1992) in its type locality in the Selwyn Basin.

STRATIFORM MINERALIZATION

EARN GROUP

The belt of Earn Group exposed within the map area is a northwestward continuation of the structural panel outlined by McClay *et al.* (1988) to the southeast which contains the Driftpile Creek, Bear and Saint deposits. Stratiform barite and barite-sulphide mineralization has been traced intermittently for a strike length of nearly 50 kilometres in this panel. It is theorized that the individual mineral deposits in this southern belt resulted from *ponding of mineralized fluids within local sub-basins* located along a larger basin containing widespread, more diffuse mineralization. Mineralized horizons within this same belt of rocks in the map area suggest that this large-scale metallotect continues to the north and thus has the potential to contain more, strongly mineralized sub-basins (MacIntyre, 1992; Carne and Cathro, 1982; McClay *et al.* 1988).

Barite±Sulphides

Three occurrences of barite-pyrite mineralization were seen within the lower Earn Group in the northern part of the map area during the 1994 field season. The most easterly of these is 25 metres stratigraphically above the base of the Earn and is hosted by grey to rusty weathering, dark grey to black carbonaceous shale to siliceous shale and chert. The baritic horizon is approximately 1 metre thick and contains up to 30% slightly ovoid barite nodules from 0.1 to 0.5 centimetre long. Slaty cleavage is deflected or refracted around the nodules. These are associated with pyritic horizons composed of either coarse authogenic pyrite or, more

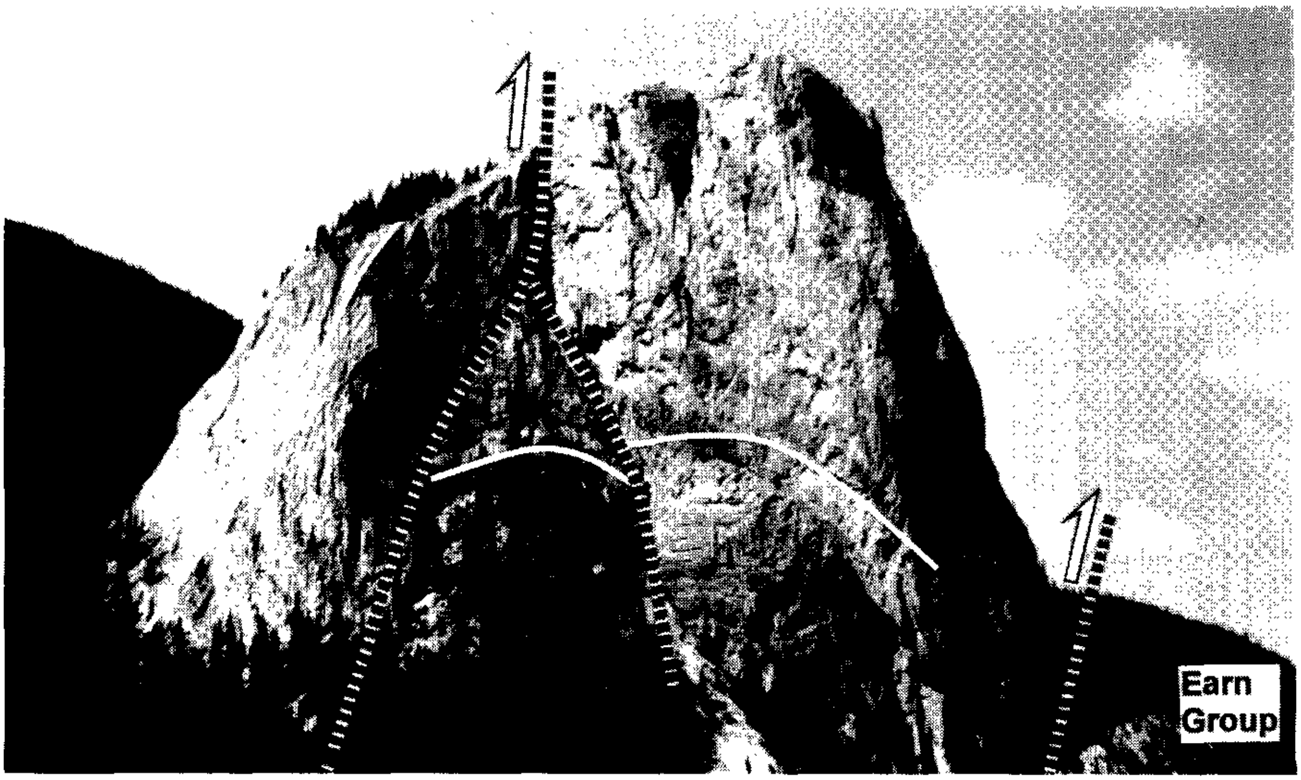

Photo 9. Looking north at a carbonate knoll approximately 2.5 kilometres north of Brownie Mountain. These Cambrian carbonates are thrust above Earn Group lithologies. This scene illustrates the common presence of northeast - verging folds along the leading edge of thrust panels carrying thick Cambrian carbonates. This fold has also been complicated by subsequent faulting. Bedding is high lighted with white lines.

importantly, thin layers of very finely crystalline pyrite. Pyritic, light coloured cherty lenses are also found along this horizon. This mineralization is similar to 'blebby' barite and exhalative pyrite horizons seen at the Driftpile Creek deposit.

The other two occurrences are within a panel of Earn rocks immediately east of Brownie Mountain. The more southerly showing is poorly exposed towards the base of the Earn Group and consists of 10 to 30 centimetres of light grey, slightly banded baritic slate with 1 to 3% disseminated pyrite. Lenses of darker slate are also found along this horizon. Surrounding lithologies consist of rusty and blue-grey weathering dark grey and black carbonaceous and blocky shale and siliceous shale.

Earn Group rocks are well exposed along a creek approximately 1 kilometre northwest of this second occurrence and consist of grey and rusty weathering, dark grey and black carbonaceous and siliceous shale, slate and siltstone. Isolated horizons of nodular barite were observed together with thin layers of finely crystalline pyrite. A limonitic seep is located immediately below this outcrop.

This belt of Earn rocks within, and immediately to the north of the map area, has been shown to contain zones of anomalous zinc concentrations (Boyle, 1978a, b; Stewart, 1980; MacArthur, 1982; Carne and Parry, 1990; Carne, 1991). Numerous limonitic seeps, ferricrete and calcrete occurrences are found within Earn rocks and contain anomalous zinc values. Many of these anomalous zones are situated along and to the south of Bluff Creek. Interest in these deposits waned due to the lack of a corresponding lead anomaly.

Nickel-Zinc-Platinum Group Elements

Re-evaluation of Earn lithologies with anomalous zinc values in the area around Bluff Creek resulted in the delineation of corresponding nickel anomalies which led Carne and Parry (1990) and Carne (1991) to suggest that these reflect stratiform nickel-zinc-PGE mineralization similar to the Nick property in the Selwyn Basin. The mineralized horizon in the Yukon is very thin (approximately 3 cm) but contains average nickel and zinc concentrations of 5.3% and 0.73%, respectively (Hulbert *et al.*, 1992). It is located at the base of the Earn Group, near its contact with the Road River Group, and is laterally extensive. Stratigraphic sequences similar to that hosting the Nick deposit (limestone ball member and succeeding phosphatic chert, see Hulbert *et al.*, 1992) were not observed in the map area, although this may reflect the relative thinness of the sequence and the relatively poor exposure of this horizon.

The present interest in this deposit is more academic than economic. The very thin nature of this deposit in the Yukon (3 centimetres) would presently not allow the economic retrieval of the nickel, zinc and corresponding PG elements.

ROAD RIVER GROUP

Greenish grey and tan siliceous and baritic tuff or tuffaceous siltstone, approximately 1 metre thick, are interbedded with Ordovician black slates of the Road River Group 4 kilometres west of Brownie Mountain. Internally this unit contains barite, pyrite and slate-rich laminations. It is exposed in three creek canyons, giving it a strike length of at least 1.5 kilometres.

Barite±sulphide mineralization of Middle to Late Ordovician age is documented from the southern part of the Kechika Basin (MacIntyre, 1992; Cecile and Norford, 1979). The Akie-Sika occurrence is a barite unit 1 metre thick, within Middle Ordovician shales, which MacIntyre (1992) believes is genetically related to coeval volcanism in the basin. This assumption is supported by the tuffaceous character of this horizon in the map area, assuming these tuffs are related to the volcanism in the southern Kechika Basin. Cecile and Norford (1979) report baritic horizons in Late Ordovician shales of the Road River Group close to the shelf edge.

KECHIKA GROUP

Green, possibly tuffaceous slate, up to 5 metres thick, is exposed at the base of the Kechika Group east of Split Top Mountain. Similar slate, although calcareous, crops out within Kechika rocks in the northeastern part of the map area. This unit is also characterized by 1 to 3-centimetre beds containing authogenic barite crystals up to 1 centimetre in size and locally comprising up to 30% of the layer. These crystals must reflect elevated barium levels during deposition. Cecile and Norford (1979) have reported scattered crystalline nodules from the base of the Kechika Group in the Ware and Trutch map areas. These occurrences suggest that some form of mineralization, possibly related to volcanism, was associated with the initiation of Kechika deposition.

VEINS

Several occurrences of vein mineralization were encountered within the map area. The first, carrying copper, occurs near the top of a steeply southwest-dipping Middle to Upper Cambrian limestone, south of Bluff Creek. Anastomosing quartz veins have a composite thickness of 3 to 4 metres; individual veins are up to 1 metre thick. The veins are approximately concordant with bedding. Lenses or sheets of limestone between the veins commonly contain strongly silicified rock which may have been siliciclastic interbeds in the host limestone.

Chalcopyrite and chalcocite were noted along several parts of the vein system. Weathered fracture surfaces in the quartz veins are coated with orange to red-brown iron oxides, and locally with extensive malachite and azurite.

The second occurrence of minor vein mineralization consists of thin tetrahedrite and barite-bearing quartz-calcite veins within the Earn Group in the northeastern part of the map area. These veins are only centimetres thick, discontinuous and contain only traces of malachite.

CONCLUSIONS

- Mapping in the project area has delineated several large thrust panels containing rocks of the Upper Proterozoic Hyland Group, Lower Cambrian Gog Group, Middle to Upper Cambrian carbonates and siliciclastics, Upper Cambrian to Lower Ordovician Kechika Group, Lower Ordovician to Lower Devonian Road River Group and Middle Devonian to lower Mississippian Earn Group.
- Middle and Upper Cambrian rocks exhibit abrupt facies changes in the map area. Carbonates, up to 1500 metres thick in some thrust panels, are absent within a central thrust sheet and are replaced by fine siliciclastics, suggesting a shale-out.
- A belt of Earn Group rocks to the south, in the Driftpile Creek area has, been shown to extend into, and beyond the map area.
- Several new minor barite-sulphide occurrences have been discovered within the Earn and Road River groups.

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NOTES

GEOLOGY AND MINERAL OCCURRENCES OF THE TATLAYOKO LAKE MAP AREA (92N/8, 9 and 10)

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KEYWORDS: Tatlayoko Lake, Methow Terrane, Relay Mountain Group, Jackass Mountain Group, Mount Skinner Igneous Complex, Yalakom fault, Skinner gold-quartz vein.

INTRODUCTION

The Tatlayoko project, funded by the 1991-1995 Canada - British Columbia Mineral Development Agreement, was initiated in 1992 with geological mapping of the Mount Tatlow map area (Riddell *et al.*, 1993a,b). No fieldwork was done in 1993, but the project was continued in 1994 with geological mapping of the Tatlayoko Lake map area, reported on here. The project's objectives are to update the geological database for the eastern Coast Belt in portions of the Mount Waddington and Taseko Lakes map areas, and to integrate the structural and stratigraphic relationships established within this area with rapidly evolving concepts regarding the tectonic and stratigraphic framework of the region. This will provide an improved geological framework for understanding the settings and controls of known mineral occurrences in the area (*e.g.*, Fish Lake, Skinner) and for evaluating the potential for additional discoveries. The project was designed to tie in with earlier mapping by the Geological Survey Branch to the southeast, and with concurrent MDA-funded mapping directed by P. van der Heyden and P. Mustard of the Geological Survey of Canada to the northwest, thus completing a continuous belt of recent 1:50 000-scale mapping that extends for 300 kilometres along the northeast margin of the Coast Belt (Figure 1).

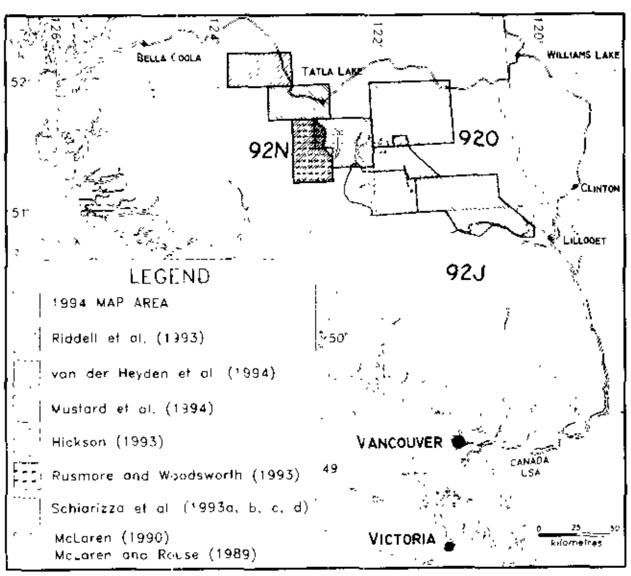

Figure 1. Location of the Tatlayoko project area and index to recent geological mapping by the GSB and GSC in adjacent parts of the southeastern Coast Belt.

The Tatlayoko Lake map area is centred about 270 kilometres north-northwest of Vancouver, and 160 kilometres west-southwest of Williams Lake. It covers the transition from the rugged Coast Mountains in the southwest, to gently rolling topography of the Fraser Plateau to the northeast. Tatlayoko Lake is accessed by an all-season road that extends south from Highway 20 at Tatla Lake. Another road branches eastward to the north end of Chilko Lake, and a seasonal road crosses the Chilko River to extend southward to Tsuniah Lake and the Nemaia valley (Figure 2).

REGIONAL GEOLOGIC SETTING

The geologic setting of the Tatlayoko project area is summarized in Figure 3. It encompasses the boundary between the Coast and Intermontane morphogeologic belts. Within the Tatlayoko project area this boundary corresponds to the Yalakom fault, a major linear feature that extends for about 300 kilometres and was the locus of more than 100 kilometres of Late Cretaceous(?) to early Tertiary dextral displacement (Riddell *et al.*, 1993a).

The eastern Coast Belt in the region of the Tatlayoko project area can be subdivided into the south Chilcotin, Methow and Niut domains of contrasting stratigraphy and structural style (Figure 3). The south Chilcotin domain includes Mississippian to Jurassic oceanic rocks of the Bridge River accretion-subduction complex, Upper Triassic to Middle Jurassic arc-derived clastic sedimentary rocks of Cadwallader Terrane, Permian ophiolitic rocks of the Shulaps and Bralorne - East Liza complexes, Upper Jurassic to mid-Cretaceous clastic sedimentary rocks of Tyaughton Basin, and Upper Cretaceous subaerial volcanic rocks of the Powell Creek formation. These partially coeval lithotectonic assemblages are juxtaposed across a complex network of

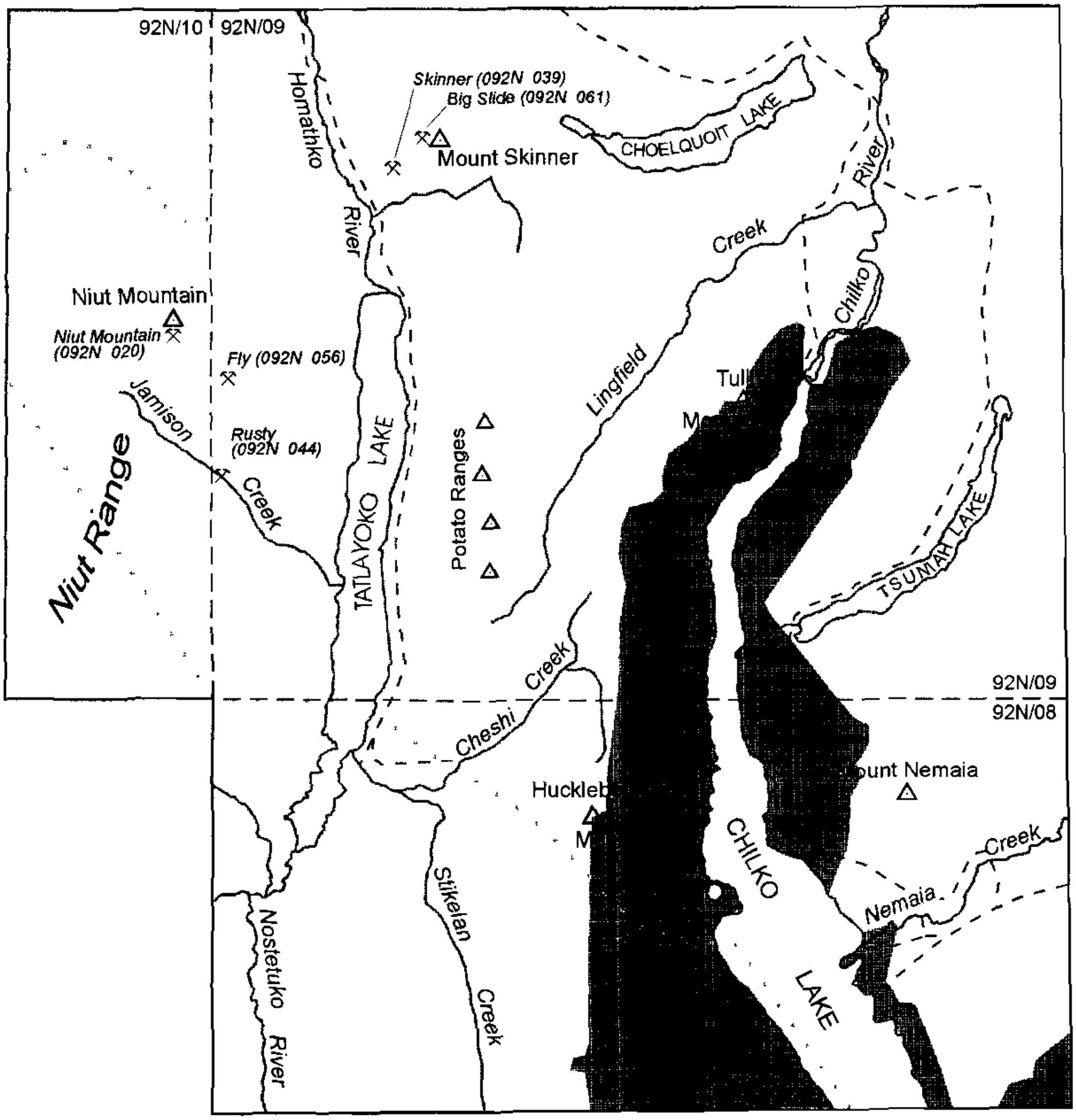

Figure 2. Main physiographic features of the Tatlayoko Lake map area. Locations of main mineral occurrences are also shown, and the shaded area indicates the location of Ts'yl-os Provincial Park.

structures that are dominated by Middle to Late Cretaceous southwest-directed contractional faults, and Late Cretaceous to Early Tertiary dextral strike-slip faults.

Methow domain occurs to the north and northeast of the south Chilcotin domain, from which it is separated in part by the Yalakom fault, and in part by an earlier structure that is offset by the Yalakom fault. This earlier structure is referred to as the Camelsfoot fault in the south (Schiarizza *et al.*, 1993b) and the Konni Lake fault in the north (Riddell *et al.*, 1993a). Methow domain is underlain by rocks assigned to Methow Terrane, which throughout most of the region comprises an unamed interval of Lower to Middle Jurassic sedimentary and volcanic rocks together with overlying Lower Cretaceous clastic sedimentary rocks of the Jackass Mountain Group. These strata are lithologically distinct from age-equivalent rocks found within the Cadwallader Terrane and the upper Tyaughton Basin of the south Chilcotin domain. They are also distinguished by a less complex structural style, as they are commonly disposed as broad homoclines between widely spaced faults and fold hinges. Within the western part of the Tatlayoko Lake map area, however, Methow Terrane also includes a succession of Upper Jurassic to Lower Cretaceous clastic sedimentary rocks assigned to the Relay Mountain Group. This blurs the stratigraphic distinctiveness of the Methow Terrane, as the Relay Mountain Group also comprises the lower Tyaughton Basin of the south Chilcotin domain.

The Niut domain is underlain largely by Upper Triassic volcanic and sedimentary rocks of the Mount Moore and Mosley formations, associated Late Triassic plutons, and Lower Cretaceous volcanic and sedimentary rocks assigned to the Ottarasko and Cloud Drifter formations (Rusmore and Woodsworth, 1991a; Mustard and van der Heyden, 1994). Both the Triassic rocks, which

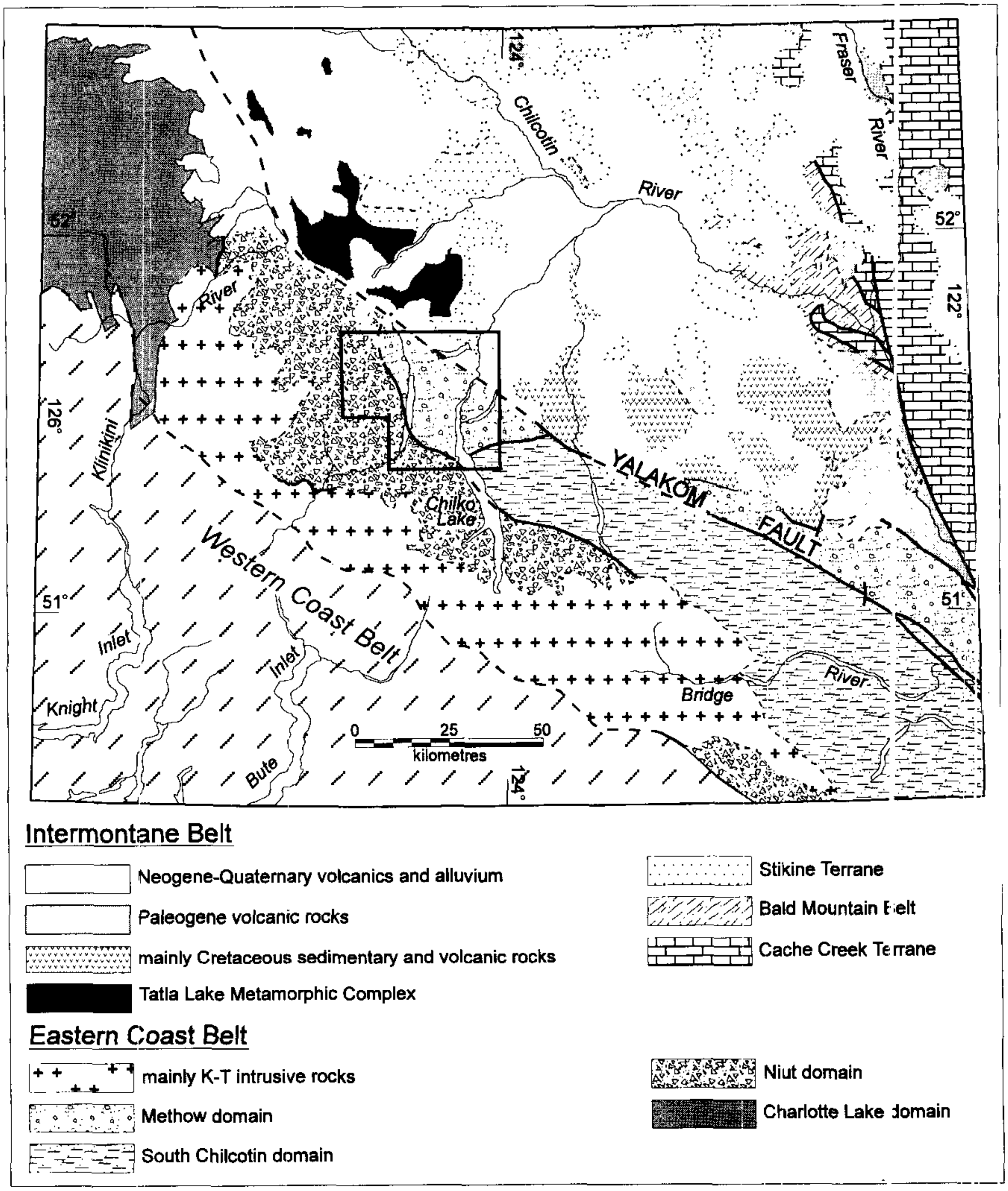

Figure 3. Geologic setting of the Tatlayoko project area.

have been correlated with those of the Stikine Terrane, and the Lower Cretaceous rocks are distinct from age-equivalent rocks to the east, but the Niut domain also includes Middle to Upper Cretaceous rocks that correlate with the upper Tyaughton Basin and Powell Creek formation of the south Chilcotin domain. The stratigraphic elements of the Niut domain are deformed by early Late Cretaceous faults of the northeast-vergent Eastern Waddington thrustbelt (Rusmore and Woodsworth, 1991b; van der Heyden *et al.*, 1994a). The northeast boundary of the domain is a system of faults that juxtaposes it against the south Chilcotin domain in the area east of Chilko

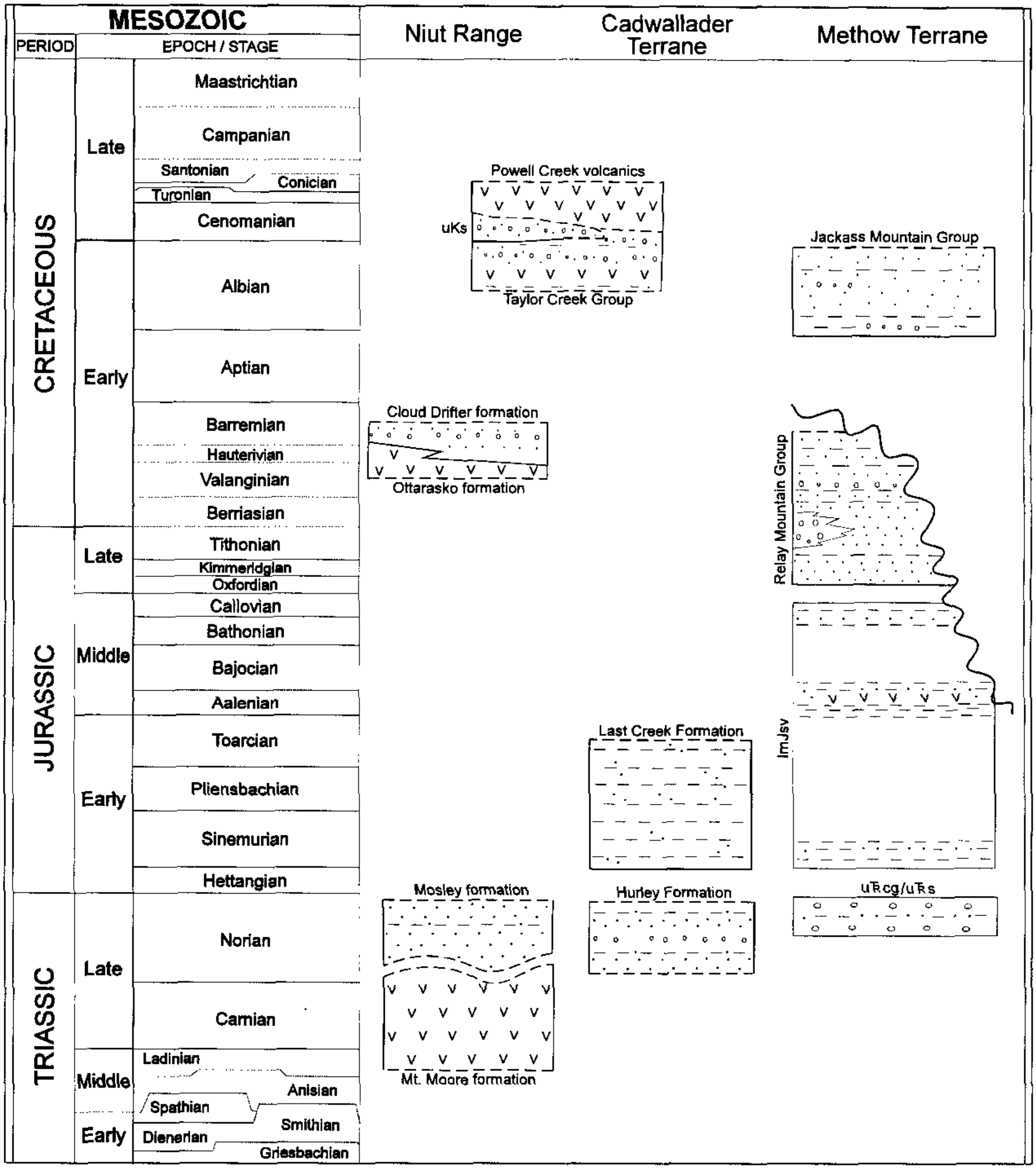

Figure 4. Main tectonostratigraphic assemblages of the eastern Coast Belt in the vicinity of the map area.

Lake, and against the Methow domain to the west of the lake (Figure 3).

The Intermontane Belt is characterized by subdued topography and sparse bedrock exposure. Pre-Neogene strata within and north of the Tatlayoko Lake map area comprise volcanic and volcaniclastic rocks that have been correlated with the Lower to Middle Jurassic Hazelton Group of the Stikine Terrane (Tipper, 1969a,b). To the west these rocks are juxtaposed against penetratively deformed metasedimentary, metavolcanic and metaplutonic rocks of the Tatla Lake Metamorphic Complex across an east to northeast-dipping normal fault. This fault formed late in the structural history of the complex, which was ductilely sheared and exhumed in Eocene time, possibly in a structural regime linked to dextral movement along the Yalakom fault (Friedman and Armstrong, 1988).

To the southeast is a belt of mainly Cretaceous sedimentary and volcanic rocks that extends from the Taseko River to the Fraser River. Near the Fraser River this belt comprises Lower Cretaceous volcanic rocks of the Spences Bridge Group and an overlying succession of Middle to Upper Cretaceous sedimentary and volcanic rocks (Green, 1990; Hickson, 1992). At the west end of the belt, Riddell *et al.* (1993a) correlated the sedimentary rocks along the Taseko River with the Lower Cretaceous Jackass Mountain Group, but did not speculate on the age or correlation of associated volcanic rocks, which in part host the Fish Lake porphyry copper-gold deposit. Fossils collected by Riddell *et al.* from a part of the sedimentary succession, and also from argillite apparently intercalated with the volcanic rocks near the Fish Lake deposit, have subsequently been assigned Hauterivian ages (J.W. Haggart, written communication 1992). This does not support correlation of this part of the sedimentary succession with the Jackass Mountain Group (mainly Aptian-Albian), but suggests that the volcanic-sedimentary succession in the Fish Lake area may be an offset equivalent of the Ottarasko and Cloud Drifter formations which occur in the Niut domain of the Coast Belt. This correlation suggests that a structure corresponding to the boundary between the Niut and Methow domains of the Coast Belt may also be present in the Intermontane Belt, within the area of extensive Neogene and Quaternary cover east of the Taseko River. The implied offset of the two corresponding boundaries would be consistent with the known offset along the Yalakom fault.

LITHOLOGIC UNITS

INTRODUCTION

Most of the Tatlayoko Lake map area is underlain by a tripart succession of mainly sedimentary rocks comprising Lower to Middle Jurassic rocks of unit lmJs, Upper Jurassic to Lower Cretaceous rocks of the Relay Mountain Group, and Lower Cretaceous rocks of the Jackass Mountain Group. The Relay Mountain Group is not present in the eastern part of the area, where it is inferred to have been eroded beneath a major sub-Jackass Mountain Group unconformity (Figure 4). This succession is assigned to the Methow Terrane based on the lithologic attributes of the Middle Jurassic and upper Lower Cretaceous rocks. Triassic sandstones and calcarenites of unit uTrs apparently underlie the succession along Tatlayoko Lake and are also tentatively included in Methow Terrane, as are conglomerates of probable Triassic age (unit uTrcg) that outcrop in the northwest corner of Methow domain.

West of Tatlayoko Lake, Methow Terrane is juxtaposed against volcanic, sedimentary and plutonic rocks of the Niut domain (units Nvs and Nqd) by a system of north to northwest-striking faults (Figure 5). The volcanic and sedimentary rocks in this area were assigned to the Lower Cretaceous by Tipper (1969a), but none of the rocks are dated and alternatively may correlate with the Triassic volcanic, sedimentary and plutonic rocks recently recognized by Mustard and van der Heyden (1994) a short distance to the northwest.

A belt of rocks assigned to the Cadwallader Terrane, including the Upper Triassic Hurley Formation and the Lower to Middle Jurassic Last Creek formation, was mapped by Riddell *et al.* (1993a,b) on the slopes south of the Nemaia valley directly east of the southern Tatlayoko Lake map area. Isolated exposures of clastic sedimentary rocks south of Nemaia Creek and along the Chilko Lake shoreline south of the creek's outlet are here assigned to these two formations. This belt of Cadwallader terrane rocks is inferred to be separated from Methow Terrane to the north by the pre-Yalakom Konni Lake fault (Riddell *et al.*, 1993a).

Upper Cretaceous clastic sedimentary rocks and overlying volcanic rocks of the Powell Creek formation outcrop in the mountains south of the Nemaia valley, where they form part of a Cretaceous belt that is separated from Cadwallader Terrane to the north by a prominent system of faults that locally includes a wedge of Bridge River Complex (Riddell *et al.*, 1993a,b). The Powell Creek formation also oucrops in the Niut domain west of Tatlayoko Lake, where it is separated from units Nvs and Nqd to the north by the Tchaikazan fault.

Bedrock exposures northeast of the Yalakom fault are sparse and consist mainly of andesitic breccias, tuffs and flows, together with gabbroic to dioritic intrusive rocks. These rocks are inferred to be Jurassic in age following Tipper (1969a), and are designated as unit Jv. Flat-lying basalt flows of the Neogene Chilcotin Group (unit MPCv) outcrop locally east of the Chilcotin River.

METHOW TERRANE

UPPER TRIASSIC ROCKS ALONG TATLAYOKO LAKE (UNIT uTrs)

An isolated exposure of Upper Triassic sedimentary rocks occurs on a low knoll along the east shore of Tatlayoko Lake, 4.5 kilometres south of the north end of the lake. Small exposures of sandstone on the opposite side of the lake are also tentatively included in this unit. The eastern exposure is dominated by thin to medium-bedded, locally crossbedded calcarenite and fossil hash, intercalated with brownish weathered, fine to coarse-grained green lithic sandstone. Calcarenite units are locally pebbly, with rounded intermediate to felsic volcanic clasts and rare subangular to subrounded granitoid pebbles. Thin beds of grey siltstone are intercalated with the lithic sandstone, and medium beds of dark grey, light grey weathering micritic limestone are intercalated with sandstone and siltstone over several metres in the lower part of the unit. The base of the unit consists of about 10 metres of light grey, coarse-grained quartzofeldspathic sandstone and granule conglomerate passing downwards into pebble conglomerate comprising angular granitoid clasts in an arkosic matrix. This basal interval is underlain by a quartz-pyrite-altered granitoid rock that is exposed along the shoreline in the southwestern part of the outcrop. The contact was observed over only a short interval, where it appeared to be a nonconformity across which the sedimentary interval was deposited on top of the altered intrusive rock.

Tipper (1969a) reports that fossils collected from unit uTrs on the east side of Tatlayoko Lake were examined by E.T. Tozer and assigned a Late Triassic, probably late Norian age. We infer that these Triassic rocks occur stratigraphically beneath the Jurassic rocks of unit lmJs,

Photo 1. Conglomerate of unit uTrcg, north of Skinner Creek.

but as the closest outcrops of the respective units are separated by more than a kilometre of Quaternary cover, such a relationship is not proven.

SKINNER CREEK CONGLOMERATE (UNIT uTrcg)

A distinctive assemblage of maroon conglomerates, with lesser amounts of finer grained sedimentary rocks and rare volcanic rocks, outcrops in an east to southeast-trending belt between the Homathko River and Choelquoit Lake (Figure 5). The main belt is bounded by the Yalakom fault to the northeast, intrusive rocks of the Mount Skinner Complex to the south, and an inferred north-striking fault to the west that separates it from exposures of Jackass Mountain Group in the Homathko River valley. However the conglomerates also occur as a thin sliver west of the Mount Skinner Complex, near the Skinner mine; this sliver is in stratigraphic or fault contact with unit lmJs to the southeast.

The dominant rock type within unit uTrcg is maroon, locally green, poorly stratified pebble to cobble conglomerate containing mainly intermediate to felsic volcanic clasts (Photo 1). These include common porphyritic varieties containing feldspar or feldspar and quartz phenocrysts. Fine to medium-grained granitoid clasts are commonly present, but typically comprise only a few percent or less of the clast population. Clasts of fine-grained clastic sedimentary rock and limestone occur locally. Clasts are typically angular, poorly sorted and either supported by, or gradational into a sandy to gritty matrix containing feldspar, quartz and lithic grains. The conglomerates are generally coarser in the northern part of the belt, where clasts locally range up to 40 centimetres across.

Sandstone and siltstone are intercalated with conglomerate throughout the belt, but are most common in the southeast. Green, brown or purple sandstones to pebbly sandstones occur mainly as poorly stratified lenses or layers that grade into conglomerate, whereas grey to purple siltststone and argillite commonly occur as distinct thin-bedded intervals, up to several metres thick, between conglomerate units. Locally, fine-grained sandstone to siltstone occurs as thin graded beds with argillite tops. Dark grey to purplish brown micritic limestone is seen rarely as medium to thick beds intercalated with argillite, or as lenses to a few metres thick within conglomerate.

Volcanic rocks are not common within unit uTrcg, but purple tuff, comprising feldspar crystals and angular volcanic fragments in a fine-grained matrix, was observed in one outcrop at the west end of the belt. Purple welded tuff occurring as an embayment or screen within the Mount Skinner Igneous Complex 2.8 kilometres west-northwest of Mount Skinner is also thought to be part ofthe unit.

Unit uTrcg is not dated, but is provisionally assigned to the Triassic following Tipper (1969a), as it is lithologically more similar to Upper Triassic rocks of the region than to younger rocks. Samples of limestone collected from the unit will be processed for conodonts in an attempt to confirm this inferred Triassic age.

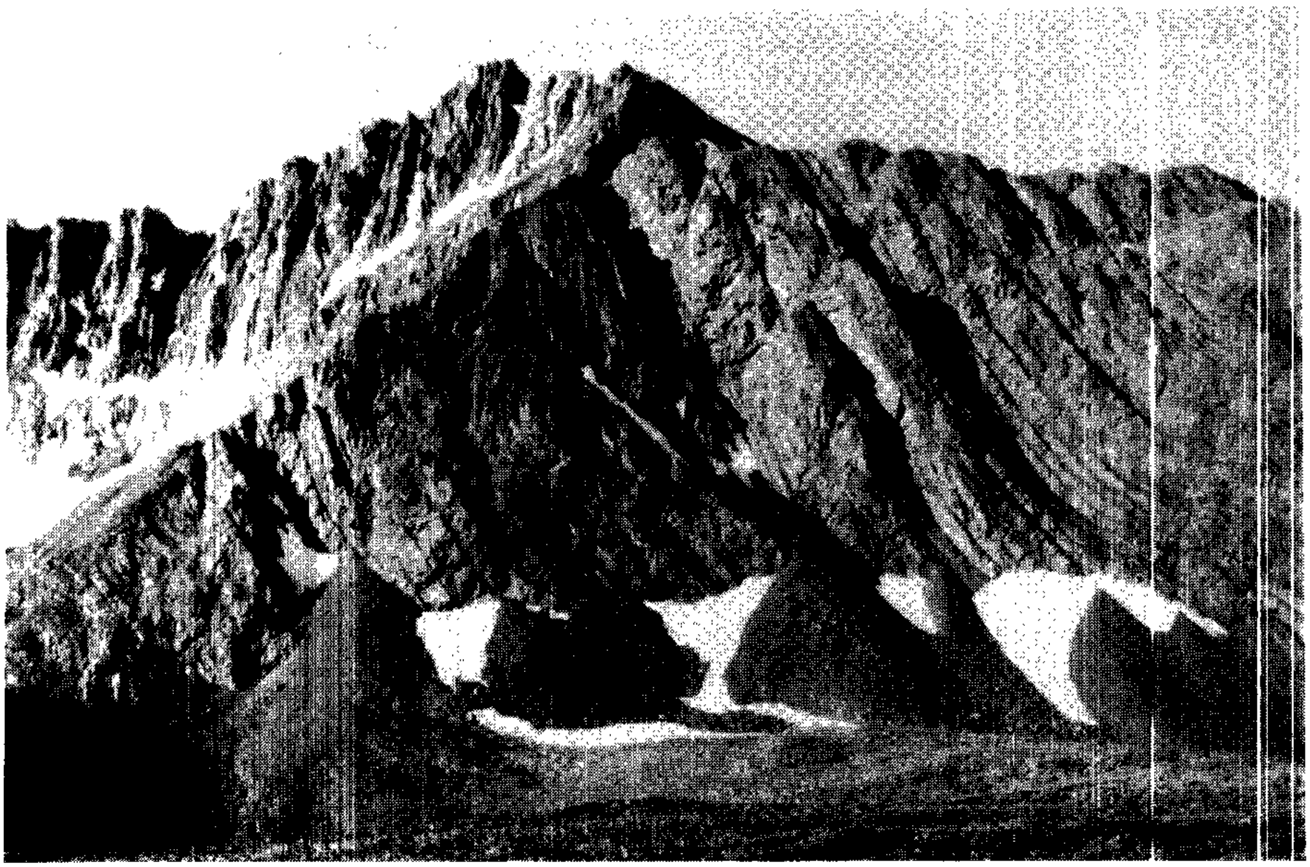

Photo 2. Looking southwest at well stratified sandstones and shales of unit lmJs, west of Mount Nemaia.

LOWER TO MIDDLE JURASSIC ROCKS (Unit lmJs)

Lower to Middle Jurassic clastic sedimentary and local volcanic rocks assigned to unit lmJs comprise the most widely distributed map unit in the Tatlayoko Lake area (Figure 5). These rocks correspond to unit 8 of Tipper (1969a) who reported fossils of Early Jurassic, Aalenian, Bajocian and Callovian age. The Lower Jurassic to Bajocian part of the assemblage was briefly described and designated the Huckleberry formation by Umhoefer and Tipper (1991), who inferred that it was a conformable sequence of early Sinemurian to early Bajocian age. Overlying Callovian rocks were not included in the formation, as they were inferred to be separated from underlying Bajocian strata by a major disconformity. The Callovian strata are presently being studied by B. Jennings as the basis for a B.Sc. thesis at the University of Victoria. They are included within unit lmJs on Figure 5 as they are lithologically very similar and cannot be confidently separated out in areas where fossil control is lacking.

Unit lmJs is characteristically a very well stratified succession that includes fine-grained clastic rocks intercalated with varying proportions of well indurated coarse-grained sandstone, gritty to pebbly sandstone, and granule to small-pebble conglomerate (Photo 2). Finer grained intervals are typically thin-bedded, laminated to crosslaminated siltstone and fine-grained sandstone, with scattered thin to thick beds of grey shale and fine to medium-grained lithic sandstone. Medium beds of laminated to crosslaminated calcareous siltstone or silty limestone occur locally. Coarser grained units are dominated by well indurated coarse-grained sandstones to gritty sandstones that occur as medium to very thick, locally graded beds. The coarse sandstones consist mainly of volcanic lithic fragments and feldspar, although quartz is locally an important component. Granule to small-pebble conglomerates occur locally as very thick, massive or weakly graded beds that are most commonly associated with intervals of coarse-grained sandstone, but also occur as isolated layers within siltstone-dominated sections. Conglomerate beds are typically dominated by intermediate to felsic volcanic clasts, and commonly include abundant shaly rip-up clasts. Limestone clasts and belemnite fragments are important constituents of some conglomerates, and rarely are the dominant clast types.

Volcanic rocks are not common in unit lmJs, but were observed in several widely scattered localities. The most extensive exposures are within the isolated set of outcrops along the west side of the north end of Tsuniah Lake (Figure 5). There, several tens of metres of volcaniclastic and volcanic rock occur within an interval dominated by massive to thick-bedded sandstones and gritty sandstones typical of the unit. The base of the volcanic section is marked by about 10 metres of poorly sorted breccia or conglomerate containing angular to subrounded clasts up to 40 centimetres in size. The clasts are almost exclusively intermediate to felsic volcanic rocks; some with irregular jagged shapes indicating very little transport, and some with red cores and green rims. This

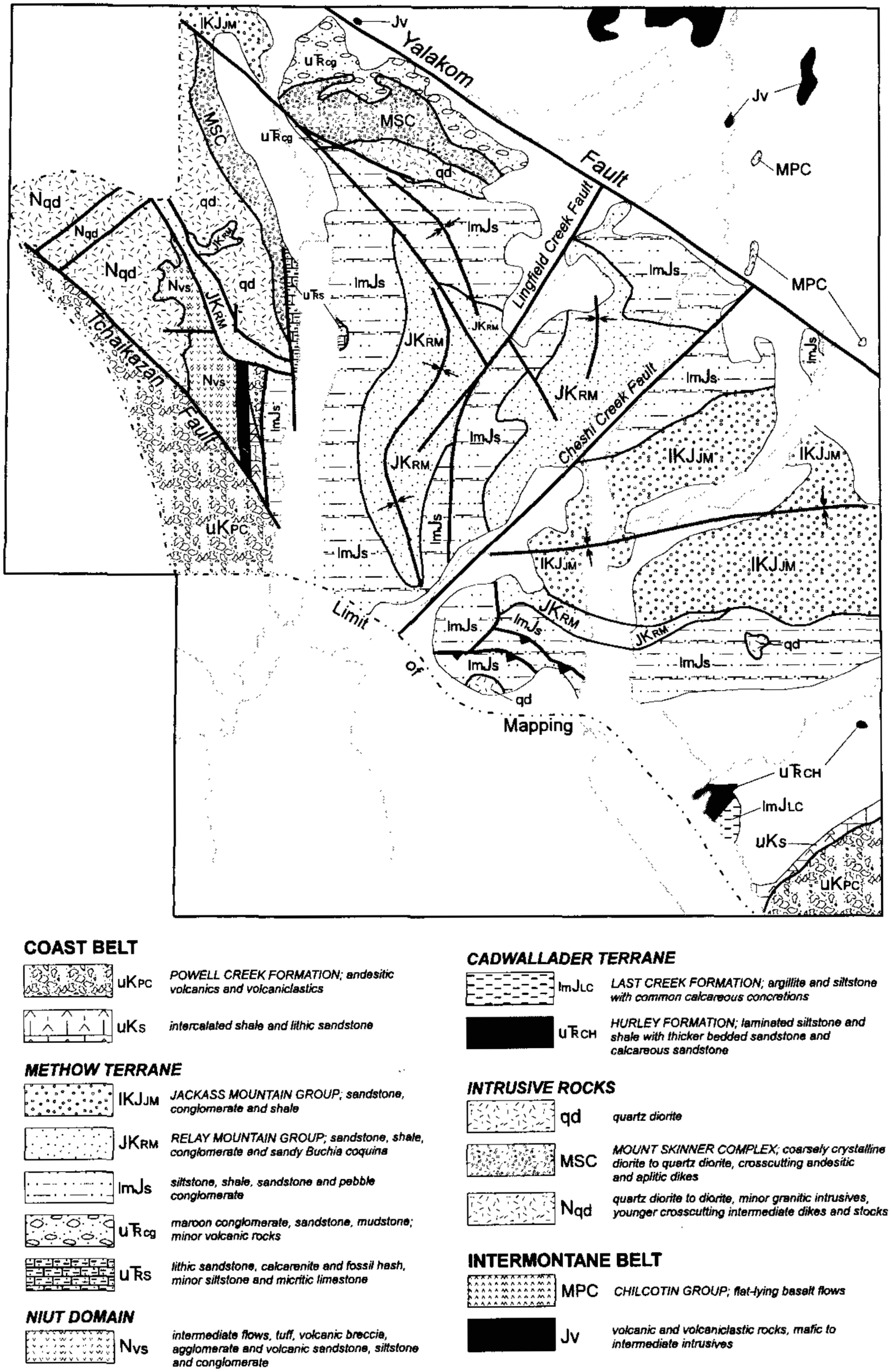

Figure 5. Generalized geology of the Tatlayoko Lake map area.

coarse-grained unit is overlain by a thicker section of poorly stratified tuffs consisting of intermediate, commonly feldspar-phyric volcanic fragments up to 3 centimetres across, together with feldspar and mafic crystals. Near the top of the tuff unit is a flow or sill consisting of feldspar and mafic phenocrysts, 1 to 2 millimetres in size, within a medium green aphanitic groundmass. The lower part of the tuff unit is a distinctive muddy tuff that consists of feldspar crystals with or without volcanic rock fragments floating in a fine-grained matrix. Similar matrix-supported tuff occurs as a layer 2 to 3 metres thick within intercalated sandstone and siltstone on the opposite side of the Tsuniah Lake syncline, directly south of Mount Nemaia. Farther east within this same belt, but apparently higher in the section, Riddell *et al.* (1993a) report an interval, less than 10 metres thick, of blue-green andesitic lapilli tuff and breccia. An interval of similar tuffs and breccias was mapped about 1.5 kilometres east of the north end of Tatlayoko Lake, and again 8.5 kilometres farther to the east, west of Lingfield Creek. These occurrences may be at about the same stratigraphic level, on opposite limbs of the Potato Range syncline.

A number of fossil collections were made from unit lmJs during the 1994 field season, but have not yet been identified. Lower Jurassic rocks are presently known to occur only in the northwestern corner of the belt, east of the Homathko River. There, early Pliensbachian fossils were collected from an interval of siltstones, sandstones and granule conglomerates (Umhoefer and Tipper, 1991). The base of the unit is not exposed, but the occurrence of these oldest-known rocks in the same area where known and inferred Triassic rocks of units uTrcg and uTrs occur suggests that the Triassic rocks may be stratigraphically beneath the Jurassic section. Most of the dated rocks included in unit lmJs are of Middle Jurassic age. An Aalenian fossil collection came from the vicinity of Huckleberry Mountain, and Bajocian fossils are known from several locations east of Tatlayoko Lake and on the south limb of the Tsuniah Lake syncline (Tipper, 1969a; Umhoefer and Tipper, 1991; Riddell *et al.*, 1993a).

Fossiliferous Callovian rocks were identified on the south limb of the Tsuniah Lake syncline by Tipper (1969a); correlative rocks may occur elsewhere at the top of unit lmJs, but have not been dated. The best exposures of known Callovian strata occur on the ridge system west of Mount Nemaia. A section measured by B. Jennings in the western part of this belt comprises 430 metres of strata that disconformably overlie rocks of Bajocian age, and are in turn disconformably(?) overlain by Upper Jurassic rocks of the Relay Mountain Group. The base of this section is marked by a prominant pebble conglomerate unit containing subangular to subrounded felsic volcanic clasts. The first 220 metres are mostly massive to graded beds of medium to coarse-grained volcanic sandstone with interbeds of laminated mudstone and siltstone. The sequence then changes to one of dominantly siltstones and very fine grained sandstones interbedded on the scale of 0.5 to 1 metre. The upper part of the unit includes 70 metres of medium to coarse-grained volcanic sandstone beds that grade into laminated siltstones and shales, overlain by 25 metres of fine to very fine grained sandstone and laminated shale at the top of the section.

RELAY MOUNTAIN GROUP

Upper Jurassic to Lower Cretaceous marine and nonmarine clastic sedimentary rocks in the Tatlayoko Lake map area were assigned to the Relay Mountain Group by Tipper (1969a). They are best exposed in the core of a syncline in the Potato Range, but also outcrop along northern Chilko Lake and Tullin Mountain, and as a narrow belt that extends from the western Nemaia Range westward across Chilko Lake to Cheshi Creek (Figure 5). Upper Jurassic conglomerate and associated finer grained clastic rocks that outcrop west of Tatlayoko Lake were assigned to a separate unit by Tipper (his units 11 and 12) but are here also included in the Relay Mountain Group.

The Relay Mountain Group ranges in age from late Oxfordian - early Kimmeridgian (Late Jurassic) to late Hauterivian - Barremian (Early Cretaceous) based on locally abundant *Buchia* and inoceramid pelecypods and uncommon ammonites. It overlies unit lmJs across an inferred disconformity that, where observed at the south end of the Potato Range and on the ridge system west of Mount Nemaia, is marked by a thin layer of belemnite coquina. The upper part of the group is missing in the western part of the southern limb of the Tsuniah Lake syncline, where Upper Jurassic Relay Mountain Group is overlain by the upper Lower Cretaceous Jackass Mountain Group. Farther east, and on the north limb of the syncline, the entire Relay Mountain Group is missing and the Jackass Mountain Group rests directly on unit lmJs. Presumably the Jackass Mountain Group once overlay the Lower Cretaceous Relay Mountain Group farther west, but nowhere are strata exposed above the youngest Relay Mountain Group in the Potato Range.

The Relay Mountain Group is on the order of 2400 metres thick in the Potato Range. The Upper Jurassic part of the group consists of about 900 metres of brown to green lithic sandstone and brown to black siltstone and mudstone with locally common marine fossils. Arkoses are present in the upper part of this sequence, which is interpreted to be off-shore marine and generally becomes shallower marine upward. It is gradationally overlain by 150 to 200 metres of interlayered lithic and arkosic sandstones that are unfossiliferous and were deposited in near-shore to marginal marine environments. The Jurassic-Cretaceous boundary is confined to this interval.

The Lower Cretaceous part of the Relay Mountain Group, about 1300 metres thick, consists mainly of dark green to black volcanic-lithic sandstones up to a few hundred metres thick with local planar laminae and low-angle cross-laminae. These sandstones are intercalated with sandy *Buchia* coquina sequences up to 140 metres thick. The coquinas are shell supported and consist of subequal amounts of fragmented, disarticulated, and whole articulated *Buchia*, with local beds of shell hash and fine-cobble volcanic and plutonic conglomerate. Both the volcanic-lithic sandstones and coquinas have rare belemnites, ammonites, and inoceramid fossils and are

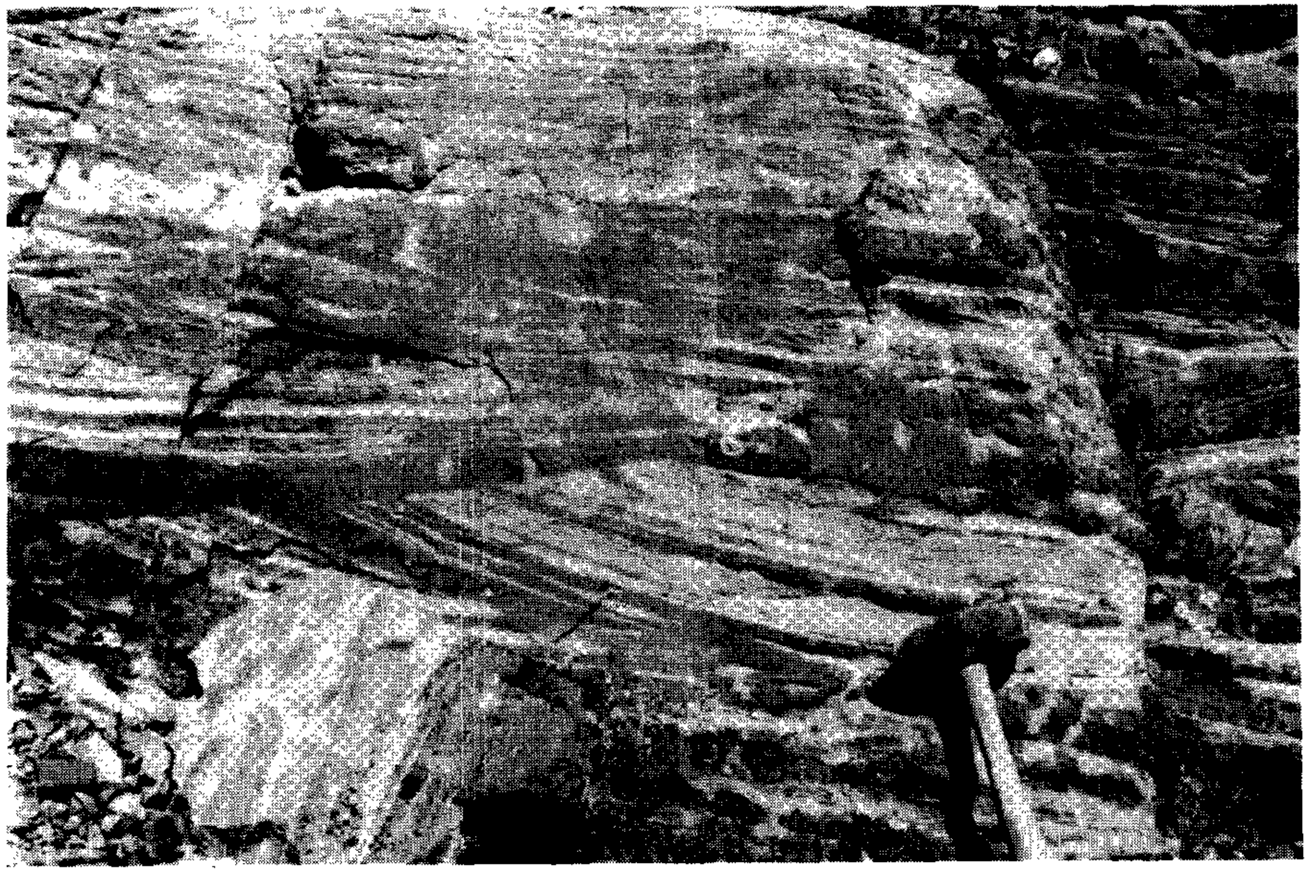

Photo 3. Crossbedded Hauterivian or Barremian lithic arkoses, upper Relay Mountain Group, northwest Potato Range.

interpreted to be shallow marine. Another common lithofacies in the Lower Cretaceous section is beige to green (commonly alternating) arkosic sandstone, tens of metres thick, most of which is interpreted to be fluvial deposits. The arkose locally has moderate to high-angle crossbeds and trough crossbeds (Photo 3), is commonly plant rich and has rare root casts. Arkoses are commonly interbedded with fissile black siltstones 1 to 5 metres thick, with plant fossils and wavy laminae. There are sparse 5 to 20-metre beds of clast-supported, mostly massive pebble to cobble conglomerate with rare plant fossils and local imbrication, that are interpreted to be fluvial channel deposits. The lower half of the Lower Cretaceous Relay Mountain Group in the Potato Range has been dated with *Buchia* and mixed inoceramid and ammonite assemblages to be Berriasian to late Hauterivian, with early to middle Hauterivian strata missing across a disconformity (Tipper, 1969a). The upper half of the Lower Cretaceous consists of unfossiliferous shallow marine and nonmarine strata, which are inferred to be mainly Barremian, because they lie conformably over the latest Hauterivian marine section.

The rocks mapped as Relay Mountain Group west of Tatlayoko Lake occur as a narrow northwest-trending belt that is in fault contact with volcanic and sedimentary rocks of Niut domain to the southwest, and with a large mass of undated quartz diorite to the northeast. A pendant of hornfelsed siltstone and sandstone within the quartz dorite body is also tentatively assigned to the group. The main belt of rocks includes conglomerates, sandstones and shales that are cut by numerous faults and intruded by abundant sills and plugs of quartz diorite. An intact section along the northeast margin of the belt, 3.5 kilometres west of Tatlayoko Lake, includes about 300 metres of conglomerate and arkosic lithic sandstone, abruptly overlain by a dark grey shale unit containing *Inoceramus* and belemnite fragments. This passes up-section into about 100 metres of thin to medium-bedded, locally crossbedded arkosic sandstone intercalated with siltstone and friable shale. Conglomerate dominates about 100 metres within the lower unit (Photo 4), and contains rounded pebbles and cobbles of felsic to mafic volcanic rocks together with a smaller proportion of granitoid rock. *Buchia* fossils are scattered throughout this lower unit, and have been identified as Upper Jurassic forms (Tipper, 1969a). The upper unit is not dated, but these rocks are lithologically very similar to the Hauterivian and(?) Barremian portion of the upper Relay Mountain Group in the adjacent Potato Range. In particular, the fossiliferous shale at the base of the interval is almost identical to the rocks directly above the Hauterivian disconformity in the Potato Range. The apparent absence of Berriasian and Valanginian rocks in the Niut Range belt suggests that here the disconformity represents much more missing section. This, in combination with the coarse-grained nature of the Jurassic rocks, suggests that the Niut Range section originated near the margin of the Relay Mountain basin, as proposed by Jeletzky and Tipper (1968).

Photo 4. Upper Jurassic conglomerate, Relay Mountain Group, northeastern Niut Range.

JACKASS MOUNTAIN GROUP

Clastic sedimentary rocks of the Lower Cretaceous Jackass Mountain Group are well exposed in the core of the Tsuniah Lake syncline, in the eastern part of the map area (Tipper, 1969a; Kleinspehn, 1985). Rocks provisionally included in the group also outcrop in the northwestern corner of the map area, within and adjacent to the Homathko River valley. Stratigraphic relationships are well displayed only in the former area, where the group is stratigraphically above unit lmJs and, locally, an intervening sliver of Relay Mountain Group.

The Jackass Mountain Group in the Tsuniah Lake syncline (Photo 5) comprises a thick succession of sandstones, with subordinate finer and coarser grained rocks. The sandstones are medium green to bluish green in colour, and typically weather light brown to brownish grey. They are predominantly medium to coarse grained, rich in feldspar, and commonly include scattered granules and small pebbles of volcanic, sedimentary and less common granitoid rock fragments. The sandstones form massive intervals many tens of metres thick, or medium to very thick beds that are in part defined by intercalations of thin-bedded siltstone or fine-grained sandstone-shale couplets. Individual sandstone beds within the well bedded intervals are locally graded, with laminated tops and thin shaly caps; some beds display rip-ups, scours and load casts at their bases. Finer grained facies typically occur as relatively minor interbeds within coarse sandstone, but intervals of thin-bedded, planar to crosslaminated siltstone to fine-grained sandstone are locally more than 100 metres thick.

The basal part of the Jackass Mountain Group in the Tsuniah Lake syncline consists of dark grey, grey to brownish grey weathered splintery siltstone, which was assigned to the Taylor Creek Group by Tipper (1969a). It is underlain by fine to coarse-grained sandstone containing thin layers and lenses of pebble to cobble conglomerate (Photo 6). The siltstone unit is best exposed on the south limb of the syncline, where it is more than 500 metres thick, and has yielded fossils of early and middle Albian age (Jeletzky, 1968). The underlying sandstone-conglomerate unit is only a few tens of metres thick, and comprises massive to thick-bedded sandstones that enclose two or more lenses of conglomerate. The conglomerate units range up to 1 metre in thickness and contain rounded clasts of mainly intermediate volcanic rocks and massive to foliated granitoid rocks. This same two-fold division occurs on the north limb of the syncline, but there the siltstone unit is less than 200 metres thick and may pinch out to the east. The underlying sandstone-conglomerate unit is correpondingly much thicker than to the south; individual conglomerate units are rarely more than one metre thick, but they occur through more than 500 metres of section. The actual contact with underlying rocks of unit lmJs was observed at one place and is tightly constrained at three others over a 6-kilometre strike length on the north limb of the syncline. Although mapped as a fault by Tipper (1969a), it appears to be a stratigraphic contact throughout this length. There is no angular discordance with underlying Jurassic rocks in the western part of this belt, but to the east the Jurassic rocks are locally folded

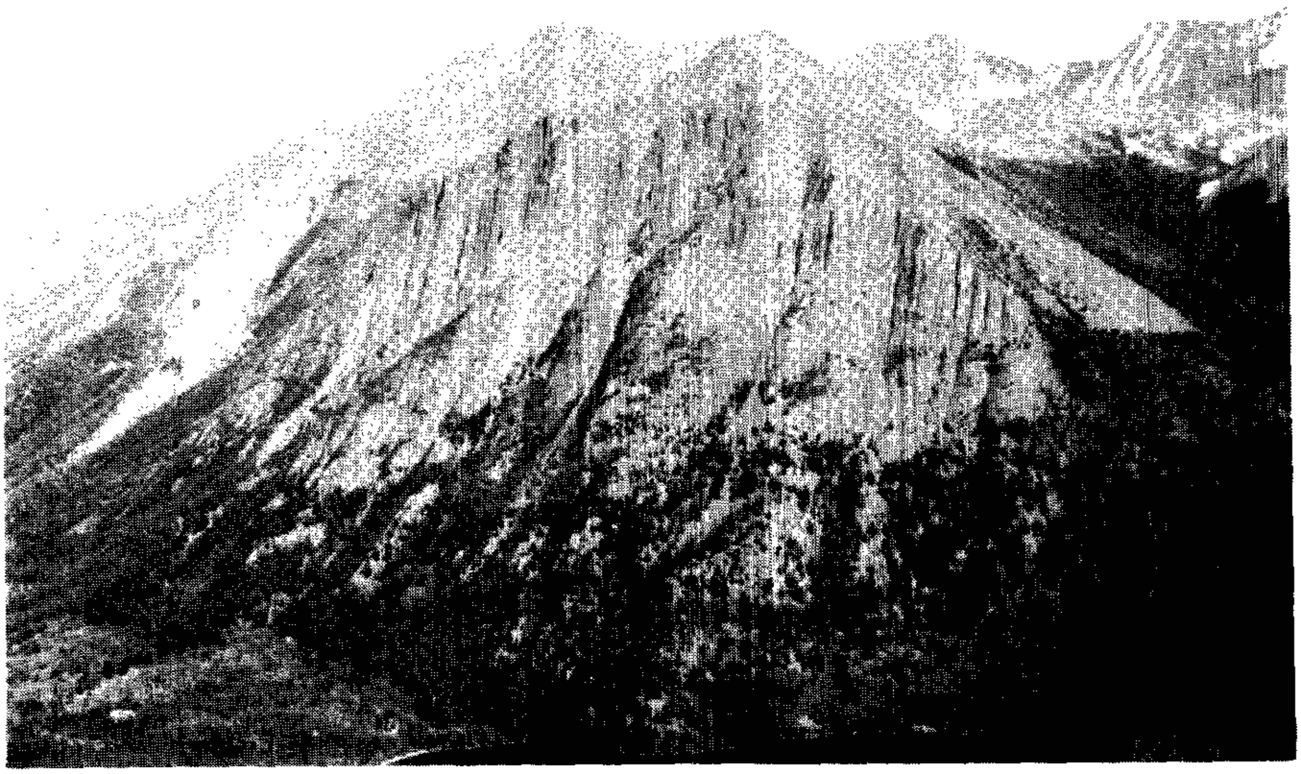

Photo 5. Looking east at Lower Cretaceous Jackass Mountain Group, south limb of Tsuniah Lake syncline, east of Chilko Lake.

and very gently dipping directly beneath the contact, whereas the overlying Cretaceous rocks maintain their moderate southward dips. The basal contact of the Jackass Mountain Group was not observed on the south limb of the syncline, but is constrained to within a few metres on the ridge system to the north-northwest of Mount Nemaia. Although this contact was mapped as a fault by Tipper (1969a), we saw no evidence for a fault along it, nor any angular discordance between the Cretaceous rocks and underlying rocks of unit lmJs. It was also mapped as a stratigraphic contact by Riddell *et al.* (1993a,b) to the east. The Jackass Mountain Group apparently rests above Upper Jurassic rocks of the Relay Mountain Group in the western part of the south limb of the Tsuniah Lake syncline. This contact was not observed, but as the Relay Mountain Group rests stratigraphically above the same Lower to Middle Jurassic basement as does the Jackass Mountain Group to the east, it is inferred to be stratigraphic, and to reflect eastward bevelling of the Relay Mountain Group beneath a sub-Jackass Mountain unconformity.

The fossiliferous shale unit that we include in the basal part of the Jackass Mountain Group was assigned to the Taylor Creek Group by Tipper (1969a), in part because he considered the Jackass Mountain Group to be predominantly nonmarine, and the Taylor Creek Group to be predominantly marine. Subsequent work, however, has established that the Jackass Mountain Group is predominantly marine (Jeletzky, 1971; Kleinspehn, 1985), and that the Jackass Mountain Group in the Camelsfoot Range includes a lithologically similar unit that is correlated with fossiliferous rocks of the Tsuniah Lake syncline because it contains the same early lower Albian *Brewericeras (Leconteites) lecontei* fauna (grey siltstone - shale division of Jeletzky, 1971). The Tsuniah Lake and Camelsfoot sections are inferred to have been continuous prior to offset along the Yalakom fault (Kleinspehn, 1985; Riddell *et al.*, 1993a). A major difference, however, is that the distinctive Albian rocks of the Jackass Mountain Group in the Camelsfoot Range are underlain by an interval of Barremian-Aptian rocks that are also included in the Jackass Mountain Group (Jeletzky, 1971; Schiarizza *et al.*, 1993b), but are not apparently represented in the Tsuniah Lake area.

The rocks tentatively assigned to the Jackass Mountain Group in the northwest corner of the map area comprise a poorly stratified succession of quartz and feldspar-rich sandstones, together with granule to cobble conglomerates. The conglomerates contain rounded clasts of intermediate to felsic volcanic and granitoid rocks, together with a smaller proportion of sedimentary and metamorphic rocks. This spectrum of clast types is similar to that found in conglomerates and conglomeratic sandstones of the Jackass Mountain Group in the Tsuniah Lake syncline. Two collections of macrosfossils from the northwestern outcrop belt may either confirm or refute their correlation.

NIUT DOMAIN

Volcanic and sedimentary rocks that are exposed in the eastern part of Niut domain are assigned to unit Nvs

Photo 6. Conglomerate, basal Jackass Mountain Group, western Nemaia Range.

(Figure 5). This assemblage is dominated by intermediate flows, tuffs and breccias with local occurrences of agglomerate and felsic tuff. Sedimentary rocks include conglomerates, sandstones and shales that are at least in part intercalated with the volcanic rocks. Volcanic and sedimentary rocks throughout Niut domain are commonly altered to an assemblage dominated by quartz and epidote, with less common carbonate, chlorite and pyrite.

An east to northeast-striking succession of generally unknown dip and facing direction that is exposed on the ridge east of lower Jamison Creek provides a partial section that includes many of the rocks characteristic of unit Nvs. The southern part of the ridge, between 1430 and 1980 metres elevation, comprises massive green, greenish brown to rusty brown weathered andesitic flows and flow(?) breccias. The andesites commonly contain hornblende and feldspar phenocrysts, 1 to 2 millimetres in size, and locally are pyroxene phyric. They pass gradationally up-slope into a succession of andesitic breccias and tuffs intercalated with a relatively minor proportion of massive flows and/or sills. The fragmental rocks typically comprise angular clasts of green to purple hornblende-feldspar and pyroxene-feldspar-phyric andesite within a matrix of smaller lithic grains and feldspar, hornblende and pyroxene crystals. Volcanic rock fragments are typically 1 to 3 centimetres or less in size, but range up to 10 centimetres in some coarse-grained units. Stratification is generally not apparent, but bedding is locally defined by thin interbeds of shale, epiclastic sandstone or fine-grained crystal-lithic tuff.

The fragmental volcanic rocks pass up-slope into an assemblage of more heterolithic sedimentary conglomerates and breccias that are well exposed between 2050 and 2150 metres elevation. The conglomerates contain a wide variety of felsic to mafic volcanic rock fragments, including abundant quartz and quartz feldspar porphyries. They also include recessive weathering fine-grained sedimentary(?) clasts and uncommon medium-grained granitoid fragments. The conglomerates are not conspicuously stratified and the poorly sorted angular clasts, which range up to 12 centimetres in size, grade into a gritty sandstone matrix that includes quartz, feldspar and volcanic-lithic grains. Light green, fine to coarse-grained lithic sandstone and grey shale form local intercalations within the coarser grained rock.

The rocks higher up on the ridge are strongly altered, but seem to include both clastic sedimentary rocks (sandstones and conglomerates) as well as volcanic breccias and andesitic flows. However, the stratigraphic relationships of these rock units to each other, or to the apparently intact section lower down on the ridge, is uncertain due to the masking effects of the alteration, and the presence of east-striking faults of uncertain displacement.

Elsewhere in the Niut domain, rocks assigned to unit Nvs consist mainly of andesitic flows, tuffs and breccias similar to those exposed along the lower part of the ridge east of Jamison Creek. In the northern part of the belt, these volcanic rocks enclose an apparently conformable succession of conglomerates and volcanic breccias, up to 300 metres thick, that has been traced for about 4 kilometres in a north-northwest direction. The conglomerates are generally purple in colour and contain poorly sorted, rounded to subrounded clasts that range from less than a centimetre to more than 20 centimetres across. The clasts include a variety of volcanic, plutonic and sedimentary rock types, and grade into a coarse sandstone matrix of similar composition. This conglomerate interval may correlate with the conglomerates exposed east of lower Jamison Creek, but the clasts are larger and more rounded.

CADWALLADER TERRANE

Rocks provisionally assigned to the Hurley Formation (unit uTrCH) in the Nemaia valley include thin-bedded, light and dark grey laminated siltstones and shales, together with thin to thick, locally graded beds of fine to coarse-grained sandstone and calcareous sandstone. They resemble much of the Hurley Formation to the east, but do not include the limestone and limestone-bearing conglomerate lenses that are most diagnostic of the formation. Dark grey argillite and siltstone with common calcareous concretions make up the southern part of the outcrop belt along the Chilko Lake shoreline. These rocks are assigned to the Last Creek formation (unit lmJLC), as the transition to predominantly argillaceous rocks with few coarser interbeds is characteristic of the Hurley - Last Creek contact directly to the east (Riddell *et al.*, 1993a,b), and in the correlative Camelsfoot belt (Schiarizza *et al.*, 1993b). Ammonites collected from this unit may provide additional constraints on its age.

UPPER CRETACEOUS SEDIMENTARY AND VOLCANIC ROCKS

UPPER CRETACEOUS SEDIMENTARY ROCKS (UNIT uKs)

Clastic sedimentary rocks of probable Middle to Late Cretaceous age underlie volcanic rocks of the Powell Creek formation on the south side of the Nemaia valley. The sedimentary section is dominated by intercalated dark grey to purple shale and brownish weathered, grey to green lithic sandstone. The sandstone is fine to coarse grained, and occurs as thin to very thick beds that are locally laminated or crosslaminated; woody debris is common in some beds. The interval also includes medium beds of light grey, commonly crossbedded arkosic sandstone, and medium to thick beds of chert-rich pebble conglomerate. The abrupt transition to overlying volcanic breccias of the Powell Creek formation occurs over a 30-metre interval of green sandstone intercalated with friable dark grey silty shale. Sandstone at the base of this unit is predominantly feldspar-lithic wacke, and encloses an interval of chert pebble conglomerate 2 metres thick. Higher in the section, sandstone beds also contain conspicuous hornblende and pyroxene crystals and are intercalated with beds of pebbly sandstone and pebble conglomerate that include clasts of pyroxene-feldspar and hornblende-feldspar-phyric volcanic rocks typical of those found in the overlying volcanic breccias of the Powell Creek formation.

Unit uKs is probably equivalent to an interval of nonmarine sedimentary rocks identified by Maxson (1992; written communication 1994) a short distance to the east in the Mount Tatlow map area. This interval was not mapped as a separate unit by Riddell *et al.* (1993a,b) who included it in the Taylor Creek Group which underlies it. Maxson assigns these rocks to the Silverquick formation, which, in its type area 90 kilometres to the southeast, comprises a thick succession of chert-rich conglomerates that in its upper part is gradational into overlying Powell Creek volcanic rocks (Garver, 1989, 1992). Although we follow Maxson's lithologic subdivisions for the area, we do not at present adopt the term Silverquick for these rocks, as we suspect that the underlying Taylor Creek Group (equivalent to the Beece Creek succession of Schiarizza *et al.*, 1993c,d) is largely a marine eqivalent of the Silverquick formation in its type area.

POWELL CREEK FORMATION

The Powell Creek formation (informal, Glover *et al.*, 1988) is a thick succession of Upper Cretaceous andesitic volcanic and volcaniclastic rocks. It overlies unit uKs across a gradational stratigraphic contact in the mountains south of the Nemaia valley, and also outcrops south of the Tchaikazan fault in the area west of Tatlayoko Lake. The formation was not examined in any detail in either of these two areas, but the exposures east of Chilko Lake are at the west end of an extensive outcrop belt that was described by Riddell *et al.* (1993a) in the Mount Tatlow map area to the east. Here it comprises two mappable divisions. The lower part of the formation consists of well stratified coarse volcanic breccias and conglomerates in beds ranging from a few metres to many tens of metres thick, that are in part separated by thin interbeds of purplish siltstone or epiclastic sandstone. This unit was tentatively assigned to the Silverquick formation by Riddell *et al.* (1993a), but was subsequently included in the Powell Creek formation (Riddell *et al.*, 1993b). Overlying rocks, which make up most of the formation, comprise a heterogeneous succession of andesitic flow breccias, crystal and ash tuffs, laharic breccias, flows and volcaniclastic sandstones and conglomerates.

INTRUSIVE ROCKS

Large, mappable plutonic bodies are restricted to the western part of the Tatlayoko Lake map area (Figure 5). They include the heterogeneous Mount Skinner Igneous Complex (unit MSC) and associated quartz diorite (unit qd) that occur within the Methow domain on either side of the Homathko River valley, as well as a large quartz diorite to diorite pluton (unit Nqd) exposed within Niut domain to the southwest. The only other intrusive bodies sufficiently large to be shown on Figure 5 are two small stocks of undated quartz diorite that intrude unit lmJs, one to the south of Huckleberry Mountain and one on the ridge directly west of Mount Nemaia. Dikes and sills are common throughout most of the area, however, and are particularly abundant in the vicinity of Huckleberry Mountain and to the southwest of Tullin Mountain, between the Lingfield Creek and Cheshi Creek faults. The dikes and sills are of a variety of compositions, the most common being fine-grained diorite, hornblende feldspar porphyry, and light grey felsite with or without quartz and feldspar phenocrysts.

The Mount Skinner Igneous Complex is an assemblage of intermediate plutonic rocks and associated mafic to felsic dikes that outcrops in an east-west belt centred near Mount Skinner, east of the Homathko River valley. It is dominated by medium to coarse-grained diorites and quartz diorites that seem to comprise at least two distinct phases. The apparently older component is a coarse-grained diorite to quartz diorite containing zero to 15% quartz, and characterized by strongly chlorite-epidote-altered mafic clots, and epidote-altered feldspars which give the rock a distinctive motttled appearance. The younger phase is a medium to coarse-grained hornblende quartz diorite that contains 20 to 35% quartz and is less altered. Associated with the diorites and quartz diorites are abundant finer grained mafic rocks that include discrete dikes and dike swarms of aphanitic basaltic rock, diabase and hornblende±feldspar porphyry, as well as irregular masses, to many tens of metres thick, of fine-grained dark greenstone that may be dike complexes or screens of older volcanic or dike rock within the plutonic rock. These mafic rocks are most common within the older dioritic rock, but also occur as relatively rare planar dikes, 10 to 100 centimetres wide, within the younger quartz diorite phase. Aplite dikes cut all of the aforementioned rock types and seem to be spatially associated with the younger quartz diorite. They range from 1 to 60 centimetres wide and contain tiny rounded quartz phenocrysts in a pinkish white, very fine grained sugary groundmass. Quartz feldspar porphyry, comprising 1 to 3-millimetre phenocrysts in a grey siliceous aphanitic matrix, was noted at one place within the complex, where it occurs as a number of metre-scale patches that are apparently intrusive into a surrounding zone of greenstone.

A preliminary U-Pb date on zircons from the older diorite to quartz diorite unit of the Mount Skinner Igneous Complex is Late Triassic (R. Friedman, personal communication 1994). The other components of the complex are undated, but a sample from the younger quartz diorite phase has also been submitted for U-Pb dating of zircons. This might be a slightly younger Late Triassic phase, or it might be considerably younger and related to Cretaceous and Tertiary plutonism that is documented in the region (van der Heyden *et al.*, 1994a). Along its northern margin, parts of the igneous complex are apparently intrusive into unit uTrcg, although the contact is not well exposed and only mafic and aplite dikes were actually seen to intrude this unit. The southern margin of the complex is in part a northwest-striking fault, and in part a body of biotite-hornblende quartz diorite to granodiorite that is mapped as a separate unit, although it may correlate with the younger quartz diorite phase of the complex. The contacts between this igneous body and adjacent map units were not observed, although it is presumed to intrude unit lmJs to the south.

An assemblage of igneous rocks similar to those of the Mount Skinner complex, with which they are tentatively correlated, outcrops on the slopes west of the north end of Tatlayoko Lake and the adjoining Homathko River valley (Figure 5). These rocks are in apparent fault contact with sedimentary rocks of unit uTrs to the east, and are bounded by a more homogeneous body of massive, coarse-grained hornblende quartz diorite to the west. This quartz diorite unit is in contact with Jura-Cretaceous sedimentary rocks of the Relay Mountain Group to the southwest, across a contact that, wherever observed, is a fault. However, as similar quartz diorite occurs as small plugs and sills intruding sedimentary rocks within the adjacent Relay Mountain belt, it is suspected that the large quartz diorite pluton is Cretaceous or younger in age.

An apparently separate quartz diorite to diorite pluton (unit Nqd) crops out farther to the southwest, within the fault-bounded Niut domain. It is in large part compositionally similar to the large intrusive body to the east and northeast, but locally grades into a quartz-poor hornblende diorite. This pluton intrudes volcanic and sedimentary rocks of unit Nvs which, together with the pluton, are also intruded by a suite of dikes and small plugs that includes fine-grained diorite, hornblende feldspar porphyry and pyroxene feldspar porphyry. Dike orientations are variable, but east or northeast strikes are most common. Small bodies of mafic-poor medium-grained granitic rock also occur locally within unit Nqd.

None of the intrusive rocks within Niut domain are presently dated. A sample of quartz diorite from the eastern part of unit Nqd has been submitted for U-Pb dating of zircons, and a hornblende feldspar porphyry plug within unit Nvs was sampled for K-Ar dating of hornblende. These dates will provide some control on the timing of plutonic activity in this area, and will also help constrain the age of the volcanic and sedimentary rocks within this part of the Niut domain. The possibility that unit Nqd is, at least in part, Late Triassic in age is suggested by a 215 Ma U-Pb zircon date from what is apparently the same pluton, just 4 kilometres northwest of the limit of our mapping (Mustard *et al.*, 1994).

LITHOLOGIC UNITS NORTHEAST OF THE YALAKOM FAULT

JURASSIC VOLCANIC ROCKS AND ASSOCIATED INTRUSIVE ROCKS

Rocks mapped as unit Jv on Figure 4 include volcanic and volcaniclastic rocks of probable Jurassic age, as well as a variety of mafic to intermediate intrusive rocks, some of which may be coeval with the volcanics and some of which are younger. The volcanic rocks include tuffs, breccias and volcanic conglomerates as well as andesitic flows. Fragmental volcanic rocks are poorly stratified and include angular green, red and purple aphyric and feldpar-phyric volcanic fragments, generally less than 5 centimetres across, in a silty to sandy matrix that commonly includes feldspar and mafic crystals as well as volcanic-lithic grains. Less common epiclastic rocks include compositionally similar volcanic conglomerates that are better stratified and include rounded clasts, as well as thin beds of feldspathic sandstone. Andesitic flow rocks are medium to dark green or mottled green and purple. They are fine to very fine grained, and locally contain small feldspar and less common mafic phenocrysts, as well as quartz-epidote amygdules.

Medium-grained, equigranular diorite and gabbro occur locally as poorly defined masses within andesitic volcanics and may be of broadly the same age. Medium-grained hornblende quartz diorite that outcrops at the southeast end of the western outcrop belt north of Choelquoit Lake is probably younger, as is a small stock of coarse feldspar porphyry exposed in the belt east of the Chilko River. Northeast and northwest-striking dikes of feldspar porphyry, hornblende feldspar porphyry and very fine grained mafic rock are common north of Choelquoit Lake, where they cut the volcanic rocks as well as a gabbroic intrusion.

CHILCOTIN GROUP

Flat-lying basalt flows of the Chilcotin Group (Tipper, 1978; Bevier, 1983) crop out locally on the slopes east of the Chilko River and on a low hill east of the north end of Tsuniah Lake. The basalts are dark to medium grey, orange-brown weathering, dense to highly vesicular, and locally contain olivine and plagioclase phenocrysts. Individual flows are typically a few metres thick and are commonly columnar jointed. These basalts are part of the southwestern margin of an extensive belt of Early Miocene to early Pleistocene plateau lavas that covers 25 000 square kilometres of the Interior Plateau of south-central British Columbia (Mathews, 1989).

STRUCTURE

THE YALAKOM FAULT

Leech (1953) first used the name Yalakom fault for a system of steeply dipping faults bounding the northeast margin of the Shulaps Ultramafic Complex along the Yalakom River, more than 100 kilometres southeast of the Tatlayoko Lake map area. The fault was subsequently traced northwestward through the Taseko Lakes and Mount Waddington map areas (Tipper, 1969a, 1978), and southeastward to the Fraser River (Duffell and McTaggart, 1952; Roddick and Hutchison, 1973; Monger and McMillan, 1989), for a total strike length of almost 300 kilometres. Within the Tatlayoko Lake map area, the Yalakom fault separates volcanic rocks of unit Jv on its northeast side from Triassic(?) and Jurassic sedimentary rocks of units uTrcg and lmJs to the southwest. The fault is not exposed, and its position is well constrained only along the northern edge of the map area, where it is inferred to separate outcrops of unit uTrcg from those of unit Jv north of Skinner Creek. This constraint, combined with the fault's established location to the southeast (Riddell *et al.*, 1993b) and northwest (Tipper, 1969; Friedman and Armstrong, 1988), indicates that it probably follows a linear west-northwest trace through the area, as indicated on Figure 5.

Tipper (1969a) postulated that the Yalakom fault system was the locus of 80 to 190 kilometres of right-lateral displacement, based on the regional distribution of volcanic *versus* sedimentary facies in Middle Jurassic rocks. A similar estimate of 150±25 kilometres was made by Kleinspehn (1985), who matched the Lower Cretaceous Jackass Mountain Group exposed on the southwest side of the fault at Tsuniah Lake with exposures on the northeast side of the fault in the Camelsfoot Range along Nine Mile Ridge. This estimate was revised by Riddell *et al.* (1993a), who postulated about 115 kilometres of dextral displacement based on the offset of a structural succession comprising Bridge River, Cadwallader and Methow terranes, the latter including the same belts of Jackass Mountain Group on which Kleinspehn's calculation was based.

The Yalakom fault displaces mid-Cretaceous and older rocks, and is overlapped by Neogene plateau lavas of the Chilcotin Group (Schiarizza *et al.*, 1993b,c,d; Riddell *et al.*, 1993b). Coleman and Parrish (1991) relate dextral shear within Bridge River schists and associated 46.5-48.5 Ma intrusions in the southern Shulaps Range to movement on the adjacent Yalakom fault, suggesting that at least some of the displacement was Eocene in age. Eocene movement is also indicated by relationships just to the north and northwest of the Tatlayoko Lake map area, where the Yalakom fault defines the southwestern boundary of the Tatla Lake Metamorphic Complex (Figure 3). Friedman and Armstrong (1988) document 55 to 47.5 Ma extensional shear along subhorizontal west-northwest-trending mineral lineations within the mylonite zone comprising the upper part of the complex, followed by folding and brittle faulting during the final stages of uplift. Although they implicate the Yalakom fault only in the post-ductile deformation phase of folding and brittle faulting, the earlier ductile strain is also kinematically compatible with dextral slip along the Yalakom system. The Yalakom fault has not been mapped beyond the Tatla Lake Complex but we infer that it, or a kinematically linked extensional fault segment, extends north-northwestward from there, along the Dean River, to mark the western limit of a belt of metamorphic tectonites that are locally exposed beneath an extensive cover of Quaternary alluvium and Late Tertiary volcanics (Figure 3; Tipper, 1969b). The right-stepping, extensional geometry of the system is consistent with the regional pattern of Eocene dextral strike-slip and associated extension that has been documented by numerous workers in the province, including Price (1979), Ewing (1980), Price and Carmichael (1986), Coleman and Parrish (1991) and Struik (1993).

STRUCTURE SOUTHWEST OF THE YALAKOM FAULT

METHOW DOMAIN EAST OF TATLAYOKO LAKE

The rocks of Methow Terrane between Tatlayoko Lake and the Nemaia valley are separated into three structural blocks by the northeast-striking Lingfield Creek and Cheshi Creek faults. The western block encompasses the Potato Range and adjacent mountains between Tatlayoko Lake and Lingfield Creek. The structure of this area is dominated by an open syncline cored by the Relay Mountain Group. The trace of the fold's axial surface is broadly Z-shaped, as it plunges north-northwest and south-southeast at its south and north ends, respectively, but trends north-northeasterly in the central part of the range. The fold is truncated by a prominent northwest-striking fault east of the north end of Tatlayoko Lake. Its probable continuation to the north is a tight syncline within unit lmJs, which shows 2 to 3 kilometres of dextral offset from the southern fold segment. The Potato Range fold deforms Barremian(?) and older rocks, and is cut by a northwest-trending dextral strike-slip fault that may be related to the Yalakom fault system. It is suspected that it is middle to early Late Cretaceous in age, as this was a period of major contractional deformation within the eastern Coast Belt (McGroder, 1989; Journeay and Friedman, 1993; Rusmore and Woodsworth, 1991b). The present sigmoidal trace of the fold may reflect rotation during later dextral strike-slip faulting (Umhoefer and Kleinspehn, 1994).

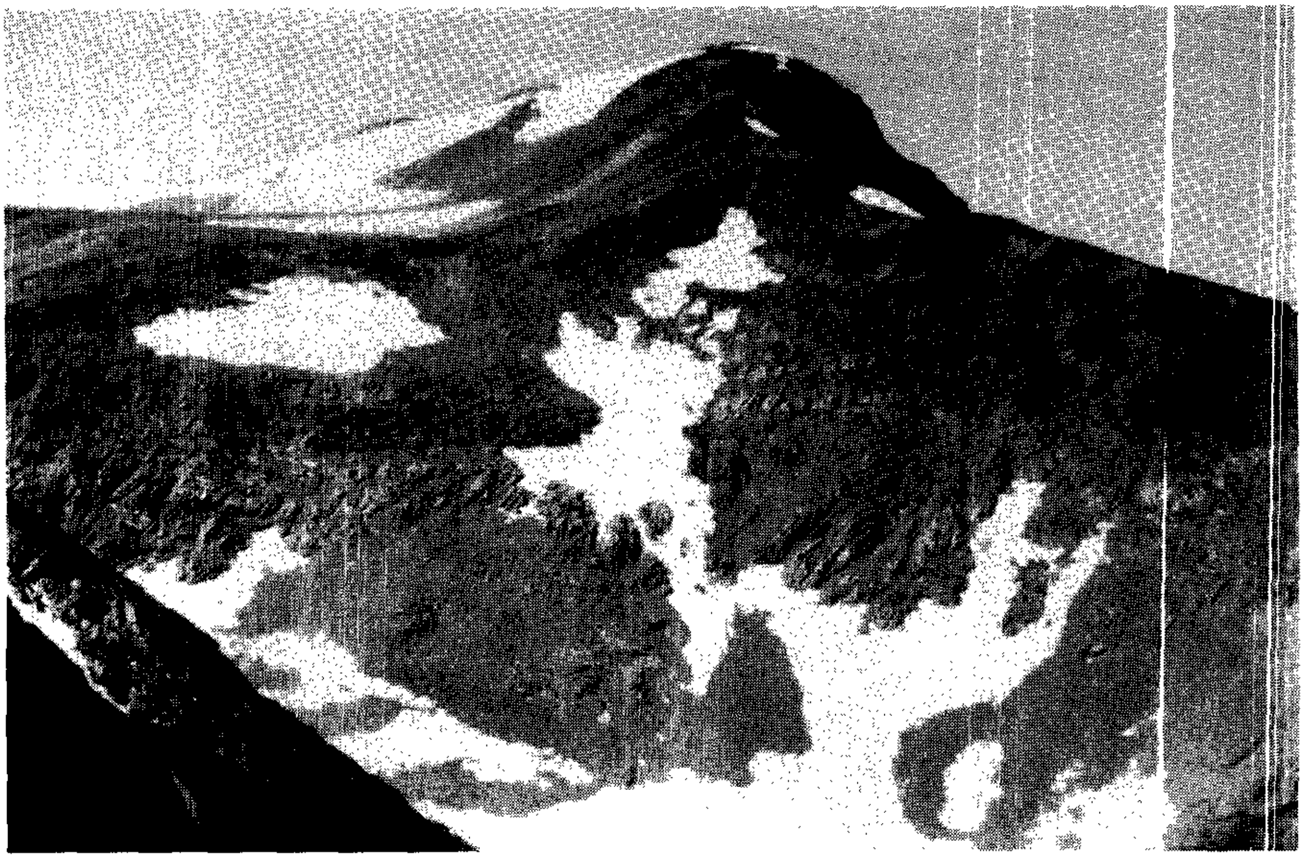

Photo 7. Looking west-southwest at overturned antiform in units lmJs, south limb of Tsuniah Lake syncline, west of Chilko Lake.

The structure of the Tullin Mountain area, between the Lingfield Creek and Cheshi Creek faults, is also generally synclinal in nature, as it includes Relay Mountain Group strata which are underlain by unit lmJs to both the northeast and west. A northerly trending syncline that is well defined by the internal stratigraphy of the Relay Mountain Group 1.5 kilometres southwest of Tullin Mountain, is apparently the dominant structure within this domain. A subsidiary anticline-syncline pair deforms the basal contact of the Relay Mountain Group into a Z-shape north of Tullin Mountain, and an S-shaped fold pair is outlined by the same contact to the southwest, on the opposite side of the main syncline. Just to the north of the latter area the contact is offset several hundred metres to a kilometre across a northwest-trending dextral strike-slip fault. If this fault correlates with the dextral fault north of the Potato Range, then it shows about 1.5 kilometres of apparent sinistral offset across the Lingfield Creek fault. Farther southwest, the Lingfield Creek fault apparently traces into a relatively minor northwest-side-down normal fault in the southern Potato Range, and the main displacement transfers to a south-striking splay that extends from the head of Lingfield Creek southward to the Cheshi Creek valley. This fault separates east-facing rocks of unit lmJs within the Tullin Mountain block from correlative west-facing strata on the east limb of the Potato Range syncline.

The strata southeast of the Cheshi Creek fault are disposed as a large, upright, gently east-plunging, open to closed syncline (the Tsuniah Lake syncline) that is truncated by the Yalakom fault to the east. The fold is cored by the Jackass Mountain Group, which is underlain by unit lmJs throughout most of the block, but by an intervening eastward-tapering sliver of Relay Mountain Group in the western part of its southern limb. West of Chilko Lake, unit lmJs on the southern limb of the fold is deformed by a series of south-dipping thrust faults and associated northerly overturned folds (Photo 7). The Tsuniah Lake syncline deforms the Albian Jackass Mountain Group and so is Late Cretaceous or younger in age. It is discordant to the more northerly trending folds to the west, suggesting that it may have formed in a different structural regime. The orientation of the fold is consistent with it having formed during dextral movement on the adjacent Yalakom fault (Wilcox *et al.*, 1973) this was predominantly an Eocene event, although older movement cannot be ruled out. The thrust faults and overturned folds on the south limb of the syncline may be older structures, but their age is not well constrained.

METHOW DOMAIN WEST OF TATLAYOKO LAKE

On the west side of Tatlayoko Lake, Methow domain is represented by narrow belts of units uTrs and lmJs along the shoreline, and by a northwest-trending belt of Relay Mountain Group that extends to the northwestern limit of our mapping. These strata are associated with abundant plutonic rocks, including a large mass of undated quartz diorite and a more heterogeneous unit that is included in the Mount Skinner Igneous Complex. They are juxtaposed against rocks of Niut domain to the southwest, across a system of north to northwest-striking faults.

Sedimentary rocks of unit uTrs near the shoreline at the north end of Tatlayoko Lake are in contact with plutonic rocks of units MSC and qd to the west. The contact was not observed, but is suspected to be a northerly striking fault or shear zone as easternmost exposures of the Mount Skinner Complex in this area display a steeply east-dipping mylonitic foliation and an associated stretching lineation that plunges 45° to the south-southeast. This fault system is inferred to truncate the belt of Relay Mountain Group to the south and from there extend into Tatlayoko Lake (Figure 5). Its presence there is suggested by a zone of steeply east dipping brittle faults and fractures within unit lmJs along the lake shoreline.

The northeastern contact of the belt of Relay Mountain Group rocks in the eastern Niut Range is a fault, or system of faults, placing the unmetamorphosed sedimentary rocks against quartz diorite and, locally, a pendant of hornfelsed metasedimentary rocks. This fault contact was observed locally; it is vertical to steeply east or northeast dipping, but no movement sense was established along it. The quartz diorite is not dated, but is lithologically identical to several smaller igneous bodies within the Relay Mountain belt, some of which are clearly intrusive into the sedimentary rocks. Furthermore, the hornfelsed metasediments within quartz diorite northeast of the fault are provisionally correlated with the Relay Mountain Group on the basis of their inferred protolith lithology. These relationships suggest that the fault may have juxtaposed relatively deep or internal portions of a pluton against shallower or more distal environs adjacent to the same igneous body. A component of northeast-side-up movement is therefore suspected along this fault, although significant transcurrent motion cannot be ruled out.

A fault that is thought to have accomodated southwest-directed thrust or reverse movement has also been traced for several kilometres within the southern part of the Relay Mountain Group belt. This fault was observed in several places and dips between 35° and 75° to the east-northeast. It is generally parallel to bedding in the footwall rocks, and commonly places them against small bodies of quartz diorite in the immediate hangingwall. In one place this fault places quartz diorite that intrudes upright, northeast dipping *Buchia*-bearing Upper Jurassic conglomerates and sandstones above shales, siltstones and sandstones that are thought to be Lower Cretaceous in age. This older-over-younger relationship suggests reverse movement along the fault, as does a tight syncline within the footwall rocks directly beneath it.

NIUT DOMAIN

The northeastern limit of sedimentary, volcanic and plutonic rocks of the Niut domain is a system of north to northwest-trending faults that separates them from the Relay Mountain Group to the north and from unit lmJs along Tatlayoko Lake to the south (Figure 5). Where exposed, the northern fault strand dips steeply east to east-northeast, and is commonly marked by a metre-wide zone of brittle faults and fractures; Niut domain rocks are typically silicified and quartz veined along the fault whereas the adjacent Relay Mountain Group is not. The fault truncates the northeast-dipping thrust fault within the Relay Mountain Group on its northeast side, as well as east-striking faults within Niut domain to the west. Locally, the rocks on both sides of the main fault are slivered into several parallel fault strands, resulting in a fault zone several hundred metres wide.

Farther south, volcanic rocks at the eastern edge of Niut domain are separated from unit lmJs to the east by an intervening north-striking fault panel about a kilometre wide. Exposure is poor in this area, but outcrop constraints suggest that this panel trends northerly and is truncated by the more northwesterly striking boundary fault to the north and by the Tchaikazan fault to the south (Figure 5). Easternmost exposures within the panel include hornblende-phyric andesitic volcanic rocks that are associated with fine to coarse-grained, locally gritty, quartzofeldspathic sandstone with sparse detrital muscovite flakes. Farther west are exposures of intercalated brown calcareous sandstones, calcarenites, shales and limestone-cobble conglomerates. The andesitic volcanics within this panel are similar to those of the Niut domain, but are also similar to rocks found in the Powell Creek formation. The associated sedimentary rocks are dissimilar to any rocks observed within the Niut domain; the western assemblage is lithologically similar to the Hurley Formation of the Cadwallader Terrane, while the muscovite-bearing arkoses are most readily correlated with Middle to Upper Cretaceous rocks of unit uKs. Although these correlations are speculative due to the limited amount of exposure, this panel is mapped as thin fault slices of Hurley Formation, unit uKs and Powell Creek formation. The presence of fault slivers derived from the south Chilcotin domain along the boundary between Methow and Niut domains is not unreasonable as this same sequential arrangement of belts occurs east of Chilko Lake (Figure 3).

The internal structure of the Niut domain is not well understood. Steeply dipping, east-striking faults are locally prominent in the southern part of the belt, and in part mark the contacts between volcanic and sedimentary rocks. On the ridge east of lower Jamison Creek, faults within the volcanic succession apparently control several narrow east-trending zones of intense quartz-epidote veining containing patchy sulphide mineralization. In the western part of the domain, two northeast-striking faults are mapped within plutonic rocks of unit Nqd. These faults are marked by steeply dipping zones of fracturing and brecciation, several tens of metres wide, that are colinear with prominent topographic lineaments.

TCHAIKAZAN FAULT

The northwest-striking Tchaikazan fault cuts across the southwest corner of the Tatlayoko Lake map area, where it separates the Upper Cretaceous Powell Creek formation from units Nqd, Nvs and lmJs to the north. The fault was not observed, although its location is constrained to within a few tens of metres at the head of

Jamison Creek. Tipper (1969a) interpreted the Tchaikazan fault as a right-lateral transcurrent fault based on speculative correlation of two faults that were offset by about 30 kilometres along it. More recently Mustard and van der Heyden (1994) have postulated 7 to 8 kilometres of apparent dextral displacement based on offset of a distinctive fossiliferous limestone unit within the Mount Moore formation, a short distance to the northwest of the Tatlayoko Lake map aerea.

STRUCTURE NORTHEAST OF THE YALAKOM FAULT

The structure of pre-Neogene rocks northeast of the Yalakom fault is not well known due to sparse exposure. Outcrop-scale brittle faults are common, and most dip at moderate to steep angles to the northeast. Where movement-sense could be determined these faults typically show components of normal and dextral displacement. They may be Eocene in age, and related to the east to northeast-dipping fault system that separates this same package of rocks from the Tatla Lake Metamorphic Complex a short distance to the northwest.

MINERAL OCCURRENCES

SKINNER (MINFILE 92N 039)

The Skinner gold-quartz vein system occurs within quartz diorite and diorite of the Mount Skinner Igneous Complex, 5 kilometres north of the north end of Tatlayoko Lake. The veins were discovered in 1990 by Louis Berniolles of Ottarasko Mines Ltd. The property was optioned to Northair Mines Ltd in 1991, which conducted a diamond drilling program consisting of six holes totalling 250 metres (Visagie, 1992). It was subsequently turned back to the owner, and from 1992 to 1993, Ottarasko Mines Ltd extracted a 172-tonne bulk sample from the Victoria vein. The ore was milled at the Premier gold mine and produced over 11 000 grams of gold (average grade 65.83 g/t) and 8000 grams of silver (Meyers, 1993, 1994; Schroeter, 1994). Cheni Gold Mines Inc. optioned the property in 1994 and drove an adit and vertical raise, but have since terminated the option and turned the property back to the owner (Cheni Gold Mines, News Release, September 30, 1994).

Work to date has been concentrated on the Victoria vein, which strikes between 050° and 060° and dips steeply to the northwest. It, together with veins located 300 and 600 metres to the east-northeast, comprises part of a system of en echelon veins within a presumably structurally controlled lineament that trends 070° (Berniolles, 1991). The vein walls are defined by slickensided faults, and the veins themselves are cut by parallel faults. In the Victoria vein workings at least some of these faults accomodated sinistral movement.

The Victoria vein has been traced for more than 130 metres. It pinches and swells, locally attaining a thickness of 1.4 metres. From drilling data, the vein pinches out to the east and is still open to the west (Visagie, 1992). It consists almost entirely of quartz, with minor amounts of pyrite, chalcopyrite, malachite and rare visible gold. Clay gouge commonly occurs along the vein walls, and sericite and chlorite occur locally along fault surfaces. White mica locally lines vugs and open fractures within the vein quartz; some of this has been collected for K-Ar dating in an attempt to constrain the age of the veining. Gold values are variable, and concentrations as high as 136 g/t gold across 0.65 metre have been recorded (Berniolles, 1991). Copper shows little relationship to gold, and is locally concentrated in the wallrock adjacent to the vein.

BIG SLIDE (MINFILE 92N 061)

The Big Slide occurrence is located on the west-facing slope of Mount Skinner, 1600 metres northeast of the Victoria vein. There, the Mount Skinner Complex hosts a number of subparallel northwest-striking sheeted quartz veins, typically 2 to 15 centimetres wide, that dip 40° to 45° southwest. The veins carry gold and copper mineralization with grades up to 56 g/t Au and 0.72% Cu (Berniolles, 1991).

FLY (MINFILE 92N 056)

The Fly porphyry copper occurrence is located in the Niut Range, about 4 kilometres southeast of Niut Mountain. It was originally staked in 1968 and has seen intermittent exploration since that time. Mineralization is strongest in the Ridge zone, which extends for more than 200 metres within quartz diorite of unit Nqd and an adjacent body of hornblende feldspar porphyry that intrudes along the contact between the quartz diorite and altered volcanic and sedimentary rocks of unit Nvs to the east. Mineralization consists of malachite and azurite, with lesser amounts of pyrite and chalcopyrite, that occur as disseminations and as a minor component of quartz-epidote-carbonate veins and fracture fillings. A pyrite halo is developed mainly within altered volcanic rocks to the east of the intrusions. The intrusive and volcanic rocks display a predominantly vein-controlled propylitic alteration suite of epidote - chlorite - sericite ± silica ± carbonate. The highest copper value reported is 0.68% from a grab sample containing chalcopyrite, pyrite and malachite (Watson, 1988). A malachite-rich quartz diorite sample collected during the 1994 field season contained 0.52% Cu and 0.03% Zn. Mineralized quartz diorite was sampled for U-Pb zircon dating in order to constrain the age of mineralization.

RUSTY (MINFILE 92N 044)

The Rusty occurrence was not visited, but is described as disseminated chalcopyrite in sedimentary rocks along Jamison Creek, 5 kilometres west of Tatlayoko Lake. This location suggests that the occurrence is hosted by rocks of unit Nvs a short distance east of their contact with quartz diorite of unit Nqd.

NIUT MOUNTAIN (MINFILE 92N 020)

The Niut Mountain copper occurrence is within a conspicous red gossanous zone developed within pyritized volcanic(?) rocks of unit Nvs on the southeast flank of Niut Mountain. Small amounts of malachite and chalcopyrite occur locally in the pyrite-rich rocks, and they are reported to contain trace amounts of gold (Tipper, 1969a). These rocks are intruded by quartz diorite of unit Nqd to the north and west. Float of malachite-stained quartz diorite observed in the glacier bowl just below the gossanous zone suggests that the quartz diorite is also mineralized.

OTHER OCCURRENCES

Veins and silicified zones within altered volcanic rocks of unit Nvs to the east of the Fly occurrence carry variable gold values. A sample of a strongly silicified and pyritized rock from approximately 1 kilometre east of the occurrence contained 0.21% Cu and 1.8 g/t Au, and a grab sample from a vein approximately 500 metres northeast of the occurrence returned a gold value of 0.75 g/t (Ashton, 1992). Higher values of gold (2 to 6 g/t) have been reported from veins in the same area (Watson, 1988).

The volcanic and sedimentary rocks of unit Nvs on the ridge northeast of lower Jamison Creek are cut by several easterly trending zones of pyritization, silicification and quartz-epidote veining. One of these, at about 1970 metres elevation, is a malachite-stained zone, three metres wide, of quartz-epidote veins and quartz-epidote-altered andesites. A sample from this zone contained 0.53% Cu with minor zinc (345 ppm). Another zone, at 1850 metres elevation, comprises about 2 metres of quartz veined and intensely silica flooded andesite that has patchy malachite staining and rarely contains visible pyrite, chalcopyrite and sphalerite. A sample from this zone contained 0.46% Cu with minor amounts of silver (300 ppm), zinc (184 ppm) and gold (5 ppb).

Unit Nqd west and northwest of Niut Mountain, includes a number of conspicuous gossanous zones. These include zones of pyritized quartz diorite, as well as pendants of pyrite-altered volcanic or sedimentary rock. Unit Nqd in this area also hosts several small bodies of granitic rock. One of these, located approximately 1.5 kilometres west of Niut Mountain, displays potassic alteration and malachite mineralization; a grab sample from this mineralized intrusive returned a copper value of 0.19%.

North to northwest-striking fault zones within unit Jv near the northeast end of Choelquoit Lake locally control narrow gossanous zones of pyrite-pyrrhotite mineralization, but samples from these zones did not contain anomalous concentrations of base or precious metals. Outcrops of unit Jv on the east side of the Chilko River, 5.5 kilometres to the southeast, are brecciated and veined with quartz, epidote and calcite over a large area. A calcite-rich vein containing malachite and azurite, collected from the north end of this outcrop belt, assayed 0.08 % Cu.

DISCUSSION

The Tatlayoko Lake map area is in large part underlain by a succession of Jurassic and Cretaceous clastic sedimentary rocks that we assign to the Methow Terrane. This assignment is based on the lithologic characteristics of the Lower to Middle Jurassic rocks of unit lmJs, and the upper Lower Cretaceous Jackass Mountain Group. Rocks correlative with these two units are characteristic of Methow Terrane from the present study area southeastward to the international border. Over this distance the Methow Terrane is the easternmost terrane within the southern Coast Belt. The belt of Methow Terrane rocks is offset by the Yalakom fault, which separates rocks within the Tatlayoko Lake map area from the correlative succession in the Camelsfoot Range (Kleinspehn, 1985; Riddell *et al.*, 1993a), as well as by the Fraser fault system, which separates the Camelsfoot Range belt from correlative rocks in the area of Manning Park and the contiguous Pasayten and Methow drainage basins of Washington State (Kleinspehn, 1985; Monger, 1989; Monger and McMillan, 1989; Mahoney, 1993).

The distinctive Jackass Mountain Group has long been recognized within all three segments of the Methow Terrane belt (Duffell and McTaggart, 1952; Jeletzky and Tipper, 1968; Tipper, 1969a; Coates, 1974; Kleinspehn, 1985). In the Manning Park area, underlying Lower to Middle Jurassic rocks comprise the Ladner Group, which in its upper part includes a distinctive assemblage of upper Toarcian to Bajocian volcanic and sedimentary rocks assigned to the Dewdney Creek Formation (O'Brien, 1986, 1987). The Dewdney Creek Formation includes a proximal eastern facies that includes pyroclastic rocks and lava flows together with clastic sedimentary rocks, and a more distal western facies that consists of volcanic-derived coarse-grained sandstones and conglomerates intercalated with thin-bedded sandstone, siltstone and argillite (Mahoney, 1993). Monger and McMillan (1989) recognized that rocks correlative with the Ladner Group are present in the southern Camelsfoot Range, and Schiarizza *et al.* (1990) noted that Lower to Middle Jurassic rocks that underlie the Jackass Mountain Group in the northeastern part of the range are lithologically similar to the Dewdney Creek Formation. These correlations were confirmed by Mahoney (1992), who specifically correlated the Lower to Middle Jurassic rocks of the Camelsfoot Range with the distal western facies of the Dewdney Creek Formation (Mahoney, 1993).

Middle Jurassic rocks that underlie the Jackass Mountain Group on the south limb of the Tsuniah Lake syncline in the Mount Tatlow map area were correlated with the Jurassic rocks of the Camelsfoot Range by Riddell *et al.* (1993a). This correlation is confirmed by our mapping of the adjacent Tatlayoko Lake map area. Unit lmJs consists largely of Aalenian and Bajocian strata that are lithologically very similar to age-equivalent rocks of the Camelsfoot Range, which Mahoney (1993) assigns to the western distal facies of the Dewdney Creek Formation. These strata are characterized by thick beds of volcanic-derived sandstone and granule conglomerate, as well as local occurrences of andesitic breccias, tuffs and flows, within a succession of predominantly siltstones, shales and fine-grained sandstones. These Middle Jurassic rocks are markedly different from age-equivalent strata found within other major tectonostratigraphic assemblages of the southeastern Coast Belt: the Middle Jurassic portion of Cadwallader Terrane is predominantly shale with no coarser clastics and no volcanic rocks (Umhoefer, 1990; Schiarizza *et al.*, 1993b), and the Middle Jurassic of the Bridge River Terrane is mainly chert (Cordey and Schiarizza, 1993).

The Jura-Cretaceous Relay Mountain Group occurs within the Methow Terrane succession in the western part of the Tatlayoko Lake map area, but is missing to the east, where it has apparently been eroded away beneath a major sub-Jackass Mountain Group unconformity. Correlative rocks are also missing in the Camelsfoot Range, but are in part locally preserved in the Manning Park area, where they are represented by Upper Jurassic *Buchia*-bearing sandstones of the Thunder Lake sequence (O'Brien, 1986, 1987). The type area of the Relay Mountain Group is within the south Chilcotin domain, 100 kilometres to the southeast of the Taylayoko Lake map area. There the group is in part structurally interleaved with Lower to Middle Jurassic rocks of the Cadwallader Terrane, but no stratigraphic contact between the two successions is actually preserved (Schiarizza *et al.*, 1993a,c,d). Despite this stratigraphic ambiguity, the presence of Relay Mountain Group strata within the interior part of the eastern Coast Belt, a considerable distance southwest of the belt of Methow Terrane rocks, suggests either that it overlaps more than one terrane in the eastern Coast Belt, or that there was structural shuffling of terranes (*e.g.*, Monger *et al.*, 1994), prior to middle to early Late Cretaceous contractional deformation, at which time the present linear arrangement of terranes and associated synorogenic clastic sedimentary rocks was largely established (Garver, 1989, 1992).

The Upper Triassic rocks of units uTrs and uTrcg, which apparently underlie the Jurassic rocks of unit lmJs, are not recogized within Methow Terrane anywhere to the southeast. These rocks do resemble, in some respects, the Upper Triassic Tyaughton Group of the Cadwallader Terrane, which includes a red bed sequence of conglomerates and sandstones containing volcanic and plutonic clasts, as well as overlying nonmarine to shallow-marine clastic rocks that include a similar *Cassianella* fauna to the one collected from unit uTrs on the east side of Tatlayoko Lake (Tipper, 1969a).

Unit uTrcg also resembles the Upper Triassic Mosley formation of the Niut domain, which includes red conglomerates and sandstones intercalated with carbonate and volcaniclastic rocks (Rusmore and Woodsworth, 1991a; Mustard and van der Heyden, 1994). This correlation is supported by the association of unit uTrcg with Late Triassic diorite to quartz diorite of the Mount Skinner complex. Late Triassic plutons occur within Niut domain, but have not been recognized elsewhere within Methow domain, nor within Cadwallader Terrane of the south Chilcotin domain.

As shown in Figure 3, the Methow domain comprises the easternmost element of the southeastern Coast Belt. Cadwallader Terrane is structurally interleaved with Bridge River Terrane throughout much of the south Chilcotin domain, but from the Bridge River northward comprises the easternmost element of this domain, such that it occurs between Methow Terrane to the east and Bridge River Terrane to the west (Schiarizza *et al.*, 1993a,b; Riddell *et al.*, 1993a,b). In the Manning Park area, the basement to Methow Terrane is a sequence of ocean-floor basalts and associated gabbros referred to as the Spider Peak Formation (Ray, 1986, 1990). These rocks are not dated, but resemble, both lithologically and geochemically, Permian greenstones, gabbros and diorites of the Bralorne - East Liza Complex, which are structurally interleaved with Cadwallader Terrane throughout much of the eastern part of the south Chilcotin domain (Schiarizza *et al.*, 1993a,b). This association, as well as the similarity between the Tyaughton Group and units uTrs and uTrcg, suggests the possibility that the Cadwallader and Methow terranes may represent different parts of the same arc-basin complex that was floored by oceanic crust to the east of the Bridge River accretion-subduction complex. The similarities between Stikine and Cadwallader terranes indicated by Rusmore *et al.*, 1988, Umhoefer, 1990, and Rusmore and Woodsworth 1991a, suggest that this belt may have Stikine Terrane affinities. This is corroborated by the similarity of unit uTrcg and associated Late Triassic plutonic rocks of the Mount Skinner complex to Stikine terrane rocks found within Niut domain.

A separate belt of Upper Triassic volcanic rocks that has been assigned to the Cadwallader Terrane outcrops in the Pemberton area to the west of the Bridge River Complex (Journeay, 1993; Riddell, 1992). The relationship of these rocks to Cadwallader Terrane in its type area to the east is problematical; assuming that the correlation is valid, these rocks may have been offset from the eastern Cadwallader belt by pre mid-Cretaceous sinistral displacements (*e.g.*, Monger *et al.*, 1994).

SUMMARY

The Tatlayoko Lake map area is underlain in large part by Lower Jurassic to Lower Cretaceous clastic sedimentary rocks of Methow Terrane, which comprises the easternmost element of the Coast Belt from the present study area southeastward to the international border. Continuity of this belt is disrupted by dextral offsets along the Yalakom and Fraser faults. Within the Tatlayoko Lake map area the Methow Terrane is represented mainly by Lower to Middle Jurassic clastic sedimentary rocks and local volcanic rocks of unit lmJs, together with overlying clastic sedimentary rocks of the Upper Jurassic to Lower Cretaceous Relay Mountain Group and the Lower Cretaceous Jackass Mountain Group. The Relay Mountain Group is missing in the eastern part of the map area, and in most of the Methow Terrane belt to the southeast. This omission is thought to reflect erosion beneath a sub-Jackass Mountain Group unconformity. Upper Triassic conglomerates and sandstones, locally associated with volcanic rocks and Late Triassic plutonic rocks, are inferred to underlie unit lmJs near the north end of Tatlayoko Lake. Correlative rocks are not recognized elsewhere in the Methow Terrane belt, but these Triassic rocks are lithologically similar to age-equivalent rocks found within Cadwallader

Terrane to the southeast and within Stikine Terrane to the west.

The eastern part of the Niut Range, in the western part of the Tatlayoko Lake map area, is underlain by an assemblage of andesitic volcanic and volcaniclastic rocks, together with intercalated conglomerates and sandstones, assigned to unit Nvs. These rocks are lithologically distinct from the adjacent rocks of Methow Terrane, from which they are separated by a system of north to northwest-striking faults of uncertain age or sense of displacement. They probably correlate with the Lower Cretaceous Ottarasko Formation, as indicated by Tipper (1969a); alternatively, however, they may correlate with Triassic volcanic and sedimentary rocks mapped as Mount Moore Formation just 10 kilometres to the northwest. The latter possibility is suggested by the apparent continuity of an extensive unit of quartz diorite that intrudes unit Nvs with a Late Triassic pluton that intrudes the Mount Moore Formation. A sample of the quartz diorite from the present study area has been submitted for zircon U-Pb dating in an effort to resolve this question.

The most prominent structure in the map area is the west-northwest-striking Yalakom fault, which separates the lithotectonic assemblages of the Coast Belt from a poorly exposed assemblage of Jurassic(?) volcanic and volcaniclastic rocks which underlies the Intermontane Belt in the northeastern part of the map area. Relationships from outsde the map area indicate that the Yalakom fault was the locus of more than 100 kilometres of mainly Eocene dextral strike-slip displacement. Structures within the Coast Belt that may be linked to the Yalakom system include northwest-striking faults with apparent dextral offsets in the northwestern part of the belt, and the east-plunging Tsuniah Lake syncline to the southeast. The volcanic rocks northeast of the Yalakom fault are commonly cut by outcrop-scale northeast-dipping faults with components of normal and dextral displacement that may also be linked to the Yalakom system. Post-Hauterivian northerly trending folds within the Methow Terrane between Tatlayoko and Chilko lakes may be older structures, related to middle to early Late Cretaceous contractional deformation that is well documented elsewhere in the southeastern Coast Belt

Most of the known mineralization in the area is in the Niut Range, where it consists of disseminated copper in quartz diorite of unit Nqd, as well as copper-gold-bearing veins and fracture fillings in younger hornblende feldspar porphyry intrusions and volcanic and sedimentary rocks of unit Nvs. The only production, however, has come from the Skinner occurrence, where fault-controlled northeast-striking gold-quartz veins cut Late Triassic quarz diorite and diorite of the Mount Skinner Complex, a short distance southwest of the Yalakom fault. Bulk samples totalling 172 tonnes taken from the Victoria vein in 1992 and 1993 returned more than 11 000 grams of gold and 8000 grams of silver.

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GEOLOGY AND MINERALIZATION OF THE STUHINI CREEK AREA (104K/11)

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(Contribution to the Canada - British Columbia Mineral Development Agreement 1994-1995)

KEYWORDS: Stuhini Creek, Tulsequah, Stikine assemblage, Stuhini Group, Laberge Group, Sloko Group, Eocene deformation, copper, gold, lead, provenance, ammonite biostratigraphy

INTRODUCTION

Regional geologic mapping in 1994 extended previous 1:50 000-scale mapping of the Tulsequah River mapsheet (104K/12; Mihalynuk *et al.*, 1994a, b) eastward into the Stuhini Creek map area (104K/11, Figure 1). Approximately 20% of the Tulsequah River and 45% of the Stuhini Creek map sheets has been previously mapped as Upper Triassic Stuhini Group (Souther, 1971). More recently, fossil and isotopic age data indicate that most "upper Triassic" rocks within the Tulsequah River map area are in fact Paleozoic (Nelson and Payne; 1984; Mihalynuk *et al.*, 1994a; Sherlock *et al.*, 1994), including rocks that host two past-producing volcanogenic massive sulphide deposits, the Big Bull and Tulsequah Chief. A primary objective of fieldwork in 1994 was to search along strike in 104K/11 for correlative Paleozoic strata, in large areas previously identified as Stuhini Group. Other objectives included identification of potential for shallow submarine hydrothermal mineralization in fine Stuhini Group clastics (e.g. Eskay Creek style) and evaluation of potential for gold mineralization in east-west cross faults.

PREVIOUS WORK

Mineral exploration in the area dates back to at least 1923 with discovery of the Tulsequah Chief deposit. However, systematic regional mapping was not begun until Kerr's investigations in 1930 and 1932 (Kerr, 1931a, b, 1948). In 1958 to 1960 Souther (1971) completed 1:250 000-scale mapping of the Tulsequah area. Monger (1980) mapped parts of the northern Stuhini Creek area, with a focus on Upper Triassic stratigraphy. Geological mapping since that time has been primarily restricted to company reports with limited distribution. Maps produced by Cominco Ltd. (Payne and Sisson, 1988) cover a large part of 104K/12. Regional surveys by Anglo Canadian Mining Corporation (Payne *et al.*, 1981) touched on isolated parts of 104K/11, but were published at very small scale in largely schematic form (Nelson and Payne, 1984).

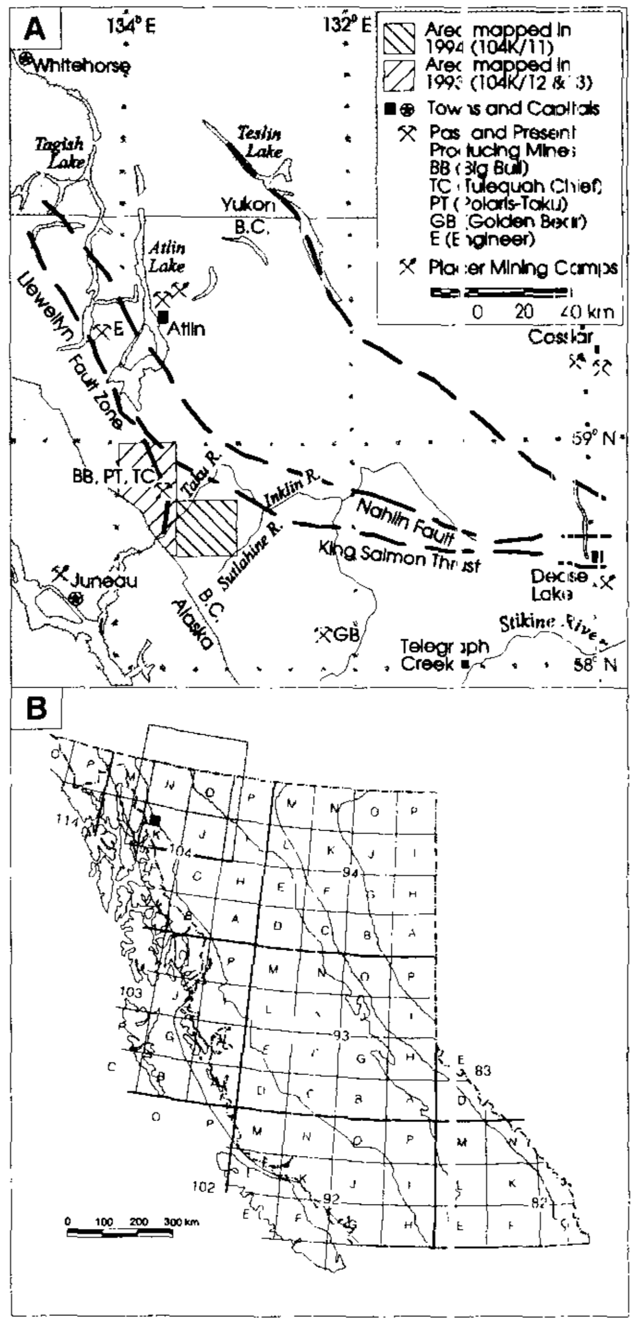

Figure 1. (a) Location of the Tulsequah project showing prominent geographic and cultural features. (b) Location of the map area within the National Topographic System. Tectonostratigraphic belts are also outlined.

LOCATION, PHYSIOGRAPHY AND ACCESS

Stuhini Creek map area covers about 800 square kilometres of the Coast Mountains, centred 75 kilometres northeast of Juneau, Alaska and 100 kilometres south of Atlin, British Columbia (Figure 1). Braided channels and flanking sloughs of the southwest-flowing Taku River occupy a swath 2.5 kilometres wide in the northwest corner of the map area. West-flowing Stuhini Creek, formerly known as the "South Fork of Taku River" (*cf.* Mandy, 1930), drains about 30% of the map area. Stuhini Creek and major parallel drainages north and south, the Sittikanay River and Zohini Creek respectively, are deeply incised, and meet the Taku River on grade. Other streams occupy U-shaped hanging valleys and freefall into the Taku River. Such streams are in turn, commonly fed from hanging valleys. Travel from one valley to the next is often not possible without technical climbing. Mount Lester Jones, on the northern edge of the map area, marks the division between rugged, glaciated Coast Mountains and relatively gentle, dry Stikine Plateau uplands.

Rock and temperate rainforest comprise roughly equal proportions of the Stuhini Creek area, with about 5% outcrop beneath forest canopies. Areas of 100 % cover are restricted to glaciers, river bottoms and swamps which collectively amount to about 15% of the area. Geological fieldwork is challenged by steep topography, snow and ice cover, dense brush in major valley bottoms and generally poor weather, but the summer of 1994 was drier than usual.

Access to the region is either by fixed or rotary-wing aircraft or by shallow-draft boat or barge up the Taku River. Nearest centres for aircraft charter are Atlin and Juneau, although helicopters are intermittently based in the Tulsequah valley. Two gravel airstrips are serviceable. Northwest of the confluence of the Taku and Tulsequah rivers, a strip more than a kilometre long will accommodate a DC-3 or Caribou aircraft, but is subject to flooding two or more times each summer. A less flood prone, much shorter strip at the Polaris-Taku minesite will accommodate small aircraft or those with short take-off capability. There are no roads or established trails within the map area; travel from airstrips to other localities is most effectively done by helicopter.

GENERAL GEOLOGIC AND TECTONIC SETTING

Four major building blocks constitute the terrane superstructure of northwestern British Columbia (Figure 2): a western block of polydeformed, metamorphosed Proterozoic to middle Paleozoic pericontinental rocks (Nisling assemblage (of Yukon Tanana Terrane as used by Mortensen, 1992)); an eastern block of exotic oceanic crustal and low-latitude marine strata (Cache Creek Terrane of Coney *et al.*, 1980); central blocks including Paleozoic Stikine assemblage (Monger, 1977; Brown *et al.*, 1991) and Triassic arc-volcanic and flanking

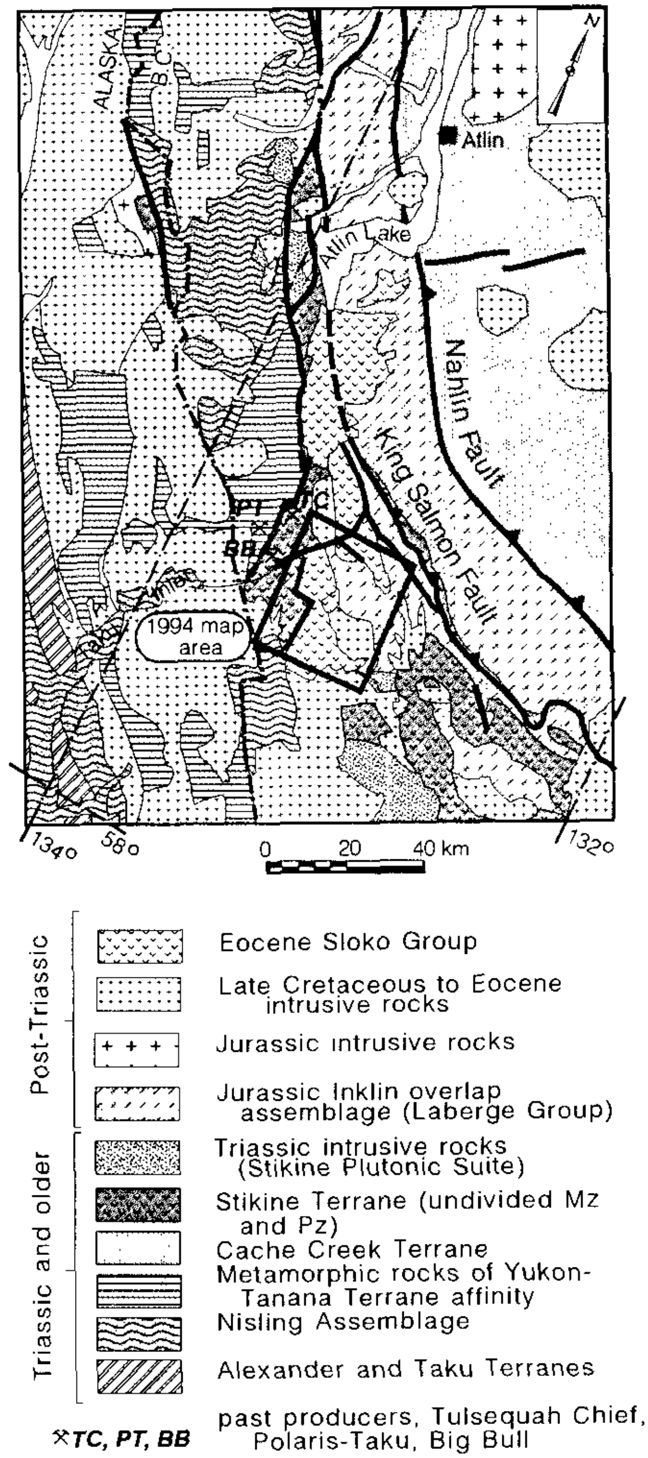

Figure 2. Simplified geologic map of the Atlin and Tulsequah area after Wheeler and McFeely (1991), Monger (1980), Mihalynuk and Rouse (1988) and Mihalynuk *et al.* (1989, 1990, 1994b), showing major faults and lithotectonic elements. The Tulsequah map area straddles parts of the Jurassic Inklin overlap assemblage, Stikine Terrane, and metamorphic rocks of mixed arc and siliciclastic affinity and uncertain (possibly Yukon-Tanana) terrane assignment.

sedimentary rocks of Stikine Terrane, and overlying Late Triassic to Middle Jurassic arc-derived strata of the Whitehorse Trough (including the Inklin overlap assemblage of Wheeler *et al.*, 1991). Mesozoic rocks of the Stuhini Creek map area are dominated by arc-flanking strata of the Whitehorse Trough: parts of the Upper Triassic Stuhini Group and the Lower to Middle Jurassic Laberge Group. These are overlain by Tertiary continental arc volcanic rocks of the Sloko Group which are intruded by partly comagmatic Coast plutons. The Stikine assemblage is restricted mainly to the south and western margins of the map area, but probably extends beneath much of the Mesozoic and Tertiary cover. On the northern and southern edges of the map area, the geology is influenced by two major crustal structures. Eastern splays of the transcurrent Llewellyn fault system juxtapose ductilely deformed Paleozoic rocks with Mesozoic rocks between Sittakanay River and Stuhini Creek. To the north, southwest-verging frontal thrusts of the King Salmon fault system interleave Jurassic and Triassic Whitehorse Trough strata Second order normal, or high-angle reverse faults, juxtapose Tertiary volcanics with Mesozoic and Paleozoic rocks. Deformation generally increases in intensity with age.

Relicts of a past continental glaciation are everywhere in evidence. Glacially carved U-shaped valleys have been modified little since retreat of expansive ice sheets. Remnants of this ice persist as alpine glaciers which produce a rich array of glaciomorphic features and glaciofluvial deposits.

STRATIGRAPHY

Excellent exposure, lack of widespread ductile deformation, and good fossil age control make for relatively clear-cut lithological relations in marine sedimentary strata. However, several volcanic lithologies belonging to different major rock suites are strikingly similar. Without solid age data, discrimination between such lithologic divisions (even Tertiary versus Paleozoic) is not without ambiguity. For example, similarity of Paleozoic and Triassic augite-phyric breccias, flows and tuffs has historically caused correlation problems. We outline lithologic criteria which can be used to help distinguish between these look-alikes (Table 1). Rare earth element analyses currently in progress will hopefully point to a less subjective method of descriminating between the two.

More than 30 new macrofossil collections greatly increase the available fossil age data for the area. A further 15 samples were collected for microfossil extraction; results are pending. All macrofossil and most microfossil samples are from Mesozoic strata, placing good constraints on stratigraphy of this age. Two Paleozoic samples were collected in 1993 from just off the western edge of the Stuhini Creek map sheet. They yielded Late Carboniferous (Moscovian) fusulinaceans (Rui, 1994; C-208180) and Late Carboniferous to Early Permian conodonts (Orchard, 1994; C-208199), establishing with certainty that the Paleozoic Stikine assemblage extends to south of the Taku River.

PALEOZOIC

Paleozoic Stikine assemblage strata crop out along the western margin of the map area on both sides of the Taku River (Figure 3). North of the river they can be traced from the west side of Mount Metzgar (104K/12) where mapped in 1993. Rocks south of the Taku River, on Sittikanay Mountain, can also be confidently correlated with the Stikine assemblage, but unlike well preserved, correlative strata to the north, polyphase deformation, indistinct lithologies, and precipitous terrain prevent extensive subdivision of these rocks. Mount Erickson lies midway between these two areas. It is largely underlain by rocks that are tentatively correlated with the Stikine assemblage. A tenuous correlation is also made with metamorphosed rocks in the southeast corner of the map area, in the Sutlahine River valley.

Rocks at Mount Metzgar can be correlated on a unit by unit basis with well defined Pennsylvanian to Permian Stikine assemblage rocks of the Mount Eaton block (Mihalynuk *et al.*, 1994a, b). Although distinctive, many units are too thin to be represented on a 1:50 000-scale map, and are, of necessity, grouped with the dominant lithology. They are probably correlative with one of two broad packages recognized south of the Taku: a structurally higher, heterolithic, well layered upper package that contains distinct, mappable units and conspicuous white-weathering carbonate. It contrasts with a structurally lower package dominated by indistinct mafic volcanics and fine-grained sediments with minor impure carbonate. Correlation of the lower package is

TABLE 1. CRITERIA FOR DISTINGUISHING STIKINE ASSEMBLAGE AND STUHINI GROUP PYROXENE PORPHYRY UNITS.

Criteria	*Stuhini Group pyroxene-phyric*	*Stikine assemblage pyroxene-phyric*
weathering	olive green to orange brown	grey green to dark green
other lithologies	typically monomict, minor carbonate clasts, others rare	variable: feldspar porphyry, carbonate clasts, rare dacite
matrix	commonly calcareous	may be calcareous
metamorphism	variable, typically lower greenschist	greenschist, hornfelsed to higher grade
fabric	folded, but not schistose	phyllitic zones common, at least two phases of deformation well displayed

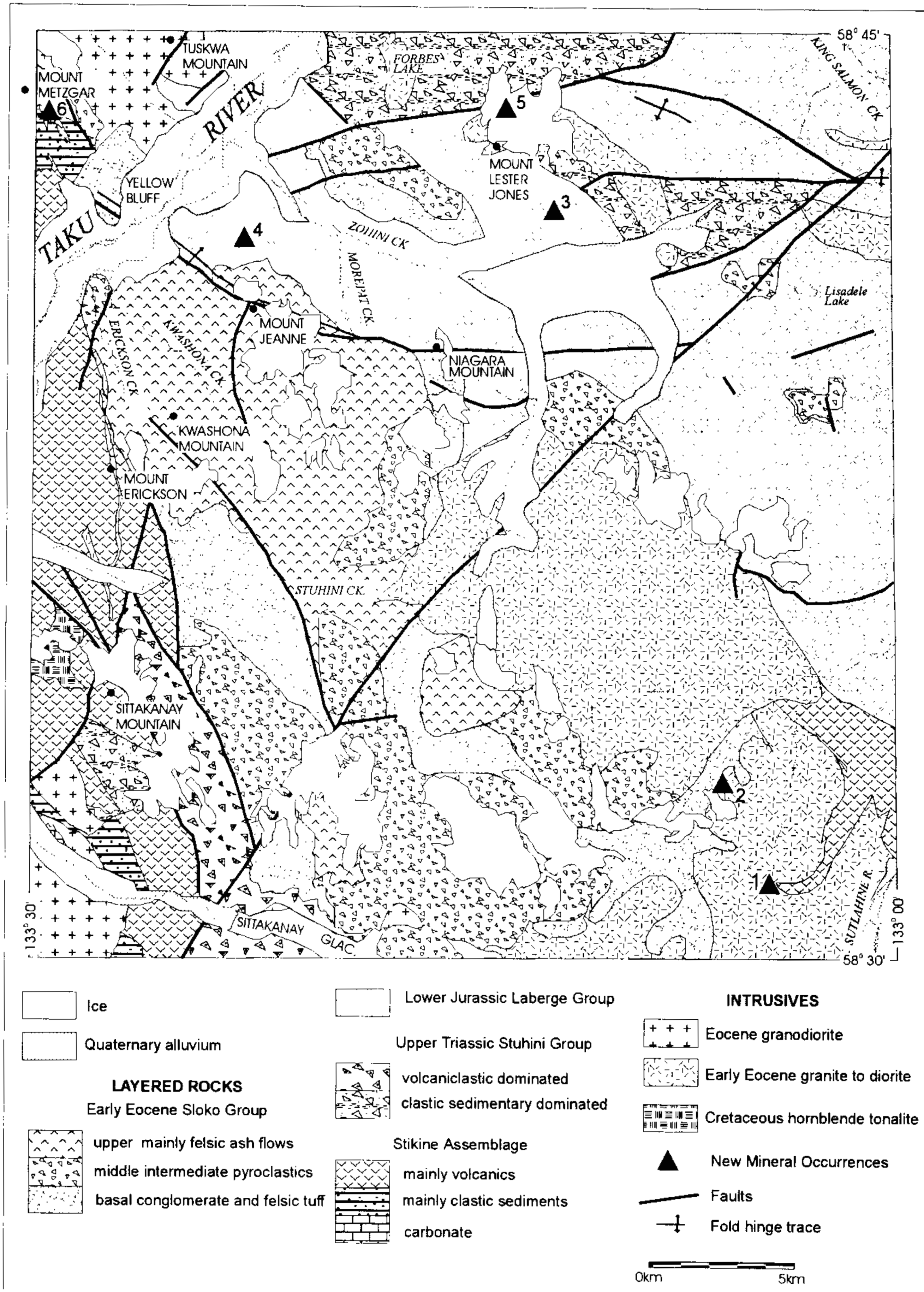

Figure 3. Generalized geology of the Stuhini Creek mapsheet.

less certain, but it most closely resembles Mississippian to Pennsylvanian rocks of the Mount Eaton block.

MOUNT METZGAR

A wide variety of arc lithologies crop out along the eastern cirque of Mount Metzgar. From north to south these include: maroon and green, fine-grained lapilli ash tuff; well bedded, tan bioclastic limestone; bedded to massive chert; sulphidic, calcareous, rusty, black, well bedded argillite and siltsone; decimetre-thick interbeds of limestone and chert; bright green, chlorite and calcite amygdaloidal, monomict andesite tuff; light grey, stretched limestone-cobble debris flow; purple to green, pyroxene-phyric pillow breccia with a calcareous matrix; dark green, flattened, lapilli tuff of probable basaltic andesite composition; and centimetre to decimetre interbeds of argillite and cherty, tuffaceous siltstone. The last few units apparently change along strike down-slope into dark brown and green, fine-grained tuffaceous sediments and sparse lapilli tuffite, that form locally developed, albeit inconspicuous, centimetre to decimetre-thick beds. More commonly these form disrupted beds with metre-scale close to isoclinal folds. Matrix compositions are typically siliceous, with carbonate locally predominating. Hornfelsing is common, possibly due to plutonic rocks in the near subsurface.

Structural disruption is clearly evident, but no duplication of stratigraphy was identified. Well developed shear zones undoubtedly result in juxtaposition of originally disparate units, but their involvement in drastic down-slope lithologic change is uncertain. Perhaps a severe facies change is preserved on these lower slopes of Mount Metzgar. Similar examples of southeastward fining are seen downstream along this side of the Taku River.

Rhyolite is reported from this area (Sorbara, 1983), but none was observed during our field investigation. Farther west along the southern ridge of Mount Metzgar, dark green volcanic breccia and bedded tuff predominate, as indicated by landslide debris on the slopes below.

MOUNT SITTIKANAY (AND SOUTH)

In general, ductile deformation increases in intensity while confidence in correlation decreases both northeast and southwest of Mount Sittikanay. Northeast of Mount Sittikanay, in the Stuhini Creek valley, dynamothermally metamorphosed phyllite and schist are cut by discrete shear bands within the Sittikanay shear zone (see 'Structure' below). To the southwest, extensive intrusion by Coast Belt plutons caused widespread thermal metamorphism. Primary sedimentary component decreases to the northeast where a lower succession of massive volcanic strata is dominant. Protolith textures are best preserved in a belt of distinctive units that extend south into the Sittikanay River valley. Mapping within this belt has focused mainly on the westernmost map margin, on Mount Sittikanay. The belt is outlined by conspicuous white-weathering carbonate layers, two of which yield Late Carboniferous microfossil ages (see previous section). Some distinctive individual units can be correlated with those in the Tulsequah River area, where unit designations are those of Mihalynuk *et al.* (1994b).

An **interbedded chert and phyllitic argillite and minor bioclastic carbonate** unit is probably equivalent to the tuffaceous mudstone greywacke unit (MPEst). It is white weathering with beds 2 to 30 centimetres thick. Unlike unit MPEst, thin bioclastic carbonate units are not common throughout, but occur only at the structural top of the unit. It may be a deeper water equivalent of typical unit MPEst. **Pyroxene porphyritic breccia and maroon lapilli tuff** are affected by tight folding, but otherwise are identical to units PEvt and MPEva. Massive white chert in layers up to several metres thick and grey, phyllitic argillite and grey-green, fine-grained cherty basalt lack distinctive features which permit correlation. A thick section of intermixed siliceous argillite and fine-grained to locally medium-grained and holocrystalline, green basalt tuff or flow and sill layers up to 10 metres thick sits structurally below the carbonate belt. These intermixed rocks are suitable protoliths for muscovite and actinolite phyllite and schist that occur low in both the Sittikanay River, Stuhini Creek and Taku River valleys.

MOUNT ERICKSON

The peak and southern flanks of Mount Erickson are underlain by dark green to black, fine to medium-grained, basaltic pyroxene±feldspar porphyry breccia, lesser flows and intrusive equivalents. Epidote-chlorite alteration of matrix and along fractures is pervasive, but is less intense in pyroxene phenocrysts that comprise 10% to rarely 50% of the rock. Hypabyssal gabbroic intrusions are believed to be comagmatic with volcanic strata. Both are cut by veins of epidote, hornblende and potassium feldspar.

Sediments and fine-grained basalt dominate the northern slopes of Mount Erickson, together with fine-grained, black basalt flows with relict pillow features. Included in the sedimentary package are hornfelsed dark green and purplish cherty siltstone and conspicuous, contorted white and black banded carbonate and massive white marble layers, 6 metres or more thick. Hornfelsed siltstone is commonly interbedded with green to pink, laminated carbonate, at one locality containing basaltic 'clasts' up to 40 centimetres in diameter. Pervasive thermal alteration of these rocks has produced widespread silicification, development of fine-grained biotite(?), and formation of epidote-actinolite-chlorite-quartz veins and knots. Grossularite occurs in isolated pockets. These sediments are similar to those exposed low on the eastern slopes of Mount Metzgar (see above).

SUTLAHINE RIVER

Immediately west of the Sutlahine River, a screen dominated by foliated, mafic volcanic rocks is migmatitic where in contact with enclosing granite of probable Eocene age. Relict pillows and well bedded, highly indurated tuffaceous sediments are preserved in rare instances. Calcsilicate pods within foliated metabasalt are interpreted to be interpillow micrite remnants. These pillow basalts are important because they host disseminated blebs and veins of chalcopyrite (see "Oksarah" below)

Correlation of these rocks is based upon: lithologic similarity with Paleozoic rocks, particularly the sediment-dominated unit at Mount Erickson, and proximity and continuity of units at this locality with another series of Paleozoic exposures just east of the Sutlahine River (Souther, 1971). Furthermore, several hundred square metres of Laberge conglomerate apparently rests on the probable Paleozoic rocks, but they are not ductilely deformed, thereby placing a minimum age limit on deformation of the underlying rocks.

TRIASSIC: THE PYROXENE PORPHYRY PROBLEM

Discrimination between Paleozoic and Triassic strata remains problematic, even two full decades after publication of Souther's 1:250 000-scale map of the Tulsequah area, and with considerably more isotopic and paleontologic data at our disposal. This is particularly true for crowded augite-porphyritic volcanic rocks which are now known to be relatively widespread in the upper Paleozoic Stikine assemblage (Bradford and Brown, 1993; Gunning, 1993; Mihalynuk *et al.*, 1994a, b; J.M. Logan, personal communication, 1994), but which are generally considered a hallmark of the Upper Triassic Stuhini Group. Similar ambiguities exist for the feldspar-porphyry-dominated lithologies of the Eocene Sloko Group.

In the Tulsequah River map area (104K/12), crowded coarse pyroxene porphyritic breccia (pyroxene up to 2 cm), flow units and pyroxene crystal tuff are well dated as middle Pennsylvanian and older on the basis of associated fossiliferous strata. Pyroxene porphyry blocks within fossiliferous tuffaceous limestone containing fusulinids provide a minimum Moscovian age (middle Pennsylvanian; Rui, 1994). Pyroxene porphyry flows incorporate sediment and are backveined by penecontemporaneous dikes. They underlie a carbonate debris flow unit that contains Wolfcampian to Sakmarian fusulinids (late Pennsylvanian - early Permian; Rui, 1994). Slightly higher in the section, blocks of pyroxene crystal tuff occur in a debris flow with a fossiliferous rudstone matrix. All of these occurrences are interpreted to stratigraphically overlie up to 1500 metres of pyroxene porphyry dominated breccia, which in turn overlies early Mississippian rhyolite (Sherlock *et al.*, 1994) and sediment (Mihalynuk *et al.*, 1994b). These pyroxene porphyry breccias and flows bear close resemblance to Upper Triassic augite porphyry of the Stuhini Group, and in both field and microscopic examination, may be visually indistinguishable. Some criteria that may collectively aid in discrimination between the two suites are listed in Table 1, but singularly these criteria are of limited use.

A thick, intermediate to rhyolitic succession was mapped by Souther (1971) as part of the Stuhini Group. Although not characteristic, such felsic Stuhini Group units are dated in the Iskut River area where Anderson (1989) includes them with a distinct, western felsic facies.

In the Stuhini Creek area, we exclude felsic rocks from the Stuhini Group for several reasons.

- Just above the Sittikanay Glacier terminus, a well exposed, polymictic basal conglomerate rests on an incised paleosurface above steeply dipping, crowded augite porphyries believed to be Stuhini Group (Photo 1). This conglomerate grades upwards into volcanic strata of the felsic unit.
- Clastic and felsic volcanic strata can be traced from Niagara Mountain, where they overlie the Laberge Group (a relationship previously mapped by Souther, 1971), across Morepat Creek, into an area previously

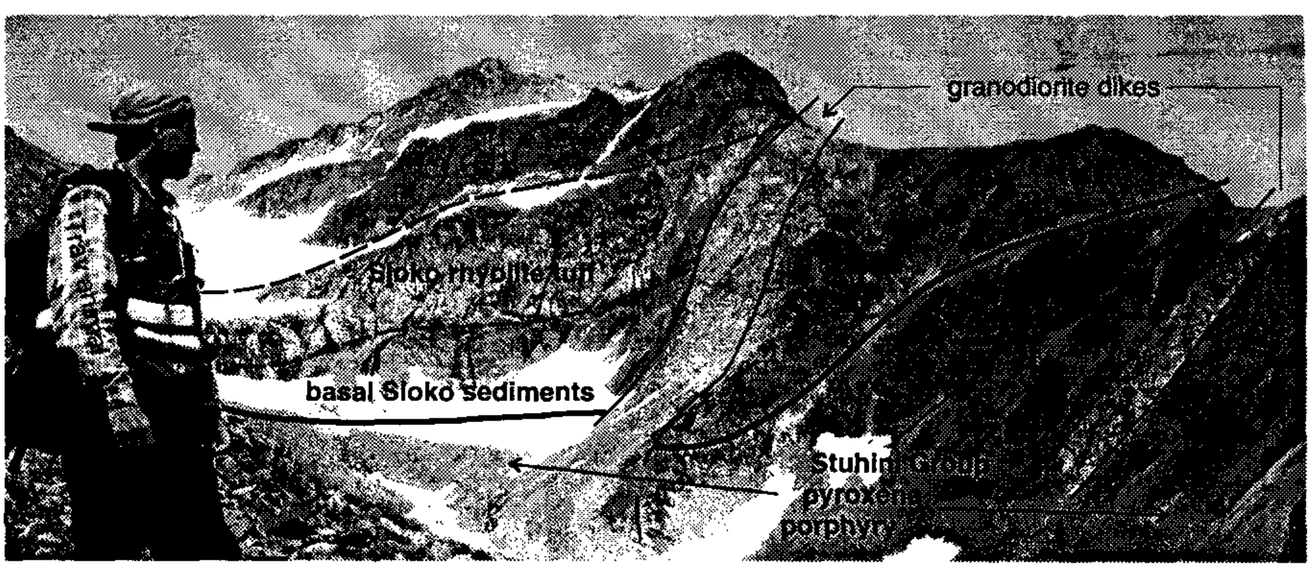

Photo 1. Steeply bedded augite porphyry, probably Stuhini Group (uTS), is unconformably overlain by gently dipping polymictic conglomerate, rhyolite and variegated breccia, interpreted to be Sloko Group (eES). Both units are later cut by granodiorite dikes (eTg) 10 to 50 metres thick.

mapped as Stuhini Group.

- *Some lithologies within the felsic volcanics* are identical to units clearly within the Sloko Group outside the map area.
- Drag folds across a major normal fault at Mount Jeane are consistent with upward motion of Laberge strata with respect to the adjacent felsic volcanic strata (Photo 2).
- Pyroclastic dikes, believed to be subvolcanic feeders to volcanic rocks at Mount Jeane, clearly cut Laberge strata.

Two major belts of Stuhini Group are present in the map area (Figure 4). A southwest belt is dominated by primary volcanic strata and detritus derived almost exclusively from this source. It is apparently fault bounded, except where in contact with unconformably overlying Sloko Group. A northeast belt is dominated by conglomerate sheets within fine-grained clastics; volcanic flows are uncommon.

Photo 2. Laberge strata are drag folded along a high-angle normal fault that juxtaposes them with Sloko Group strata on the west face of Mount Jeane. Over 2 kilometres of vertical displacement has occurred. About 1.4 kilometres of relief is shown in the photo. Low-angle fault cutoffs are seen in the cliff face (see arrow to left of shadow).

SOUTHWEST BELT

A thick monomict section of crowded pyroxene porphyry breccia and derived sandstone crops out in a belt 1 to 3 kilometres wide and broadening to the southeast, that extends from lower Stuhini Creek to the toe of Sittikanay glacier. These rocks are lithologically identical to Stuhini Group in the Tagish area to the north where there is good fossil age control (*e.g.*, Mihalynuk and Mountjoy, 1990). It is olive brown to olive green, with coarse, dark green, euhedral pyroxene commonly comprising more than 25% of the rock. Pyroxene weathers positively on slightly weathered surfaces and negatively on deeply weathered surfaces. Zones of abnormally high calcite content commonly weather orange, especially where fractures are abundant. Breccias are massive, but fine-grained clastics may display *delicate ripple cross-stratification, grading, scouring and*

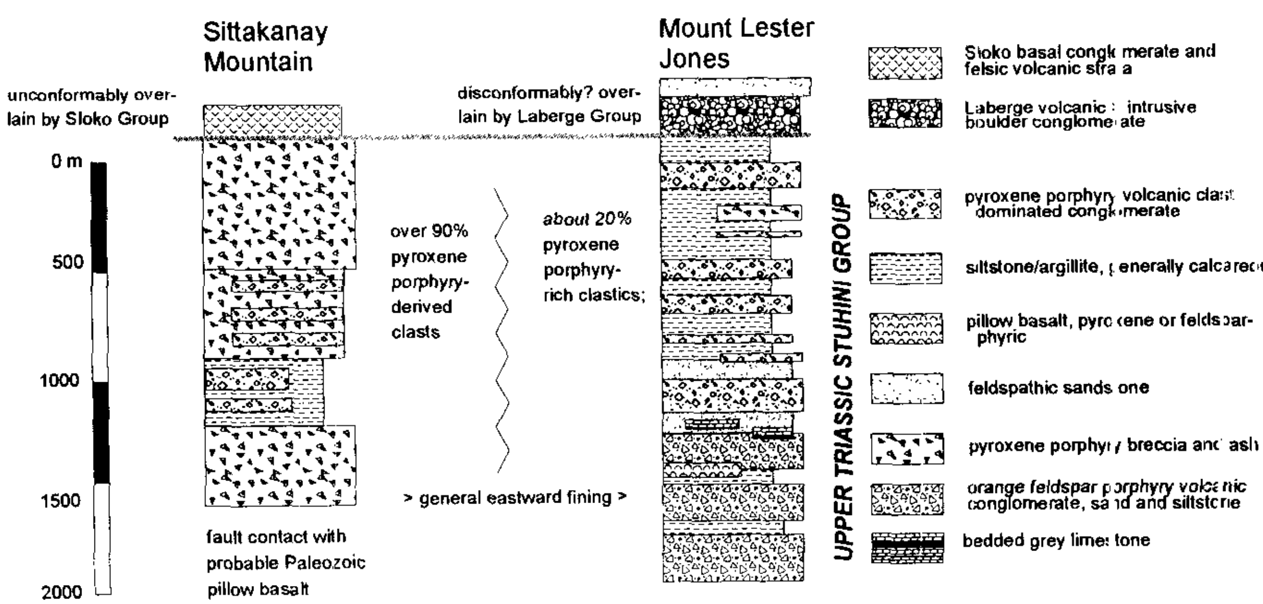

Figure 4. Stylized stratigraphy of the Upper Triassic Stuhini Group.

load structures.

Only two units within the southwestern belt show derivation from sources not completely overwhelmed by the pyroxene-porphyry component. A well bedded conglomerate contains round clasts of pyroxene porphyry, tabular feldspar porphyry and sparse carbonate. It has a calcareous sandstone matrix. Contorted, tan and black, centimetre to decimetre-scale silt-argillite couplets occur at one interval. They show evidence of soft-sediment deformation and are riddled with minor faults having apparent offsets of 10 centimetres or less.

Folding within this belt of Stuhini rocks is intense. It is difficult to recognize in massive breccia units, but can be clearly seen in the derived clastics where open to close folds are common. Brittle faults follow two dominant trends: northwest and west.

NORTHEAST BELT

Two lithologies comprise most of the northeastern belt: conspicuous lobes and sheets of pyroxene porphyry and carbonate cobble and boulder debris flows (Photo 3), and enveloping dark brown to black calcareous siltstone and argillite. The argillite contains ammonites, halobiid bivalves and belemnites. Locally it contains massive, fine-grained lenses of pyrite up to several metres long and a few centimetres thick - probably of biogenic origin, resulting from deposition in a primarily euxinic environment. Composite sheets and lenses of conglomerate are 90% derived from pyroxene-porphyry breccia, tuff and tuffite: lithologies that are common in the southwestern belt. Carbonate boulders up to 0.5 metre in diameter comprise about 10% of the clasts on average. Individual conglomerate beds can be mapped intermittently along strike for distances of more than 2 kilometres and some may be more than 250 metres thick. One distinctive conglomerate unit also contains up to 30% grey 'chert' clasts. Some of these clasts contain sparse blades of plagioclase, obviously derived from a mainly aphanitic volcanic unit.

Structurally below the conglomerate-argillite unit is a monomict, orange-weathering, tabular (2-3 mm, subhedral to euhedral) feldspar porphyry cobble conglomerate (and tuffite?) with khaki interbeds of feldspathic sandstone and siltstone. It is more than 300 metres thick and is regionally extensive. Overlying it, in apparent stratigraphic continuity, is a mixed succession of feldspathic sandstone; disrupted carbonate beds up to 10 metres thick, but typically less than a metre thick; pyroxene crystal tuff and heterolithic debris flows. North of the map area, near Sinwa Mountain, this unit grades into carbonate framework reefs .

Nowhere within the map area can Stuhini Group rocks be unequivocally shown to rest on Paleozoic Stikine assemblage strata. The upper contact with the Laberge Group, on the other hand, is apparently exposed on the southeast flank of Mount Lester Jones (Photo 4), and is probably disconformable as previously suggested by Monger (1980). At this locality a heterolithic conglomerate containing a large proportion of clasts of Stuhini feldspar-porphyry conglomerate, cuts down into the calcareous argillite and interbedded pyroxene-porphyry and carbonate-cobble conglomerate. However, the interval in which this contact occurs is poorly dated. At most other localities a structural contact is displayed.

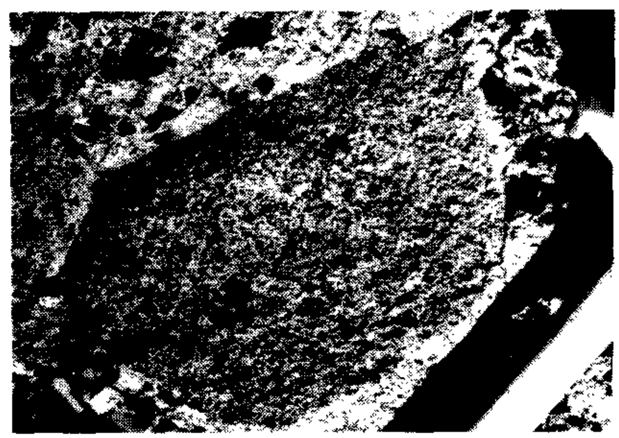

Photo 3. Coarse Stuhini Group conglomerate is dominated by boulders of pyroxene porphyry and lesser white-weathering carbonate. (b) A boulder of crowded euhedral-pyroxene porphyry.

Although direct correlations cannot be made, it appears that coarse conglomerates of the northern Stuhini belt were derived from the southwest (or similar) volcanic belt, consistent with the observations of Monger (1980). Sparse paleoflow measurements from both belts indicate northerly paleoflow, supporting this contention.

JURASSIC

A large part of the northeast quadrant of the map area is underlain by a succession of volcanic and intrusive clast dominated conglomerates, sandstone, feldspathic wacke, siltstone, minor metamorphic clast rich and chert-pebble conglomerate and rare tuffite of the Laberge Group. With the exception of metamorphic-clast rich conglomerate and chert-pebble conglomerate, constituent lithologies are quite similar to those found in the Atlin Lake area (Bultman, 1979; Mihalynuk *et al.*, 1989; Johannson, 1993).

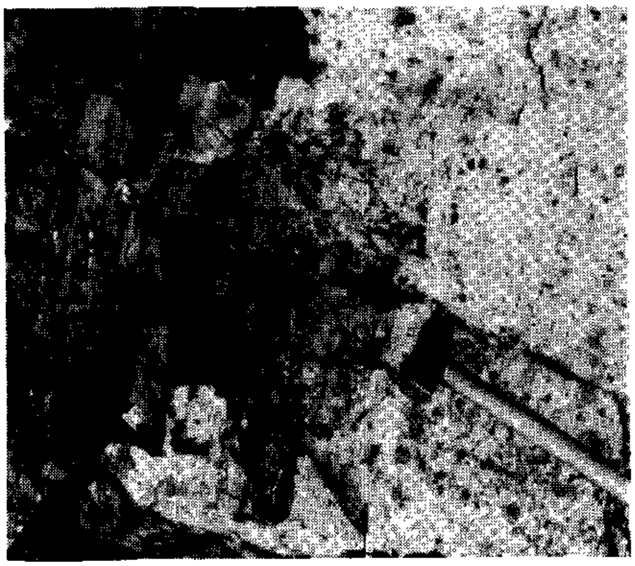

Photo 4. Polymictic volcanic conglomerate cuts down into Upper Triassic argillite on the east flank of Mount Lester Jones.

Fossil ammonites are abundant. Numerous collections from the area should provide good age control on the Laberge strata. Faunal constraints indicate a sub-boreal to boreal paleobiogeography. Other fossils, notably bivalves, gastropods and ichnofossils locally occur in profusion.

Accumulations of Laberge strata may reach 3000 metres. Southeast of Lisadele Lake, intrusive and volcanic-clast conglomerate alone, attain a thickness in excess of 1000 metres. However, structural complexities make estimates of true thickness difficult, especially in the absence of pending fossil age control. Laberge strata record depositional settings that span lower shoreface through basin plain environments. Much of the succession represents shallow-marine deposition and sedimentological observations suggest a prograding fan delta setting with distal equivalents.

CONGLOMERATE

Distinctive clast populations permit subdivision of conglomerate into several mappable units. There is a general up section progression from Pliensbachian volcanic to Toarcian intrusive clast dominated conglomerate (Figure 5). A distinct interval of metamorphic clast rich intrusive conglomerate occurs in the middle to upper Toarcian. Chert-granule to pebble conglomerte occurs near the top of the Laberge succession, in the Lower Bajocian.

Clasts typically have high sphericity, are well rounded and range from granules to coarse boulders (up to 2 m diameter) with cobbles most abundant (except chert-clast granule conglomerate). Individual bed thickness ranges from around one metre to several hundreds of metres. Bed thicknesses in the 1 to 10-metre range are most common. Beds commonly have scoured

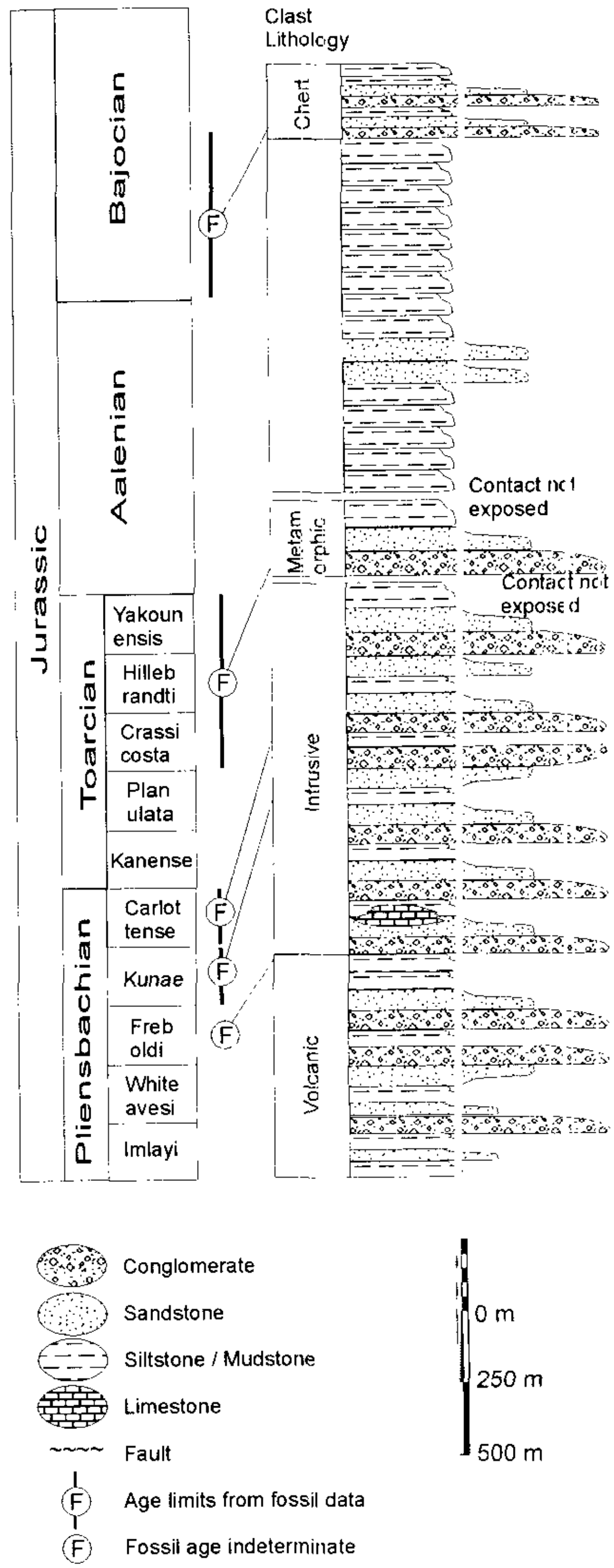

Figure 5. Indirectly measured sections representing lithologic variability of the Lower Jurassic Laberge Group within the map area.

bases and normal grading; however, reverse grading occurs locally. Individual conglomerate layers can be surprisingly continuous. One conglomerate sequence is mapped intermittently for over 7 kilometres.

Conglomerates are invariably mixtures of different clast types. Mixtures of intrusive, volcanic and lesser sedimentary intraclasts comprise the lower conglomerate units. **Intrusive** clast lithologies include: leucocratic quartz monzonite, monzonite, granodiorite, quartz monzodiorite, granite and monzogranite. A common clast lithology is potassium feldspar megacrysts in a holocrystalline pink hornblende-biotite granodioritic groundmass. It is less commonly foliated, and rarely displays a fine-grained, dark grey groundmass enclosing bladed plagioclase phenocrysts, and is invariably epidotized. Unusual but conspicuous alaskitic clasts are cut by dense sets of hairline fractures with black coatings. **Volcanic** clast lithologies include: phyric to aphanitic intermediate to felsic volcanics, trachytic fine hornblende -phyric green and maroon andesites, green to brown coarsely bladed feldspar porphyry, and lithic crystal ash to lapilli tuffs. They are dominated by tan to grey or green-weathering feldspar porphyries. Feldspars are dominantly plagioclase ranging in size from 2 millimetres to 2 centimetres and comprising 5% to 40% of the clast. Distinctive dark green-weathering, crowded pyroxene porphyry clasts are locally predominant. **Metamorphic** clasts are generally white-weathering, leucocratic, quartz-rich feldspathic mica schist and mylonite (Photo 5a). Compostions of quartz-rich schist clasts range from feldspathic quartz-mica schist to quartzite, both non-carbonaceous and carbonaceous and strongly foliated to gneissic. Metamorphic vein-quartz is also common. Possible provenance affinities include the Yukon-Tanana Terrane and metamorphosed Stikine assemblage. **Chert** pebbles and granules are buff, black to white and less commonly red in colour (Photo 5b); some with visible radiolarians. Many cherty clasts are derived from rhyolite as indicated by the presence of feldspar and quartz microlites in thin section. Chert conglomerate beds display good normal grading, are several decimetres thick or occur in sets up to several metres thick. They are very well sorted, well rounded, and monomict in nature, with cherty clasts comprising at least 95% of the rock. Although relatively thin, they are very distinctive and appear to be continuous over large distances, and thus show great promise as stratigraphic marker horizons. They occur at the highest stratigraphic levels, and are believed to be Aalenian to Bajocian (lower Middle Jurassic) in age.

SANDSTONE, SILTSTONE, MUDSTONE

Massive, thick-bedded, green, coarse-grained arkosic wacke is the dominant lithology in the Atlin area, but is subordinate to conglomerate and fine-grained clastics in the Stuhini Creek area. Spherical calcareous concretions are relatively common and somewhat diagnostic of these sandstones. A very distinctive light-weathering, porous and permeable tuffaceous litharenite crops out in the Lisadele Lake area. It is similar to units on Atlin Lake

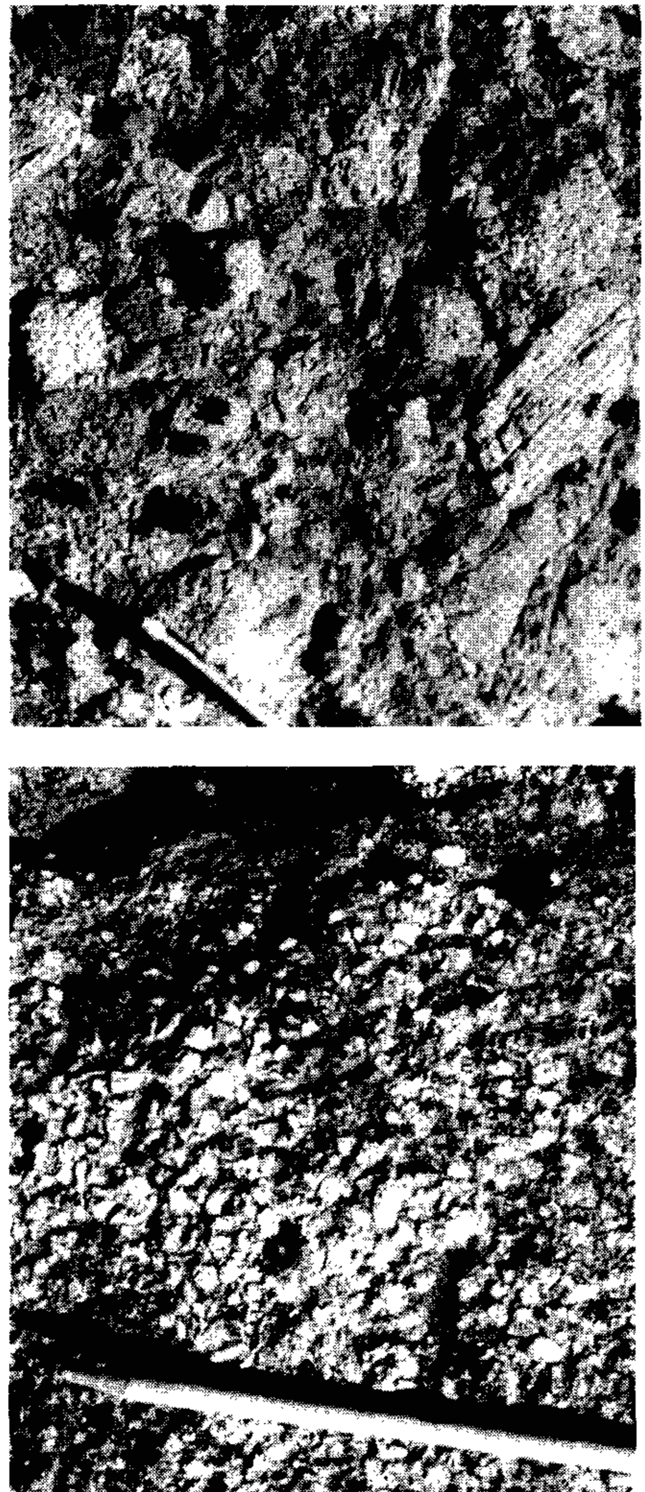

Photo 5a. Laberge Group metamorphic clast rich conglomerate at the conglomerate-argillite transition. (b) Chert granule to pebble conglomerate in the upper shale-dominated Laberge Group lithologies.

correlated with the *circa* 185 Ma Nordenskold dacite (Johannson, 1993; preliminary GSB age data).

Siltstone and mudstone generally occur as thin-bedded silt-argillite couplets and laminae and fine sand-mud couplets that commonly display the partial Bouma sequences T_{ce}, T_{de} and T_{bcde}. These rocks are normally moderately well indurated, but a distinctive, fossiliferous mudstone along King Salmon Creek is so poorly indurated that minor abrasion on a wet surface returns the rock to mud. Depositional environments include both shallow-marine and deep-marine fan-fringe to basin plain settings.

LIMESTONE

Bioclastic and biogenic limestone units include rudstones and patch reefs. Rudstones appear to be laterally extensive as the same lithology occurs at similar stratigraphic intervals where it is mapped intermittently across the northern part of the map area. Less useful markers are the bioherms which pinch out over distances of tens to hundreds of metres. One rudstone is a bivalve hash 2 to 3 metres thick, blue-grey to black-weathering and comprised of up to 80% fossil fragments, mostly bivalve material with a minor gastropod component. Some bivalve fossils are preserved in the growth position (Photo 6). A more extensive, rusty buff weathering rudstone horizon, several metres thick is composed almost exclusively of gastropods.

A bioherm of probable Pliensbachian age occurs low within the volcanic clast dominated succession near Lisadele Lake. It is over 8 metres thick and light grey except for local maroon discoloration associated with minor faults.

TERTIARY SLOKO GROUP

Geological mapping in 1994 indicates that Sloko Group lithologies are much more extensive than previously thought. Most of the rocks around Yellow Bluff, Kwashona Creek and Stuhini Creek are here included in the Sloko Group. Unlike 'typical' Sloko volcanics to the north, these strata are steeply dipping, and locally are folded.

Sloko Group volcanics are bimodal, but dominated by felsic lithologies. They rest unconformably upon a high-relief paleosurface that was etched into Mesozoic and Paleozoic strata. Voluminous air-fall units are regionally mappable, but the distribution of flow and epiclastic units is profoundly affected by paleotopography and synvolcanic faulting. These units occur as more isolated and sporadic units.

Photo 6. Robust bivalves in arkosic biomicrudite are locally in the growth position.

Due to rapid facies changes within the Sloko volcanics, not all units comprising the Sloko Group in the Tulsequah area (Mihalynuk *et al*, 1994b) occur within the Stuhini Creek map area. Previous regional mapping outlined six different mappable units including: a basal conglomerate; massive, well indurated, black pyroclastics (Opposer formation); massive, tan-weathering breccias (Mount Haney formation); interlayered feldspar-phyric flows and volcaniclastics (Nakonake formation); rhyolite domes and tuffs; and trachyte flow succession(s). In the Stuhini Creek area, several additional units are required to describe the Sloko

TABLE 2. CRITERIA FOR DISTINGUISHING SLOKO GROUP BASAL CLASTICS FROM LABERGE GROUP STRATA.

Criteria	*Sloko Group sediments*	*Laberge Group*
induration	poor	moderate to strong
matrix (both are feldspathic)	grey tuffaceous	green wacke
fracture	fractures around clasts (variable)	commonly fractures through clasts
weathering	grey (mainly non-calcareous)	orange (carbonate matrix common)
common clasts	Laberge clasts most common	Intrusive, volcanic, pyroxene-phyric
Laberge clasts	rounded (except paleo-colluvium)	angular intraformational ripups

Group. Two of these units are sufficiently persistent to warrant informal formation designation: coarse sandstone and Laberge Group clast rich conglomerate and siltstone (Niagara formation); and vitrophyric tuff containing fragments of feldspar crystals, pumice, coarse ash and fine lapilli (Teepee formation). Other units include: thick, bleached and silicified, indurated, feldspar-phyric flows and lesser interflow breccia and tuff; green hornblende and feldspar-phyric breccias; chaotic intermediate to felsic feldspar-phyric lapilli tuff to breccia; well bedded fine tuff or tuffite; and biotite and sanidine-phyric breccias.

NIAGARA FORMATION (INFORMAL)

Well bedded, black, white, tan and rust-weathering conglomerate, siltstone, epiclastics, tuff and tuffite are deposited in grabens atop the Laberge Group. Bedding is several centimetres to tens of metres thick. Thickness generally increases with the proportion of primary volcanic material. Black layers are carbon rich. Fossil swamp grasses, palm logs and palm fronds are common in siltstone and conglomerate (Photo 7a). Interbedded tuff is mainly pumice rich, feldspar±quartz-phyric and probably of dacitic composition. In the absence of associated tuffs, dominantly sedimentary Sloko strata are difficult to distinguish from Laberge rocks. Some distinguishing criteria that may be helpful are listed in Table 2.

TEEPEE FORMATION (INFORMAL)

Dark brown to tan-weathering vitrophyric tuff is a resistant, peak-forming unit. It caps Kwashona Mountain and several of the high, craggy peaks southwest of Morepat Creek. Coarse columnar jointing is common. Lithic lapilli (up to 15%) and angular feldspar fragments (up to 20%) float in a densely welded black matrix of vitric lapilli and ash (Photo 7b and 7c).

This unit is widespread within the map area, and may be typical of a series of regional eruptive units. For example, an identical unit caps ridges at Teepee Peak, about 120 kilometres to the north, near the Yukon border.

FELDSPAR-PHYRIC FLOWS

Thick, monotonous plagioclase-phyric flows and minor interflow breccia and tuff constitute this unit. The flows are dark blue-grey to black or green and well indurated. They contain 5 to 30% subhedral plagioclase phenocrysts, generally less than 0.5 centimetre long, in a glassy to very fine grained groundmass. These units typically weather a medium to dark grey and are massive, however, individual flows may be visible when viewed from a distance. Some flows are pyritic, and weather to an orange-brown gossanous surface.

Interflow or interlayered breccias are generally the same colour and composition as the flows. They contain plagioclase-phyric fragments in a finer-grained, plagioclase-phyric groundmass. The plagioclase phenocrysts in the fragments are larger than those in the groundmass, and the fragments may be 0.5 metre or larger in long dimension. Tuffs within this sequence contain variable amounts of fragments which are almost exclusively of volcanic origin.

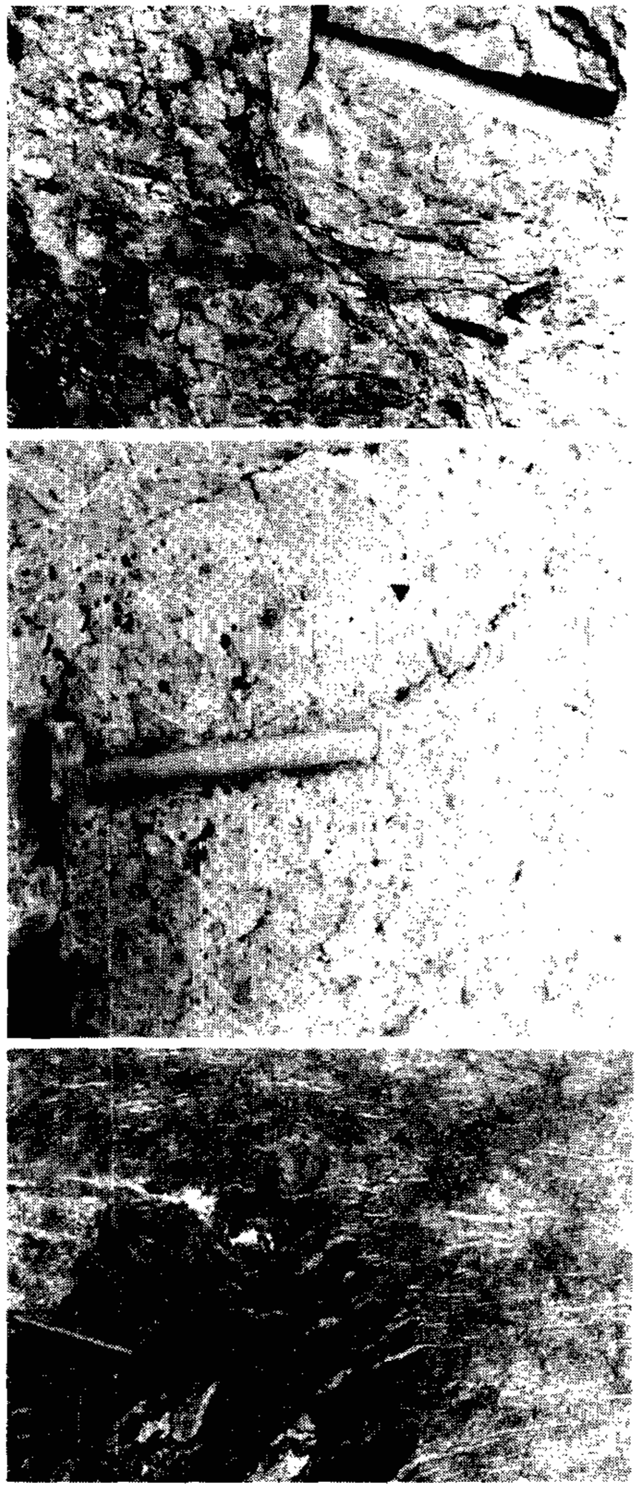

Photo 7a. Sloko volcanic sediments with carbonized wood and swamp grass debris; a palm frond stock is above the hammer. (b) Sloko welded ignimbrite flow with flattened pumice blocks up to 40 centimetres in diameter and 1 centimetre thick. (c) Sloko volcanic breccia; note partially welded bomb (at arrowhead).

DEBRIS FLOWS/BRECCIA/TUFFS

A thick fragmental sequence is composed of chaotic lapilli tuff to breccia and/or debris flows. These rocks are maroon to grey on fresh surfaces and light to dark grey depending on the overall felsic or mafic component. The fragments range in size from coarse ash to lapilli, but some are up to house size (Photo 8). Fragments are felsic to intermediate in composition and dominated by plagioclase porphyries.

Photo 8. Light coloured rhyolitic blocks contrast with darker matrix in a megabreccia on the east face of an unnamed peak north of Stuhini Creek. This unit is believed to have formed along a fault scarp; perhaps as an intracaldera facies.

FINE TUFF/TUFFITE

Interlayered ash to fine lapilli tuff, or tuffite, underlie the Niagara formation near Niagara Mountain. These range from fine-laminated, slightly pyritic, black ash tuffs or very fine grained siltstones to grey-blue, fine-grained bleached and silicified ash (lapilli) tuffs. All tuffs contain abundant feldspar fragments and minor fine volcanic lapilli fragments. The rocks weather rusty in areas where minor pyrite is present, to light brown-buff where the more extensive siliceous tuffs outcrop. The overlying Niagara formation conglomerate commonly scours and channels into these underlying lithologies, possibly obliterating them in some areas.

RHYOLITIC AND DACITIC VOLCANICS (FLOWS, LAHARS, BRECCIAS, TUFFS, WELDED TUFFS)

Rhyolitic and lesser dacitic volcanics constitute the basal units of the Sloko Group in some parts of the map sheet. The rhyolite flows vary from grey-white and massive to pinkish with fine flow bands and spherulites. Intimately associated with the flows are both lahars and breccias containing felsic volcanic fragments in a red, muddy matrix, as well as welded tuffs with flattened pumice fragments.

PLUTONIC ROCKS

Intrusive rocks in the Stuhini Creek map area can be grouped into three suites. Their age ranges can be only broadly assigned based on stratigraphic relationships, due to lack of isotopic age determinations. They are (?)Triassic to Cretaceous biotite hornblende diorite to tonalite, Early Eocene granite, monzonite and diorite and Eocene or younger granite and granodiorite.

TRIASSIC TO CRETACEOUS (?)

Weakly to moderately foliated hornblende tonalites to hornblende diorites are interpreted to be the oldest intrusives of the map area. They outcrop along the western map area boundary, on the northern flanks of Sittakanay Mountain. The rock is dominantly fine to medium grained. Hornblende is partly altered to epidote and chlorite.

EARLY EOCENE

This suite of plutonic rocks underlies a large part of the southeastern quadrant of the map area It is a series of east-west elongated, high-level, multiphase plutons and stocks. In outcrop, these intrusions weather white, light grey, tan, pink or orange. They are compositionally and texturally variable, ranging from fine to medium-grained quartz-feldspar-porphyritic monzonite and diorite to granite with as much as 15% biotite, magnetite, and/or hornblende. This variability probably results in part from different degrees of assimilation of large foundered blocks and scattered screens of volcanic and sedimentary country rocks. Contacts with solid country rock are sharp and chilled.

These plutons and stocks are spatially associated with, and most probably comagmatic with, Sloko Group volcanics; although they display a cannibalistic relationship. They are crosscut by northeast-trending faults resulting in brittle deformation and subsequent local alteration, hydrothermal alteration, and precious and base metal mineralization (*i.e.*, auriferous arsenopyrite with sphalerite and galena in clay alteration zones, and molybdenum along fractures in gossanous zones).

EOCENE AND YOUNGER

The youngest known plutons within the map area are pinkish grey medium-grained granite to tonalite bodies in the extreme northwest and southwest corners. They have long northeast-trending apophyses that extend far into the country rocks. Modal mineralogy of holocrystalline intrusions is 35 to 45% quartz, 20 to 40% orthoclase, 30 to 50% plagioclase and 5 to 15% biotite (less commonly with up to 10% hornblende). The intrusion in the southwest corner of the map contains spectacularly exposed, subequant xenoliths of Carboniferous tuffaceous rocks ranging from tens to hundreds of metres in length, indicative of high-level emplacement. The degree of xenolith assimilation (if any) is unknown.

Also included with this group of intrusions are subvertical dikes that comprise a swarm 6 kilometres wide that trends northeast from the toe of Sittakanay Glacier. Individual dikes are 2 to 50 metres thick. Together they comprise up to 50% of the rock mass over distances of several hundred metres, and about 10% over the width of the swarm. They are commonly porphyritic. In some instances, emplacement of these bodies appears to have occurred along northeast-trending faults.

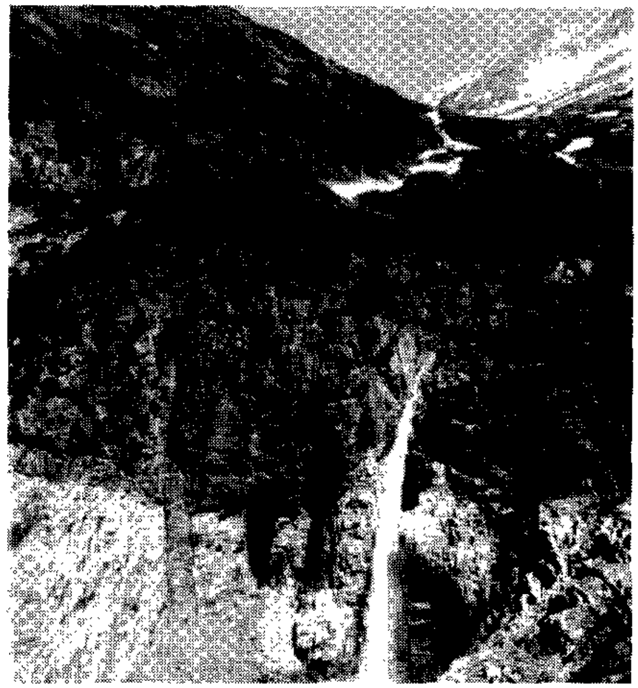

Photo 9. Rapid isostatic rebound in response to glacial retreat has resulted in streams deeply incised into U-shaped valley bottoms.

QUATERNARY

Glaciation in the Stuhini Creek area is typical of many coastal regions where alpine glaciers are resilient remnants of a once widespread continental ice cap. The Quaternary history of this specific region is relatively poorly understood as no detailed Quaternary studies have been conducted. From the drainage pattern of the creeks and rivers, present-day glacier movement, glacial striae, P-forms and other paleoflow indicators found in the area, it is apparent that ice in the region flowed through the Sittakanay, Stuhini and Zohini stream valleys, into the Taku River valley and west toward the Pacific Ocean. The position of hanging valleys in the Taku River valley suggests a thickness of ice of approximately 580 metres.

Quaternary deposits in the area include terminal, lateral and medial moraines, lodgment and melt-out tills, glaciofluvial and fluvial accumulations, and colluvium. Any of these deposits may be, to some degree, reworked by fluvial and/or mass movement processes. Lacustrine deposits in the region are of limited areal extent.

Rapid retreat of thick ice sheets in the Coast Mountains has resulted in significant isostatic rebound. In response to this rebound, many creeks are deeply incised into U-shaped valley bottoms (Photo 9).

STRUCTURE

Deformation in the Stuhini Creek map area generally increases in intensity with the age of the affected strata, indicating a progression of widespread deformational events. Two to three folding events have affected Paleozoic strata, whereas, Tertiary rocks are generally block faulted and rarely tightly folded. Partitioning of high-angle brittle and ductile fabrics, particularly in the southwestern part of the map area, can in part be related to proximity of a major crustal structure, the Llewellyn fault zone. A second crustal-scale structure, the King Salmon fault, is associated with a Jurassic thrust belt that affects the northeastern quadrant of the map area. A series of Tertiary, high-angle normal and oblique faults is largely responsible for the juxtaposition of Mesozoic and Tertiary strata; although faults with the greatest amount of offset do not have the most prominent topographic expression.

MESOZOIC AND OLDER FOLDING

On Mount Sittikanay, pyroxene-phyric breccia and maroon lapilli ash tuff display two coaxial northeast-trending, high-amplitude chevron fold sets (Mihalynuk *et al.*, 1994a). They are also deformed by a more open set of north-northwest-trending folds. However, relationships that clearly demonstrate the relative ages of these folds are lacking.

On Mount Jeane, tight east-west minor folds crop out in the core of a late (Eocene), open, northwest-trending antiform. Elsewhere within Mesozoic strata of the northern map area, northwest-trending folds are open with wavelengths of 1 to 3 kilometres. These folds affect the youngest Laberge Group strata which are unconformably overlain by Eocene Sloko volcanics unaffected by the folding. This widespread folding is believed to be early Middle Jurassic in age; part of the same deformation event that produced the King Salmon thrust belt.

TERTIARY FAULTING AND FOLDING

High-angle normal, reverse and oblique-slip faults were the most widespread structural modifiers of Eocene and post-Eocene geology. Two major episodes of high-angle faulting can be resolved. A dominantly easterly oriented set has individual vertical offsets that may exceed 2 kilometres, and are in part synchronous with deposition of Eocene Sloko Group rocks. These faults are cut by a later northeast-oriented set of Eocene and younger(?) faults with dip-slip offsets generally less than 500 metres. Late faults typically have a greater topographic expression than earlier faults that have greater offset.

Folding of Tertiary strata is induced by drag along major block faults; by draping of volcanic strata over preexisting topographic irregularities, and apparently, by compressional deformation acting locally over areas of less than a few hundred square kilometres.

Drag folds affect both Tertiary and Mesozoic rocks along faults that juxtapose the two. One of the best examples is well displayed on the southwest face of Mount Jeane. Here Laberge rocks have been down-warped adjacent to down-dropped Sloko Group volcanics (Photo 2). Warping of some Tertiary strata may have been synchronous with their deposition. An example of this is seen on the ridge between Zohini and Red Cap creeks. Here, Eocene strata steepen and thin northward toward a high-standing Laberge Group fault block. These rocks contain a significant proportion of Laberge Group clasts, probably derived from the Laberge block as it was uplifted to form a fault-basin for Sloko Group deposition.

Paleozoic rocks were subjected to older regional deformational events, making it difficult to resolve the affects of late block faulting. Block faults do however, bring Paleozoic rocks to the surface. On the northeast face of Mount Erickson, Paleozoic and Tertiary strata are juxtaposed across a high-angle reverse fault (Photo 10). If our interpretation of Sloko Group offsets are correct, the Mount Erickson fault has a minimum vertical displacement of about 2 kilometres.

LLEWELLYN FAULT ZONE

Mihalynuk *et al.* (1994a, b) traced the Llewellyn fault from Atlin Lake, south through the Tulsequah River area, but lost it in the broad Taku River valley. No single dominant trace of the fault could be identified south of the Taku. Field observations reported here confirm an apparent fanning of the Llewellyn fault with distribution of ductile and later brittle faults over several widely spaced traces. Two of these traces are interpreted to affect Paleozoic strata underlying Mount Sittikanay. Deformation along the fault splays is dominated by ductile fabrics at this structural level. As mapped, the fault strands juxtapose locally foliated Paleozoic volcanics with Triassic volcanics in which intense ductile fabrics are less commonly developed.

KING SALMON THRUST BELT

Souther (1971) mapped the King Salmon thrust as a structural discontinuity that is focused at the base of Upper Triassic Sinwa carbonate. However, this overthrust event probably affected a belt of rocks that extends west to Red Cap Creek where a complexly deformed, west-verging imbricate stack of Jurassic and perhaps Triassic strata is exposed. It may even extend to west of Mount Jeane, where low-angle fault cutoffs are well exposed in cliff faces (Photo 2). Unfortunately the nature of this compressional deformation event is masked by later block faulting, and in the western part of the map area, by thermal overprinting by the Coast intrusions.

Age of thrusting is constrained outside the map area, near Cry Lake, to be Toarcian to middle Bajocian (Thorstad and Gabrielse, 1986). More recent evidence from farther south, suggests that initiation of thrusts like the King Salmon, responsible for emplacing oceanic Cache Creek Terrane above Stikinia, is recorded in latest Toarcian to Aalenian strata of the basal Bowser Lake Group (Ricketts and Evenchick, 1991). Jurassic Laberge

Photo 10. A well exposed high-angle reverse fault along the base of Mount Erickson (at Bruce's feet) that juxtaposes deformed basalt of probable Paleozoic age (to right) with quartz-phyric breccia (left of fault) here assigned to the Eocene Sloko Group

Group strata of the Stuhini Creek area also record this event with deepening of the basin in late Toarcian time, and introduction of chert-granule conglomerate, presumably derived form uplifted Cache Creek Terrane, in the early Bajocian. A corollary of Bajocian Laberge Group deposition in the Stuhini Creek area is that overthrusting of the Sinwa Formation by the King Salmon fault could not have extended as far west as the map area before Bajocian time.

MINERAL PROSPECTS

A wide variety of mineral occurrences are found in the Stuhini Creek map area. Paleozoic strata contain volcanogenic massive sulphide accumulations, Tertiary intrusions at the Red Cap have reported porphyry copper potential, and Tertiary volcanics host base metal sulphide veins with sporadic, elevated gold and silver values. Four occurrences are well explored prospects, and have been drilled: base metal sulphide lenses at the Erickson-Ashby; auriferous antimonial shear-hosted veins at the Zohini; antimonial veins at Red Cap and auriferous arsenical porphyry-hosted veins at the Go.

Field mapping in 1994 provided new data on known occurrences, helped to further outline volcanogenic massive sulphide potential in Paleozoic rocks and resulted in the discovery of three significant metal sulphide vein occurrences. These new occurrences are tetrahedrite-chalcopyrite-sphalerite veins at the Lisadele; galena-chalcopyrite-sphalerite veins at the Blackfly, and chalcopyrite-magnetite veins at the Oksarah. A number of smaller showings or indicators were also discovered and are reported on below.

ERICKSON-ASHBY

The Erickson-Ashby property is an advanced prospect which was discovered in 1929 by two prospectors (Erickson and Ashby). Since 1929 most assessment work was performed to maintain the claims in good standing, however, the property has been subjected to geological mapping, geochemical sampling, trenching and diamond drilling. An adit was driven adjacent to one of the mineralized zones in 1964.

The property is underlain by probable late Paleozoic volcanic and associated sedimentary lithologies cut by Tertiary granitic dikes. They consist of massive to locally brecciated and epidotized basalts and andesites interlayered with lesser purplish siltstones, cherty siltstones, cherty argillaceous carbonate, and carbonate with mafic volcanic clasts. Payne (1979) reports that rhyolite and rhyolitic tuffs are present within the sedimentary intervals, however, these rock types were not encountered during our limited examination. All lithologies are hornfelsed; basalts and andesites to a lesser degree than the more porous sedimentary rocks. Mineralization is restricted to cherty and carbonate intervals, and has been described as being syngenetic volcanic (VMS) in origin (Payne, 1979) and epigenetic skarn mineralization (Bernius, 1963; Bojczyszyn, 1988).

Lithologies are cut by a north-northeast-trending dextral fault (Bracken fault) with a maximum offset of up to 200 metres. Southeast of the fault are interlayered basalts and andesites and sedimentary exhalatives, whereas to the northwest are mostly siltstones and interlayered exhalatives. Mineralization is present on both sides of the fault but is more extensive and higher grade to the southeast (Payne, 1979).

Mineralization occurs within at least thirteen different zones, each of which contains one or more discontinuous lens-shaped bodies of disseminated to massive sulphide (Payne, 1979). The sulphides are almost exclusively a mixture of pyrrhotite, sphalerite, pyrite, and galena. Assemblages range from massive pyrrhotite or pyrite with up to 25% sphalerite and galena, to massive sphalerite or sphalerite and galena in equal proportions. Malachite staining is visible on weathered surfaces, but no other copper minerals were seen. Analysis of a sample collected during our examination returned 1.57% Pb, greater than 10% Zn, 258 g/t Ag and negligible copper (see sample SSE94-42.100, Table 3). Mineralization cuts across the sedimentary layering but the bounding mafic flows are not mineralized.

Base metal assemblages, associated hostrocks and the location of the mineralized pods suggest that sulphide accumulation was syngenetic with the enclosing sediments, probably during a hiatus in basaltic/andesitic volcanism. The present skarn mineralogy (actinolite-rhodonite-diopside-tremolite-magnetite) represents a later contact metamorphic effect due to intrusion of nearby monzonitic sills. An increased thermal gradient seems to have succeeded only in recrystallizing the sulphides with little sulphide remobilization.

GO-1

The Go-1 claims covers mineralized portions of a Tertiary quartz monzonite stock east of Mount Lester Jones. Mineralized sections consist of gold±silver-bearing arsenopyrite within planar, light-coloured alteration zones that strike 110° and dip 75° south. Within these zones, feldspar and hornblende are replaced by phyllosilicates. Carbonate alteration (siderite) is pervasive, but epidote and chlorite alteration is conspicuously absent. Arsenopyrite and pyrite are the dominant sulphides with locally abundant pyrrhotite, chalcopyrite, galena, sphalerite, and stibnite (Lintott, 1981). Nine holes were drilled in 1981 with the best assays returning 7.1 g/t Au and 514 g/t Ag over 13 centimetres (Lintott, 1981). No base metal assays have been reported.

A brief examination during regional mapping revealed that there are at least eleven separate drill collars and three small blast pits. Analysis of a grab sample of intergrown green quartz and arsenopyrite from one of these pits yielded values of 0.26% Cu, 0.44% Pb, 190 g/t Ag and 8 g/t Au (see Table 3, number MMI94-45.070).

GOAT CLAIMS

The Goat Claims blanket the south flank of Mount Metzgar west of the Taku River. Minor disseminated pyrite, sphalerite and chalcopyrite are locally present in the underlying felsic and intermediate tuffs, andesite, volcanic sandstones, and the variably graphitic argillites. Reported assays are very low with the best sample returning 0.19% Zn from a rhyolitic tuff (Photo 5 in Sorbara, 1983). Weak horizontal-loop EM and magnetic anomalies are generally associated with graphitic portions of the argillites.

In the course of regional mapping, traverses were made both north and south of the main exploration focus at the Goat claims. While no good rhyolite units were observed, indications of mineralization were encountered. Massive sulphide boulders were discovered in moraine to the north (see Other New Occurrences) and minor lead-zinc mineralization occurs in hornfelsed sediment to the south (0.4% Pb and 0.3% Zn; Table 3, number MMI94-42.020).

ZOHINI

The Zohini occurrence is a shear-related auriferous and antimonial base metal sulphide vein with good continuity, hosted by Sloko Group volcanic strata. Mineralization within the shear zone averages about 2 metres in width, but ranges up to nearly 8 metres. In 1994, a series of ten short diamond-drill holes tested the northern and down-dip extensions of the vein. Results of the drill program are pending.

RED CAP

An impressive gossanous alteration zone is developed within volcaniclastics and a polyphase porphyry intrusion at the Red Cap property. Anomalous copper, molybdenum and silver in soil samples across the alteration zone were thought to indicate porphyry potential. However, a series of six short drill holes (up to 7.2 metres) showed lower bedrock grades than indicated by the soils (Archer, 1972). Subsequent deeper drilling and geochemical surveys also failed to locate porphyry-style mineralization although stockworks of thin quartz veins with elevated gold and polymetallic sulphide veins were discovered (Rye, 1991, and references therein).

Three field traverses were made over the Red Cap property in 1994. A propylitic alteration zone extends well into clastic country rocks. This is overprinted by biotite and local strong bleaching and argillic alteration within the gossanous cap. A sample from this alteration zone returned 0.1% Cu (Table 3, number MMI94-9.060). A nearby quartz-flooded zone a few square metres in extent, returned 2.7 g/t Au (Table 3, number MMI94-9.080). Bounding Red Cap to the east is an extensively quartz veined fault zone; quartz veins and chalcedonic breccias are 10 to 20 metres wide. One sample collected from this zone (MMI94-11.070) showed no elevated metal values.

Although low-grade mineralization at the Red Cap lacks continuity, widespread alteration and extensive vein sets indicate a substantial hydrothermal system.

NEW SHOWINGS

Three new showings were discovered in the course of our regional mapping. These are persistent base metal veins (Oksarah, Lisadele) and vein networks (Blackfly) with contained gold values of less than 2 grams per tonne. Several less significant indications of mineralization were also encountered and are reported below.

OKSARAH

A set of subparallel veins are foliated to varying degrees within greenstone that displays rare relict pillows. Most continuous of these is a chalcopyrite vein, 15 to 70 centimetres wide, that can be traced for about 75 metres (Photo 11). A set of magnetite-chalcopyrite veins up to 20 centimetres wide is oriented roughly orthogonal to the main chalcopyrite vein set. Assays from the widest veins of these two sets are, respectively: 6.4% and 0.6% Cu, 279 g/t and 10 g/t Ag (see Table 3, numbers MMI94-23.021 and 022). Vuggy, quartz-flooded breccia zones up to 10 metres wide and several hundred metres long are spatially associated with the copper-silver mineralization, but do not have elevated metal contents. Wide-

Photo 11. A chalcopyrite vein at the Oksarah showing (dark and hackly) extends from the foreground, where it is 70 centimetres wide, to beyond the treed horizon, where it thins to 15 centimetres. Magnetite veins up to 20 centimetres thick form a set oriented roughly perpendicular to the main vein.

TABLE 3. ASSAY DETERMINATIONS FOR SELECTED SAMPLES FROM THE STUHINI CREEK MAP AREA.

Sample number		*UTM*		*Cu*	*Pb*	*Zn*	*Ag*	*Au*	*Mo*	*Co*	*Fe*	*As*	*Sb*	*Ba*	*NOTES*
		easting	*northing*	*%*	*%*	*%*	*ppm*	*ppb*	*ppm*	*ppm*	*%*	*ppm*	*ppm*	*ppm*	
BMA 94	21.030	597350	6509000	0.10	1.20	0.03	160.4	15600	1	121	16.42	16934	10796	2	Zohini vein at surface
DMF 94	20.010	605800	6503000	0.00	0.00	0.00	1.5	510	88	49	0.73	189	5	65	Gossan, Stuhini-Zohini headwaters
MMI 94	9.060	599850	6512350	0.10	0.00	0.00	1.1	77	1	126	12.64	23	5	18	Alteration at Redcap
MMI 94	9.080	600750	6512150	0.00	0.00	0.00	0.4	2700	1	36	1.04	9751	110	38	Quartz stockwork at Redcap
MMI 94	11.050	601300	6512200	0.60	0.14	0.28	101.1	3340	5	165	20.41	>10%	394	4	Red Cap trench
MMI 94	11.070	601550	6511000	0.00	0.01	0.00	0.7	54	64	100	0.78	143	6	162	Red Cap quartz-flooded zone
MMI 94	15.010	609600	6507750	0.03	0.02	0.03	2.1	124	11	78	6.94	3515	11	25	upper King Salmon Creek
MMI 94	16.070	607400	6488650	0.32	0.08	0.32	43	16	11	84	10.24	12	6	22	float on glacier
MMI 94	19.031	614300	6503300	2.26	0.59	0.23	164	683	10	158	8.44	2084	12929	8	Lisadelle
MMI 94	19.032	614300	6503300	2.18	1.80	0.80	161.8	579	5	186	7.94	4199	9767	16	Lisadelle
MMI 94	22.050	599000	6504500	0.22	1.71	2.73	151.6	3	223	75	5.2	27	8	7	Blackfly breccia
MMI 94	22.060	599050	6504450	1.85	0.71	0.15	209.2	5	56	121	9.96	86	12	18	Blackfly galena lens
MMI 94	22.072	599000	6504200	0.00	0.01	0.00	0.6	b.d.	15	59	1.31	24	34	63	Blackfly quartz-flooded country rock
MMI 94	22.080	drill	core	0.02	1.47	4.01	148.5	9650	1	2	5.83	159	14499	4	Zohini drill intersection DDH94-Z10 84.03-83.93 m
MMI 94	23.021	615350	6492400	6.44	0.02	0.04	278.7	39	6	194	25.34	47	21	11	Oksarah 0.7 m chalcopyrite vein
MMI 94	23.022	615350	6492500	0.62	0.00	0.03	10.4	b.d.	1	248	15.75	55	3	22	Oksarah 0.2 m magnetite vein
MMI 94	23.023	615250	6492350	0.00	0.00	0.00	0.5	12	7	120	1.83	28	4	40	Oksarah quartz-stockwork/silicified country rocks
MMI 94	26.020	604550	6486600	0.05	0.26	2.72	27.1	4	41	60	5.13	6	2	20	Fault gouge in Sloko volcanic strata
MMI 94	30.030	599500	6501150	0.01	0.00	0.00	121.2	210	21	85	1.41	164	4	47	Bull quartz vein near Niagara Mtn.
MMI 94	37.090	587150	6510500	0.00	0.00	0.00	0.1	b.d.	5	69	16.05	8733	93	4	Massive sulphide boulder Mt. Metzgar
MMI 94	42.020	587600	6508650	0.03	0.42	0.31	7.7	65	1	25	4.59	344	5	4	Goat claim
MMI 94	43.030	603000	6511500	0.06	1.14	1.15	28.5	13	1	47	3.92	50	9	5	Stuhini conglomerate; 5 cm chalcopyrite-galena vein
MMI 94	45.070	607250	6509250	0.24	0.45	0.03	190.2	13400	1	175	25.54	>10%	1956	4	Go-1 trenched arsenopyrite mineralization
SSE 94	36.030	612750	6497900	0.00	0.00	0.01	0.3	212	7	85	19.77	1531	7	12	Gossanous zone - east map area
SSE 94	42.100	588850	6502600	0.00	1.57	>10	257.7	-38	6	20	4.12	4799	3551	2	Ericksen Ashby sulphide pod
SSE 94	47.050	611400	6491050	2.69	0.00	0.00	90.6	6	8	62	4.16	6	2	76	Float boulder in eastern map area

Au analyses are by instrumental neutron activation. Other elements are analysed by Inductively Coupled Plasma Emission Spectroscopy. A 0.500 g sample is digested in 3 ml of 3-1-2 HCl-HNO_3-H_2O at 95°C for one hour and is diluted to 10 ml with water; it is partial for Fe.

spread deformation and metamorphism have obscured primary textures, thus the source of mineralization is uncertain. A hydrothermal origin is possible, but quartz, carbonate or other gangue minerals are scarce. A volcanogenic origin is supported by the submarine setting of the hostrocks (as indicated by relict pillows), but sulphides occur as veins both within and cutting fabrics that are interpreted to be much younger than the hostrocks.

BLACKFLY

Mineralization at the Blackfly showing is focused within the basal Sloko Group, just above its contact with Laberge Group strata on the west ridge of Niagara Mountain (Photo 12). Acicular hornblende porphyry hosts an irregularly spaced (5 to 10 m) network of veins and linear breccia zones up to 50 centimetres wide (more commonly 5 to 10 cm). A probable hypabyssal origin for the porphyry hostrocks is indicated by a lack of volcanic textures and large, quartz-lined, miarolitic cavities. Galena, sphalerite, quartz, epidote and chalcopyrite dominate the vein assemblage. In one case, a lens of nearly pure galena occupies a vein segment 2 metres by 30 centimetres in cross-section. Analysis of grab and chip samples returned values up to 1.9% Cu, 1.7% Pb, 2.7% Zn and 209 g/t Ag (see Table 3, numbers MMI94-22.050 to 072).

Because units hosting the Black Fly are ridge-cappers, they have been largely removed by erosion. We were unable to trace the relatively flat-lying mineralized zone around either side of the ridge during our preliminary investigations. It may be limited to an area of roughly 50 by 125 metres. However, similar mineralization is reported on the adjacent Niagara 8 claim block (Aspinall, 1991) centred about 1 kilometre to the east, well within the Laberge group rocks.

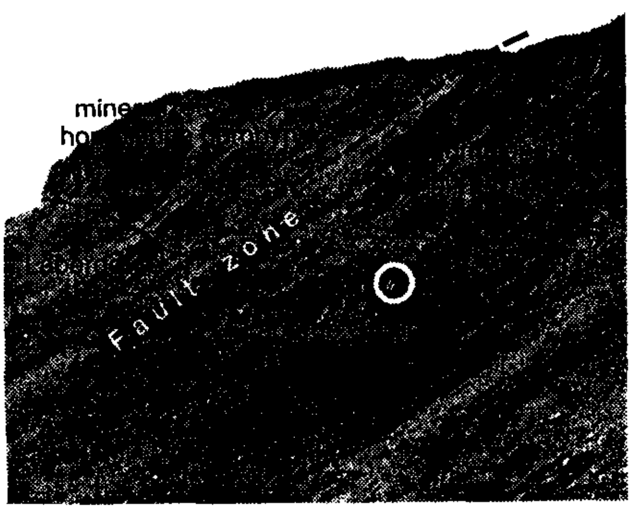

Photo 12. Galena-chalcopyrite mineralization at the Black Fly showing occurs as an irregularly spaced (5-10 metres) network of veins and linear breccia zones up to 50 centimetres wide on the west ridge of Niagara Mountain. This mineralization is best developed where Sloko Group hornblende porphyry (resistant, dark-weathering) crops out above Laberge Group argillite (more lightly coloured and rubbly).

Photo 13. A view northwest along strike of the Lisadele occurrence at the contact between resistant Sloko Group and underlying, relatively recessive Laberge Group strata. Parallel tetrahedrite-chalcopyrite-sphalerite veins 1 to 5 centimetres wide, can be traced along strike for at least 125 metres. Mount Lester Jones is on the far left horizon. Flat-lying Sloko Group rocks cap folded Laberge Group strata in the near right horizon.

LISADELE

The Lisadele occurrence is at the contact between Sloko and Laberge Group strata (Photo 13). Parallel tetrahedrite (± very fine grained ?stibnite and galena)-chalcopyrite-sphalerite veins 1 to 5 centimetres thick (rarely to 40 cm), extend for at least 125 metres along strike and are focused in a zone 5 metres wide, but occur widely spaced over a width of about 40 metres perpendicular to strike (Photo 13). The best analytical results are 2.2% Cu, 1.8% Pb, 0.8% Zn and 161 g/t Ag (see Table 3, numbers 19.031 and 032).

OTHER NEW OCCURRENCES

Molybdenite found near the extreme southeast corner of the map area is now named the Missing Creek occurrence (Figure 3, ▲1). Patchy molybdenite is present with fine-grained cubic pyrite along fracture surfaces in a gossanous zone within grey, fine to medium-grained granitoid intrusive composed of subhedral plagioclase (70%), quartz (15%), and biotite (15%). This gossanous zone also includes infrequent, 3 to 5-centimetre 'knots' of massive pyrite, presumably filling cavities. The attitude of the zone is undetermined, however it is present in outcrop for 10 to 12 metres along the stream.

A narrow vein (<1 cm) of massive chalcopyrite was found in granitic float in the southeast part of the map area (Figure 3, ▲2). The float is composed of quartz eyes and light green, altered plagioclase feldspars (together totaling 10 to 15%) in a fine-grained, pinkish brown groundmass. Minor mafic minerals are also present in the groundmass. Fractures are mostly coated with malachite. Granitic rocks outcropping in this area overlie a sequence of plagioclase-phyric volcanics and lesser lapilli tuffs. Epidote alteration is common near the granitic-volcanic contact. The nature of the surrounding topography indicates that the copper-rich float is probably sourced locally from the south-southwest.

Massive crystalline barite float has been found at three locations. The first is on the southeast face of Mount Lester Jones (Figure 3, ▲3) and consists of a 100 by 40-centimetre boulder of very coarse grained barite and lesser, crudely formed barite rosettes. Smaller boulders of similarly crystalline barite also occur in a small cirque approximately 2 kilometres north of Mount Jeane (Figure 3, ▲4). The coarse crystalline nature of the barite from these two float occurrences suggests a hydrothermal vein origin. However, in the latter case, the barite is spatially associated with submarine arc volcanic rocks and could be exhalitive.

The third occurrence of barite float is on the north side of Mount Lester Jones near an intrusive contact (Figure 3, ▲5). The barite here is medium to coarse grained and partially intergrown with crystalline quartz.

Boulders comprised almost entirely of fine-grained massive pyrite occur along the southern terminus of an unnamed glacier originating on the east face of Mount Metzgar (Figure 3, ▲6); they have apparently not been seen prior to our field mapping. These boulders are angular and up to 30 centimetres in diameter. They form an isolated train that rests on scoured bedrock of the Paleozoic Stikine assemblage. The boulders occur within about 20 metres of the margin of glacial ice and may have been melted out in just the past few years. Airphotos of 1974 vintage indicate that the area was more extensively snow covered at that time. The boulders are about 1 kilometre north of the Goat Claim block, but are not mentioned in assessment work reports (Sorbara, 1983).

Almost certainly the sulphide boulders are derived from the eastern cirque of Mount Metzgar. A traverse across the headwall of the cirque failed to identify areas of sulphide mineralization; although access to outcrops was limited by extensive bergschrund development. At the head of the cirque is a section of massive to well bedded rusty chert; a conspicuous unit that carries through to the north side of the mountain where it was mapped in 1993 (Mihalynuk *et al.* 1994b). Other lithologies include: brown, bioclastic limestone, vesicular basalt breccia, carbonate debris flows, sulphidic siliceous argillite, pillow breccia and tuffaceous turbidites. Considered collectively, the units most closely resemble the middle Pennsylvanian portion of the Mount Eaton succession. Extensive structural disruption at Mount Metzgar, including thrust faults that are well exposed on the northern face, may interleave a wide range of Paleozoic strata.

Analysis of the boulders indicate near background levels of copper, lead and zinc. Nevertheless they are an important exploration indicator in the immediate area.

GEOLOGIC HISTORY AND SUMMARY

The geological history of the Stuhini Creek area is summarized diagrammatically in Figure 6. Pre-Tertiary geology is mainly a product of two episodes of arc building and dissection. Arc rocks include Mississippian to Permian volcanics of the Stikine assemblage that probably represent at least three major arc-construction pulses in the early Mississippian, middle Pennsylvanian and Early Permian; and Upper Triassic volcanics of the

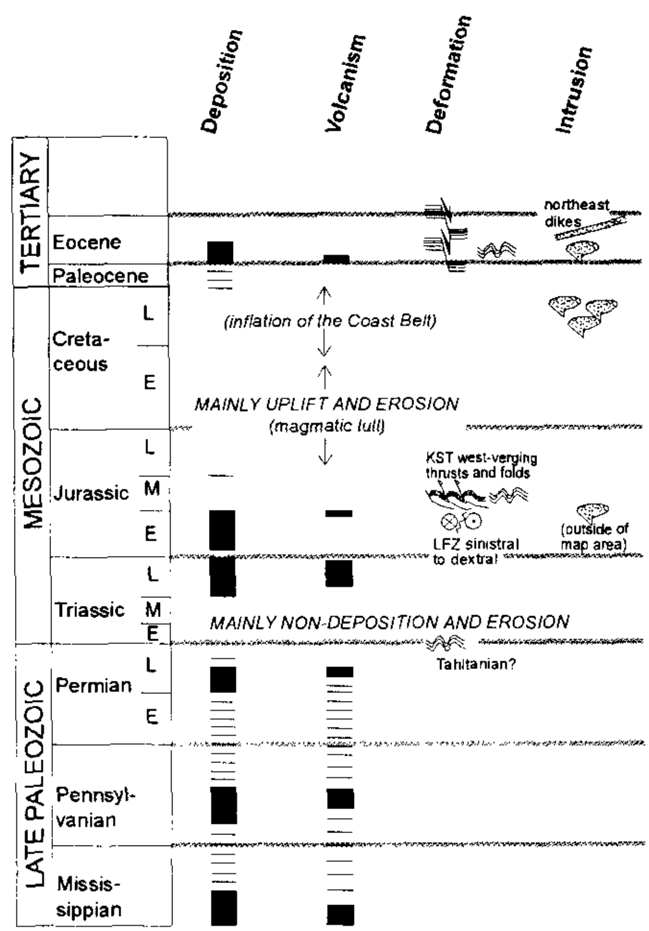

Figure 6. Summary diagram showing the geological history of the Stuhini Creek map area.

Stuhini Group. Early Mississippian felsic volcanism is particularly important because of local syngenetic massive sulphide accumulations (*i.e.*, Big Bull and Tulsequah Chief deposits to the north). Sulphide deposition at the Erickson-Ashby deposit may be coeval, but age data are currently lacking.

Evidence of Late Permian to Middle Triassic deposition appears to be absent. Perhaps this is a consequence of the Triassic global rise in sea level, or perhaps to removal of these strata during a pre-Upper Triassic deformational event known as the Tahltanian orogeny (Souther, 1971). However, the Tahltanian orogeny is not clearly manifest in the Stuhini Creek area.

The nascent Stuhini arc was presumably constructed on a Paleozoic arc substrate, however, there is no clear evidence of this in the map area. Generally, contact relationships are obscured by later faulting. Axial portions of the Stuhini arc appear to have lain mainly west of the map area; a coarse volcaniclastic arc-apron displays a northeastward (basinward?) increasing sedimentary component and northeast paleoflow.

Cessation of volcanism and uplift of the Stuhini arc in the Early Jurassic led to deep arc dissection and production of volcanic clast dominant conglomerate, followed by igneous clast dominant conglomerates of the Laberge Group. Arc dissection gradually waned, decreasing the production of coarse detritus. Aggradation of the basin in which Laberge strata accumulated slowed dramatically. Intermittent debris flows delivered coarse detritus from the lowest levels of Stuhini arc dissection, represented by metamorphic clast rich conglomerate.

Initial emplacement of the Cache Creek Terrane onto the inboard edge of the Stikine-Stuhini arc complex caused a late Toarcian to Aalenian deepening of the basin. Continued obduction resulted in a westward-migrating deformation front with major detachments localized near the top of the Stuhini Group (*i.e.*, King Salmon thrust; see Monger, 1980). Uplift and erosion of the oceanic Cache Creek Terrane is reflected in deposition of chert-pebble conglomerate within the youngest basinal strata. Deformation culminated in Bajocian time resulting in a period of non-deposition and erosion.

Continental-margin arc magmatism that ensued in the Late Cretaceous, caused mainly inflation and uplift of the Coast Belt. In the Early Eocene, large-scale block faulting of eroded Mesozoic and Paleozoic strata accompanied voluminous felsic volcanic outpourings and edifice construction. Hydrothermal circulation locally focused along this unconformity resulted in the formation of vein occurrences such as the Black Fly and Lisadele. Hydrothermal circulation restricted to fault zones produced veins like the Zohini. Small, mineralizing stocks of this age may be represented by the Red Cap prospect.

Remobilization of Eocene and older faults and sculpting by Pleistocene to Recent glaciation have dispersed mineralization at surface and produced the landscape present today.

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TATOGGA LAKE PROJECT, NORTHWESTERN BRITISH COLUMBIA (104H/11, 12)

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KEYWORDS: Economic geology, Tatogga Lake, Iskut, volcanic stratigraphy, Stikine Terrane, Hazelton Group, Stuhini Group, Red-Chris, porphyry copper-gold.

INTRODUCTION

The Tatogga Lake project is a geologic and metallogenic mapping program initiated in 1994. It will investigate the geologic setting of mineral deposits

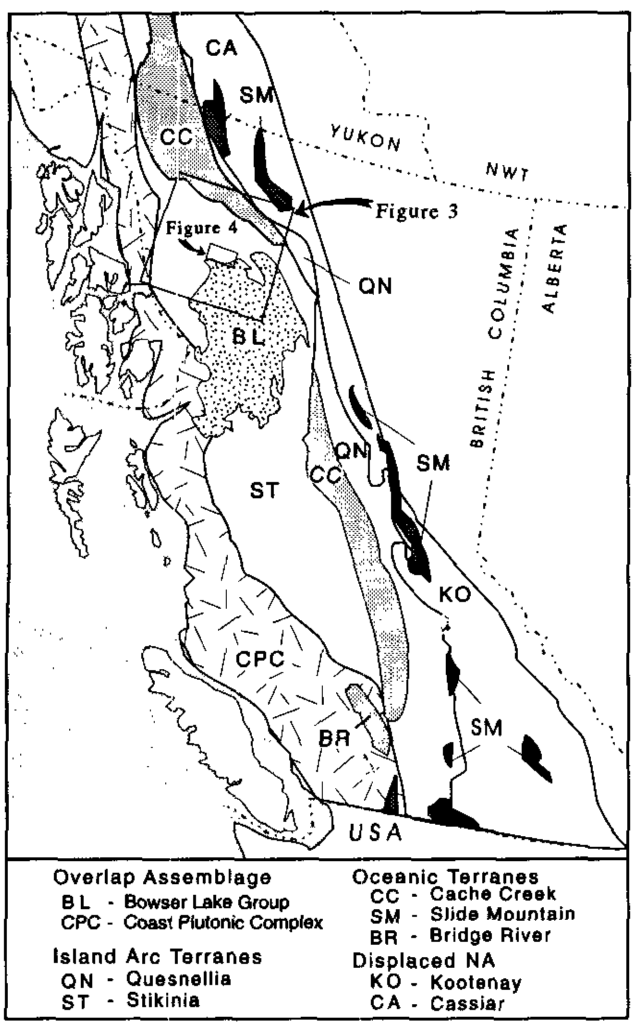
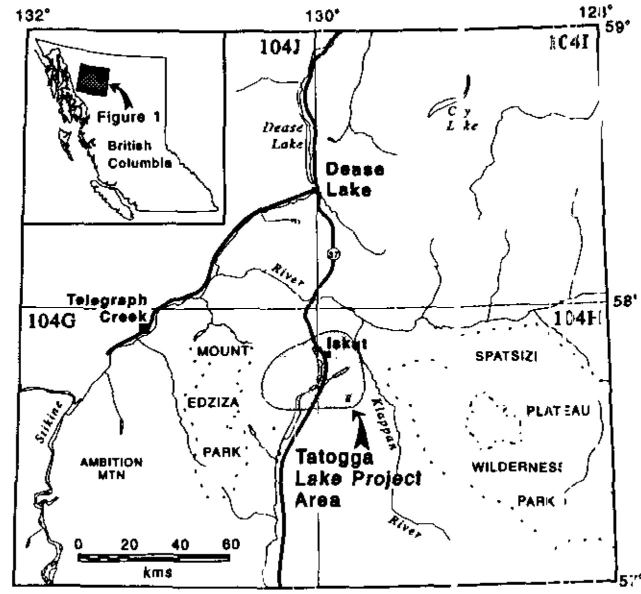


Figure 1. Regional geological setting of the Tatogga Lake map area.



Figue 2. Location of the Tatogga Lake map area.

in late Paleozoic and early Mesozoic Stikine terrane arc-volcanic rocks along the northern margin of the Bowser Basin in northwestern British Columbia (Figure 1). The project area is located 80 kilometres south of Dease Lake, and is transected by the Stewart Cassiar Highway, south from the village of Iskut (Figure 2). It includes parts of NTS map sheets 104G/9 and 16, and 104H/12 and 13.

Stikine Terrane arc rocks in the region host several copper-gold and copper-molybdenum occurrences (MINFILE 104 G and H). The volcanic stratigraphy hosting these deposits is, however, poorly constrained. The Tatogga Lake project will attempt to characterize individual deposits, describe their local and regional stratigraphic and structural settings, and determine the ages of magmatism and associated alteration.. The lithogeochemical character of the volcanic and associated plutonic rocks will be documented.

This report introduces the project area and discusses preliminary results obtained during fieldwork conducted from August 8th to September 26th which was restricted to the eastern half of the project area. Results of 1:20 000-scale mapping, will be released following mapping in the western sector which is planned for the 1995 field program.

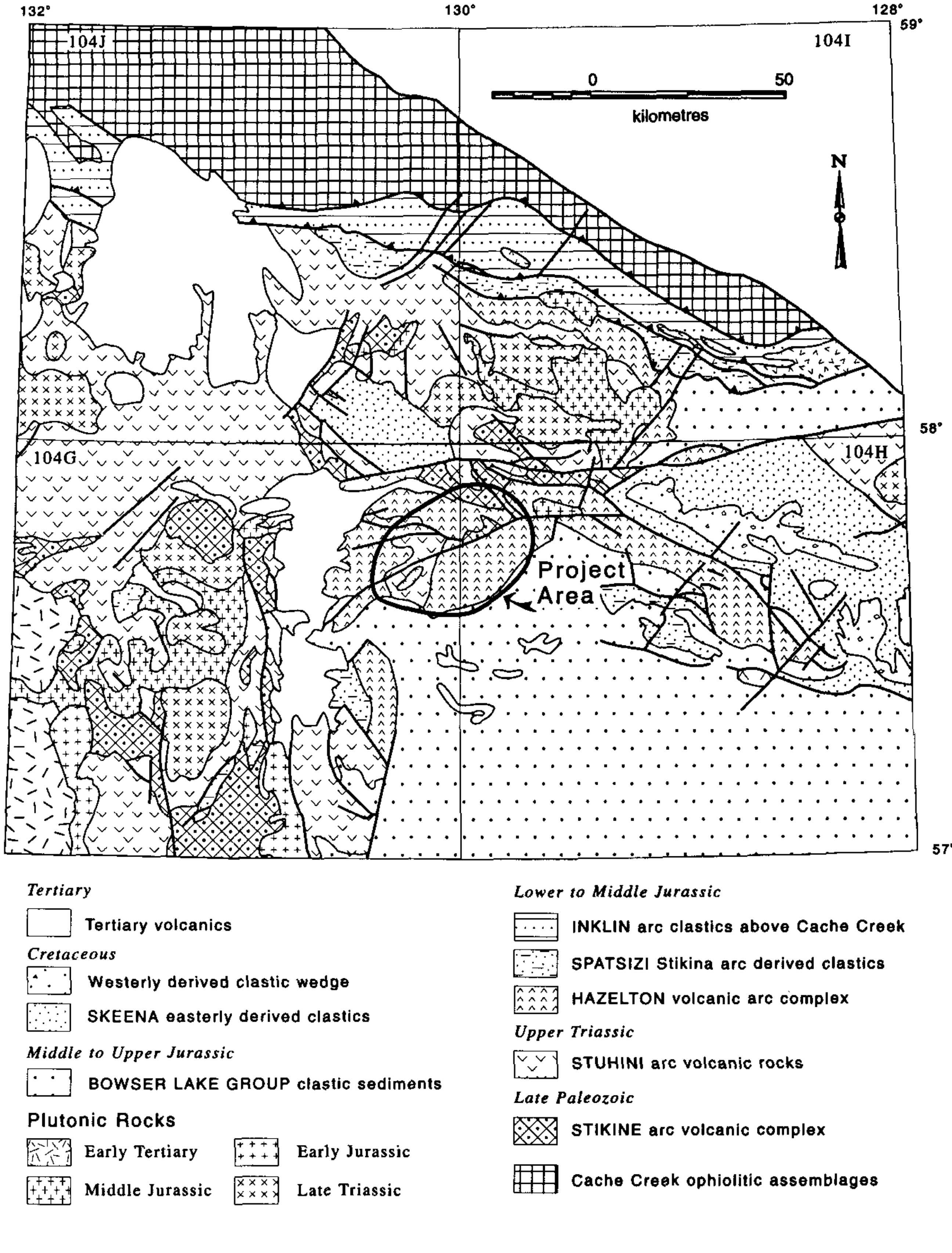


Figure 3. Geological setting of the Tatogga Lake Project area in northwestern British Columbia. Simplified after Wheeler and McFeely (1991).

The Red-Chris copper-gold deposit is the only active exploration project in the area. Extensively drilled by Texasgulf Inc. during the 1970s (Newell and Peatfield, in preparation), the deposit has recently been the focus of an aggressive deep drilling program by American Bullion Minerals Ltd.

PHYSIOGRAPHY

The study area covers the Klastine Plateau, part of the Stikine Plateau, along the northern margin of the Skeena Mountains. Locally the area is further dissected into a number of individual rolling plateaus at elevations between 1500 and 1800 metres that are bounded by steep-sided, U-shaped valleys with forested, flat valley bottoms below 950 metres. For the purpose of the following discussion we have assigned informal names to these plateaus.

Outcrops are generally absent in valley bottoms. Large areas of the individual plateaus are veneered by several metres of glacial till with vegetation limited to low shrubs (buckbrush), grass and moss. Outcrop is generally sparse, except in areas with abrupt changes in elevation. Best exposures are found on slopes between valleys and plateaus.

PREVIOUS WORK

Mapping by Souther (1972) of the Telegraph Creek sheet (104G) published at a scale of 1:250 000, and by Gabrielse and Tipper (1984) for the Spatsizi sheet (104H), published at a 1:125 000 scale, represent the regional geological database. Read (1984) and Read and Psutka (1990) produced 1:50 000 geological maps which include parts of the northeastern and eastern margins of the study area, respectively. Masters thesis research, including mapping, and deposit studies, was conducted in the area of the Red-Chris deposit by Schink (1977) and in the area of the Rose and Edon showings on the Eddon plateau by Cooper (1978). Leitch and Elliot (1976) also mapped the immediate area of the Red-Chris deposit. Templeton (1976) described the geology over most of the Todagin plateau as an honours B.Sc. thesis mapping project. The geological setting and history of Bowser Lake Group rocks along the southern margin of the study area have been documented as part of the multidisciplinary Bowser Basin project (Evenchick, 1991a, b, c; Evenchick and Green, 1990; Evenchick and Thorkelson, 1993; Green, 1991; Poulton *et al.*, 1991; Ricketts, 1990; Ricketts and Evenchick, 1991). Thorkelson (1992) recently conducted a study of Mesozoic Stikine Terrane arc rocks immediately east of the study area. Substantial contributions to the understanding of the Red-Chris deposit by J.R. Forsythe, and other Texasgulf geologists in the 1970s, are summarized in a soon to be published paper by Newell and Peatfield (in preparation).

REGIONAL GEOLOGICAL SETTING

The Tatogga Lake study area is within the Stikine Terrane in northwestern British Columbia (Figures 1 and 3). This terrane, which forms a broad northwest-trending belt through the centre of the province, includes mainly early Mesozoic and lesser late Paleozoic island-arc volcanic strata with related subvolcanic intrusions. Stikinia arc rocks are subdivided regionally into the upper Paleozoic Stikine assemblage, Upper Triassic Stuhini Group and Lower to Middle Jurassic Hazelton Group (Figure 3). Stuhini Group rocks are dominated by submarine, calcalkaline basaltic volcanic rocks which are commonly augite phyric (Souther, 1991). In contrast, the Hazelton Group is dominated by subaerial volcanics that range in composition from basalt to rhyolite.

The Late Triassic and Early and Middle Jurassic oceanic island arcs that that comprise Stikinia, formed outboard of the ancient North American continental margin (Monger 1984; Gabrielse, 1991). Arcs evolved along the western margin of the intervening late Paleozoic Cache Creek ocean basin in response to its closure by westerly subduction. Early Middle Jurassic arc-continent collision, related to docking of Stikinia with ancestral North America, resulted in southwesterly tectonic emplacement of oceanic Cache Creek Terrane above the younger volcanic arcs. Vast quantities of flysch sediments were subsequently shed from the uplifted oceanic crust southwards into the newly developed Bowser Lake successor basin

Later Middle Cretaceous and Tertiary tectonism has disrupted the local stratigraphy, in large part by faulting. Lateral displacements of up to 800 kilometres have been suggested for this region of the province (Gabrielse, 1985). Foreland fold-and-thrust-belt styles of deformation affect Bowser Lake Group stratigraphy and record as much as 160 kilometres of northwest shortening (Evenchick, 1991c).

Quaternary to Recent Edziza olivine basalt flows overlie Stikinia rocks in the northwestern sector of the map area. Several small isolated volcanic necks are also present.

LOCAL STRATIGRAPHY

The map area is dominated by a largely undifferentiated sequence of early Mesozoic arc-volcanic, plutonic and derived sedimentary rocks (Figure 4). Older, late Paleozoic metavolcanic and metasedimentary rocks (Read, 1984; Gabrielse and

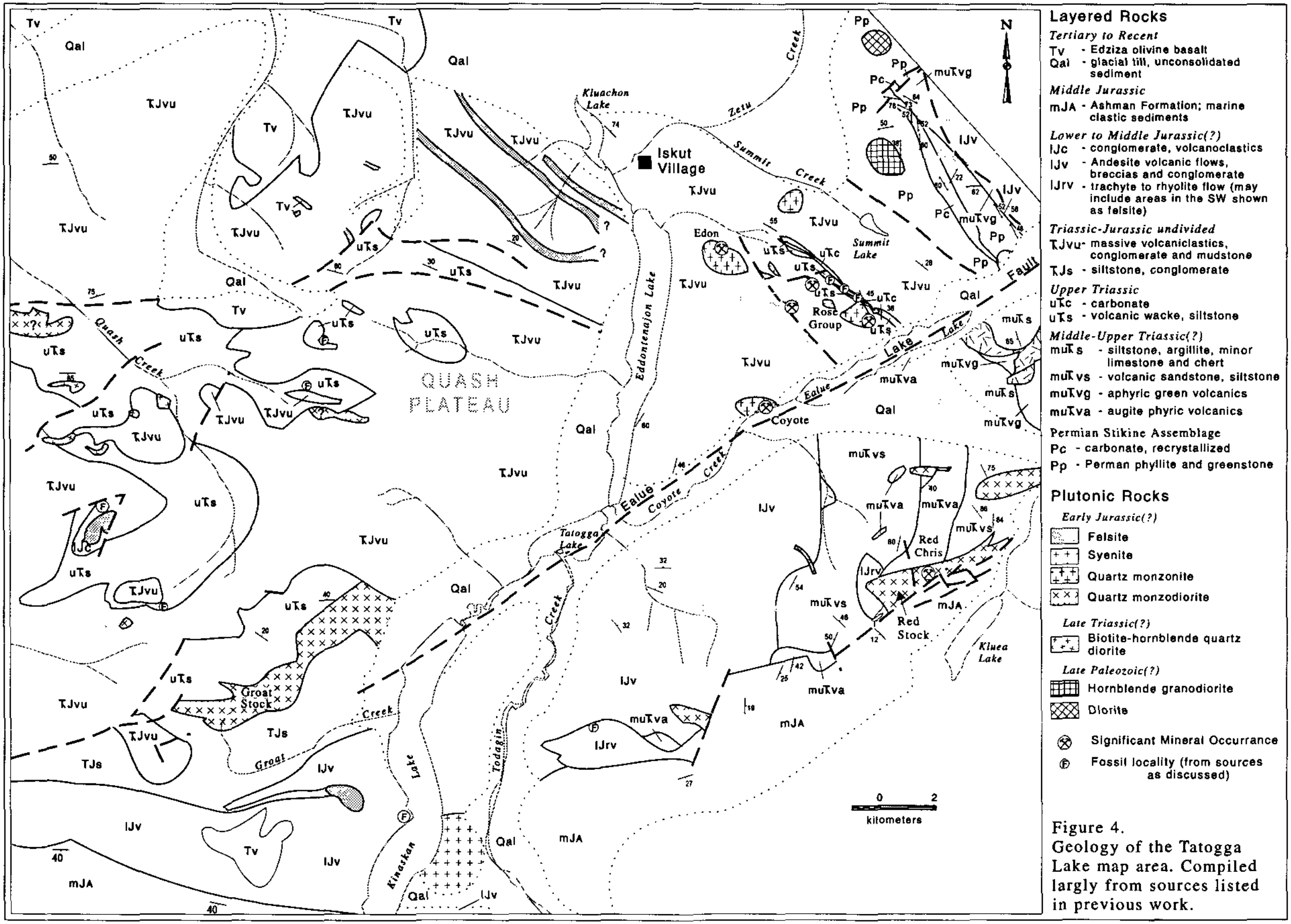


Figure 4.
Geology of the Tatogga Lake map area. Compiled largely from sources listed in previous work.

Tipper, 1984), form a northwest-trending penetratively deformed belt which is faulted against and possibly overlain by Mesozoic volcanic strata. To the south, Mesozoic rocks are overlain by and locally faulted against Middle Jurassic marine clastic stratigraphy of the Bowser Lake Group. Pre-Bowser Lake Group rocks are intruded by a range of mineralogically and texturally distinctive plutonic rocks.

Published geological maps that cover all or portions of the study area indicate general, though not unanimous agreement that Stikinia rocks are early to middle Mesozoic in age. Further subdivision of the local volcanic stratigraphy, however, into either Upper Triassic Stuhini or Lower Jurassic Hazelton assemblages shows consistent variability. Souther (1972) assigned volcanic rocks north of the Ealue Lake fault on the 104G sheet a Late Triassic age but suggested that those south of the fault are Middle Jurassic. On the adjoining 104H sheet, Gabrielse and Tipper (1984) assigned rocks underlying the Eddon plateau a Middle to Late Triassic age. A similar age was suggested for volcanics underlying the western half of the Todagin plateau, while those to the east were designated as Lower Jurassic. In contrast, Read (1984) grouped volcanic rocks underlying the Eddon plateau mainly as undivided Triassic-Jurassic strata. He interpreted one narrow northwest-trending belt of sediments as Upper Triassic and considered several other areas to be Early Jurassic.

Wheeler and McFeely (1991) assigned an Early to Middle Jurassic age to most of the volcanic rocks and considered isolated areas to be Late Triassic and late Paleozoic (Figure 3). More recently, Evenchick and Thorkelson (1993) combine all volcanic strata south of the Ealue Lake fault as 'undivided Triassic-Jurassic' but separate rocks north of the fault into both Permian and Early Jurassic volcanic arc assemblages.

Souther (1972) emphasized difficulties in differentiating Upper Triassic from Lower Jurassic volcanic stratigraphy along the eastern part of the Telegraph Creek sheet (104G). He wrote:

> "In the eastern part of the map area the distinction between Upper Triassic and Lower Jurassic rocks is not so clearly defined. Granitic clasts are sparse or absent and Lower Jurassic clastic sediments are similar to Triassic fragmental volcanics from which they are derived."

Recognition of original volcanic stratigraphy may be further complicated by regional folding and faulting. Mapping of volcanic rocks immediately to the east (Thorkelson, 1988) and west (Evenchick, 1991a) of the current study area found that contacts, previously interpreted as stratigraphic, are thrust faults.

UPPER PALEOZOIC STRATIGRAPHY

The oldest known rocks in the area are assigned to the upper Paleozoic, and possibly Lower Triassic, Stikine assemblage and include phyllitic greenstone, pale and dark grey banded limestone and brown phyllitic siltstone. Pale and dark grey, recrystallized, well banded limestone is exposed along a prominent northwest-trending ridge in the core of the belt. Banding is defined by thinly laminated, 3 to 8 millimetre, dark and light to buff-grey limestone. Locally buff to tan-brown marly limestone is banded on the 1 to 2-centimetre scale with light to dark grey varieties. Local minor folds with broken fold hinges are common. Broad open folds are also evident and, like the minor folding, are symmetrical and upright. Near its contact with phyllitic siltstone the laminated limestone contains folded bands of sheared phyllite that are parallel to the banding.

Outcrops of phyllitic and schistose rocks are less common because these units are generally friable and recessive. Individual exposures are commonly folded and locally crenulated. Foliation fabrics in these metamorphic rocks display a dominant northwest orientation with local deviations caused by folding. Folding is generally, open and upright with fold hinges plunging at shallow angles toward the northwest and southeast.

MESOZOIC STIKINIA ASSEMBLAGES

Lack of new fossil data at this early stage of the project precludes any attempt to refine previous interpretations of the volcanic stratigraphy. However, we have been able to subdivide volcanic rocks in the area mapped on the basis of distinctive lithological and textural characteristics. Conveniently, the geographic distribution of our subdivisions of volcanic rocks coincides with the individual plateaus (Figure 4).

EDDON PLATEAU

The Eddon plateau, and the area to the north surrounding the village of Iskut, is underlain by green and maroon volcaniclastic rocks that are intruded by more massive, texturally similar hypabyssal stocks and irregular bodies. Volcaniclastic rocks are dominated by tuff-breccias with lesser lapilli tuffs and rare flows. Individual outcrops may be entirely maroon, green or combinations of the two. There is, however, no notable textural or mineralogical change in the rock across colour boundaries. Colour contrasts appear to simply reflect differences in the oxidation state of the 3 to 5% of finely disseminated iron oxide phase present. Green volcanic rocks contain finely disseminated magnetite and are typically magnetic. In contrast, maroon volcanics contain hematite and are not magnetic.

Massive tuff-breccias, most likely lahars and debris flows are dominated by plagioclase±hornblende-porphyritic andesite. Clasts contain from 15 to 30%, 1 to 3-millimetre, tabular plagioclase phenocrysts and lesser hornblende phenocrysts of comparable size, in modal abundances of 3 to 10%. Subrounded to subangular volcanic clasts are usually from 2 to 6 centimetres across, but range from one to several tens of centimetres in size, in a fine to medium-grained fragmental groundmass. Breccias vary from matrix to clast supported and are dominated by clasts of porphyritic andesite. Individual clasts vary in both phenocryst size and abundance. Locally, breccias may be more heterolithic containing aphanitic green volcanic, limestone and distinctive red-brown, usually angular, mudstone clasts in addition to the dominant porphyritic clasts. The matrix of heterolithic breccias is much more poorly sorted and displays a wider grain size variation than in the other breccia type. The more heterolithic breccias are also typically dominated by maroon clasts in a predominantly maroon volcanic matrix.

Lapilli and sparse-lapilli tuffs are locally dominant in outcrops along the Stewart Cassiar Highway on the west side of the Eddon plateau. This unit is particularly well exposed in a quarried hillside east of Iskut village. Lapilli are dominated by cryptic fragments that vary from trace amounts to locally over 20%. Such fragments are not readily identifiable on fresh surfaces, and rarely on weathered surfaces, due to their colour and textural similarity to the matrix. Slabbed surfaces are particularly useful in detecting the fragmental character of this unit. Darker, very fine grained aphyric, angular fragments, from 0.5 to 2 centimetres in diameter, are much more obvious though less abundant, comprising less than 1% of the unit.

These volcanic breccias are predominantly massive, but occasionally bedding is well developed in laterally discontinuous lenses of laminated volcanic sandstone and red mudstone. Bedded zones are usually associated with the more heterolithic breccias. Relatively massive maroon mudstone, with 3 to 5%, 0.5 to 3-millimetre rounded to subangular volcanic fragments is exposed in outcrops spatially associated with the lapilli tuffs in the low-lying area west of the Eddon plateau. The mudstone unit is well bedded where it is associated with local sandstone and poorly sorted volcanic pebble conglomerate beds.

The most persistent sequence of sedimentary rocks in this area of the Eddon plateau includes a northwest-trending, southwest-dipping belt of siltstone, limestone and greywacke that is up to 300 metres thick. Cooper (1978) established a Late Triassic age for this sequence based on the presence of the pelecypod *Monotis*. He also concluded that the sediments were interlayered with and overlain by the andesitic volcaniclastic rocks. Interestingly, Read (1984) reported Early Permian conodonts from limestone recovered from the same stratigraphic sequence. To account for these conflicting paleontological data he suggested the limestone was most likely a Late Triassic olistostrome containing Early Permian limestone blocks.

To the west, Souther (1972) described volcanic rocks underlying the Quash plateau as being dominated by massive purple and green volcaniclastic rocks with minor related sediments. We tentatively correlate these rocks with volcanic rocks on the Eddon plateau. Souther (1972) also collected *Monotis* fauna from sediments lithologically comparable to those reported from the Eddon plateau by Cooper (1978). Souther established that these sediments are also conformably overlain by the volcaniclastic rocks. Bedding orientation in both these areas is consistently northwesterly (Figure 4).

Souther (1972) also identified sponge-like forms in limestone on the Quash plateau; although undiagnostic he considered them to be most likely Upper Triassic, due to the presence of similar macrofossils in Norian Sinwa limestone in both the Tulsequah and Dease Lake map areas.

EAST TODAGIN PLATEAU

A lithologically distinctive stratigraphic sequence, dominated by sediments with lesser and locally interbedded augite-porphyritic mafic volcanic rocks, is exposed on the eastern half of Todagin plateau.

Plagioclase-rich volcanic sandstone with interbeds of laminated siltstone and fine sandstone is the predominant unit exposed in this area. The volcanic sandstone weathers tan-brown to grey and is light grey on fresh surfaces. Tan-brown weathering exposures appears to be the result of carbonate alteration, which is common throughout this area. Volcanic sandstones are characteristically massive and lack obvious sedimentary features. Typically they are fine to medium grained and equigranular, except for sparse, dark grey to black, angular siltstone fragments from 3 to 15 millimetres in size. Abundance of siltstone fragments is usually from 1 to 2%, but ranges from areas where they are sparse, to zones, adjacent to siltstone interbeds, containing from 10 to 20% fragments, typically larger than those noted elsewhere. Massive coarse-grained, poorly sorted varieties of the sandstone with similar siltstone fragments are also common locally.

Dark grey to black siltstone interbeds that range from less than a metre to several tens of metres in thickness occur intermittently throughout the massive sandstone sequence. They may be interbedded with massive sandstone on a scale of several metres over distances of several tens of metres or consist predominantly of siltstone and silicious siltstone over similar distances. Siltstone beds are usually well bedded on a 5 to 15-millimetre scale. Siltstone units containing very fine grained volcanic sandstone interbeds display well developed sedimentary features such as graded bedding, scour marks and load structures. These features are useful in providing stratigraphic tops. Bedding within the unit typically strikes between northeast and southeast with steep to moderate dips to the north. Sedimentary structures usually indicate that bedding is right way up, and is locally overturned in some steeply dipping beds. Whether this is the result of folding or rotation by brittle faulting is not certain. Brittle gouge zones are common throughout the unit. Broad, open upright folding of some siltstone beds is also evident.

Samples of black siliceous siltstone from several areas were found to contain radiolarians. Unfortunately they are recrystallized and not diagonostic (Fabrice Cordey, personal communication, 1994).

Augite-phyric basalts are dark green with characteristic 5 to 15%, black, euhedral augite phenocrysts from 1 to 2 millimetres in size. Plagioclase as a phenocryst phase is usually absent, but may occur locally as 0.5 to 1-millimetre microphenocrysts where augite phenocrysts are locally more abundant. The unit is dominated by pillowed flows and flow breccias intercalated with siltstone and siliceous siltstone on a scale of metres to tens of metres. Locally, in the immediate area of the Red-Chris deposit, the unit is informally designated the Dynamite Hill volcanics (Schink, 1977). Amydgules from 2 to 5 millimetres in diameter commonly comprise from 5 to 15% of the rock. These are filled with an amorphous, pink material, which Schink identified as feldspar.

Augite-porphyritic basalt is also exposed discontinuously for 1.7 kilometres along the south-central shore of Ealue Lake. In this area the unit is dominated by tuff-breccia with intermittent massive and locally pillowed flows. Augite phenocrysts are more abundant and larger than those in the volcanics on Todagin plateau, comprising from 15 to 30% of the rock, and are from 2 to 6 millimetres in size. Volcanic breccias locally contain intervals of limy mudstone which is currently being evaluated for possible conodont fauna.

On the basis of augite as a phenocryst phase, Read and Pustka (1990) suggested that these rocks are probably equivalent to similar volcanic rocks at the top of the Middle Triassic Tsaybahe Group mapped to the east and northeast. In the Iskut map area to the southwest augite-phyric volcanic rocks characterize upper Triassic Stuhini volcanics (Anderson, 1989).

WEST TODAGIN PLATEAU

Rocks on the western side of the Todagin plateau are lithologically distinctive from those to the east. This area is dominated by grey-green to locally maroon-weathering, plagioclase-hornblende-porphyritic massive and pyroclastic flows, monomictic lapilli tuff-breccias and derived volcanic conglomerates. Texturally the unit is characterized by 10 to 20% plagioclase laths, 1 to 3-millimetres long and 5 to 10%, 2 to 6-millimetre euhedral black amphibole. Volcanic breccias, possibly debris flows, are heterolithic, matrix supported, with subangular to subrounded 2 to 6-centimetre clasts that include siltstone, feldspar-porphyritic and hornblende and feldspar-porphyritic clasts. Locally these contain centimetre-scale interbeds of red mudstone.

Lithologically and texturally, the unit is in many respects similar to rocks underlying the Eddon plateau. However, unlike the massive character of volcanics northeast of the Ealue Lake fault, these tend to be well stratified on a 2 to 5-metre scale.

Previously, the contact between the volcaniclastic rocks to the west and the sedimentary-volcanic sequence to the east has been interpreted as a fault (Gabrielse and Tipper, 1984). Where exposed in the bed of a creek flowing north from the east end of Todagin Mountain, the contact is clearly disrupted by brittle faulting, however, massive to brecciated hornblende-plagioclase-porphyritic volcanics near the contact contain 5 to 10-centimetre subrounded clasts of the underlying siltstone.

Pliensbachian ammonites have been collected from the upper part of these volcanic sequences on the west flank of Todagin Mountain (Newell and Peatfield, in preparation). Further, Evenchick and Green (1990) have delineated a thin interval of Middle Jurassic (Pliensbachian) Spatsizi Group sediments conformably below Bowser Lake Group strata. Volcanic rocks to the west of Kinaskan Lake, that are dominated by tuff, tuff-breccia and volcanic sandstone, are also known to contain Pliensbachian fossils near the top of the volcanic succession (Evenchick, 1991a)

EALUE PLATEAU

The Ealue plateau on the eastern margin of the map area is underlain by regionally distinctive sedimentary and volcanic rocks. Sediments are dominated by very fine grained siltstone, chert and argillite. Exposures are dark to medium brown and massive with no penetrative fabric, but are usually well fractured and blocky. Read and Psutka (1991) correlated these sediments with similar, dated rocks and suggested that they were most likely the Middle Triassic, Tsaybahe Group lithologies. Very silicious siltstone or dark grey chert, collected from this area, contains radiolarians which are unfortunately recrystallized, and not diagnostic (Fabrice Cordey, personal communication, 1994).

Volcanic rocks are less abundant and apparently restricted to the western part of the Ealue plateau. They are aphyric, green-grey to green, light grey-green weathering, commonly aphanitic and massive, but locally contain from 2 to 5%, 0.5-millimetre equant to tabular microphenocrysts of plagioclase. The unit is typically magnetic, very fresh, megascopically fractured and blocky. In addition to the contrasting fine-grained massive nature of these volcanics, the salmon-orange weathering colour that is locally developed on most other volcanic units is lacking.

Similar volcanics form a relatively continuous belt along the western contact of the Permian metasediments, are massive, grey-green weathering nondescript rocks mapped as greenstone.

BOWSER LAKE GROUP

In contrast to the stratigraphic uncertainty surrounding the volcanic arc rocks discussed above, the stratigraphic, sedimentalogical and structural character of the Bowser Lake Group to the south is well constrained. Middle Jurassic (Bathonian to early Oxfordian) marine clastic sedimentary rocks (Gabrielse and Tipper, 1984; Poulton *et al.*, 1991) of the Bowser Lake Group that crop out along the southern margin of the map area are assigned to the basal Ashman Formation and comprise siltstone, chert-pebble conglomerate and sandstone (Evenchick and Thorkelson, 1993). Sedimentalogical studies indicate that Bowser Lake rocks become progressively younger to the south and that deposition was from the north into the tectonically active northern margin of the Bowser Basin (Ricketts, 1990; Ricketts and Evenchick, 1991; Green, 1991).

Distinctive chert-pebble conglomerates crop out along the northeastern slope of Todagin Mountain. In this area the unit varies from massive to well bedded. It consists of subrounded 0.5 to 3-centimetre, generally light and dark grey or green chert pebbles in a tan-brown to grey sandstone matrix. Massive outcrops comprise 40 to 60% clasts with either clasts or matrix sandstone being locally dominant. Bedded exposures comprise layers defined by an upward reduction in both size and abundance of chert clasts, repeatedly over thicknesses of 5 to 15 centimetres.

PLUTONIC ROCKS

BIOTITE-HORNBLENDE QUARTZ DIORITE TO MONZODIORITE

Biotite±hornblende quartz diorite and lesser biotite monzodiorite characterize an apparent differentiated suite of plutonic rocks that underlies a large part of the Ealue plateau. The rock weathers light grey to buff-white to locally salmon pink and is dark grey on fresh surfaces. It is medium grained, equigranular and isotropic. Mafic mineral content and type are variable throughout the intrusion. Characteristic 25 to 30% mafics may increase locally to 60%. Biotite is usually the dominant mafic phase and shows rare, though conspicuous 1 to 2-centimetre oikocrysts, poikotically enclosing plagioclase. Hornblende is usually a minor mafic constituent but may be present in amounts equal or greater than biotite, or may be the only mafic mineral present. Quartz content varies from 10 to 15% and occurs as isolated 1 to 2-millimetre grains or as larger 5 to 10 millimetre oikocrysts. White, stubby, 1 to 3-millimetre subhedral feldspar, predominantly plagioclase, may also include some potassium feldspar. The rock contains several percent finely disseminated magnetite and is strongly magnetic.

The southwestern extension of the body is texturally distinctive and may represent a more differentiated phase of the intrusion. In this area the rock contains from 8 to 15%, pink-weathering, coarse to megacrystic potassium feldspar. Potassium feldspar is also present in the medium-grained groundmass consisting of 40%, 2 to 3-millimetre tabular plagioclase, 15 to 20% smoky grey quartz and 5 to 7% biotite.

Intense hornfelsing of fine-grained sediments and aphanitic, aphyric grey-green volcanic rocks, extending for several tens of metres from the intrusive contact, is well developed and was noted in a number of locations.

This body was included with the Railway Plutonic Suite by Read and Psutka (1990) which is dated elsewhere by U-Pb zircon methods, at 227±9 Ma.

HORNBLENDE-PLAGIOCLASE-PORPHYRITIC QUARTZ MONZODIORITE

Hornblende-plagioclase-porphyritic quartz monzodiorite comprises a suite of stocks and dikes exposed along the northern margin of the Bowser Basin. The rock weathers a buff white to light grey. Distinctive medium to coarse-grained hornblende and plagioclase phenocrysts are randomly oriented in an aphanitic grey groundmass. Plagioclase is the dominant phenocryst phase, occurring as 2 to 5-millimetre subhedral tabular grains comprising from 30 to 45 modal percent of the unit. Hornblende phenocrysts are less abundant, comprising from 6 to 12 modal percent, they are usually of similar grain size, but also locally form coarser tabular phenocrysts up to 1 centimetre long, that are a diagnostic feature of the unit. The groundmass mineralogy comprises microcrystaline, anhedral, granular quartz and feldspar, the later of indetermined composition.

We tentatively include the 'Red stock', an elongate east to northeast-trending intrusion which hosts the Red-Chris copper-gold deposit, with this plutonic suite. Its close proximity, comparable geometry and obvious textural similarity suggest that it is probably an altered equivalent. Previous detailed investigations of the Red stock have determined it to be monzonitic in composition (Schink, 1977; Leitch and Elliot, 1976) based on the identification of microscopic potash feldspar as a significant component of the groundmass mineralogy. In our opinion, it remains to be established whether the fine-grained, granular potash feldspar and quartz in the matrix of this pervasively altered rock is of primary or secondary origin, and characterization of the original composition of the Red stock remains equivocal.

The apparent age of the Red stock is presently constrained at latest Triassic. Schink (1977) reported a wholerock K-Ar isochron age of 210±7 Ma, suggesting at least a minimum age for the pervasive stage of phyllic alteration affecting the stock. A less altered northeast-trending stock of plagioclase-hornblende-porphyritic monzodiorite to the west of Kinaskan Lake, the 'Groat stock', was dated by hornblende K-Ar at 195±8 Ma and by wholerock K-Ar at 189±? Ma (Schmitt, 1977).

These ages are clearly consistent with a regionally significant Early Jurassic (200 Ma) episode of porphyry copper mineralization, well defined elsewhere throughout the province (J. Mortensen, personal communication, 1994). Samples of two separate stocks from the area, including one of the Red stock, are currently being processed for U-Pb, zircon analysis.

GRANODIORITE AND DIORITE

An isolated intrusive body of buff-white to pink weathering, medium-grained hornblende granodiorite outcrops along the east side of Summit plateau. It consists of 30 to 35%, white, stubby to tabular plagioclase feldspar from 2 to 3 millimetres long. Mafic minerals, weather a dark grey-green, and are completely replaced by chlorite and lesser epidote which combined comprise from 25 to 30 modal percent. Interstitial, fine-grained, anhedral, highly strained quartz forms the remainder of the rock. Internally the body is relatively homogeneous but displays a moderate foliation near its margins, defined by secondary chlorite. Contacts with the variably deformed and metamorphosed aphyric volcanic hostrocks were not observed.

Several kilometres to the north a small intrusion of medium to coarse-grained equigranular diorite was mapped in the aphyric grey-green Permian(?) volcanics. The unit is buff-white weathering and varies from medium to coarse grained equigranular with local grain size variation common. This small stock is characterized by equal to slightly varied abundances of mafic and felsic minerals that are completely replaced by secondary chlorite and sericite, respectively.

SYENITE-TRACHYTE

Two distinctive types of potassic intrusive rocks are present locally. One is melanocratic with coarse porphyritic to megacrystic potassium feldspar in a fine to medium-grained, melanocratic groundmass. The other type includes a number of dikes and small stocks of massive leucocratic syenite and quartz syenite.

A relatively large, though isolated, outcrop area of coarse feldspar-porphyritic to megacrystic syenite is exposed on the north side of the Ealue Lake road, roughly 1.5 kilometres northeast of the eastern end of Ealue Lake. Megacrystic rocks have 10 to 30%, 1 to 3-centimetre, elongate tabular, pink feldspars in a dark green, fine to medium-grained equigranular groundmass of potassium feldspar, amphibole and possibly quartz. Coarse-porphyritic varieties have 3 to 8-millimetre equant feldspars in a similar dark green groundmass. Compositional variability is recognized locally between potassium feldspar rich syenite and a finer grained, dark green melanocratic rocks; a feature which is emphasized by differential weathering of the two phases.

This unit is probably equivalent to plutonic rocks on the east-central shore of Kinaskan Lake which Souther (1972) included in a suite of syenite, orthoclase porphyry, monzonite and pyroxenite. He describes these as commonly porphyritic and very coarse grained with a high content of potash feldspar.

Syenite is buff-white, pink or smoky grey weathering. Where identified as dikes, it is usually aphyric and massive but may locally contain up to 5% irregular quartz phenocrysts. These dikes are usually less than a metre to several metres wide, dip steeply and strike between north and northwest. Several are well exposed along the north side of the Ealue Lake road, near the west end of Ealue Lake. In this area, a swarm of eight dikes, spaced from 5 to 50 metres appart, intrudes maroon, plagioclase-porphyritic flows and breccias along a 200 to 300-metre semicontinuous roadside outcrop. Epidote alteration, characterized by thin veinlets, patches and granular disseminations, is commonly developed in volcanic rocks intruded by these dikes. In larger dikes or small stocks the syenite or quartz syenite contains 5 to 10% anhedral quartz grains, 2 to 4-millimetres across. One to three-millimetre tabular, white plagioclase grains locally comprise from 3 to 7% of the rock.

Souther (1972) mapped a series of thin, laterally continuous dike-like bodies of white to light grey, fine-grained aplitic rock at the north end of the Quash Plateau (Figure 4). We tentatively correlate these rocks with the syenite-trachyte unit.

FAULTING

Brittle faulting is evident throughout the area on a variety of scales. The east-northeast-trending Ealue Lake fault, projected along the Coyote Creek - Ealue Lake valley, is the most prominent structural feature in the map area. To the east of the map area, where designated the McEwan Creek fault, this structure has been traced for an additional 30 kilometres by Read and Psutka (1990). They determined movement on the fault in this region to be south side down.

Though not exposed in the study area, the structure is well established by contrasting lithologies and styles of alteration on either side of the inferred contact. Zones of intense and pervasive carbonatization, with localized areas of ankerite flooding are prevalent in rocks to the south of the fault. These vary from several hundreds of metres to over a kilometre in width, and sometimes contain local concentrations of pyrite as stringers and disseminations. This particular style of alteration is absent both north of the Ealue Lake fault and also in overlying Middle Jurassic Bowser Basin Lake Group sediments. The origin and geological significance of these features are at present uncertain, but association with a currently undefined regional structural feature is considered most likely.

East to northeast oriented faults also define structural contacts locally along the northern edge of the Bowser Basin.

A number of less prominent, though locally significant northwest-trending faults are also prevalent throughout the area.

ECONOMIC GEOLOGY

Twenty mineral occurrences are recorded for the study area (MINFILE 104G and H). All appear to be related to high level, subvolcanic dikes and stocks which intrude volcanic and sedimentary rocks throughout the area. In almost all instances copper mineralization is dominant but is commonly associated with elevated concentrations of gold and silver. Chalcopyrite as fracture controlled veinlets or disseminations commonly associated with quartz stockwork is the dominant style of mineralization. Mineralization is commonly hosted by the intrusions but may also be developed in the stratified volcanic and sedimentary country rocks. The Red-Chris deposit is the only active exploration target.

RED-CHRIS DEPOSIT

The Red-Chris copper-gold deposit is hosted by the "Red stock", an east-northeast elongated intrusive body of pervasively quartz-sericite-ankerite-pyrite (phyllic) altered, plagioclase hornblende porphyry (Panteleyev, 1973, 1975; Leitch and Elliott, 1976; Schink, 1977; Figure 5). Chalcopyrite and localized concentrations of bornite are commonly associated with zones of quartz stockwork and sheeted quartz veining. The quartz stockwork forms a steeply dipping, high-grade core zone associated with intense and pervasive carbonatization that is surrounded by and gradational into barren to weakly mineralized, phyllic (quartz-sericite-ankerite-pyrite) altered host stock (Figure 6). Quartz stockwork zones dip steeply to the north and parallel the long axis of the Red stock.

Earlier drilling of this deposit by Texasgulf Inc. included 118 percussion and diamond drill-holes, totaling 16 476 metres. Drilling outlined two zones of copper-gold mineralization which were designated the Main and East zones (Forsythe, 1977; Newell and Peatfield, in preparation; Figure 5). Using a cutoff grade of 0.25% Cu, irrespective of gold, Texasgulf estimated an open-pit mining inventory of 34.4 million tonnes, grading 0.51% Cu and 0.27 g/t Au to a depth of 270 metres in the Main zone and 6.6 million tonnes grading 0.83% Cu and 0.72 g/t Au to a depth of 150 metres in the East zone.

Between late June and early November, 1994, American Bullion Minerals Ltd. drilled 21 417 metres of HQ and NQ core in 58 holes, to an average depth of 370 metres. Several holes exceeded 500 metres. Approximately 74 kilometres of cut grid line were established over the property. Induced polarization and ground magnetic geophysical surveys were conducted to help outline mineralization and identify potential new drill targets. The drilling program has successfully defined continuity of high grade copper-gold reserves along strike and to depth from previously outlined mineralization. It has established that the deposit becomes both wider and richer with depth. Drilling has more or less doubled its down dip extension, and it remains open at depth. Significant and continuous intersections of high-grade bornite mineralization have also been identified in the East zone.

Cross-sections through the East and Main zones (Figure 5, 7 and 8) were constructed by logging several holes and examining portions of others, supplemented by American Bullion drill logs. Sections indicate that most of the higher grade copper and gold is contained within quartz stockwork zones. Local intersections of laterally discontinuous intense quartz stockwork, with narrow zones of sheeted quartz material are flanked by moderate to strongly developed quartz stockwork which invades carbonate-sericite-pyrite altered plagioclase-hornblende porphyritic hostrocks.

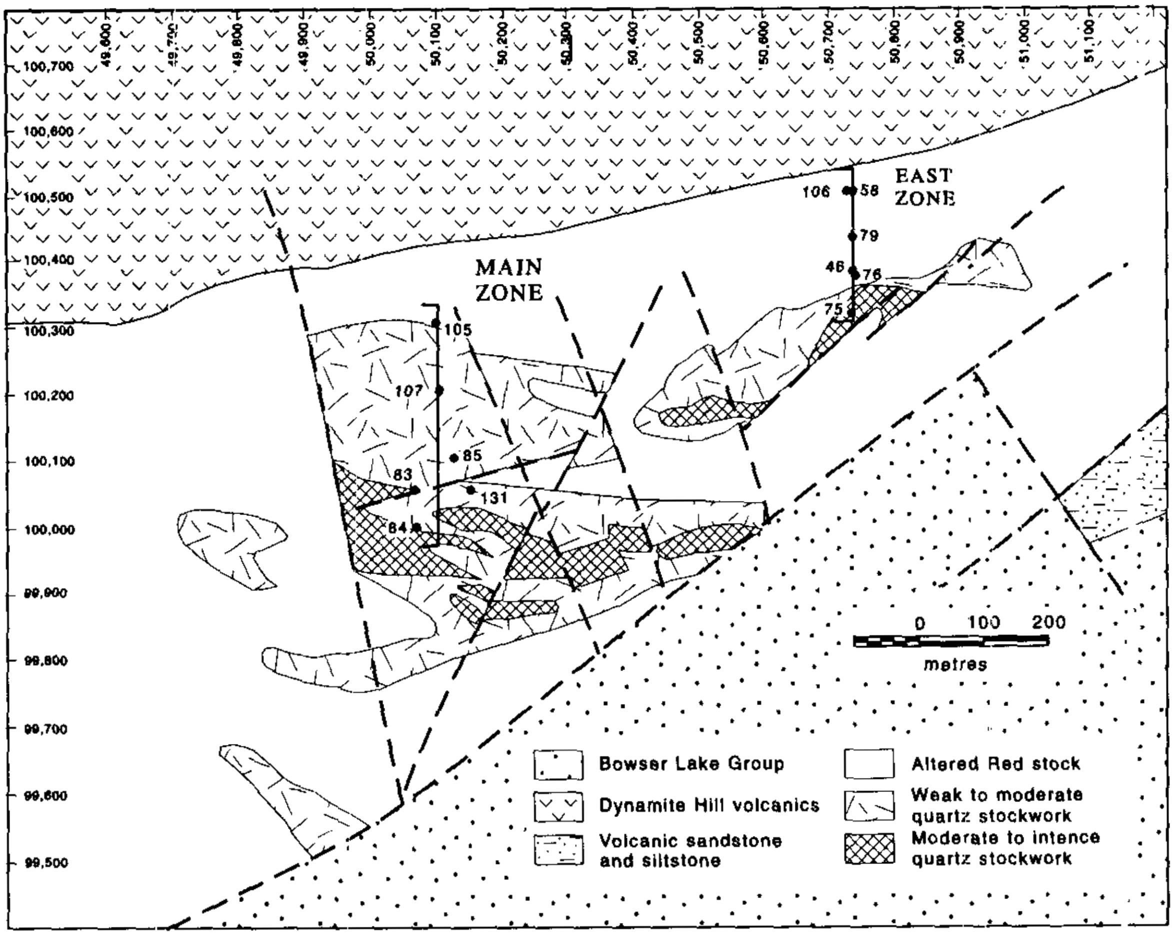


Figure 5. Setting of the East and Main zones of mineralization at the Red-Chris deposit (after Forsythe, 1977).

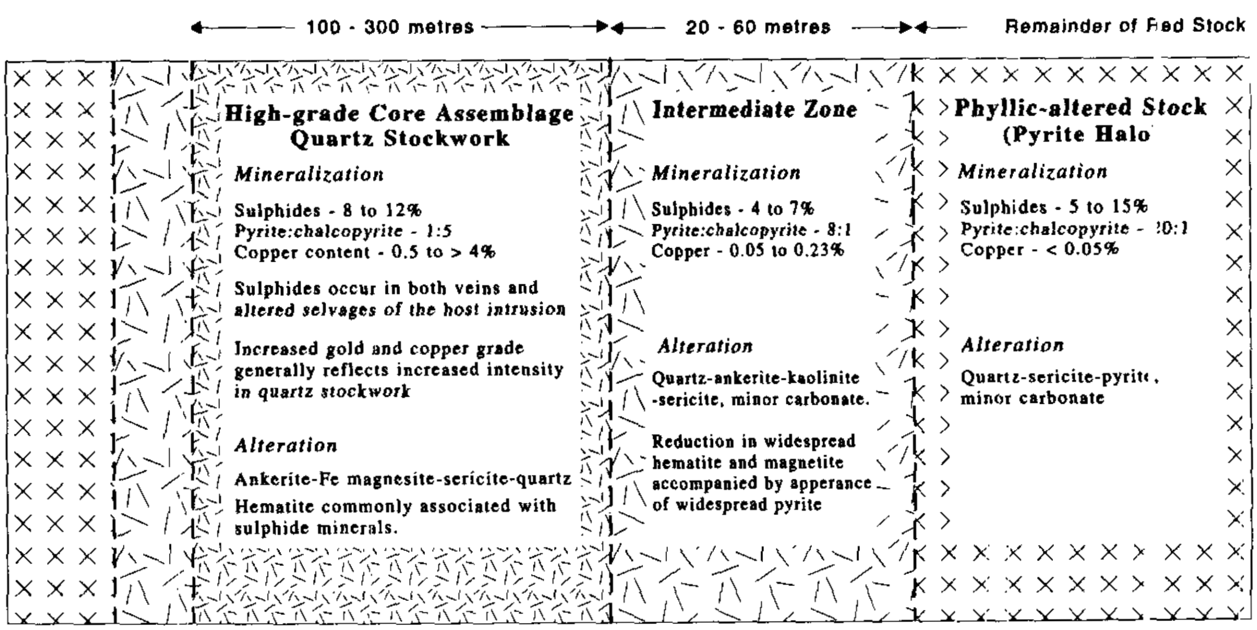


Figure 6. Generalized characteristics of mineralization and alteration at the Red-Chris deposit. Compiled largely from data by Leitch and Elliott (1976) and Schink (1977).

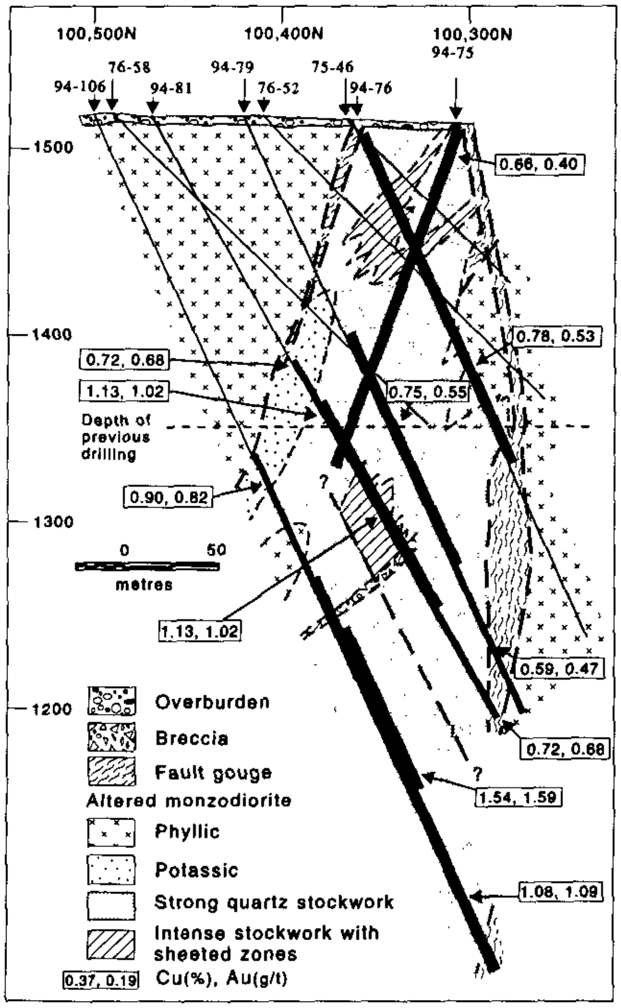


Figure 7. Generalized cross-section through the East zone along section 50 100 looking east. Abundant small-scale faults are not illustrated. Line of section shown on Figure 5.

Quartz stockwork consists of planar, grey quartz envelopes and vein-fill material characterized by sharp contacts with the host plagioclase hornblende porphyry. Veinlets are from 2 millimetres to 2 centimetres wide and form a randomly orientated network pattern with at least two generations of veining. To log the intensity of quartz stockwork on a consistent basis, American Bullion Minerals geologists have designated weak, moderate and strong stockwork by arbitrary values of less than 12, 12 to 30 and more than 30 veins per metre, respectively. Disseminated chalcopyrite, in addition to minor pyrite, hematite and bornite are commonly found as both disseminations and thin veinlets in both quartz veins and selvages of hostrock between the veins.

In the stockwork zones the host intrusion is affected by intense and pervasive carbonate alteration associated with lesser fine-grained quartz, sericite and sulphides. Mafic minerals are intensely altered to a probable combination of chlorite, sericite and ankerite. Plagioclase phenocrysts are locally kaolinized, but are more often strongly sericitized. Although difficult to detect in fresh drill core, orange-brown weathering of exposed core emphasizes the presence of abundant fine-grained iron carbonate. Preliminary scanning electron microprobe investigation indicates that hostrock selvages are dominated by roughly equal abundances of ankerite and iron-rich magnesite. These two minerals occur as a fine-grained, anhedral granular intergrowth with lesser pyrite and sericite.

Several zones of sheeted quartz-sulphide material associated with zones of intense silica flooding and quartz stockwork occur in the East zone. The fabric defined by the sheeted zone strikes between 070° and 090°. Discontinuity of sheeted zones in drill core is most likely a function of later faulting (Figure 7). Sheeted material consists of 2 to 4-millimetre alternating bands of light and dark grey microcrystalline quartz carrying chalcopyrite and pyrite, with minor bornite. Dark grey quartz bands contain skeletal hematite and remnants of hostrock that are intensely altered to sericite, hematite and clay. In drill core the upper transition from intensely developed quartz stockwork mineralization to sheeted material is gradational, whereas the lower contact is faulted. This is indicated by the abrupt truncation of sheeting and intense stockwork by carbonate breccia.

Hole 94-106 cut a significant intersection of bornite mineralization (Figure 7). Between 206 and 495 metres depth bornite comprises more than half of the copper bearing mineral and locally dominates. It occurs as disseminations and thin 1 to 3-millimetre, fracture-filling stringers with hematite within the altered stock and to a lesser degree in quartz veins were it is locally abundant.

In order to characterize the base and precious metal elemental character of the Red-Chris deposit, a total of 23 samples, including three or four representative of each of the individual styles of alteration and mineralization were collected from drill core. These samples were analysizd by both inductively coupled plasma emission spectroscopy (ICPES, 32 elements) and instrumental neutron activation analysis (INAA, Au + 34 other elements). Results for both precious and base metal elements are summarized in Table 1. These data demonstrate a correlation of high copper with elevated gold and silver. They also demonstrate that the highest concentrations of these elements are present in quartz-rich samples, either sheeted or stockwork.

Other base metal concentrations are typically low with zinc being weakly anomalous. These elements appear to show no correlation with copper and gold values.

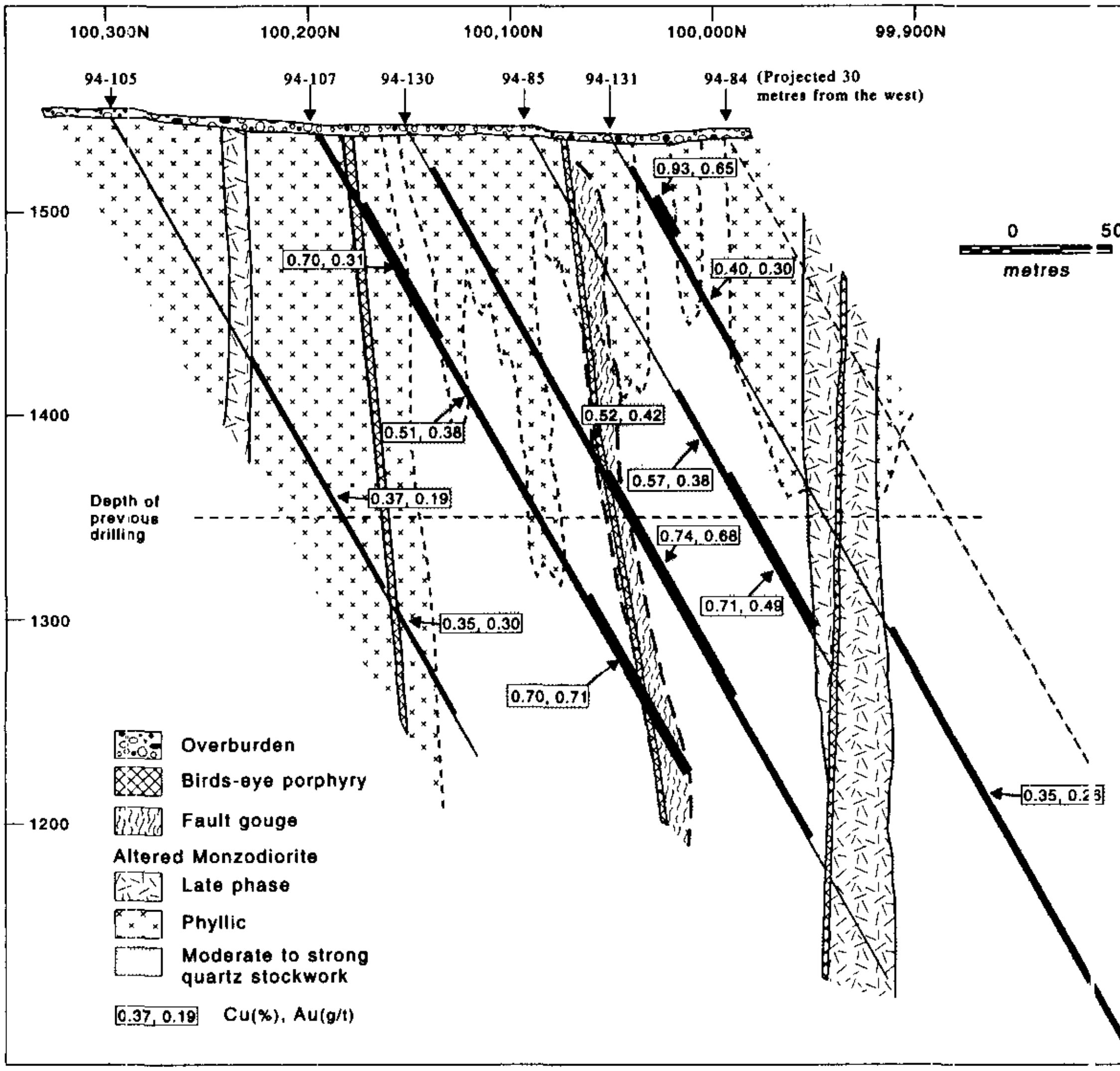


Figure 8. Generalized cross-section through the Main zone along section 50 740 looking east. Abundant small-scale faults are not illustrated. Line of section relative to locations of the individual drill holes is shown on Figure 5. Section does not include all previous drilling data.

Iridium was the only platinum group element assayed for. Abundances are below the detection limit of 5 ppb in all samples.

ALTERATION

Four main alteration types are evident at Red-Chris. The most prominent consists of phyllic (+carbonate) with interfingering mottled phyllic alteration and extends over an area of 2 to 3 square kilometres. Potassic alteration is sporadic and limited in both extent and intensity. Propylitic assemblages are prevalent in the mafic volcanics to the north of the Main and East zones and has been identified locally in late phase dikes.

Phyllic alteration is generally pervasive and is the most widespread alteration type. Generally the altered rock is pale grey and retains some primary texture. Weak phyllic (to weak argillic) alteration of the Red stock has altered plagioclase to sericite and kaolinite. Locally plagioclase has a bleached appearance and typically hornblende is intensely altered to completely destroyed. In places, the groundmass appears to be silicified. However, the orange-brown colour of weathered drill core suggests the presence of significant amounts of carbonate. Preliminary review of thin sections and SEM investigations suggest that carbonate material is composed predominantly iron-magnesite and ankerite, with usually 10 to 20% replacement of the hostrock. Vein pyrite exceeds disseminated pyrite for a total content of 5 to 10%. Weak quartz-pyrite± chalcopyrite stringers are cut by late, white calcite veins.

Mottled phyllic alteration partially destroys primary porphyritic texture. It is characterized by distinctive, 3 to 7-millimetre spherical and irregular

TABLE 1
METAL ABUNDANCES OF DRILL CORE FROM THE RED-CHRIS DEPOSIT

DDH	Intersection	Rock Type	Au	*Ag	*Cu	*Mo	*Pb	*Zn	As	Hg	Sb	Co	*Ni	Cr
			ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
94-79	190-195 m	Potassic alteration, East Zone	448	1.1	5510	4	9	89	2.5	-1	2.1	40	3	12
84-81	150-154 m	Potassic alteration, East Zone	91	0.1	1176	1	12	142	2.1	-1	2.4	24	4	23
94-84	280-283 m	Potassic alteration, Main Zone	55	0.1	2203	1	6	64	7.8	-1	3.4	17	3	14
94-85	84-88 m	Potassic alteration, Main Zone	133	0.5	2067	3	14	127	7.5	-1	1.3	27	4	15
94-81	242-246 m	Sheeted qtz-sulphide, East Zone	2230	3.3	16947	1	7	55	23	2	23	70	4	-5
94-76	47-49 m	Sheeted qtz-sulphde, East Zone	2290	3.7	41160	2	13	79	19	4	11	63	3	6
94-76	80-85 m	Sheeted qtz-sulphide, East Zone	1870	3.1	21514	1	17	133	8.6	6	34	51	3	6
94-81	285-291 m	Moderate qtz stockwork, East Zone	376	0.1	2788	2	8	68	4.7	4	15	27	2	9
94-76	117-120 m	Moderate qtz stockwork, Main Zone	335	0.8	4614	3	12	83	20	-1	6.9	26	3	15
94-83	53-54 m	Moderate qtz stockwork, East Zone	116	0.5	5642	3	9	137	19	-1	58	24	2	7
94-81	29-40 m	Phyllic alteration, East Zone	31	0.1	118	2	3	25	13	-1	12	21	6	-5
94-106	86-90 m	Phyllic alteration, East Zone	61	0.1	754	12	6	95	6.8	-1	11	37	4	-5
94-84	193-204 m	Phyllic alteration, Main Zone	21	0.2	148	1	13	188	5.5	-1	1	19	7	20
94-107	65-72 m	Phyllic alteration, Main Zone	167	0.1	5792	2	2	21	8.9	2	6.9	49	3	-5
94-81	92-97 m	Mottled phyllic alteration, East Zone	126	0.2	1474	16	12	20	13	-1	3.9	23	5	8
94-106	23-26 m	Mottled phyllic alteration, East Zone	23	0.1	84	3	2	21	28	-1	3.6	46	99	180
94-106	161-162 m	Mottled phyllic alteration, East Zone	116	0.1	985	35	3	24	4.4	-1	3.1	27	11	-5
94-76	140-145 m	Strong qtz stockwork, East Zone	263	1	4263	3	4	89	38	6	68	22	7	50
94-106	308-313 m	Strong qtz stockwork, East Zone	2840	12.3	25859	6	3	69	0.9	2	3.4	79	2	8
94-84	99-103 m	Strong qtz stockwork, Main Zone	1330	2.1	12943	3	7	102	13	-1	2.3	61	2	6
94-81	312-315 m	Weak qtz stockwork, East Zone	255	0.4	2322	2	2	86	20	3	22	16	3	9
94-105	342-345 m	Weak qtz stockwork, Main Zone	612	0.6	7470	2	8	18	9.6	2	14	39	5	11
94-85	88-92 m	Weak qtz stockwork, Main Zone	127	0.3	2031	3	14	135	30	1	3.9	32	8	12

* Analyses by instrumental neutron activation (INAA), elements without an asterisk analyzed by inductively coupled plasma emission spectroscopy.

pale grey patches of intense quartz-sericite alteration that comprise from 10 to 15% of the rock. Typically fine-grained to blebby pyrite occurs near the centre of these patches. Altered groundmass is beige, probably indicating significant ankerite replacement. Pyrite veins are common and have well developed sericite-quartz envelopes. Total pyrite content varies from 5 to 10%.

On the whole, areas of potassic alteration are minor, representing roughly 5 to 10% of the total alteration zones. Potassic zones are generally only a few metres wide and are discontinuous, with gradational to sharp contacts with the phyllic-altered host and quartz stockwork. Although locally the porphyritic texture is preserved, it is often totally destroyed and replaced by fine-grained potassium feldspar, giving the rock a light orange-brown to salmon colour. The potassic alteration assemblage includes 2 to 7% hematite after magnetite (martite) and finely disseminated magnetite and rare veins. Generally 2 to 4% disseminated pyrite is fine-grained to blebby, with few pyrite stringers. Narrow quartz stingers contain pyrite and chalcopyrite. Locally, hornblende is altered to fine-grained, felted brown biotite. Panteleyev (1975) commented on the fact that hematite and siderite impart a buff pink appearance to hand specimens that may be mistaken for potassium feldspar flooding.

Propylitic alteration, as discussed by Schink (1977), is poorly developed. It consists of 5% disseminated epidote and 2 to 5% finely disseminated pyrite and has only been identified in the augite porphyry (Dynamite Hill) volcanics immediately to the north of the main zones of stockwork mineralization. No epidote was noted in drill core during the 1994 drilling program.

A gypsum zone located west to south-west of the Main zone contains weak to strong gypsum veining but its extent is poorly defined. These veins appear to be late and cut mineralization (Schink, 1977). Drilling during the 1994 field season was concentrated within the East and Main zones with very little work done in this area.

Carbonate veins and alteration of groundmass minerals to ankerite and iron-rich magnesite are widespread throughout the Red stock. Surrounding volcanics and sediments are also locally intensely carbonatized. Generally the zones external to the stock are barren of sulphides, appear to be very late and may be unrelated to the main copper-gold mineralizing event, at least in part.

FAULTING

Prominent east-northeast-trending structures have controlled the orientation of the Red stock and the zone of mineralization. Faults active either before or during the mineralizing event are generally healed and associated with intense silicification. Schink (1977) and Leitch and Elliott (1976) defined the fault orientation as striking 060°-090° and dipping approximately 75° to the south. These are normal faults with dominantly dip-slip movement.

Fault gouge zones produced by reactivation of earlier structures vary from several centimetres to 50 metres in width and are a prominent feature throughout the drill core. The gouge material contains rounded centimetre-sized fragments of altered and mineralized (pyrite-chalcopyrite) Red stock in a matrix of clay, quartz and carbonate. As emphasized by Newell and Peatfield (in preparation), disruption of the mineralized zone by faulting is an important aspect of the deposit but difficult to characterize on sections due to uncertainity in correlating the many fault zones from drill hole to drill hole.

CLASSIFICATION OF THE RED-CHRIS DEPOSIT

The Red-Chris has been characterized, genetically as a porphyry copper-gold deposit (Panteleyev, 1973, 1975; Schink, 1977) or alkaline porphyry deposit (McMillan, 1991; Newell and Peatfield, in preparation). Both Schink (1977) and Newell and Peatfield (in preparation) have emphasize the apparent ambiguity of features that are indicative of both alkalic and calcalkalic deposit types (Table 2). The overall size and, in particular, the metal signature, with significant gold values associated with higher grade copper and a molybdenum deficiency are clearly indicative of alkaline porphyry deposits. The nature of the mineralization, however, as predominantly quartz stockwork zones associated with intense and pervasive carbonatization and phyllic alteration of the host intrusion is not. Classification of the Red Chris deposit as to the type of porphyry remains problematical. Reference to the deposit as strictly a copper-gold porphyry with no attempt to further refine the porphyry type is preferable at this stage.

TABLE 2. CHARACTERISTICS OF THE RED CHRIS DEPOSIT.

Alkalic Porphyry Deposits	***Calcalkalic Porphyry Deposits***
Exclusively copper and gold mineralization	High quartz content of the mineralized zone
molybdenum deficiency	calcalkaline composition of the Red Stock
High level, sub-volcanic character of the stock	Phyllic alteration
Relative small size of stock and limited lateral extent of mineralization	Association with minor amounts of sphalerite, galena and tourmaline

NEW MINERAL OCCURRENCE

Small areas of previously undocumented gossans with associated sulphide mineralization were identified during the course of mapping. Areas of gossan were found primarily in Mesozoic volcanics and to a lesser degree in sediments. In almost all cases the only metallic mineral identified was pyrite, occurring as disseminations and thin stingers, and less commonly as massive 2 to 4-centimetre clots. Chip samples taken throughout the areas of alteration, with preference for sulphide-bearing rock fragments, were analyzed for precious and base metals.

Two sulphide samples from one of the gossanous areas sampled returned anomalous copper values (Table 3).

TABLE 3. PRECIOUS AND BASE METAL ABUNDANCES OF SULPHIDE SAMPLE.

	Au	Ag	Cu	Mo	Pb	Zn
	ppb	ppm				
CAS-30A	11	71	20611	1	27	77
CAS-30B	18	13	14527	1	12	44

This mineralized outcrop is located on the east side of the Eddon plateau roughly 3.5 kilometres due north of the centre of Ealue Lake, at an elevation of 1600 metres (5200 feet), (UTM 45040E by 6410705N). A 3 by 5 metre area is exposed in a near-vertical, northeast-facing rock face, 150 metres long by 6 to 8 metres high. Chalcopyrite mineralization is hosted by a polymictic volcanic lapalli-tuff breccia. Volcanic breccia varies from matrix to clast supported, with subangular to subrounded, 1 to 4-centimetre plagioclase-hornblende-porphyritic volcanic clasts in a poorly sorted plagioclase phyric tuffaceous matrix. Chalcopyrite and pyrite forms thin stringers and fine to locally coarse disseminations comprising from 10 to 15% of the rock over widths of less than 0.5 metre within the broader rusty stain zone.

ACKNOWLEDGMENTS

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BRITISH COLUMBIA AGGREGATE INVENTORY PROJECT

By Peter T. Bobrowsky, Caleen E. Kilby, Gavin Manson and Paul F. Matysek

KEYWORDS: aggregate, digital database, inventory, potential mapping, sand and gravel

INTRODUCTION

In 1994, the Geological Survey Branch initiated a program focused on provincial aggregate resources. The goal of this new effort is to establish an inventory of both natural and crushed aggregate pits in British Columbia. A long-term aim of this program is to provide products which will assist planners and decision makers as well as industry producers, in their management and use of this finite resource. The success of future decisions regarding the availability, sustainability and possible sterilization of aggregate resources rests on the quality and availability of the existing information source (inventory database). Aggregate inventory information (*i.e.* number of pits, location, deposit size, volume, etc.) is presently incomplete and widely scattered. To improve the reliability of provincial evaluation and land-use decisions regarding aggregate resources, several short-term objectives were targeted in the aggregate program (Bobrowsky and Kilby, 1994).

The immediate objectives of this program can be summarized as:

- Establish a digital database inventory of all aggregate pits (active and abandoned, as well as public and private) in British Columbia, consisting of an identification label and location referenced to the geological database;
- Identify the geological landform and surficial deposit represented by each pit;
- Improve information transfer and data management (*e.g.*, through MINFILE), between key provincial ministries (Transportation and Highways, Forests) and external parties which are actively involved with aggregate resources;
- Sponsor an "aggregate potential mapping" (APM) workshop to develop acceptable scientific methods for evaluatingaggregate resources.

BACKGROUND

Excluding local studies completed by the Geological Survey of Canada some 25 to 40 years ago (*e.g.*, Armstrong, 1953; Learning, 1968), regional aggregate studies are rare and consist only of two published by the Ministry of Energy, Mines and Petroleum Resources (Hora and Basham, 1980; Hora, 1988). These two studies, which were completed a decade ago, are the most recent summaries of the entire industry in British Columbia. They provide a benchmark analysis of a significant part of the provincial aggregate industry and include reviews of aggregate-related legislation, principal participants, production, use and estimates of reserve life. However, the inventory information contained in the two reports is not current, which is an important factor for land-use decisions. Although several topical studies have appeared in the last few years (*e.g.*, Goff and Hicock, 1992; Levson, 1993) which address aggregate identification on a local scale, there is still a need for a province-wide study.

The need to establish and maintain an inventory of aggregate pits and deposits in the province is a reflection of the growing importance of the resource For example, Figure 1 shows the value of sand and gravel (in $ millions) for the years 1976 to 1992. During this period the production value of sand and gravel has steadily increased from a low of $48 million to a high of $151 million. The amount of sand and gravel produced over the same period shows no clear trend (Figure 2) and it is interesting that the amount produced in 1992 approximates the level produced in 1978, but the value has doubled. In the absence of an aggregate pit and deposit inventory, which would allow long-term monitoring of aggregate resources, a reliable quantitative estimate of rates of depletion and expected resource life is not possible.

DIGITAL DATABASES

INVENTORY

Information on aggregate resources in British Columbia resides with several provincial ministries (Environment, Lands and Parks; Transportation and Highways; Energy, Mines and Petroleum Resources, Forests), federal departments (Fisheries and Oceans; Transport Canada), local governments (municipalities and Regional Districts) as well as the aggregate producers. The nature of their interest ranges from revenue and planning to inspection/auditing and permitting/licensing. Most interested parties support some form of selective inventory adapted to particular needs. None of them manage a pan-provincial inventory, but all support the concept. This study seeks to address this data gap by establishing a basic inventory of aggregate data accessible to all interested parties. Such an inventory is required in areas where there is currently a demand for the resource or where a future demand is anticipated.

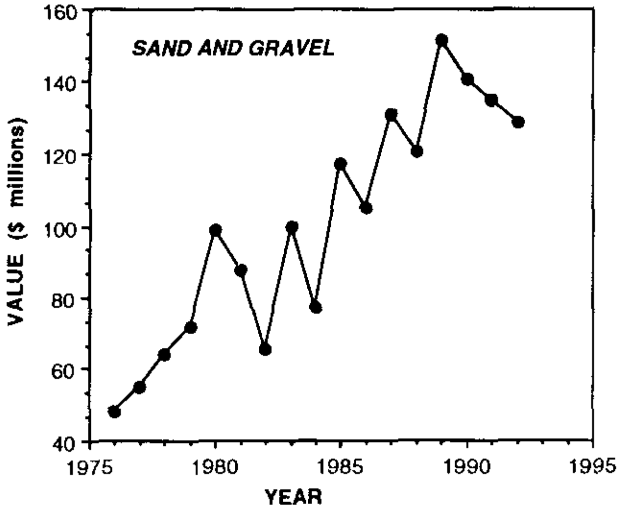

Figure 1. British Columbia statistics for sand and gravel value in $ millions for the period 1976 to 1992.

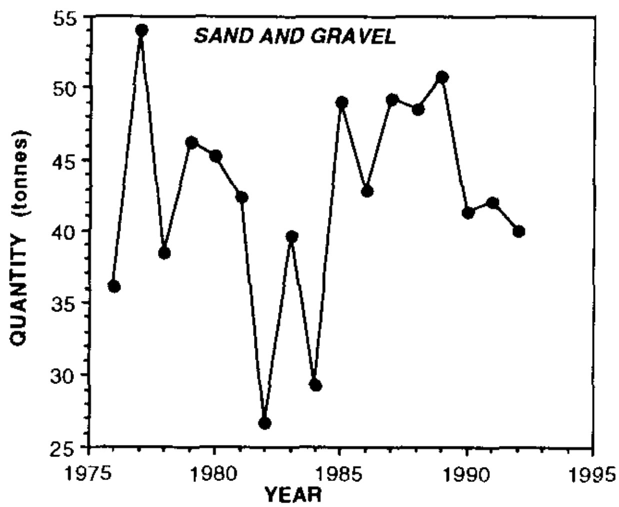

Figure 2. British Columbia statistics for sand and gravel production in tonnes for the period 1976 to 1992

In this discussion, two types of aggregate pits are recognized, public and private, and most of the information pertaining to the number and location of the pits is managed primarily by two ministries: Ministry of Energy, Mines and Petroleum Resources (MEMPR) and Ministry of Transportation and Highways (MoTH).

In British Columbia, all aggregate pits are designated as mines. Through the *Mines Act* and the Health, Safety and Reclamation Code for Mines, the Ministry of Energy, Mines and Petroleum Resources is concerned with the planning, management and regulation of mines on both Crown and private land. Because responsibilities include permitting, health, safety and reclamation, considerable effort is often expended on aggregate issues by the Land Management and Policy Branch of MEMPR. In the Land Management and Policy Branch, private aggregate pits are identified by a reclamation number and managed by Mining Inspection Districts. Moreover, the branch relies on completed Notices of Work forms to collect information on aggregate pits such as location, size and production estimates. However, Notices of Work indicate only expected production over the life of the permit and contain limited information on pit location and estimates of size. On submission of an application for a permit, information is abstracted from the Notices of Work and entered directly into digital format on a system called MIS (Mining Information System).

The Ministry of Transportation and Highways, through the Geotechnical and Materials Engineering Branch and Maintenance Branch, is responsible for ensuring that an adequate quantity and quality of gravel is available for construction, maintenance and rehabilitation of highways in the province (Ministry of Transportation and Highways, 1994). The MoTH gravel management program addresses its aggregate concerns by estimating gravel demand, establishing gravel supply strategies, finding new deposits, managing Ministry pits and purchasing new gravel. For the last several years, aggregate data have been mnaged by MoTH using three systems: ADIS (aggregate deposit information system), ARMS (aggregate resource management system) and RAAMS (regional aggregate account management system). The quality of the data captured is variable, as the location and status of many pits are unknown or incomplete. A new system, GMSS, which is a compilation of the above three systems, is expected to be adopted by MoTH following regional testing. This new database should eliminate errors and complete missing information fields. The Ministry uses its own aggregate identification system and manages data according to Highways Districts.

Our efforts to establish a digital inventory of pit frequency and location has begun with the use of reclamation files (which include Notices of Work) and the ADIS database as primary data sources. Individual pit identification and location are obtained, plotted on base maps and then digitized using QUIKMAP. The information is being compiled in a simple dBase format.

OTHER DATABASES

At present the project is using MELP digital 1:250 000 (NAD 82) topographic information as base-maps for data accumulation. These maps provide a general framework for viewing pit locations and are available for the entire province.

Using TRIM (Terrain Resource Information Management) data compiled at 1:20 000-scale as base maps could provide more accurate and detailed digital information. Specific groups of data layers are available at this scale and can be purchased individually. A pilot project explored the potential uses of these data for the map sheet 92G. The project relied on "designated areas" layers for all 1:20 000 maps in 92G which included layers for gravel pits, abandoned gravel pits and quarries. A complete base map of 92G was compiled with polygon forms for designated pit sites. Although the results of the pilot project are of interest, the data storage requirements of polygon information are high and preclude continuation until all basic inventory data have been compiled.

Once completed, the basic inventory will consist of approximately 6000 pits and contain information on locations, geology and other related data. Our intention is to maintain a current accounting of the aggregate pits and to provide this information to interested parties as quickly and efficiently as possible. The problem of long-term data management and dissemination was considered and the use of MINFILE was recognized as a potential solution. The potential for merging inventory information with MINFILE was tested in our pilot project in 92G. The long-term use of MINFILE for the aggregate inventory is still under review.

AGGREGATE POTENTIAL MAPPING

Once established, the basic inventory of aggregate pits can be further expanded to include aggregate potential. As used here, the term 'aggregate potential mapping' denotes the identification and ranking of landforms suited for sand and gravel extraction, including probabilistic estimates of the quality and quantity contained based on a quantitative analysis of existing pit attributes and field observations. The concept of aggregate potential mapping is not new, especially the qualitative ranking of landforms, although the application of quantitative techniques has only recently been emphasized. For example, based on their work in Ontario, Gartner *et al.* (1981), provided a simple linear ranking of landforms in order of decreasing importance: outwash > esker > glaciofluvial delta > kame > raised beach > hummocky moraine > end moraine > glaciolacustrine delta > glaciomarine delta. In contrast, relying on their work in Alberta, Edwards *et al.* (1985) illustrated the inherent errors of qualitative aggregate potential analysis. Instead, they devised an economic potential procedure based on a deposit by deposit ranking using six geological factors: predominant material, deposit thickness, overburden thickness, potential for water table problems, material availability and deposit area (*e.g.* Fox *et al.*, 1987).

In British Columbia, Hora (1988) discussed aggregate potential by qualitatively categorizing deposits into three groups: known resources (A), probable resources (B) and possible resources (C). Where possible, additional subcategories were identified based on texture and sorting. His unpublished maps extended to a width of 5 kilometres along major transportation corridors throughout much of the province. Later, Levson (1993) qualitatively ranked deposits for a single map sheet into three categories: high potential (glaciofluvial and deltaic deposits), moderate potential (fluvial and alluvial deposits) and low potential (flood plain, muddy alluvial fan, talus and colluvial deposits).

Bliss (1993) has approached the need for aggregate potential mapping through quantitative modeling methods. He has generated descriptive statistics for volume and area on mixed landform assemblages based on sample sizes in excess of 200 cases. The method is derived from mineral deposit models of economic geologists.

We will examine the pros and cons of the above methods in relation to client needs.

SUMMARY

We anticipate that once completed, the inventory will be of use to industry producers, geologists, engineers, planners, managers and many others interested in the aggregate industry of British Columbia. Comprehensive planning and resource management strategies rely on a sound information source which, in this case, includes a knowledge of the distribution of active sand and gravel pits, as well as their geological setting. Success in such strategies may be further enhanced by the use of probabilistic estimates regarding resource potential (aggregate potential mapping). Access to digital inventory data should increase the number of users and client needs.

ACKNOWLEDGMENTS

Rob Buchanan and Stephen Lee provided ready access to MoTH aggregate databases. Greg McKillop provided access to MEMPR Notice of Work information. Ward Kilby assisted in database structure and data transfer. Dan Hora provided access to unpublished highway corridor aggregate potential maps. The paper was reviewed by Z.D. Hora and J.M. Newell. D.H. Huntley graciously formatted the paper. We appreciate the efforts of all of the above individuals towards improving this program and report.

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SOME NEW DIMENSION STONE PROPERTIES IN BRITISH COLUMBIA II

By Z.D. Hora and K.D. Hancock

KEYWORDS: industrial minerals, dimension stone, building stone, granite

INTRODUCTION

The first part of this report was published in Exploration in British Columbia 1992. During the 1993 field season, several additional quarry sites and dimension stone prospects were visited and the following text provides descriptions of individual properties.

REGIONAL GEOLOGY

Quarry sites described in this article are situated in southeastern British Columbia. Two of them are in the Coast Plutonic Complex, and the other four represent several types of granitic intrusions in the Okanagan area. The Cayoosh Creek and the Elaho River quarries opened in two separate quartz diorite intrusions of uncertain age, both part of the Coast Plutonic Complex. The two McNulty Creek sites are in the Pennask batholith of Middle Jurassic age; the Little White Mountain prospect is in the northern part of the (Late Cretaceous) Okanagan batholith and the Allendale Lake project is in a small isolated plug of Eocene Coryell syenite (Roddick *et al.*, 1979; Tempelman-Kluit, 1989).

PROPERTY DESCRIPTIONS

McNulty Creek - East (Pacific Rose)

Location: Lat. 49° 34' Long. 120° 04' 92H/9 Osoyoos Mining Division. Approximately 31 kilometres west of Summerland.

Access: From Highway 94 on a logging road west of Summerland.

Owners: D. Sandberg and R. Bechtel

Operator: None at present. Pacific Granistone Ltd. in 1992-93

Commodities: Dimension stone - granite

LOCAL GEOLOGY

This site is located in medium to coarse-grained pink and white granite of the Middle Jurassic Pennask batholith. Granite outcrops form an elongate, east-west oriented ridge with bare rock ledges, faces and a granite boulder field on the lower part of the slope. The great size of the boulders and massive outcrops indicates low fracture density. The rock is homogeneous with only occasional dark inclusions (Photo1).

In 1992 and 1993, Pacific Granistone Ltd. optioned this site and produced a number of blocks which were processed into facing-stone sheets (Photo 2). Under the trade name "Pacific Rose" granite, this stone was used as floor tile and outside facing in the Jack Davis Building in Victoria. This structure houses the B.C. Ministry of Energy, Mines and Petroleum Resources.

PETROGRAPHY

Pacific Rose stone is an attractive medium to coarse-grained pink two-feldspar granite. Major constituents are pink orthoclase, white plagioclase, glassy grey quartz and greenish white microline. Minor minerals are sphene, apatite, rutile, biotite and magnetite (1-2%). Microline imparts a faint greenish cast to the otherwise white matrix. The texture and colour are uniform with no fabric present. The rock is quite fresh with minor sericitization of plagioclase and no alteration of biotite. The rock takes a very good polish (8-9/10) with no iron staining. Grains are well interlocked but the stone developed underspread intragranular cracking. Some minor pitting occurs on biotite grains or on feldspars where cleavage intersects intragranular cracks.

McNulty Creek - West (Paradise Rose)

Location: Lat. 49° 34' Long. 120° 09' 92H/9 Osoyoos Mining Division. Approximately 36 kilometres west of Summerland.

Access: From Highway 97 on a logging road west of Summerland.

Owners: Don Sandberg, R. Bechtel and F. Arnold

Operator: None

Commodities: Dimension stone - granite

Photo 1. McNulty Creek - East - Massive rock outcrops of Pacific Rose granite

Photo 2. McNulty Creek - East. Split boulders of Pacific Rose granite used to produce stone for the Jack Davis Building

Photo 3. Little White Mountain prospect. Large massive granite outcrops on the hillside.

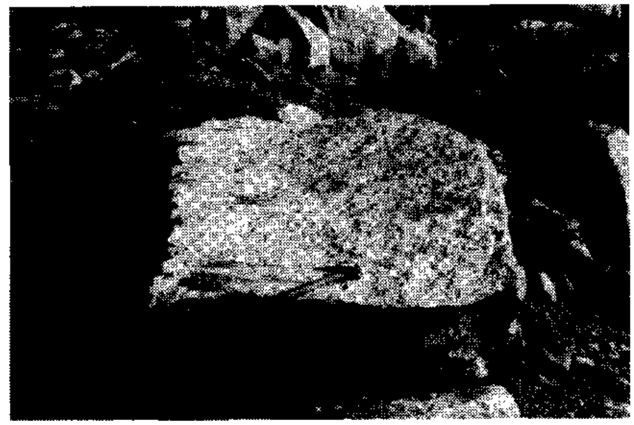

Photo 4. Little White Mountain prospect. Split boulder for testing the market.

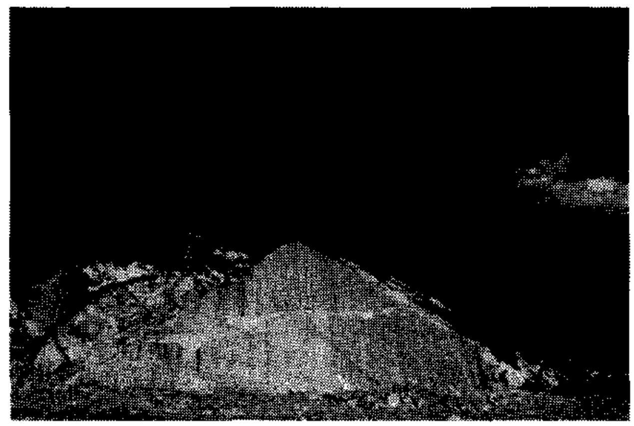

Photo 5. Elaho River quarry site of Pacific Quarry Industries Ltd.

Photo 6. Cayoosh Creek quarry of Northwest Granite Ltd.

LOCAL GEOLOGY

Paradise Rose is a stone similar to Pacific Rose. It is a lighter colour, medium to coarse-grained pink and white quartz syenite of the Middle Jurassic Pennask batholith. Large boulders and massive outcrops form a northeast elongate hill. No dark inclusions were observed on scattered boulders or rock outcrops. There is no production record from this locality.

PETROGRAPHY

Paradise Rose stone is a bright pink and white quartz syenite. The rock is medium to coarse grained, uniform in both colour and texture. Major mineral constituents are pink orthoclase, white plagioclase and grey quartz. Small biotite crystals pepper the surface but make up only 5% of the rock. Minor minerals are (clino?)zoisite, sphene, chlorite after biotite, hornblende, magnetite and pyrite. The rock appears to be fairly fresh but, in thin section, plagioclase is moderately sericitized. Orthoclase has some microperthitic texture and some grains are glomeroporphyritic, enclosing biotite and plagioclase. There are abundant cracks in orthoclase crystals which can be seen on the polished face. The rock takes a high polish (8/10) but some cracks are up to 0.5 millimetre deep and there are a few through-going fractures. There is some pitting of biotite grains and scattered flaking out of orthoclase fragments along cleavages intersecting with intracrystal cracks. There is no staining by pyrite or magnetite (<1% combined).

Little White Mountain

Location: Lat. 49° 42' Long. 119° 15' 82E/11 Greenwood Mining Division. Approximately 36 kilometres southeast of Kelowna.

Access: From Highway 94 and Highway 33 on a logging road southeast of Kelowna.

Owners: D. Sandberg and R. Bechtel

Operator: None at present, Pacific Granistone Ltd. in 1992-93

Commodities: Dimension stone - granite.

LOCAL GEOLOGY

The Little White Mountain site is located in a coarse-grained phase of the Late Cretaceous Okanagan batholith. This stone prospect forms a north-trending ridge with many large rock outcrops and scattered boulders below it (Photo 3). Available exposures and boulder sizes indicate low fracture density in the bedrock. The rock is homogeneous with no dark inclusions observed.

In 1992, Pacific Granistone produced some blocks to test the market (Photo 4). Processed slabs were used as a floor tile in some private residences and one Vancouver mall. This stone was given the trade name of Pacific Pearl.

PETROGRAPHY

Pacific Pearl stone is a cream-yellow-grey quartz syenite. Large, 1 to 2-centimetre, yellow orthoclase crystals are prominent. The coarse texture is quite uniform. The medium-grained groundmass is made up of grey quartz, white plagioclase and black biotite. Minor constituents, less than 1% each, are apatite, chlorite after biotite, zircon, sphene and magnetite. The rock appears fresh and shows no iron staining. In thin section, there is little alteration with only a small amount of chlorite after biotite. Microperthitic texture is well developed in the orthoclase phenocrysts and may account for some pearly yellow-white schiller seen on the polished rock face. All grains are well interlocked with no developed fabric. The rock takes a good polish (7/10) with minor surface cracks and some small pits at biotite grains. The cracks visible on the polished surface are tight and occur in orthoclase and quartz grains.

Allendale Lake

Location: 49° 24' Long. 119° 22' 82E/6 Osoyoos Mining Division. Approximately 20 kilometres east of Okanagan Falls.

Access: From Highway 94 on a logging road east of Okanagan Falls

Owners: D. Sandberg and R. Bechtel

Operator: None

Commodities: Dimension stone - granite

LOCAL GEOLOGY

This unusual type of stone prospect forms a round hill with a scattered boulder field along its edges. When cut and polished, this stone has a dark blue colour with occasional light irridescense in some feldspar grains. The rock is a very coarse grained, dark grey syenite. The colour and texture of the stone varies slightly in individual boulders and rock outcrops. The presence of many small boulders indicates a high fracture density. Therefore, in spite of its very attractive appearance in finished slabs, potential development of this site will probably be limited to monument work and interior projects only.

PETROGRAPHY

This distinctive stone is a dark grey to black alkali-feldspar syenite. The rock is very coarse with large (1 to 2 cm) phenocrysts of grey orthoclase and black augite. It has a poorly developed linear fabric defined by the augite crystals. The rock is partially altered with pseudomorphs of chlorite after augite and some chloritization of biotite. Quartz is absent, nepheline may be present as a minor constituent of the finer groundmass. Minor constituents are apatite, magnetite and pyrite. The rock takes a good polish (7-8/10) with some pitting on chlorite or biotite grains. There are tight intergranular cracks throughout the rock and individual grains also show some cracking. Grains are well interlocked and there is no iron staining from either the pyrite or magnetite (2-3%). The polished rock exhibits bluish iridescence from some feldspar crystals.

Cayoosh Creek

Location: Lat. 49° 32' Long. 122° 11' 92J/9 Lillooet Mining Division. Approximately 55 kilometres northeast of Pemberton.
Access: On Highway 99 between Pemberton and Lillooet
Owners: Northwest Granite Ltd.
Operator: Northwest Granite Ltd.
Commodities: Dimension stone - granite

LOCAL GEOLOGY

Cayoosh Creek quarry is located in a fine to medium-grained quartz monzonite plug which intrudes Bridge River Group sedimentary rocks (Photo 6). The quarry area is characterized by horizontal ledges several metres thick, of massive monzonite, overlain by a more densely fractured zone. The existing quarry face allows removal of blocks several cubic metres in size (Photo 7). The stone is homogeneous with uniform texture. No dark inclusions can be seen on quarry faces.

The quarried blocks are split into masonry and facing shapes and marketed under the trade name Arctic White granite (Photo 8). It has been widely used around Whistler and in the Vancouver area.

Photo 7. Cayoosh Creek quarry face

PETROGRAPHY

Arctic White is a bright white fine to medium-grained quartz monzonite. The texture is very uniform but has a strong planar fabric defined by biotite. Major minerals are white plagioclase, orthoclase, microcline, clear, colourless quartz and black biotite. Minor constituents are sphene, (clino?)zoisite and chlorite with sericitization of plagioclase. The polished surface is good

Photo 8. Cayoosh Creek quarry site - splitting the stone into masonry blocks

(7-8/10) and pitting is limited to crystal corners where cleavage planes intersect the surface. There is no staining as iron oxides or sulphides are essentially absent.

Elaho River

Location: Lat. 50° 08' Long. 123° 28' 92J/3 Vancouver Mining Division. Approximately 60 kilometres north of Squamish.
Access: From Squamish by logging road upstream along the Squamish River
Owners: Pacific Quarry Industries Ltd.
Operator: Pacific Quarry Industries Ltd.
Commodities: Dimension stone - granite

LOCAL GEOLOGY

The Elaho River quarry is opened in a quartz diorite phase of the Coastal Plutonic Complex. The stone is fine to medium grained with a parallel texture well defined by orientation of mica flakes. The rock is exposed in steep cliffs and along the banks of the Elaho River, some 7.5 kilometres upstream from its confluence with the Squamish River. The fracture spacing, several metres apart, allows removal of large blocks from the quarry face with a minimum of waste. The only observed inhomogenities in the quarry area are two light-coloured fine-grained aplitic dikes 10 to 20 centimetres thick.

The square-shaped blocks are processed into granite tile in Surrey, British Columbia and marketed under the trade name of Whistler White granite.

PETROGRAPHY

Stone from Elaho River is a distinctive white granodiorite that has a prominent parallel fabric defined by the mafic minerals. It is fine to medium grained with a uniform texture. Major constituents are white plagioclase, colourless glassy quartz and black biotite. Chloritization of biotite and virtual total replacement of minor augite gives the mafics a greenish tinge. Notable highlights are small (±1 mm) red garnets that are scattered through the rock. Minor minerals are sphene, (clino?)zoisite, apatite, magnetite and pyrite. The grains are well interlocked and the fabric seen at the macroscopic scale is not apparent under the microscope. The rock is reasonably fresh, considering the modest amount of chloritization, and the feldspars are unaltered. There is no iron staining from the pyrite or magnetite (± 1% combined). The polish is very good (8-9/10) with only slight pitting on biotite-chlorite grains and there are no fractures or significant cracks.

SUMMARY AND CONCLUSIONS

Steady progress is being made in developing British Columbia's dimension stone resources and bringing back an industry which was once vibrant, but gradually declined. More and more sites with different varieties of colours and textures are becoming producers and prospectors are bringing to industry's attention numerous potential deposits with excellent chances for development. Although data on physical properties are lacking from most of the locations, the study of thin sections and correlation with similar stones from established producers indicates possibilities for even the most demanding applications.

ACKNOWLEDGMENTS

The authors thank Joe Jelincic, Sante Iacutoni and Don Sandberg for helping to visit all the prospects and quarry sites. Editorial comments of J.M. Newell and B. Grant are most appreciated.

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NOTES

THE GEOCHEMISTRY OF MINERALIZED SKARNS IN BRITISH COLUMBIA

By G. E. Ray and I.C.L. Webster

KEYWORDS: economic geology, skarns, geochemistry, metal ratios.

INTRODUCTION

In this paper we present geochemical assay data for mineralized samples collected from over 60 skarns distributed throughout British Columbia (Figure 1). These samples were collected from all seven classes of calcic metallic skarn present in the province (Fe, Cu, Au, Mo, Pb-Zn, W and Sn) and represent both major producing deposits and smaller prospects (Table 1).

In addition to examining the varying metallic geochemistry (particularly the Au, Ag, Cu and Zn geochemistry) of the various skarn classes, we present some plots of metal element ratios that can assist prospectors and exploration geologists to geochemically differentiate gold, copper and iron skarns.

SAMPLES AND SAMPLE LOCATIONS

A total of 181 samples of mineralized skarn were collected for this study and a synopsis of the name and British Columbia MINFILE number of each sampled deposit or property is presented in Table 1. Each skarn class is represented by the following number of samples: iron skarns, 24; copper skarns, 84; gold skarns, 29; lead-zinc skarns, 10; tungsten skarns, 12; tin skarns, 10; molybdenum skarns, 12.

GEOCHEMICAL ASSAY RESULTS

Assay results for the 181 mineralized samples from the seven skarn classes are summarized in Table 2. It should be noted that all the samples were assayed for elements such as gold, silver, copper, lead, and zinc, but some samples were not analyzed for such elements as cesium, fluorine and mercury.

Some of the magnetite-rich iron skarn samples contain up to 10% sulphides, including chalcopyrite; this accounts for the unusually high average copper content (2.2%) of this skarn class compared to the copper skarns which average 3.3% copper. When the data for the magnetite-rich iron skarn samples are subdivided into sulphide-lean and sulphide-rich sets, it shows that the latter have a comparatively higher average content of gold, silver, copper, zinc, cobalt and arsenic (Table 3). The low gold and copper values in the sulphide-lean magnetite samples are more typical of iron skarn deposits in British Columbia.

Gold averages 20 ppm in the gold skarns, 8 ppm in the molybdenum skarns and 1.5 ppm in the copper skarns. The high average gold content of the molybdenum skarns is due to samples collected from the Novelty (82FSW107) and Giant (82FSW109) deposits at Rossland; these are unusual molybdenum skarns that contain anomalous gold, uranium, bismuth, cobalt, arsenic, nickel and tungsten (Fyles, 1984; Webster *et al.*, 1992; Ray and Webster, unpublished data).

The ore samples of tungsten skarn have the lowest gold content (<7 ppb) of all the skarn classes. Iron, tin and lead-zinc skarns are also low in gold although the more sulphide-rich magnetite iron skarn samples average 1206 ppb gold (Table 3).

Two of the three tin skarn prospects sampled, the Silver Diamond and Atlin Magnetite (MINFILE 104N 069 and 126) contain high amounts of silver (up to 459 ppm) which is reflected in the high average silver content of 85 ppm for this class. Lead-zinc and copper skarns also have high average silver contents (c. 70 ppm) whereas tungsten and molybdenum skarns have exceedingly low silver values (Table 2).

VARIABLE METALLIC ELEMENT CORRELATIONS IN THE SKARN CLASSES

The analytical results suggest that correlations between certain metals, particularly between gold, silver and copper, are highly variable in the different skarn classes. In iron skarns, there are good to excellent positive correlations between gold, silver and copper (Figure 2A, B and C). In copper skarns, copper and silver correlate positively with each other (Figure 3A), but neither of these two metals show a marked correlation with gold (Figure 3B and C). In gold skarns, however, there is no apparent correlation at all between gold, silver and copper (Figure 4 A, B, and C).

Although gold skarns are characterized by the highest average arsenic content of any skarn class (avg. 0.3% As) as well as very high bismuth abundances (Table 2), no significant correlation between gold and arsenic or between gold and bismuth is noted in this

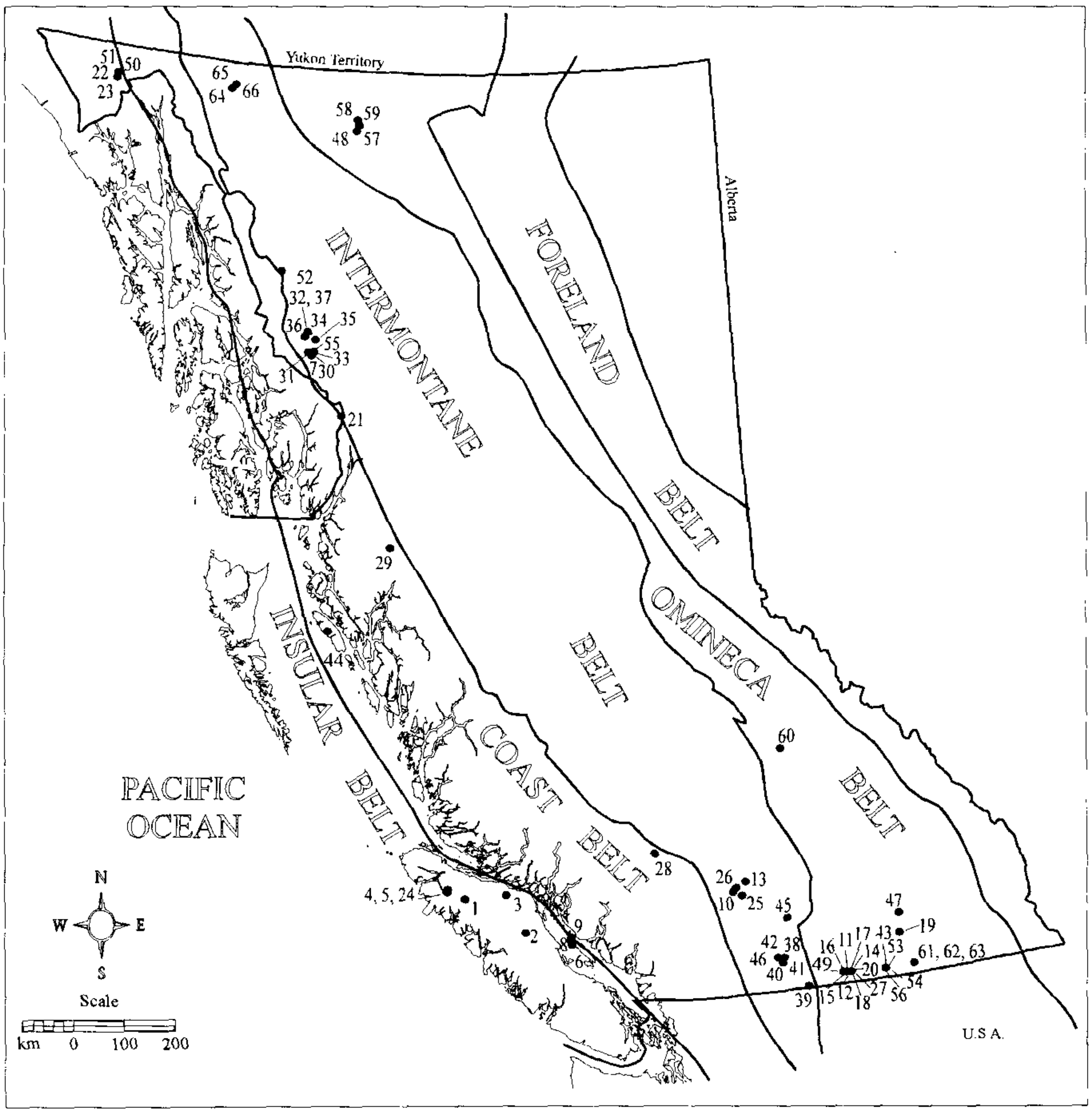


Figure 1. Location map of skarns sampled for this study. See Table 1 for property names.

Table 1. SKARN PROPERTIES IN BRITISH COLUMBIA SAMPLED FOR THIS STUDY.

	No. on Fig. 1	PROPERTY NAME	MINFILE No.		Map No.	PROPERTY NAME	MINFILE No.
Fe Skarns				**Au Skarns**			
	1	Iron Crown (Nimpkish Iron)	092L 034		38	Canty	092HSE064
	2	Iron Hill (Argonaut)	092F 075		39	Dividend-Lakeview	082ESW001
	3	Iron Mike	092K 043		40	French	092HSE059
	4	Kingfisher	092L 045		41	Good Hope	092HSE060
	5	Merry Widow	092L 044		42	Nickel Plate(Mascot)	092HSE036&38
	6	Prescott /Paxton /	092F 106/107		43	Jumbo	082FSW 111
		Yellow Kid / Lake	258/259		44	Banks, Discovery	103G 025
	7	Kirk Magnetite	104B 362		45	Oka	082ENW 025
Cu Skarns					*46*	*Peggy*	*092HSE 066*
	8	Little Billie	092F 105	**Pb-Zn Skarns**			
	9	Loyal	092F 265		47	Piedmont	082FNW129
	10	Craigmont	092ISE035		48	Contact	104P 004
	11	Emma	082ESE062		49	Cyclops	-
	12	Greyhound	082ESE050		50	Adams	114P 010
	13	Lucky Mike	092ISE027		51	Lawrence	114P 011
	14	Marshall	082ESE031		52	Devils Elbow	104G 012
	15	Morrison	082ESE052	**Mo Skarns**			
	16	Mother Lode /Sunset	082ESE034		53	Coxey	082FSW110
	17	Oro Denoro	082ESE063		54	Giant	082FSW109
	18	Phoenix	082ESE020		55	Josh	104B 290
	19	Queen Victoria	082FSW082		56	Novelty	082FSW 107
	20	Snowshoe	082ESE025				
	21	Molly B	103P 085	**W Skarns**	57	Dead Goat	104P 079
	22	Maid of Erin	114P 007		58	Lamb Mt	104P 003
	23	State of Montana	114P 008		59	Kuhn	104P 071
	24	Old Sport	092L 035		60	Dimac	082M 123
	25	Chase	092ISE 045		61	Dodger	082FSW011
	26	Eric	092ISE 036		62	Emerald Tungsten	082FSW010
	27	Brooklyn/Idaho	082ESE 013		63	Feeney	082FSW247
	28	Chalco 5	092JNE043	**Sn Skarns**			
	29	Lady Luck	103I 013		64	Silver Diamond	104N 069
	30	Cam 9	104B 326		65	Atlin Magnetite	104N 126
	31	Stu	104B 313		66	Daybreak	104N 134
	32	Dundee	103G 137				
	33	Shan	104B 023				
	34	Ken	104B 027				
	35	Tic	104B 367				
	36	Dirk	104B 114				
	37	McLymont	104B 281				

class (Figure 4D and E). However, cobalt does correlate positively with silver and arsenic in gold skarns (Figure 4F and G).

Nearly all of the scheelite-bearing tungsten skarn samples analyzed contain no, or very little, sulphide and the gold assays are so low that no meaningful correlations between gold and other metals could be observed. However, a number of interesting element associations were detected in tungsten skarns, including positive correlations between copper and cobalt, and thorium and cesium, and a negative correlation between cobalt and cesium (Figure 5 A, B and C). Positive correlations were also noted between cadmium and fluorine and between zinc and fluorine.

It should be noted that certain arsenopyrite-rich samples from the Emerald Tungsten camp do contain significant amounts of gold (Webster *et al.*, 1992). However, these were excluded from our set of tungsten skarn samples because they do not contain scheelite and it is not yet determined whether this economically interesting and distinctive mineralization is genetically related to the tungsten skarn system.

The molybdenum skarn samples can be subdivided into two sets: those from the Rossland deposits with high gold contents and the remainder that are generally low in gold. Plots using these sets indicate gold correlates positively with cobalt, selenium, tellurium, bismuth (Figure 6 A to D) as well as with antimony and arsenic. However, gold in these skarns correlates negatively with zinc and copper (Figure 6E and F) and molybdenum correlates negatively with zinc (Figure 6G).

Although gold in the tin skarn samples only average 127 ppb (Table 2), it shows a moderate positive correlation with bismuth, nickel and cobalt (Figure 7).

In lead-zinc skarns, no correlation between the low quantities of gold present (averaging 20 ppb) and any other metal was detected. However, positive correlations between silver and antimony (probably due to the presence of tetrahedrite), and silver and lead were noted, as well as negative correlations between zinc and copper, and between arsenic and bismuth (Figure 8).

USING METAL RATIOS TO DIFFERENTIATE SKARN CLASSES

Previous studies (Ettlinger and Ray, 1989; Ray *et al.*, 1990; Myers and Meinert, 1990; Theodore *et al.*, 1991) have attempted to use metal ratios, notably gold/copper and gold/silver ratios, to characterize or distinguish between gold, copper and iron skarns. Einaudi (personal communication 1993) has also recognized that plots of gold (in ppm) versus silver/gold ratios can differentiate between some porphyry copper deposits and their related satellite copper skarns.

Table 2. SUMMARY OF ASSAY RESULTS OF MINERALIZED SKARN SAMPLES

Fe Skarns

	Average	Max	Min	Stdev	n
Au-ppb	530	4500	1	1010	24
Au-ppm	0 530	4 5	0 001	1	24
Ag	25	195	0.001	51	24
Cu	22050	133000	11	41857	24
Pb	10	50	2	13	24
Zn	537	3511	30	977	24
Co	371	2700	11	640	24
Ni	51	446	1	120	13
Mo	44	900	1	184	24
As	4624	107000	6	21810	24
Sb	3	11	1	3	11
Bi	5 9	32 0	1 5	6.3	21
Cd	19.0	37.8	0 2	27 0	2
Te	0 9	4.8	0 1	1.4	11
Se	2	12	0.1	4	11
Ba	158	1561	10	466	11
Cr	24	73	8	25	6
Rb	-	-	-	-	0
W	1	1	1	0	2
Ce	-	-	-	-	0
Th	-	-	-	-	0
F	-				0
Sr	108	673	5	199	11
Hg	73	285	10	81	11
Ag/Au	433	8474	4	1716	
Cu/Au	214426	4347826	969	881180	
Cu/Ag	799	2100	21	566	
Zn/Au	13264	152652	35	32686	
Zn/Pb	123	1756	1	353	

Cu Skarns

	Average	Max	Min	Stdev	n
Au-ppb	1503	29100	2	4040	84
Au-ppm	1 503	29 100	0.002	4.040	84
Ag	78	1800	0 4	292	86
Cu	33506	350800	33	66551	86
Pb	53	715	2	108	86
Zn	8601	210000	15	36113	86
Co	190	4860	2	560	86
Ni	53	660	1	91	73
Mo	84	2100	1	316	86
As	349	9600	1	1307	86
Sb	5	78	1	10	78
Bi	318 0	8200 0	2 0	1292 0	82
Cd	25 0	1000 0	0 1	140 0	51
Te	3.0	29 0	0 1	5.9	74
Se	18	210	0 1	34	74
Ba	172	3000	10	467	66
Cr	90	290	19	55	44
Rb	18 5	68.0	2 5	15 0	39
W	293	5800	1	969	43
Ce	12.3	100 0	1 5	20 8	39
Th	1 2	12.0	0.1	2 4	38
F	1384	40300	40	6403	39
Sr	497	8654	5	1977	20
Hg	185	2100	20	444	27
Ag/Au	1089	40000	0.1	4843	
Cu/Au	879248	26000000	4	3469249	
Cu/Ag	2635	55500	10	8264	
Zn/Au	359364	9904762	3	1646520	
Zn/Pb	495	31600	0	3433	

Au Skarns

	Average	Max	Min	Stdev	n
Au-ppb	19931	103000	137	28280	29
Au-ppm	20	103	0 137	28	29
Ag	29	715	1	132	29
Cu	2421	11800	4	3539	29
Pb	71	1500	2	277	29
Zn	134	730	12	139	29
Co	1039	17000	4	3266	29
Ni	168	850	16	206	14
Mo	30	300	2	67	24
As	34541	445000	13	98534	29
Sb	17	168	1	38	19
Bi	1514 0	32000 0	2.0	6062 0	28
Cd	1.0	2.0	-	1.0	5
Te	3 0	7.0	1.0	2.0	10
Se	17	58	1	19	10
Ba	727	1300	50	562	7
Cr	81	100	69	11	7
Rb	47.0	110 0	9 0	49.0	7
W	125	320	1	169	5
Ce	19 4	50 0	5.0	17 8	5
Th	6 0	17 0	1 0	8.0	7
F	332	460	160	141	5
Sr	582	720	444	159	5
Hg	172	380	10	140	6
Ag/Au	7	170	0	33	
Cu/Au	1065	44643	0	8424	
Cu/Ag	766	3933	1	997	
Zn/Au	57	766	0	143	
Zn/Pb	14	56	0	14	

Pb-Zn Skarns

	Average	Max	Min	Stdev	n
Au-ppb	20	119	3	36	10
Au-ppm	0.020	0 119	0 003	0 036	10
Ag	71	159	2	59	10
Cu	1964	8700	24	3051	10
Pb	16524	46900	16	18235	10
Zn	112960	385000	12700	109671	10
Co	67	290	3	89	10
Ni	131	610	1	212	8
Mo	24	105	2	36	10
As	66	250	1	98	10
Sb	194	1100	1	365	10
Bi	52.3	350.0	5 0	106.7	10
Cd	1519.0	4900.0	150 0	1477 0	10
Te	0 7	2 0	0 1	0 6	10
Se	11	35	1	12	10
Ba	656	1500	61	618	8
Cr	52	97	17	28	8
Rb	46 9	100 0	36 0	35 0	8
W	8	24	1	8	8
Ce	7.6	24.0	9 0	8.0	8
Th	1 2	5 0	0.2	1 6	8
F	291	640	120	156	8
Sr	-	-	-	-	0
Hg	-	-	-	-	0
Ag/Au	14909	41333	54	14699	
Cu/Au	430853	2175000	202	728947	
Cu/Ag	90	368	1	134	
Zn/Au	15607973	43333333	756098	15388104	
Zn/Pb	258	1938	1	602	

W Skarns

	Average	Max	Min	Stdev	n
Au-ppb	5 3	7	5	1	12
Au-ppm	0 005	0 007	0.001	0 005	12
Ag	0 8	2	0 4	0 4	12
Cu	406.9	2700	32	744	12
Pb	49.5	441	8	123	12
Zn	8421.0	97000	66	27899	12
Co	46.4	192	8	66	12
Ni	34 4	193	2	57	12
Mo	233.3	1800	2	514	12
As	1 8	4	1	1	12
Sb	1 4	4	1	1	12
Bi	10.6	40.0	8 0	13.4	12
Cd	25.9	300.0	0 1	86.3	12
Te	0.2	0 6	0.1	0.2	12
Se	1.3	5	1	1	12
Ba	170.3	340	93	113	12
Cr	97 0	390	43	96	12
Rb	130 3	530.0	35.0	176.0	12
W	14567.1	70000	35	26243	12
Ce	63.5	420.0	4 0	118.0	12
Th	24.8	150.0	0.2	42.4	12
F	4722.1	30490	300	8516	12
Sr	252.0	491	13	338	2
Hg	-	-	-	-	0
Ag/Au	148.6	320	57	88	
Cu/Au	80154.8	540000	5571	149155	
Cu/Ag	485.5	2700	64	744	
Zn/Au	1682685.8	19400000	13200	5580336	
Zn/Pb	524.9	6063	1	1744	

Mo Skarns

	Average	Max	Min	Stdev	n
Au-ppb	8457	47200	35	14153	12
Au-ppm	8	47	0.035	14	12
Ag	6	25	1	7	12
Cu	1082	3500	9	1237	12
Pb	23	57	7	15	12
Zn	81	266	6	75	12
Co	5828	48400	4	13898	12
Ni	1712	12700	2	3855	12
Mo	5151	31800	2	9271	12
As	54586	305000	4	93364	12
Sb	22	103	1	32	12
Bi	1009.8	3800.0	5 0	1378.0	12
Cd	0.5	1.0	0.3	0 3	12
Te	18.1	52.0	0.3	21 7	12
Se	24	100	5	27	12
Ba	1146	2600	10	845	12
Cr	81	120	41	26	12
Rb	151.0	240 0	24.0	84.0	12
W	2965	23000	5	7174	12
Ce	68.7	190.0	26 0	52.0	12
Th	3.7	11.0	0.1	4 0	12
F	418	560	200	100	12
Sr	-	-	-	-	0
Hg	20	20	20	0	2
Ag/Au	30	127	0	38	
Cu/Au	8395	24823	0	10161	
Cu/Ag	325	1080	3	396	
Zn/Au	844	4836	0	1397	
Zn/Pb	7	38	0	12	

Sn Skarns

	Average	Max	Min	Stdev	n
Au-ppb	127	646	5	202	10
Au-ppm	0 127	0 646	0 005	0	10
Ag	85	459	0	142	10
Cu	4092	10200	4	3939	10
Pb	1276	10400	10	3232	10
Zn	19476	165000	369	51501	10
Co	26	81	5	29	10
Ni	20	61	3	19	10
Mo	6	21	2	7	10
As	65	210	1	65	10
Sb	10	23	1	9	10
Bi	439 0	2400 0	32.0	737 0	10
Cd	348.4	2900.0	0.1	905 3	10
Te	9.7	81.0	0 1	25 2	10
Se	3	13	1	4	10
Ba	99	330	110	95	10
Cr	65	150	24	46	10
Rb	99.4	350 0	35 0	133.5	10
W	2007	5500	2	2190	10
Ce	4.1	14.0	5.0	4.1	10
Th	1.2	4.0	0.2	1.5	10
F	31422	59500	160	26823	10
Sr	36	107	5	33	8
Hg	-	-	-	-	0
Ag/Au	1988	8345	8	3090	
Cu/Au	88078	280000	122	111682	
Cu/Ag	65	175	4	57	
Zn/Au	767199	6600000	1767	2057936	
Zn/Pb	38	138	0	41	

n = number of samples assayed.

Analytical methods:
Geochemical laboratory, Ministry of Energy, Mines and Petroleum Resources, Victoria, B.C.
Au by fire assay and AAS finish;
Ag, As, Bi, Cd, Co, Cu, Ni, Mo, Pb, Sb and Zn by flame AAS,
Se and Te by hydride/AAS;
Ce and W by neutron activation at Activation Labs. Ltd., Ancaster, Ontario.

Table 3: COMPARISON BETWEEN SULPHIDE-LEAN AND SULPHIDE-RICH MAGNETITE (Fe SKARN) SAMPLES.

	Sulphide-lean	Sulphide-rich
No. of samples	11	13
Au	0.047	1.206
Ag	1.8	59
Cu	1101	51380
Pb	5	17
Zn	109	1136
Co	122	720
Ni	55	30
Mo	75	2
As	58	11016
Sb	3	3
Bi	5	7
Cd	0.2	38
Te	1.0	0.1
Se	2	2
Ba	172	10
Cr	29	13
W	1	1
Sr	55	248
Hg	70	95
Ag/Au	112	883
Cu/Au	31118	471057
Cu/Ag	624	1043
Zn/Au	11258	16072
Zn/Pb	34	248

Element data are average assay values in ppm.

samples have been used to calculate metal ratios. However, in this study we have used the assay data summarized in Table 2. Metal production statistics of mined-out skarn deposits can undoubtedly be valuable in defining some types of gold-bearing skarns (Orris *et al.*, 1987; Theodore *et al.*, 1991). However, using production statistics has several disadvantages: it limits the database to the larger deposits, historic recovery of certain metals may have been erratic due to changing economic factors and, because only the economic metals are extracted from a deposit during mining, plots are limited to a small number of metallic elements.

Plots based on assays of mineralized skarn samples may have problems due to sampling inhomogeneity, but a larger number of metallic elements can be tested in any metal ratio study. Another major advantage is that the plots can include samples from both large economic deposits and small skarn occurrences.

METAL RATIO PLOTS

A variety of metallic element ratio plots were constructed using the analytical data for gold, silver, copper, zinc, cobalt, arsenic and bismuth, summarized in Table 2. This exercise was undertaken to see whether it is possible to distinguish differences in metal element ratios in six of the seven skarn classes (due to the wide variation in gold content molybdenum skarns were not plotted).

Plots in which many of the skarn classes were successfully characterized are presented in Figure 9A to D. Copper/gold versus zinc/gold appears to be the best plot as it separates the sample points into four clusters (Figure 9A). The most distinctive cluster represents gold skarns which are characterized by the lowest copper/gold and zinc/gold ratios of all the six skarn classes. A second, marked by the highest zinc/gold ratios, is represented by lead-zinc skarns. Intermediate between gold and lead-zinc skarns are two more overlapping clusters represented by copper and iron skarns on the one hand, and tungsten and tin skarns on the other.

Plots of copper/gold versus silver/gold, copper/silver versus copper/gold and gold (in ppm) versus copper/gold are shown in Figure 9B, C and D; the first plot is similar to that used by Ettlinger and Ray (1989) and Ray *et al.* (1990). In all these three metal ratio plots, the majority of the gold skarn samples are readily distinguishable from those of the other skarn classes.

DISCUSSION

Current world mineral economics suggest that skarns containing gold±copper are the most economically attractive skarn targets for exploration. The assay data presented in this paper indicates that economically significant quantities of gold are not only to be found in gold skarns and some copper skarns but also, rarely, in some molybdenum skarns, such as those in the Rossland district. In addition, but to a much lesser degree, gold occurs in some calcic iron skarns although, as it is probably contained in chalcopyrite, economic gold ore is only likely to occur in sulphide-rich parts of the magnetite skarn.

In the field, it is often difficult to decide whether a newly discovered outcrop of skarn represents a gold, copper, iron or other class of skarn, particularly where the rocks are poorly exposed and only weakly mineralized. The opaque minerals in weakly mineralized outcrops may not necessarily be diagnostic because chalcopyrite, pyrite, pyrrhotite, magnetite and, to a lesser extent, sphalerite are among the most widely reported opaque minerals present in all classes of skarn throughout British Columbia.

This study suggests that assay data may help to differentiate gold, copper and iron skarns because the correlation between certain metals, particularly between gold, silver and copper, is markedly different in these three skarn classes. However, these different geochemical patterns indicate that particular care should be taken when sampling and testing skarn for gold. Prospectors and exploration geologists are

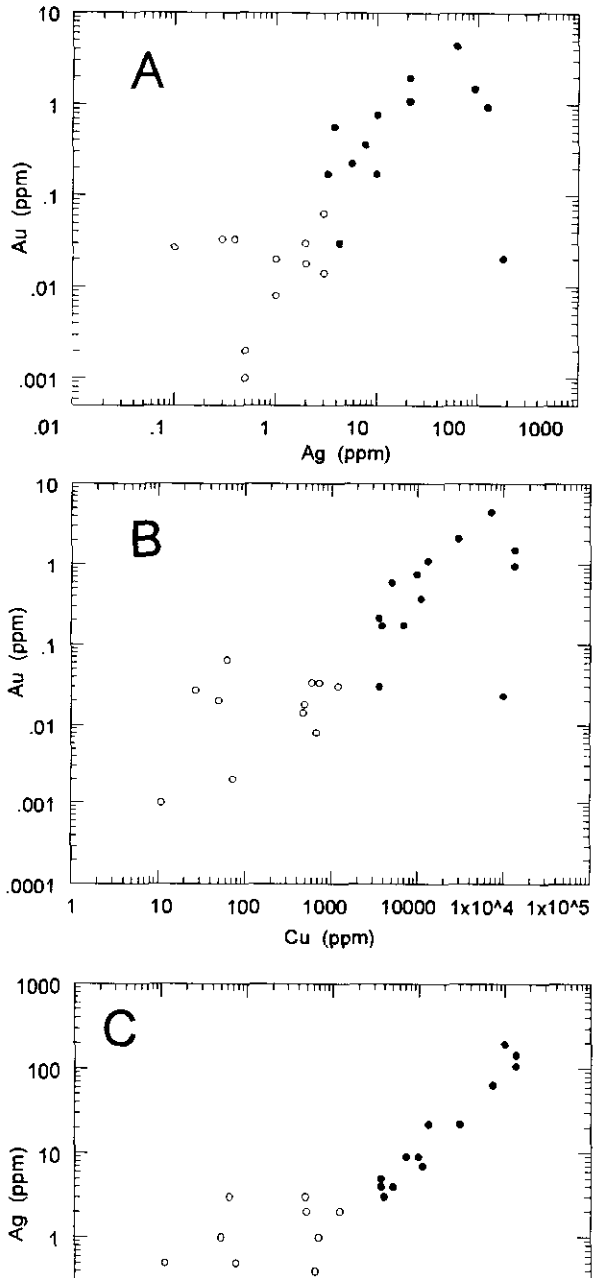


Figure 2. Plots for iron (magnetite) skarn samples (open circles = sulphide-lean; closed circles = sulphide-rich samples). A: Gold *versus* silver. B: Gold *versus* copper. C: Silver *versus* copper.

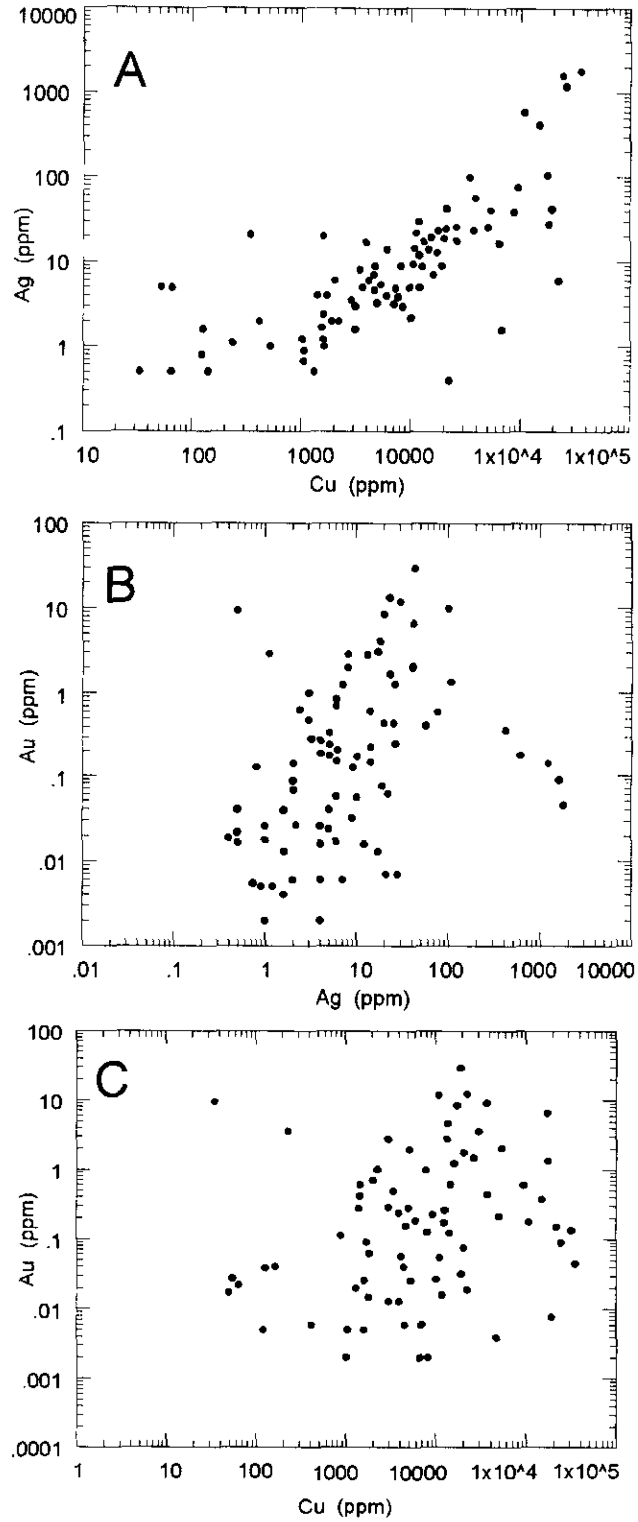


Figure 3. Plots for copper skarns. A: Silver *versus* copper. B: Gold *versus* silver. C: Gold *versus* copper.

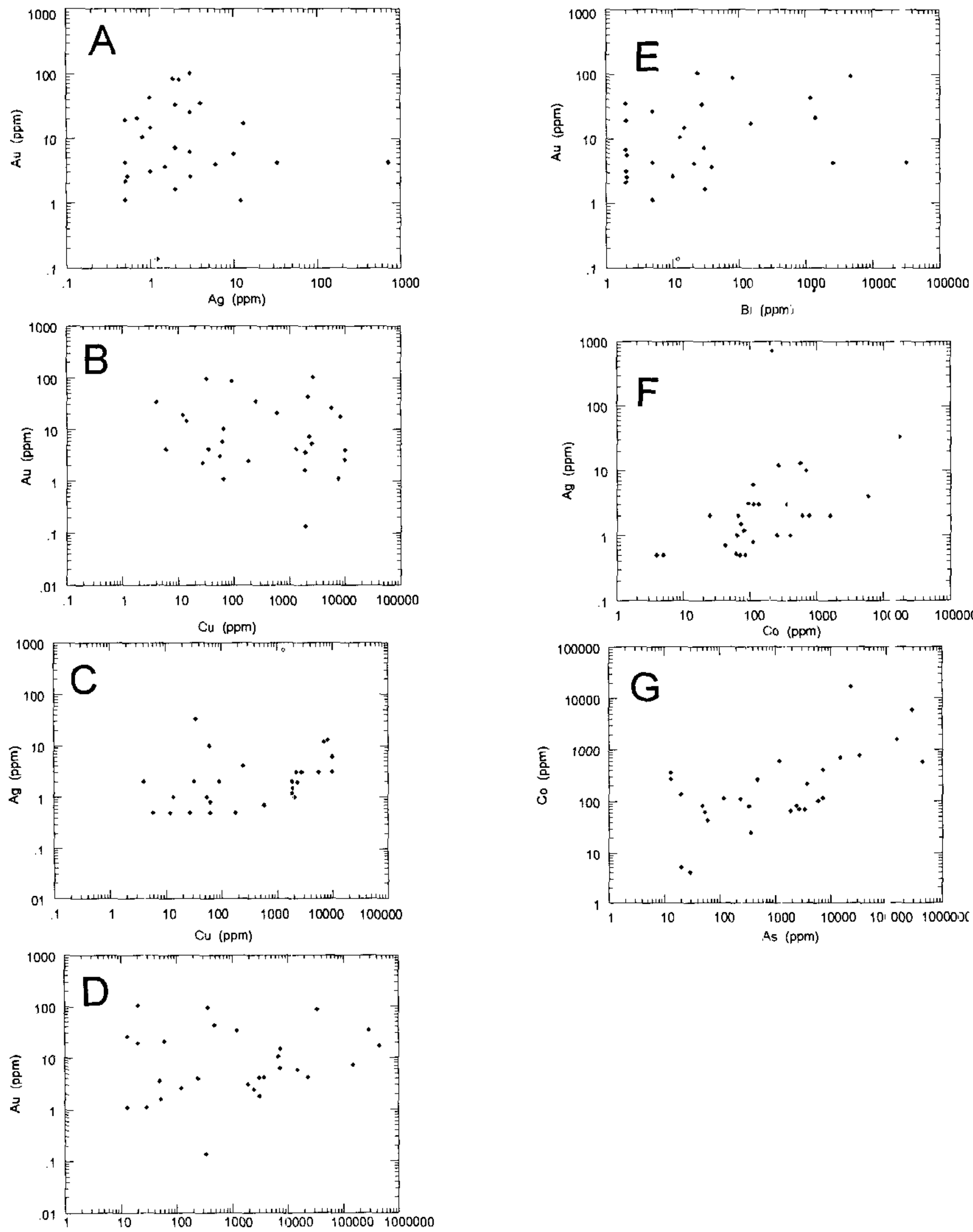


Figure 4. Plots for gold skarns. A: Gold *versus* silver. B: Gold *versus* copper. C: Silver *versus* copper. D: Gold *versus* arsenic. E: Gold *versus* bismuth. F: Silver *versus* cobalt. G: Cobalt *versus* arsenic.

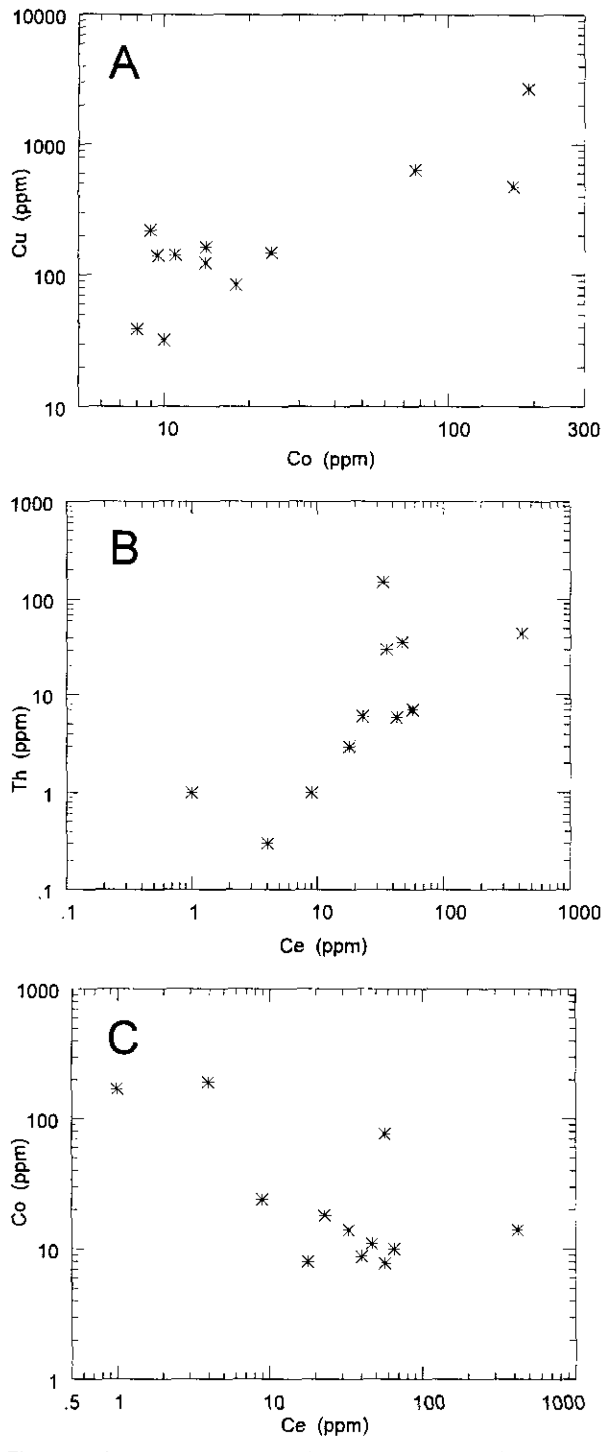


Figure 5. Plots for tungsten skarns (samples are scheelite rich and generally sulphide poor). A: Copper *versus* cobalt. B: Thorium *versus* cesium. C: Cobalt *versus* Cesium.

inclined to sample copper and/or sulphide-rich portions of a skarn prospect in the erroneous belief that these samples are most likely to contain gold. However, the absence of correlation between gold and copper in gold skarns and some copper skarns indicates that the gold potential of a skarn can easily be overlooked if copper-rich outcrops are preferentially sampled.

Although bismuth tellurides are a characteristic feature of many gold skarns (Ettlinger and Ray, 1989; Meinert, 1989; Ray *et al.*, 1990) and some gold-rich copper skarns, this study suggests that assaying for bismuth or tellurium is not reliable for detecting skarns with gold potential. This is probably because the bismuth tellurides are too erratically distributed in the skarn system to be reliably detected by analyzing grab samples.

CONCLUSIONS

- Significant amounts of gold occur not only in gold skarns, but in some copper, molybdenum and iron skarns in British Columbia. Rarely, gold-rich and scheelite-poor mineralization is also found in the some tungsten skarns, but it is uncertain whether this is genetically related to the skarn system.

- The correlation between gold and other metals such as silver, copper, zinc, arsenic, cobalt and bismuth is highly variable in the different skarn classes. For example, gold exhibits a good positive correlation with copper and silver in iron skarns but shows no association with these metals in gold skarns. These different patterns can be used to distinguish between mineralized outcrops of iron, copper and gold skarns.

- The lack of any clear association between gold and copper in gold skarns and some copper skarns indicates that the gold potential of a skarn will be overlooked if only skarn outcrops rich in copper sulphides are sampled. To successfully test a skarn for gold, all the different mineral assemblages should be sampled and assayed, including the sulphide-poor outcrops.

- This study suggests that plots of metal element ratios using analytical data obtained from mineralized grab samples can be used to differentiate some skarn classes, particularly gold, copper-iron and lead-zinc skarns. The most useful plot is copper/gold *versus* zinc/gold because gold skarns are distinguished from other skarn classes by having exceedingly low zinc/gold (<100) and copper/gold (<2000) ratios. Other useful plots include copper/gold *versus* copper/silver, copper/gold *versus* silver/gold, and gold (in ppm) *versus* either copper/gold or silver/gold.

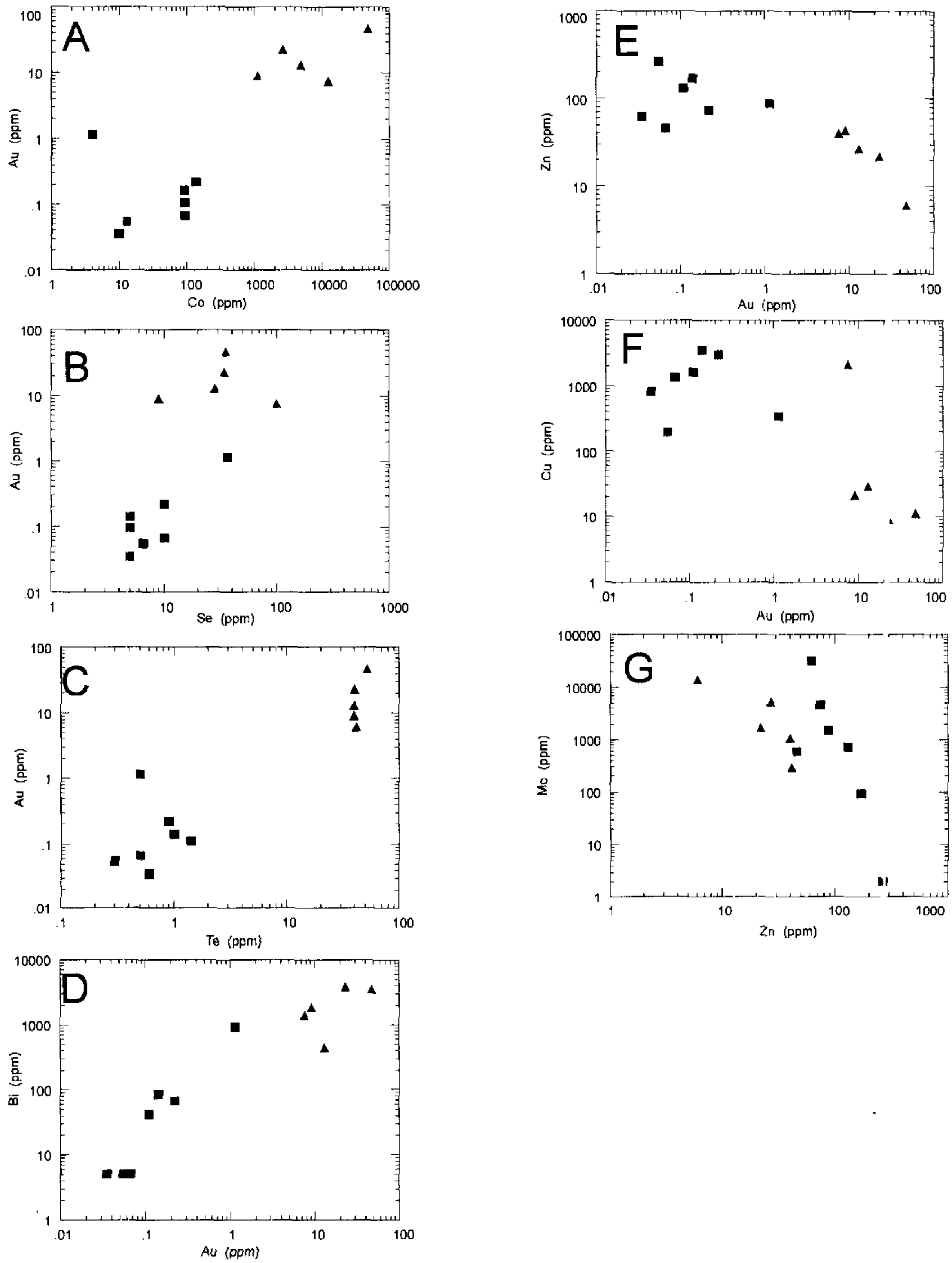


Figure 6. Plots for molybdenum skarns (triangles = gold-bearing Rossland samples; squares = other molybdneum skarn samples). A: Gold *versus* cobalt. B: Gold *versus* selenium. C: Gold *versus* tellurium. D: Bismuth *versus* gold. E: Zinc *versus* gold F: Copper *versus* gold. G: Molybdenum *versus* zinc.

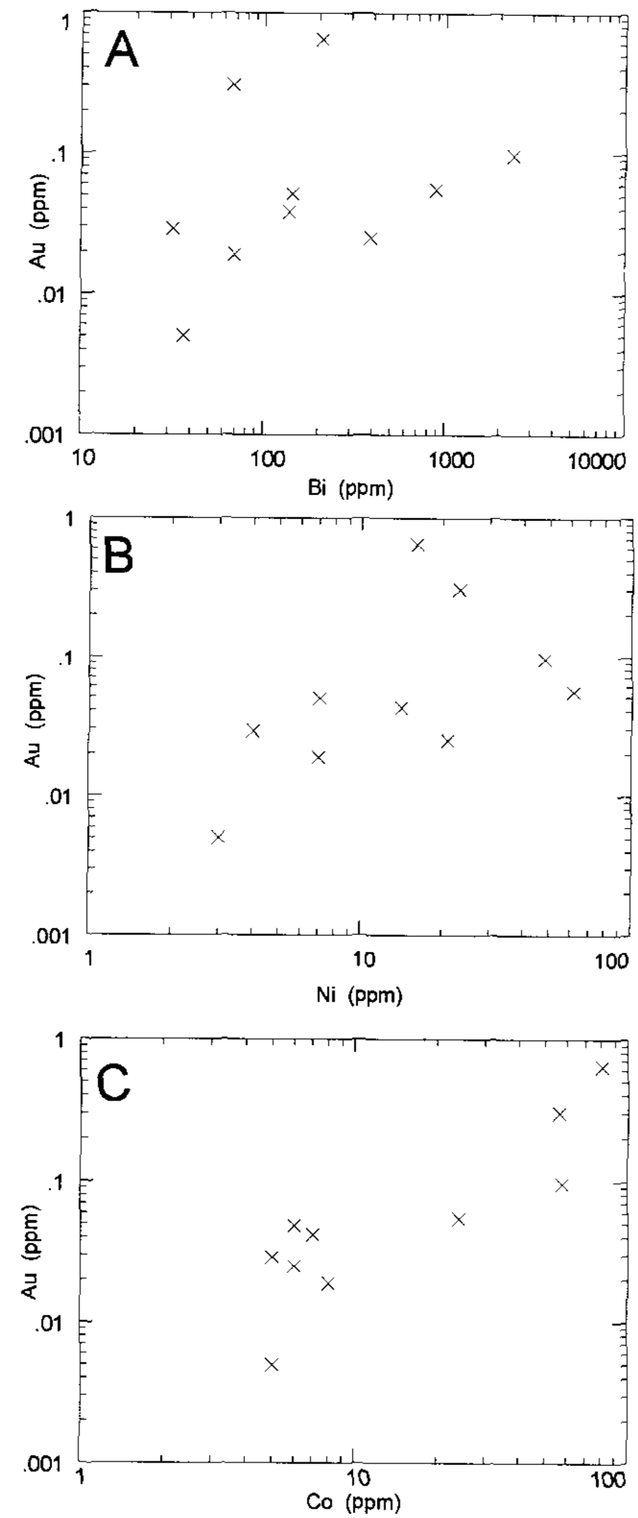


Figure 7. Plots for tin skarns. A: Gold *versus* bismuth. B: Gold *versus* nickel. C: Gold *versus* cobalt.

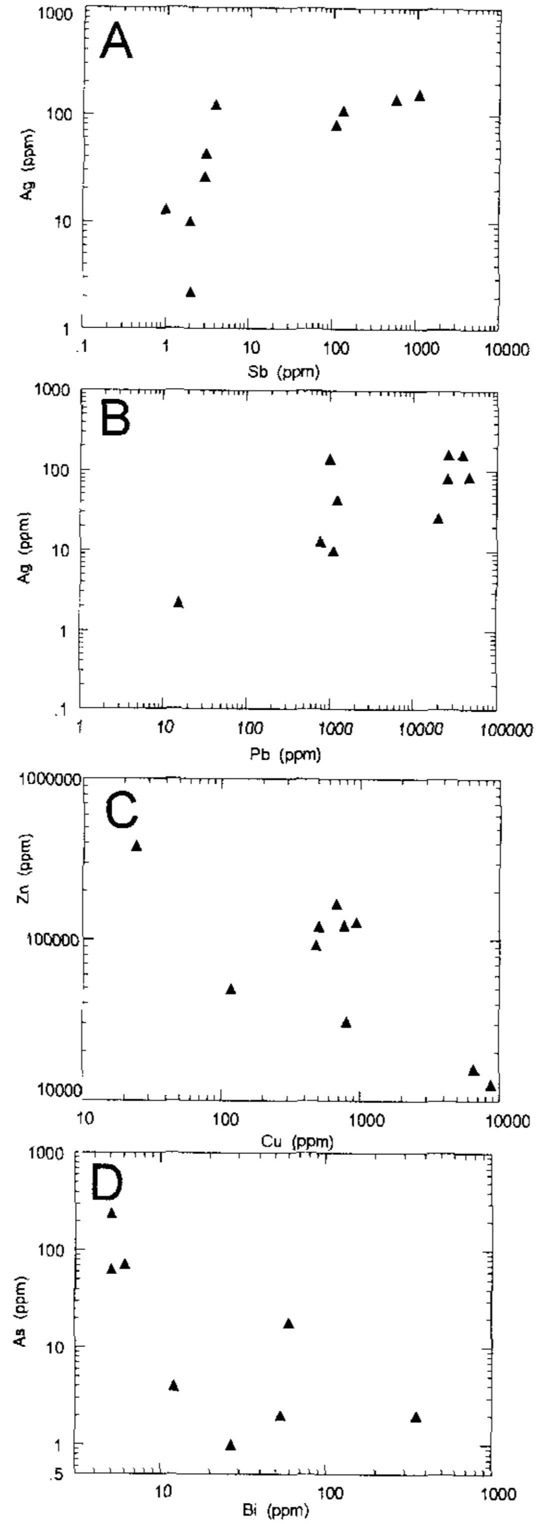


Figure 8. Plots for lead-zinc skarns. A: Silver *versus* antimony. B: Silver *versus* lead. C: Zinc *versus* copper. D: Arsenic *versus* bismuth.

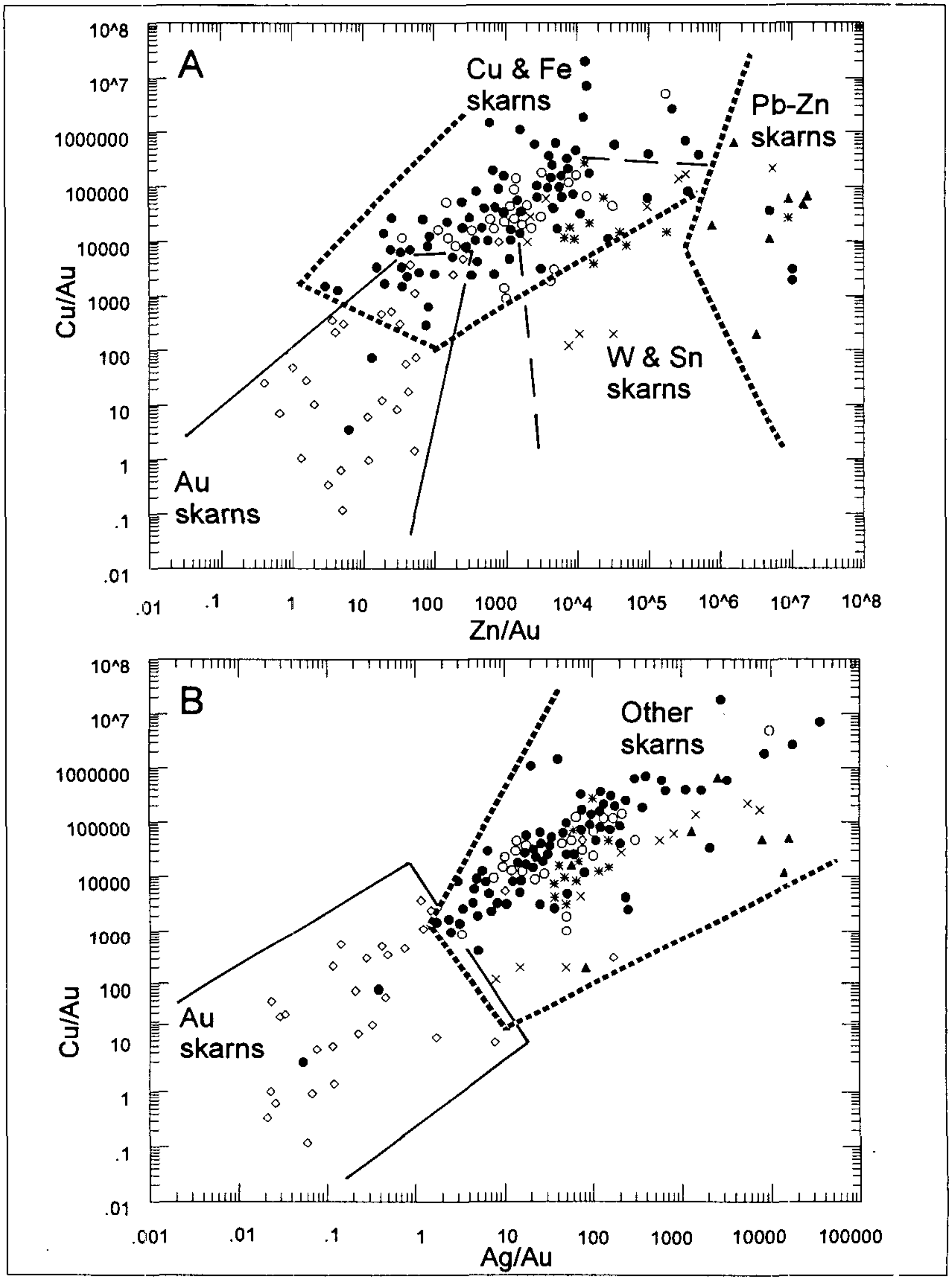
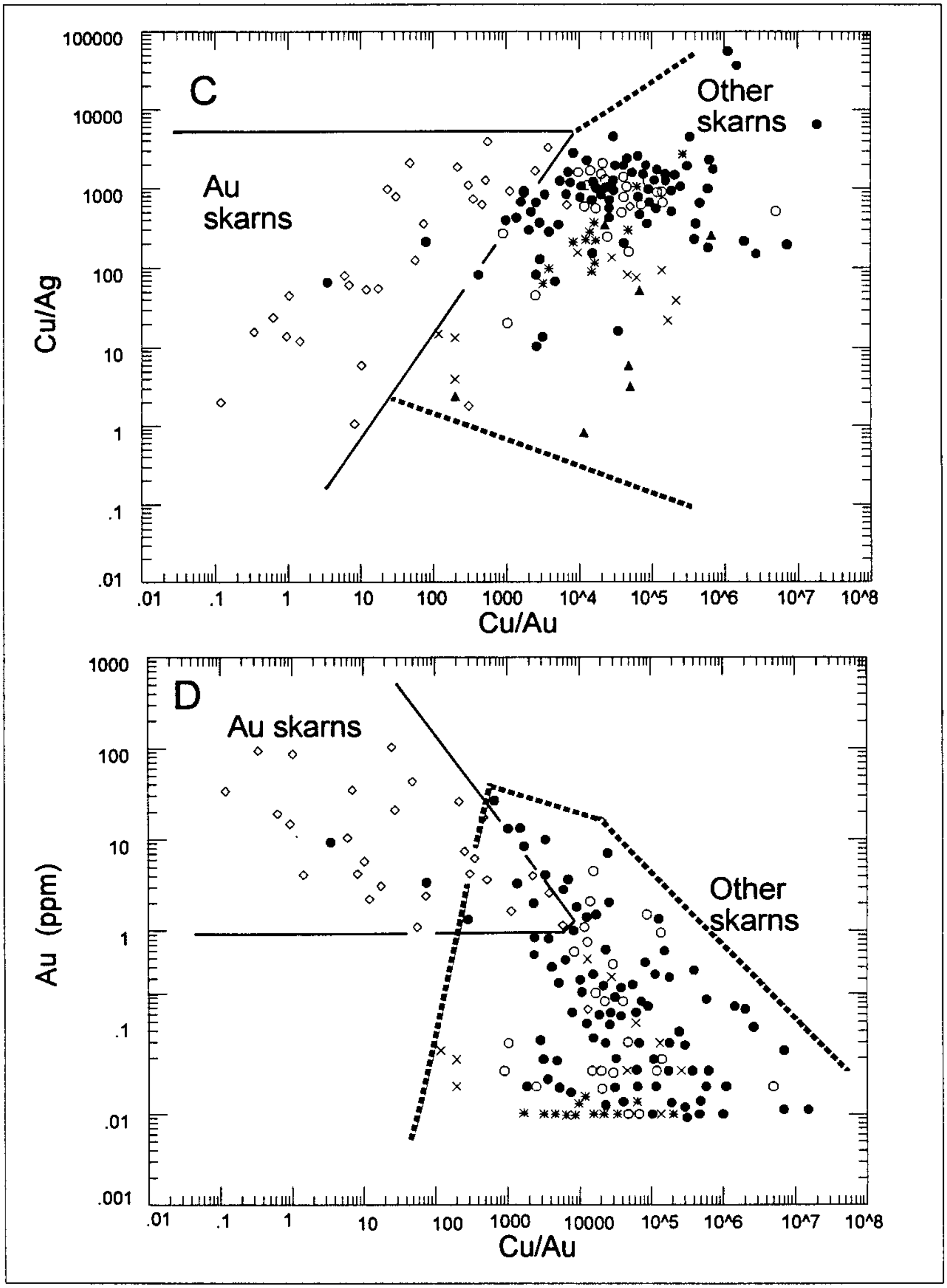


Figure 9. Plots of metal ratios for gold, iron, copper, tungsten, tin and lead-zinc skarns samples (open diamond=Au; closed circle=Cu; open circle=Fe; asteriks=W; X=Sn; triangle=Pb-Zn). A: Copper/gold versus zinc/gold. B: Copper/gold versus silver/gold. C: copper/silver versus copper/gold. D: Gold (in ppm) versus copper/gold. Note: skarn class fields have been empirically drawn around the main clustering of points.


C
Au
skarns
Other
skarns
Cu/Ag
100000
10000
1000
100
10
1
.1
.01
.01
.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
Cu/Au
D
Au skarns
Other
skarns
Au (ppm)
1000
100
10
1
.1
.01
.001
.01
.1
1
10
100
1000
10000
10^5
10^6
10^7
10^8
Cu/Au

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NOTES

ANDALUSITE IN BRITISH COLUMBIA - NEW EXPLORATION TARGETS

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KEYWORDS: andalusite, industrial minerals, low-P, high-T metamorphism, refractories, Coast Belt, Omineca Belt, Bridge River, Leech River, Lillooet.

INTRODUCTION

This paper describes new and previously reported andalusite occurrences in British Columbia. It also provides background information on currently producing andalusite mines and the andalusite market. The Leech River, Duffey Lake and Bridge River areas were the subject of reconnaissance work in 1994 and are dealt with in more detail than other regions.

Andalusite, kyanite and sillimanite are aluminosilicate polymorphs of metamorphic origin with the chemical formula: Al_2SiO_5. When calcined, these polymorphs convert to mullite, a highly refractory material. The conversion is accompanied by a volume expansion of 5, 18 and 7% for andalusite, kyanite and sillimanite, respectively (Skillen, 1993). Worldwide, andalusite is the preferred raw material because it converts to mullite at lower temperatures (1380°C) than sillimanite (1550°C). The main advantage of andalusite over kyanite is that the volume change during mullitization is negligible, therefore no calcination is required before manufacturing refractory shapes. Approximately 4.22×10^9 joules (4×10^6 BTU) are needed to mullitize one tonne of kyanite (Skillen, 1993). In North America, kyanite is the most widely used polymorph, because of its local abundance, close to markets, and availability of relatively inexpensive energy.

South Africa is by far the largest andalusite producer. Other producing countries are France, U.S.A. and China (Dickson, 1994). Most commercial andalusite concentrates from South Africa and France vary in composition from 53 to 60% Al_2O_3 and 0.8 to 1.5% Fe_2O_3. An andalusite-pyrophyllite-sericite mixture is mined in the U.S.A for a captive market. In some cases, andalusite-pyrophyllite material has applications in ceramics. It has a substantially lower Al_2O_3 content than andalusite concentrates (<35%). Chinese concentrates commonly have higher Fe_2O_3 contents (1 to 2%) than most other commercial products. Iron is a detrimental impurity in most refractory applications. Andalusite competes with other aluminosilicate polymorphs, including high-performance synthetic mullite and high-alumina calcined products, for market share. Worldwide andalusite consumption for 1990 was estimated at 270 000 to 340 000 tonnes (Skillen, 1993). In 1993, andalusite prices varied from \$US170 to \$200/tonne f.o.b. South Africa or about DM350 per tonne in European ports. Andalusite is used primarily in refractories for steel making and the current upswing in world steel output augurs well for the industry in 1995. Andalusite-based refractories are also used in cement kilns, incinerators, copper-roasting furnaces foundry sands and abrasion resistant materials.

ANDALUSITE GENESIS AND DEPOSITS

Andalusite deposits are typically formed by low-pressure, contact or regional thermal metamorphism of high-alumina, low-calcium pelitic rocks. There is a gradation between textbook contact metamorphism characterized by distinct aureoles surrounding a single pluton and regional, low-pressure metamorphism. The association of low-pressure metamorphic rocks with magmatic arcs is well described by Miyashiro (1961). Since that time, several theories have been proposed to explain regional low-pressure metamorphic belts. These include crustal extention (Grambling *et al.*, 1989), rapid uplift (Thompson and England, 1984), increased heat flux at the base of the crust (Oxburgh and Turcotte, 1971), thermal effects of pervasive and chanelized fluid flow in the deep crust (Hoisch, 1991), multiple intrusions into low-pressure metamorphic terranes (Rothstein and Hoisch, 1994; Barton and Hanson, 1989) and moderate overthickening of thinned sialic crust (Thompson, 1989). The origin of the low-pressure belts in British Columbia is beyond the scope of this paper.

On the deposit scale, the thickness, chemical composition of the protolith and temperature of the low-pressure, prograde metamorphism are the main factors influencing the formation of andalusite. Typical grades of primary or 'hard rock' andalusite ores vary from 7 to 20%. Typical production capacities of individual mines vary from 25 000 to 65 000 tonnes per year. Andalusite crystals from deposits of economic interest are relatively inclusion free. In general, the coarser the crystals, the easier it is to upgrade the ore. The diameter of andalusite crystals from currently mined deposits varies from 1 millimetre to several centimetres. Primary andalusite ores are commonly crushed, and upgraded using heavy liquids; flotation may be required for the treatment of fine-grained ores. Retrograde metamorphism of andalusite deposits may result in partial or total conversion of andalusite to lower temperature phases, such as muscovite. Placer deposits account for a substantial proportion of the andalusite produced in South Africa. Garnet and staurolite commonly coexist with andalusite and where grades and textures permit, they are recovered as byproducts.

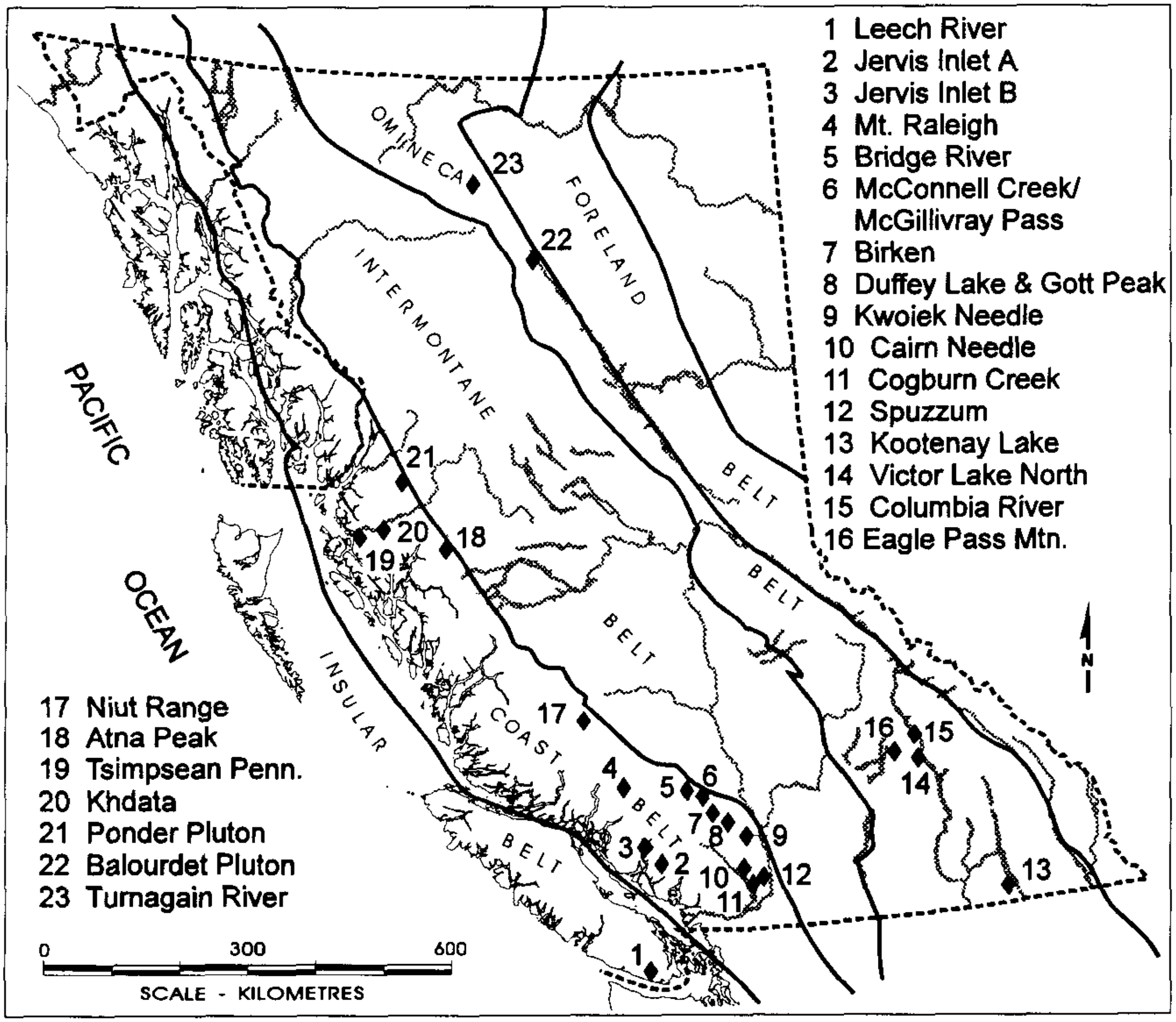

Figure 1. Andalusite occurrences in British Columbia.

ANDALUSITE IN BRITISH COLUMBIA

Information on most of the high-alumina metasilicate occurrences in British Columbia, including andalusite, was compiled by Pell (1988). Other information is available in the MINFILE database and a range of scientific literature including university theses. In most cases, literature research does not provide descriptive data sufficient to appraise the economic potential of individual showings, but it is useful for delineation of exploration areas.

The Canadian Cordillera is divided into five major tectonostratigraphic belts. The majority of andalusite occurrences are located in the Coast Plutonic Complex with a few in the Omineca and Insular belts (Figure 1). Andalusite and andalusite-pyrophyllite occurrences with sub-millimetre grain sizes, believed to be of hydrothermal origin, are not covered by this study. Examples of these include the Equity Silver mine (Wojdak, 1974; Church and Barakso, 1990) and the Taseko property (Lambert, 1991).

OMINECA BELT

The Omineca Belt (Figure 1) consists mainly of metamorphic rocks and intrusions (Gabrielse *et al.*, 1991). During the mid-Jurassic, metamorphic rocks recorded deep structural depression followed by tectonic uplift until late Cenozoic time. Another important uplift with high geothermal gradients and associated with widespread plutonism, occurred in the Eocene. Omineca Belt andalusite occurrences are related to low-pressure, high-temperature metamorphism. In many places this forms an overprint that postdates higher pressure metamorphism. Several andalusite showings (Figure 1) are reported in the southern Omineca Belt on the west side of Kootenay Lake, near Victor Lake, Eagle Pass Mountain and north of Revelstoke along the Columbia

River (Pell, 1988). In 1994, the principal authors attempted, without success, to locate the Eagle Pass Mountain showing in the area outlined by Pell (1988). Andalusite-bearing metapelites are also known in the northern Omineca Belt, within basement gneiss, 300 metres from the contact of the undeformed, Eocene Balourdet pluton in the Sifton Range and in metapelites 30 kilometres to the north (Evenchick, 1988; Greenwood *et al.*, 1991). Another andalusite occurrence is reported near the confluence of the Turnagain and Cassiar rivers (H. Gabrielse, personal communication, 1994); andalusite porphyroblasts, 3 to 4 centimetres long, partially retrograded to muscovite, are present in metasediments along the contact of an Early Cretaceous pluton.

COAST BELT

The Coast Belt is composed mainly of granitic and greenschist to granulite facies metamorphic rocks. The western part of the belt is characterized by mid-Cretaceous or older plutons and the eastern intrusions are typically Late Cretaceous or younger (Gabrielse *et. al.*, 1991). A large number of andalusite occurrences are located on the eastern edge of the Coast Belt along a northwest trend where low-pressure, high-temperature metamorphic conditions prevailed during deformation and magmatism in Middle to Late Cretaceous time. These include the Mount Raleigh, Niut Range, Bridge River, Cogburn Creek, McConnell Creek, Birken, Duffey Lake, Gott Peak, Ratchford Creek, Kwoiek Needle, Cairn Needle and Spuzzum pluton occurrences (Figure 1). The belt extends southwards into the north Cascades of Washington State (Greenwood *et al.*, 1991). During the Middle to Late Cretaceous, low-pressure metamorphism accompanied east-vergent thrusting and folding along the eastern margin of the Coast Plutonic Complex (Rusmore and Woodsworth, 1994). The peak metamorphic conditions that prevailed during deformation, believed to be responsible for andalusite formation, are estimated at less than 350 megapascals (3.5 kbars) and about 500° to 650°C. The highest metamorphic pressure within the belt was recorded in the Spuzzum area and the lowest in the Mount Raleigh area, suggesting that relative syn-metamorphic uplift decreased northwestward (Greenwood *et al.*, 1991). In several cases it is not evident if andalusite is a result of contact or regional metamorphism.

OCCCURRENCES IN THE BRIDGE RIVER AND LILLOOET AREAS

Among the 23 andalusite occurrences located on Figure 1, those in the Bridge River and Lillooet areas were covered by our 1994 reconnaissance study and are discussed in more detail below.

BRIDGE RIVER AREA

The Bridge River area is a well known gold mining camp, located approximately 180 kilometres north of Vancouver (Figures 1 and 2). The history and geology of the camp are summarized by Cairnes (1937), Stevenson (1958) and more recently by Church (in preparation) who recognized numerous mappable units comprised of bedded volcanic and sedimentary assemblages and a variety of intrusive rocks. Andalusite occurrences in the Bridge River area are hosted by black argillite, formally referred to as the Noel Formation (Cairnes, 1937; Stevenson, 1958; Church, in preparation). Rusmore (1985) and Roddick and Hutchison (1973) include the Noel lithofacies as part of the Hurley Formation, and Journeay and Mahoney (1994) suggest that the Noel is the equivalent of units 2 and/or 3 of the newly proposed Cayoosh assemblage. Regardless of the stratigraphic nomenclature used, the metamorphic equivalents of aluminous black shales represent the most favorable protolith for andalusite exploration. The Noel lithofacies is described as a sequence of mostly thinly bedded, fine-grained turbidites. Near the confluence of Cadwalder Creek and Noel Creek, it is more than 350 metres thick and consists of siltstones and black argillites accompanied by a few lenses of dark grey limestone. It is best developed in two belts near the Hurley River, described by Church (in preparation). Metamorphism of these argillites has resulted in the development of biotite, garnet, andalusite, cordierite and staurolite. The groundmass consists mainly of quartz and biotite with some pyrite. The andalusite-bearing rocks are hard, dark grey, rusty brown weathering hornfels containing up to 12% andalusite. Andalusite is grey, idiomorphic, relatively inclusion free and fine grained (1 to 7 mm in cross-section and 1 to 40 mm long). Macroscopically, andalusite porphyroblasts from Bridge River are

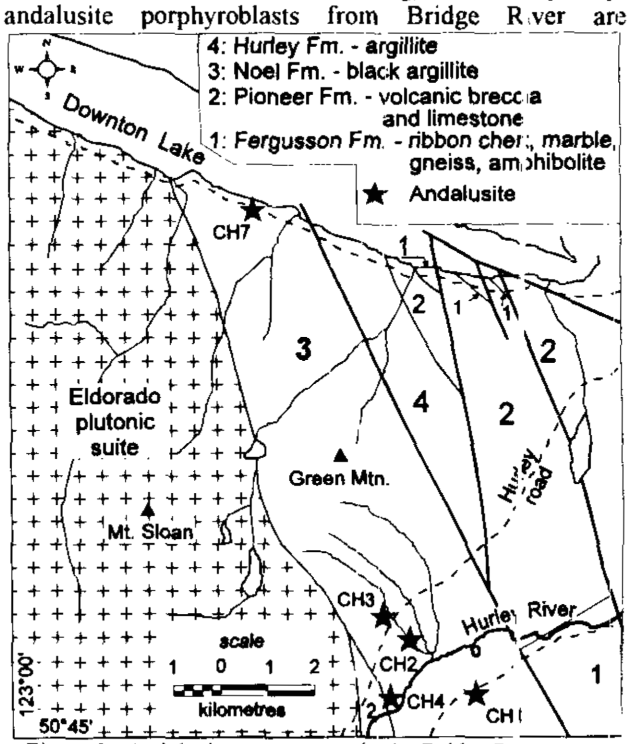

Figure 2. Andalusite occurrences in the Bridge River area.

relatively unaffected by retrograde metamorphism in comparison to those of the Leech River or Duffey Lake areas. Further microscope study will be required to quantify the degree of alteration. The individual occurrences are described below.

OCCURRENCE DESCRIPITONS

CH-1: Andalusite-bearing layers of decimetre-scale thickness are interbedded with barren layers of hornfels striking 143/58 near the old Hurley road, approximately 6 kilometres west-southwest of Bralorne. The andalusite is unevenly distributed and the maximum grade is about 7% by volume. Pseudomorphs after andalusite prisms are 1 to 7 millimetres across, several centimetres long and characterized by typical chiastolite crosses. The andalusite is almost entirely replaced by mica. Although this occurrence is not of economic interest, it demonstrates that coarse andalusite can occur in the Bridge River area if shielded from the effects of retrograde metamorphism.

CH-2: Hornfels outcrops along an old logging road, near a seasonal creek, approximately 7 kilometres west-southwest of Bralorne. The outcrop measures a few metres square and the andalusite-bearing rock is similar to that at showing CH-4, described below, which is better exposed.

CH-3: This occurrence is located on the main road connecting Pemberton and Gold Bridge, approximately 12 kilometres from Gold Bridge. The outcrop is about 45 metres long and few metres high. The hornfels is grey on fresh surfaces and breaks along heavily iron-stained fractures. Andalusite porphyroblasts are 2 to 3 millimetres across and up to 10 millimetres long. They are not uniformly distributed and soft millimetre-scale oval shaped grains, possibly altered cordierite, are also present.

CH-4: This occurrence is located approximately 8 kilometres west-southwest of Bralorne on an overgrown forestry road, about 200 metres from the Hurley River. The outcrop is approximately 30 metres long and 14 metres high (Photo 1). The hornfels is steel grey on fresh surfaces and rusty brown on weathered surfaces. Locally, weathering produces exfoliated layers several centimetres thick. Dominant compositional layering at this location is oriented 155/82 and several centimetre-scale quartz veins are oriented 147/85. Prismatic andalusite crystals are typically 5 to 20 millimetres long and 0.5 to 3.0 millimetres in cross-section. Andalusite content varies from 5 to 12% of the rock. The hornfels contains up to 1% pyrite. Several felsic dikes, several metres thick, strike approximately 120/75.

CH-6: This occurrence consists of a rounded block, 25 by 25 by 12 centimetres, containing more than 15% andalusite prisms, 2 to 3 millimetres across and 2 centimetres long. Some andalusite is partially replaced by mica. The showing is located near the main road connecting Bridge River and Pemberton.

CH-7: Andalusite crystals 1 to 3 millimetres across and 10 to 15 millimetres long (Photo 2) were observed in an outcrop along the road which follows the southern shore of Downton Lake. Here, andalusite is only erratically present and forms less than 5% of dark grey, heavily iron-stained phyllite. Texturally, this andalusite hornfels is similar to other occurrences in the area. Several felsic dikes cut this outcrop. A block containing pinkish andalusite up to 1 centimetre in cross-section was found along the road, possibly brought in during road construction.

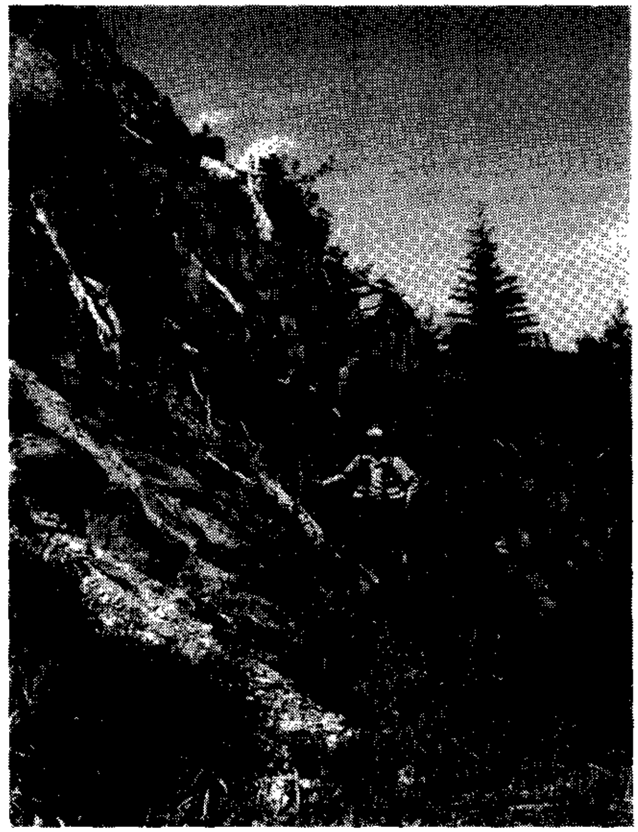

Photo 1. Well exposed andalusite occurrence CH-4, Bridge River area.

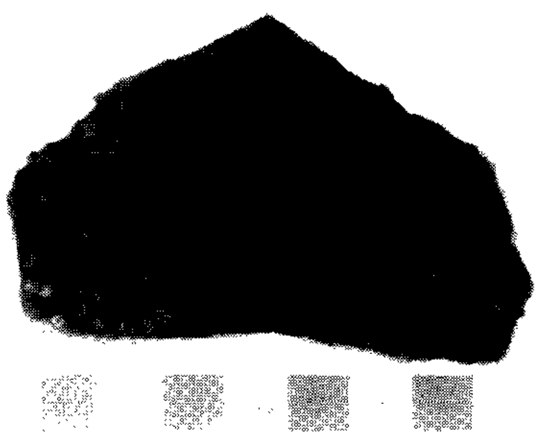

Photo 2. Andalusite porphyroblasts, CH-7 occurrence.

LILLOOET AREA

The Lillooet area is located southeast of the Bridge River camp (Figure 1). Journeay and Mahoney (1994)

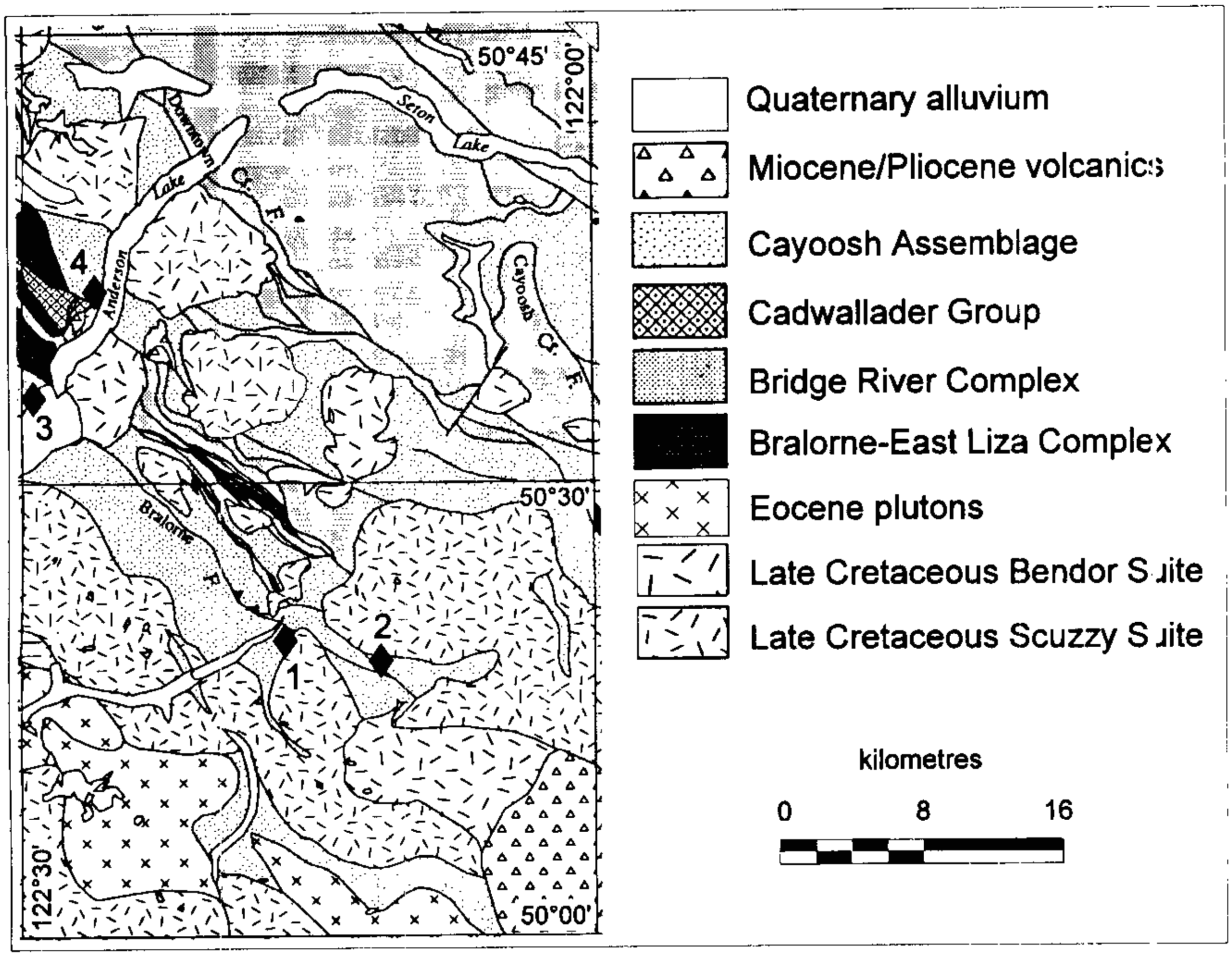

Figure 3. Andalusite occurrences in the Lillooet region (modified from Journeay and Mahoney (1994). 1 - Duffey Lake; 2 - Gott Peak; 3 - Birken (Gates), 4 - McConnell and Six Mile creeks.

describe the geology of the area in terms of the Coast Plutonic Complex, Cadwallader Terrane, Cayoosh assemblage, Harrison Terrane, Bridge River Terrane and Shulaps Complex. All the andalusite occurrences (Figure 3) are hosted by hornfels produced by a metamorphic overprint of black argillites and siltstones of the Cayoosh assemblage. The assemblage is divided into five units, all containing graphitic siltstone and phyllite beds (Journeay and Mahoney, 1994), and it is impossible to determine if all andalusite occurrences are located within units 2 and 3, without more detailed work. In any event, these phyllites are macroscopically and texturally similar to the Noel lithofacies of the Bridge River area and probably have a similar chemical composition. Coarse-grained andalusite porphyroblasts from occurrences in this area, are almost entirely retrograded to mica.

DUFFEY LAKE

The main andalusite occurrence is located in a road cut, on the west side of Highway 99 near the northern tip of Duffey Lake 0.5 to 1.5 kilometres from the nearest outcrop of granitoids of the Coast Plutonic Complex (Figure 3). The andalusite-bearing horizon is only a few metres thick, steeply dipping and is exposed over a strike length of about 60 metres. The unit is dark grey on fresh surfaces and rusty brown when weathered. A well developed tectonic fabric has aligned most grains into the plane of deformation. The groundmass is made up of biotite, quartz and possibly feldspar. Pyrite is the main opaque mineral (<1%) present in the groundmass. Garnets, 1 millimetre in diameter or smaller, were also observed. Andalusite porphyroblasts vary from 10 to 50 millimetres long and 1 to 4 millimetres across. Although chiastolite crosses are well preserved on the cross-sections of porphyroblasts, most andalusite is entirely retrograded to muscovite. Pseudomorphs after andalusite represent 2 to 15% of the rock by volume. Their concentration is strongly controlled by decimetre-scale bedding. Due to a strong retrograde overprint, the showing is not of economic interest. Nevertheless, it shows that andalusite deposits approaching economic grade and size may exist within the Cayoosh assemblage, where unaffected retrograde metamorphism.

GOTT PEAK

Andalusite occurs on the ridge north of Gott Peak in a raft of metasedimentary rocks (J.M. Journeay, personal communication, 1994) within a granitic intrusion (Figure 3). Several fresh-looking, angular boulders measuring up to 1 by 0.5 by 1 metre were found south of that area. These blocks split preferentially along a well developed fabric and contain pseudomorphs of mica after andalusite and staurolite. The pseudomorphs, measuring 3 to 8 millimetres across and several centimetres long, comprise 20% of the hostrock. These blocks may have come from the nearby Gott Peak occurrence or elsewhere.

BIRKEN (GATES)

A showing similar to Gott Peak has been documented on the eastern margin of the Mount Rohr pluton but andalusite porphyroblasts are less abundant (M. Journeay, personal communication, 1994, Figure 3). Several angular blocks containing andalusite and staurolite in a groundmass of quartz, biotite, minor iron oxide (<1%) and occasional millimetre-scale garnet were found near the contact of intercalated sedimentary and volcanic rocks with a granite intrusion near Birken. The largest block measures 20 by 5 by 25 centimetres. In some blocks, andalusite is largely retrograded to muscovite.

McCONNELL CREEK AND SIX MILE CREEK

Andalusite is reported in the McConnell Creek-Mount McGillivray area (J.M. Journeay, personal communication, 1994, Figure 3). The showing was not visited during the 1994 field season, however, rounded, dark grey hornfels boulders containing up to 15% high-alumina silicates were found in the bed of nearby Six Mile Creek. They contain 3 to 10% andalusite displaying chiastolite crosses on square cross-sections. The unusual grey colour and freshness of the porphyroblasts suggests that they may be kyanite pseudomorphs after andalusite as described by Hollister (1969a, b) and Pigage (1976). The crystals are up to 6 millimetres in cross-section and are enclosed in a quartz-biotite-feldspar groundmass. Final assessment will have to be done by x-ray diffraction or detailed microscope work. This occurrence is not of economic interest, but it is an indication of low-pressure metamorphic conditions at some time. It also illustrates the dangers of misidentifying high-alumina silicates during early stages of exploration.

An andalusite-muscovite zone is also near Ratchford Creek by Journeay (personal communication, 1994).

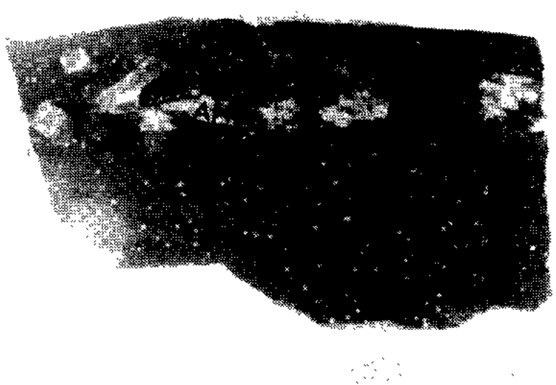

Photo 3. Relatively unaltered andalusite porphyroblasts; Mount Raleigh occurrence. **AND** - andalusite.

OTHER OCCURRENCES IN THE COAST BELT

KWOIEK NEEDLE - SPUZZUM PLUTON AREA

The Spuzzum pluton occurrences were reported by Reamsbottom (1974). In the Kwoiek area, andalusite pseudomorphs replaced by sillimanite were documented by Hollister (1969a,b). He explained their existence by metastable crystallization of andalusite in the kyanite stability field. However Pigage (1976) favoured early contact metamorphism overprinted by higher pressure metamorphism.

MOUNT RALEIGH

Andalusite at Mount Raleigh occurs in a metamorphosed roof pendant of volcanic and sedimentary rocks. Metamorphic grade increases from northeast to southwest and is Late Cretaceous in age. Andalusite is confined to beds of graphitic, pelitic schist. The main andalusite-bearing unit, the Late Jurassic(?) or Early Cretaceous(?) Styx Formation, is about 400 metres thick (Woodsworth, 1979).

Andalusite porphyroblasts are up to 2 centimetres in diameter and 15 centimetres long and form up to 10% of the rock (Photo 3). They are spread over at least 10 square kilometres in Styx Formation rocks. Quartz and graphite inclusions occur in some of the andalusite porphyroblasts.

At some outcrops, the andalusite porphyroblasts are partially to entirely retrograded to fine-grained muscovite and quartz. With increasing metamorphic grade, the andalusite is more intergrown with, and replaced by, fibrolite and coarse-grained sillimanite. These factors, together with difficult access and rugged terrain, make this area less appealing for exploration than the potential grade and tonnage may suggest.

NIUT RANGE

Andalusite-bearing rocks along the east side of the Coast Range are described by Rusmore and Woodsworth (1993, 1994). As at Mount Raleigh, metamorphic grade increases across the area from northeast to southwest through a series of southwest-dipping isograds. Metamorphism is also Late Cretaceous. Andalusite, with associated garnet, staurolite and sillimanite, is confined to pelitic rocks of the Cloud Drifter formation (informal) of Early Cretaceous age.

Andalusite forms small, inclusion-filled 'spots' and porphyroblasts less than 10 millimetres across; chiastolite texture is common. Andalusite content ranges from roughly 5 to 10%. Retrogression to muscovite has affected the andalusite in some areas, particularly in the northern part of the area.

JERVIS INLET

Andalusite and biotite-bearing metasedimentary rocks of Albian(?) age are also reported near the head of Jervis Inlet and at Phantom Lake, to the east (Woodsworth, unpublished data; Greenwood *et al.*, 1991).

PRINCE RUPERT AND TERRACE AREA

The last important period of plutonism in the Coast Belt was in Eocene time (Woodsworth *et al.*, 1991). Andalusite-bearing veins of Eocene(?) age are reported to crosscut sillimanite-cordierite gneisses within the Khdata Lake Metamorphic Complex (Hollister, 1982). Although important petrologically, these veins are not of economic interest.

Andalusite is also found within the contact aureole of the Ponder pluton north of Terrace, which is of Eocene age (Hutchison, 1982; Woodsworth *et al.*, 1983; Greenwood *et al.*, 1991). The aureole extends 3 to 5 kilometres east of the pluton and is characterized by hornfels with "spots" of andalusite and cordierite (Hutchison, 1982). Prismatic andalusite, up to 1 centimetre across, is very abundant on Mount Kenney within several hundred metres of the contact of the pluton. In Maroon Creek, at the head of Kitsumkalum Lake, boulders containing coarse (2 cm diameter) chiastolite prisms are common. The source for these is not yet known but they probably come from the contact aureole of a large pluton east of the lake.

Andalusite is reported on Tsimpsean Peninsula by Hollister (1982) and Greenwood *et al.* (1991). However this may be a mineralogical oddity as the area is affected by high pressure metamorphism.

Andalusite occurrences at Atna Peak in the Whitesail Lake area, (Evenchick, 1979) are characterized by coarse andalusite crystals. Andalusite, commonly with chiastolite cross-sections, occurs in metagreywacke and argillite over an area of several square kilometres. The occurrences are similar to those in the Mount Raleigh - Spuzzum belt (Greenwood *et al.*, 1991).

INSULAR BELT

The Insular Belt corresponds to the present Pacific margin including Vancouver Island (Figure 1). Andalusite is present in the Leech River Complex on southern Vancouver Island. The complex was affected by low-pressure metamorphism during the Late Eocene (Fairchild and Cowan, 1982).

LEECH RIVER AREA

A large number of andalusite localities are reported in the Leech River Complex on Vancouver Island (Figure 4), approximately 50 kilometres northwest of Victoria (Fairchild and Cowan, 1982). The Leech River Complex is fault bounded and consists of sedimentary and volcanic rocks intruded by a variety of igneous rocks and affected by greenschist to amphibolite facies, low-pressure metamorphism. The Late Eocene metamorphic peak is estimated to be between 150 to 350 megapascals (1.5 to 3.5 kbar) pressure and 500° to 600°C temperature.

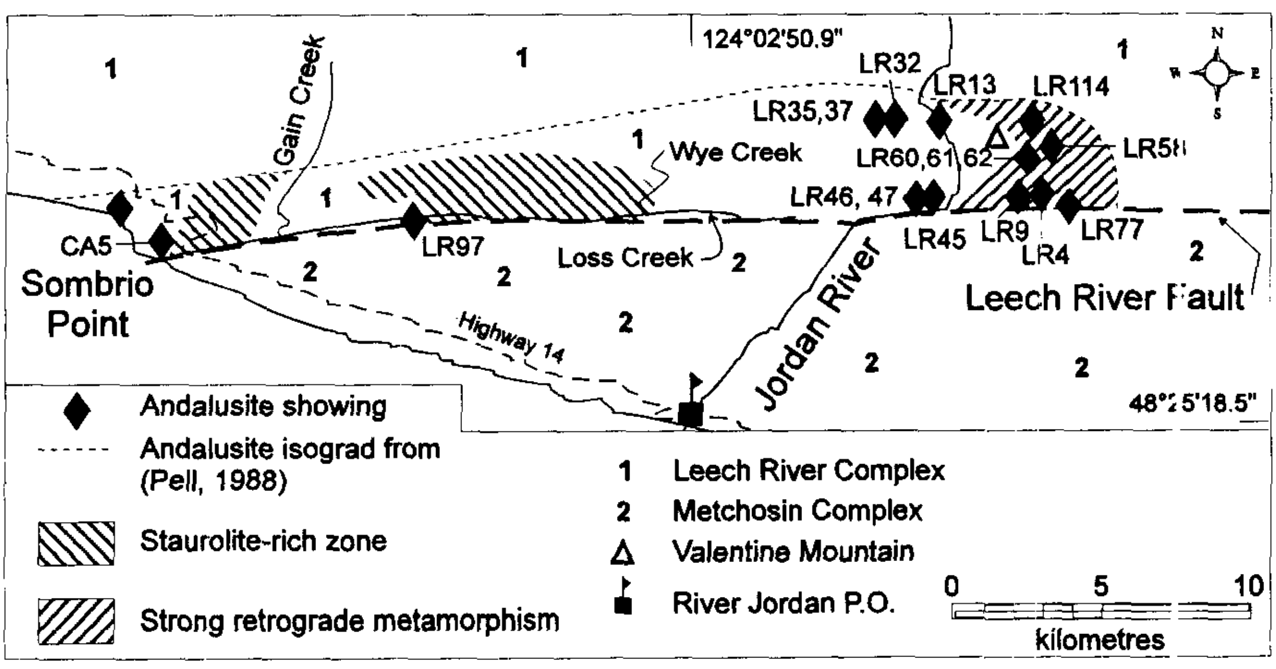

Figure 4. Andalusite occurrences in the Leech River area.

Metamorphism is believed to have continued through two episodes of deformation (Fairchild and Cowan, 1982). Isograds in the eastern and western parts of the complex are well established and truncated by the Leech River fault. The highest metamorphic grades appear to coincide with an area affected by plutonism (Fairchild and Cowan, 1982). The area prospective for andalusite of economic interest (Figure 4) was outlined by Pell (1988) from the work of Rusmore (1982), Fairchild and Cowan (1982) and Grove (1984). In most of the occurrences within the eastern part of the area delineated by Pell, and more particularly the Valentine Mountain area, andalusite is strongly or entirely retrograded to either mica and staurolite or mica and chlorite. The retrograde alteration appears to be strongest close to gold-bearing quartz veins in the nose of a large east-plunging anticline and may be genetically linked to the gold mineralization. It is possible that minerals prevoiusly identified as retrograded andalusite at some sites in the Valentine Mountain area may actually be retrograded staurolite. The degree of retrograde alteration diminishes westward from Valentine Mountain. As a result, andalusite in the showings along Jordan River and to the west is better preserved than east of the river.

This study indicates that in the western two thirds of the area of Figure 4, metapelites contain abundant staurolite porphyroblasts up to 1.5 centimetres long. However, macroscopic andalusite is lacking, considerably reducing the size of the area favourable for andalusite exploration. There are occurrences of macroscopically identifiable andalusite and others where andalusite is partially or entirely replaced by muscovite and chlorite. Variations in the degree of retrograde alteration and in the thickness of andalusite-rich zones indicate that the area delineated by Pell (1988) may contain occurrences of economic interest. An occurrence adjacent to the Leech River fault (LR-97, Figure 4), containing relatively unaltered andalusite crystals, indicates that the fault did not act as a conduit for retrograde metamorphic fluids. Rusmore (1982) identified andalusite near Sombrio Point. However this area has been designated a park and is no longer open for exploration. Individual localities where andalusite was identified are shown on Figure 4.

OCCURRENCE DESCRIPTIONS

LR-4: A zone exposed over a width of 4 metres and a length of 6 metres contains about 10% andalusite porphyroblasts almost entirely replaced by mica and chlorite. The length of the porphyroblasts occasionally exceeds 10 centimetres.

LR-9: Three small outcrops contain strongly retrograded andalusite porphyroblasts up to 2 centimetres in cross-section.

CA-5: A rounded block of hornfels, found in the bed of Loss Creek, contains up to 10% fresh, honey-coloured staurolite porphyroblasts, 0.5 to 2 centimetres long, and 5% pink, strongly retrograded andalusite porphyroblasts.

LR 13: A large zone of andalusite-bearing rocks, about 25 metres thick, outcrops in the bed of the Jordan River. Compositional layering is oriented 289/70. Partially retrograded andalusite porphyroblasts measure up to 4 centimetres across and more than 20 centimetres long (Photo 4). Locally, there are some brown, euhedral staurolite crystals within the andalusite porphyroblasts.

Photo 4. ***LR-13***: Hammer-size andalusite crystal, partially retrograded into mica, exposed in Jordan River, Leech River Complex. **AND** - andalusite.

LR 32: An andalusite-bearing zone, 5 metres thick, outcrops in a cut on the J5 road. Andalusite content varies from 2 to 8%. The zone also contains about 2% staurolite and 0.5% garnet. Some of the andalusite appears fresh and some is 50% retrograded to fine-grained muscovite.

LR-35: This is an outcrop of hornfels about 8 metres thick carrying 5% andalusite porphyroblasts that have cross-sections up to 1 centimetre and are several centimetres long.

LR-37: This is an outcrop of andalusite-staurolite-garnet-bearing rock with compositional layering oriented 286/86. It is 6 metres wide, and contains less than 7% andalusite porphyroblasts up to 10 centimetres long and 2 centimetres across, associated with dismembered, centimetre-scale quartzofeldspathic layers. The occurrence is enclosed in a felsic intrusion. Individual andalusite crystals are up to 10 centimetres long and 2 centimetres in cross-section. This andalusite occurrence is the least retrograded in the Leech River area.

LR-45: A biotite-garnet-andalusite-staurolite schist is exposed over 2 metres. Andalusite forms less than 3% of the rock and is partially retrograded.

LR-46: This is a small exposure of biotite-garnet-andalusite-staurolite schist with less than 3%, strongly retrograded andalusite.

LR-47: This zone is similar to LR-46. The andalusite-bearing layer is less than 30 centimetres thick.

LR-58, 60, 61 and 62: Outcrops of dark-coloured gneiss, interlayered with leucocratic gneiss, contain up to 8% strongly or entirely retrograded andalusite crystals, up to 2% garnet and dark, soft crystals, possibly retrograded staurolite.

STAUROLITE BYPRODUCT POTENTIAL

Currently there is no staurolite production from 'hardrock' deposits, except as a byproduct of other industrial mineral extraction. Metallurgical studies have been carried out on staurolite-bearing schists at a deposit in Ontario. Should that deposit prove to be viable, then the Leech River area staurolite zone should be re-examined in that context. The potential for producing staurolite from placer deposits within or near the Leech River Complex is not addressed by this study.

SUMMARY

The areas of the Omineca, Coast and Insular belts affected by contact metamorphism or low-pressure, high-temperature regional metamorphism have an excellent geological potential to host andalusite deposits where:

- The protolith is of favorable chemical composition and sufficient dimension.
- Andalusite was not converted to sillimanite or kyanite by a later, high-temperature metamorphic overprint.
- The andalusite did not retrograde to low-temperature, hydrated minerals such as muscovite.

The prograde metamorphic conditions favorable for the formation of andalusite were seen in all the areas selected for our current study. In the Bridge River area, several relatively fine grained, andalusite-bearing occurrences were identified. This type of deposit would be more difficult to upgrade than a coarse variety. Showings such CH-4 demonstrate that lithologies with favorable chemical composition occur over widths of tens of metres. The detrimental effect of retrograde metamorphism on the economic potential of some occurrences is seen at CH-1 where andalusite is entirely transformed into muscovite. The Bridge River area is readily accessible and could be systematically prospected for andalusite. Small-scale metallurgical tests could determine if a commercial-grade concentrate can be produced using conventional methods.

The Lillooet area occurrences have many similarities with the Bridge River area with respect to the regional geology and rock geochemistry. However, andalusite porphyroblasts from all the occurrences in the Lillooet area visited in 1994 are mostly, if not entirely retrograded to muscovite and consequently are not of economic interest.

The Leech River area has a different geological setting. A decreasing trend in the degree of retrograde metamorphism to the west is documented. The andalusite porphyroblasts in this area vary from a few centimetres to 30 centimetres long. However, most of the occurrences are of no economic interest, either because of the low grade, narrow widths or the effects of intense retrograde metamorphism. The area of greatest potential is adjacent to and west of the Jordan River as retrograde metamorphism decreases westward. The trend formed by occurrences LR 114, 13, 32, 35 and 37 is especially interesting because it projects westward into an area less affected by retrograde metamorphism. Andalusite formed in pendants within plutonic rock have good potential as they are better protected from incursion of retrograde metamorphic fluids.

Examination of hand specimens collected by the Geological Survey of Canada from the Raleigh Mountain area and the description of occurrences in the Terrace region indicate that some of the areas not covered by our reconnaissance study have good geological potential. However, the distance of the occurrences from infrastructure and the coast must be considered in preliminary selection of exploration targets. Andalusite occurrences in the southern Omineca Belt also merit examination.

ACKNOWLEDGMENTS

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QUESNEL AREA - INDUSTRIAL MINERALS ASSESSMENT

By Z.D. Hora and K.D. Hancock

KEYWORDS: industrial minerals, Tertiary, diatomite, pozzolan, clay, pre-Miocene deep weathering, residual clays.

INTRODUCTION

A number of major diatomite occurrences are known in the Quesnel area of British Columbia. Several attempts have been made over the years to develop this resource, but there has been no lasting success. This project was undertaken to map the Tertiary sediments and volcanics of the area north and south of Quesnel and assess the industrial minerals potential of units in the area.

LOCATION AND ACCESS

Most of the area mapped is on the west side of the Fraser River, between the Cottonwood River in the north and Alexandria in the south. With few exceptions, accessibility is good over the existing system of farm and logging roads. The Narcosli Creek valley, adjacent slopes and tributary gullies are difficult to reach. Some areas along the Fraser River and Baker Creek have vertical cliffs tens of metres high that are impossible to reach and sample. The elevations of the map area are from 450 metres above sea level at the Fraser River banks to 900 metres on the plateau to the west.

GEOLOGICAL SETTING AND EXPOSURE

Rocks of Tertiary age in the Quesnel area are confined to a broad valley cut in pre-Tertiary bedrock (Lay, 1940). According to Rouse and Mathews (1979), the lower to mid-Tertiary volcanic and sedimentary strata were down faulted or infolded onto the older rocks and eroded. This was followed by deposition of the latest Lower to Middle Miocene Fraser Bend Formation and younger units. The upper Tertiary sediments and volcanics are horizontally bedded and probably not affected by regional faulting. The Tertiary strata were deeply eroded by both Pleistocene glaciation and subsequent fluvial processes. Figure 1 (following page) is a stratigraphic column for the area mapped. Figure 2 is a diagrammatic cross-section showing the structural relationships of the rock units.

Quaternary sediments cover most of the Tertiary rocks and a major Pleistocene valley to the east of the present Fraser River has been infilled with younger sediments. The Fraser River and its tributaries cut up to 450 metres of soft Tertiary sediments. The upper Miocene and later units were affected by numerous block landslides and mudflows in most of the map area. This completely distorts the original elevations of individual Tertiary units. The slides probably occurred in the Late Pleistocene or early Holocene and most seem to be stabilized.

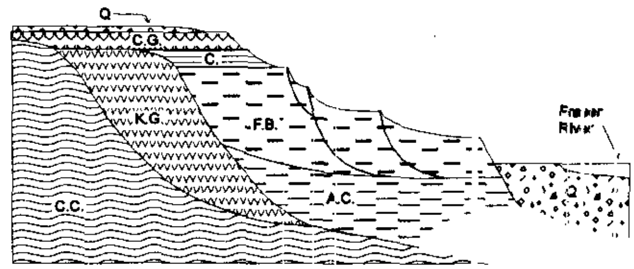
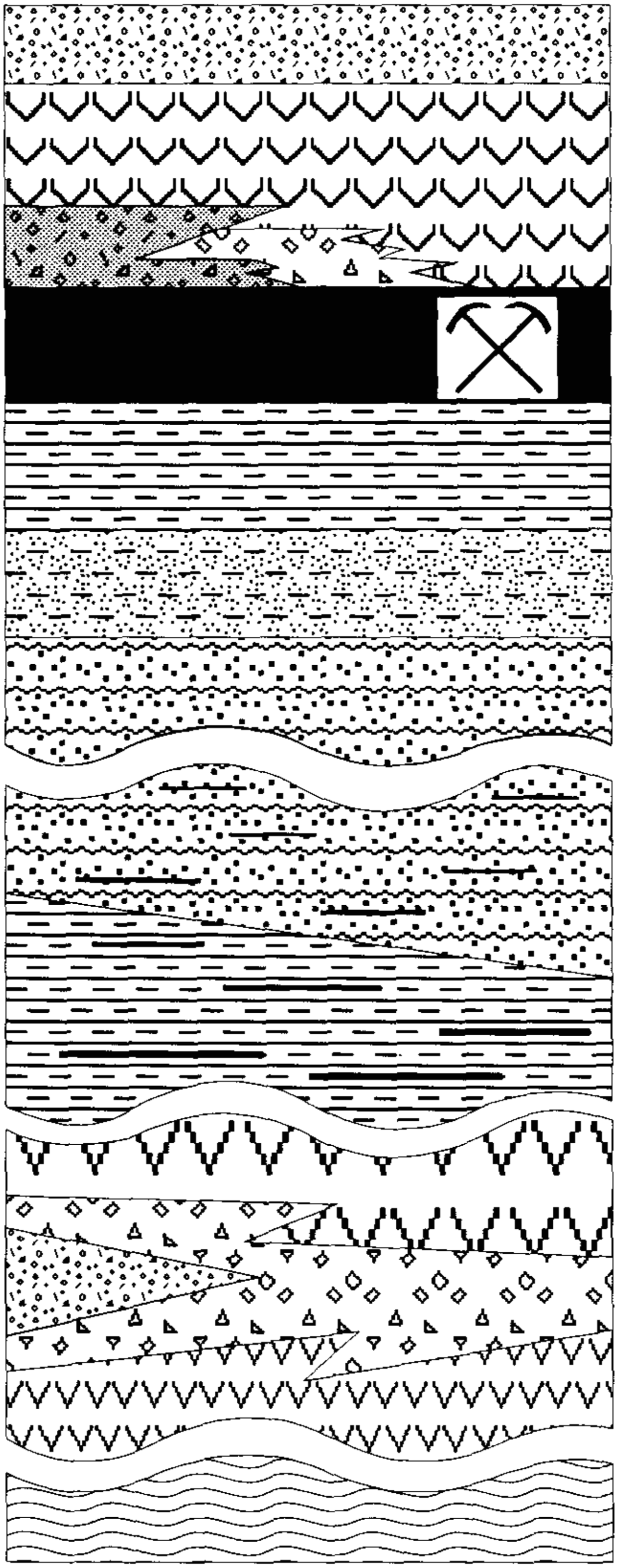


Figure 2. Diagrammatic structural cross-section of the rock units in the Quesnel area. C.C.: Cache Creek Group; A.C: *Australian Creek Formation*; F.B.: *Fraser Bend Formation*; C.: Crownite Formation; C.G.: Chilcotin Group equivalent volcanics; Q.: Quaternary sediments (modified from Rouse and Mathews, 1979).

STRATIGRAPHY

CACHE CREEK GROUP

Outcrops of the Mississippian to Triassic Cache Creek Group occur only in the northern part of the map area. Grey phyllite, locally with siliceous lenses, can be found along the Fraser River north of Big Bend and west of Quesnel along Baker Creek. Direct contact with younger units is exposed only in the upper parts of steep cliffs at Pinnacle Provincial Park, just west of Quesnel, where strongly weathered phyllites are overlain by a Chilcotin Group columnar basalt flow (Photo 1). Inaccessibility of this exposure prevents on-site examination of the unconformity. Although outcrops along the banks of both the Fraser River and Baker Creek are fresh, grey siliceous phyllites exposed in the upper parts of the slopes at Pinnacles Park are deeply weathered. This strongly weathered profile may be very thick, up to 100 vertical metres, along the slopes of Baker Creek. The phyllites have been altered to white or yellow clayey rock with illite the dominant clay mineral. Typical exposures are hoodoos and pinnacles; the result of recent erosion (Photo 2). A similar, deeply weathered profile in Cache Creek Group rocks is exposed on the west side of



Quaternary cover: Pleistocene till, glaciolacustrine and glaciofluvial sediments. Holocene sediments

Chilcotin Group: Upper Miocene flood basalt, black, vesicular and may be olivine phyric. May have yellowish palagonite breccia at the base of some flows. A thin, rusty, pebble to cobble

Crownite Formation: Late Middle Miocene lacustrine diatomite with variable clay matrix and clay interbeds. Typically buff-white and very recessive weathering. Host to two diatomite mines.

Fraser Bend Formation: Latest Lower to Middle Miocene sediments. Comprised of three subunits. Lower part is well sorted pebble (cobble) fluvial gravel. Clasts are primarily quartzite with some chert. Matrix is sand. Central part is finer gravel, less well sorted and matrix is sand - silt. Upper part is interbedded fine clay, silt, sand and some fine gravel. The formation is typified by green, grey or blue-grey clay-rich layers. Lignite fragments are present in some of the sand and gravel beds.

Australian Creek Formation: Lower Oligocene sediments. Comprised of two subunits. The lower part consists mainly of massive, fissile clays and muds. Sand and pebble to cobble conglomerates are interspersed through the section. The upper part is dominated by conglomerates and pebble-rich sandstones. The matrix is clay rich. Conglomerate clasts are mostly volcanics with some phyllitic and granitic material. Lenses of lignite are common throughout the formation.

Kamloops Group Volcanics: An Eocene package of mixed dacitic to andesitic volcaniclastics and flows. The group consists mostly of black or grey breccia, lahars and lava. These units weather red, brown or tan. Breccias are commonly monolithologic or polymictic. Ash and tuff beds are rare but a distinctive manila-yellow lapilli tuff was traced over several kilometres.

Cache Creek Group: Mississippian to Triassic black phyllite and ribbon cherts. In some locations a thick, prominent white, yellow, rusty or buff residually

Figure 1. Stratigraphic column for the Quesnel area.

the Fraser River just upstream of the Cottonwood River canyon.

EOCENE VOLCANICS (KAMLOOPS GROUP EQUIVALENT)

Volcanic rocks of this unit outcrop mostly along Narcosli Creek and to the north and south of its confluence with the Fraser River. Grey, green and red-weathering andesite is most common with subordinate pink dacite. The rocks comprise a variety of lava flows, pyroclastic deposits and volcanic sediments. Autobreccias, monomictic and diamictic debris flows, and intercalated lava flows comprise most of the section (Photos 3 and 4). Irregular and discontinuous distribution of outcrops does not allow outlining the extent or subdivision map of individual rock types. However, scattered outcrops of a distinctive manila-yellow lapilli ash-tuff occur between south Quesnel and Narcosli Creek. Direct contact with either the lower or higher stratigraphic units has not been observed in the project area.

A zone of andesite pumicite is exposed in several places along the slopes on both sides of Narcosli Creek (Photo 5). The characteristic feature of this rock is a light bluish weathering of the exposed surface. This rock was successfully tested and marketed, by a local readi-mix company, as a natural pozzolan during the late 1970s.

AUSTRALIAN CREEK FORMATION

The Oligocene Australian Creek Formation comprises a broad range of strata from claystones through to unsorted boulder conglomerates. Seams of coal are common between clay and siltstone beds. The coal seams seen in outcrop are typically 5 to 20 centimetres thick and discontinuous. With few exceptions, beds with a high clay component exhibit a high swelling and shrinking fracture pattern in outcrop, indicating a montmorillonitic character (Photo 6).

Outcrops of the Australian Creek Formation are scattered, usually low along the Fraser River banks and many of its tributaries throughout the map area. The single, most complete section in the project area is the type section in Australian Creek, south of Quesnel. Measured dips suggest an anticlinal structure approximately parallel to the Fraser River with the crest on the east side of the river. Dips rarely exceed 20°. The angular unconformity with the overlying Fraser Bend Formation is exposed in several outcrops in the Big Bend area north of Quesnel (Photo 7) and on the west side of the Fraser River in Quesnel.

The Australian Creek Formation has been of economic interest because of the presence of coal seams (Photo 8). While no site in the map area reached the production stage, a number of exploration attempts have been reported. They indicate the thickness of coal seams reaches more than 10 metres locally, but the high ash content and low calorific value have discouraged further development. We identified coal outcrops along the

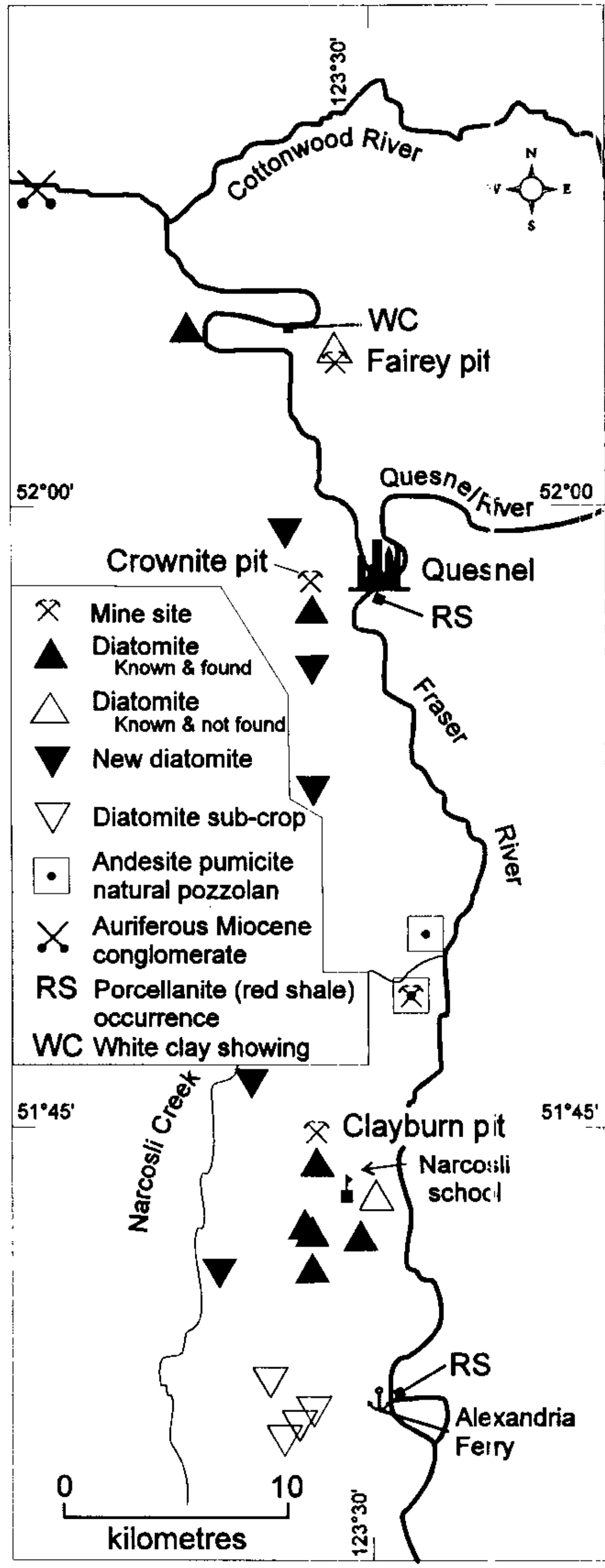


Figure 3. Location of mineral occurrences in the Quesnel map area.

Photo 1. Columnar basalt flow on strongly weathered Cache Creek Group rocks.

Photo 2. Pinnacles in strongly weathered Cache Creek Group rocks.

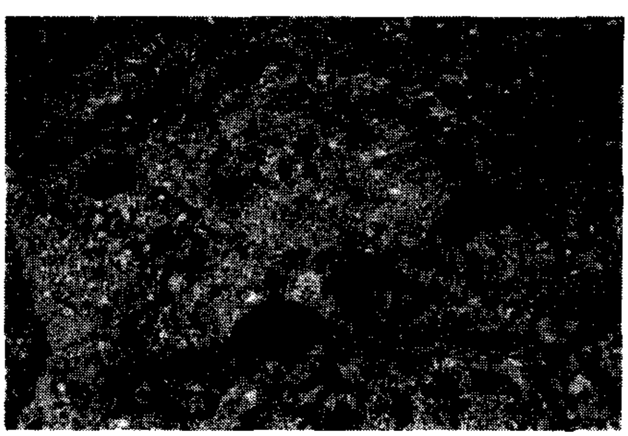


Photo 3. Agglomerate breccia north of Narcosli Creek. Clasts may reach 50 centimetres in diameter.

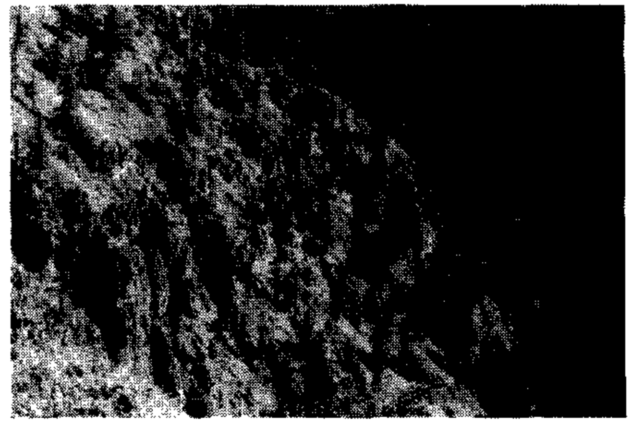


Photo 4. Agglomerate breccia outcrops, Narcosli Creek area.

Photo 5. Andesite pumicite, Narcosli Creek area.

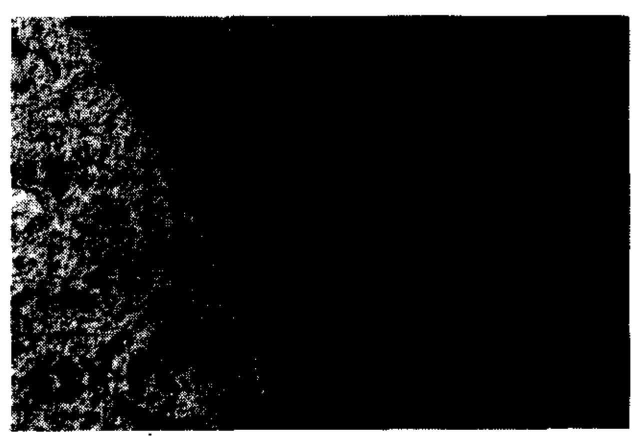


Photo 6. Australian Creek Formation clay bed with typical 'popcorn' surface indicating montmorillonitic composition.

whole area mapped from Big Bend to the old Alexandria ferry. Most are on the east bank of the river.

Outcrops of yellow to deep red porcellanite, locally called "red shale", the result of natural underground combustion of coal seams, occur at two locations (Figure 3, Photo 9). One site, on the south side of Quesnel city limits, has been called the Red Bluff and the rock was mined on a small scale for natural pozzolan and landscape aggregate. The other location, with no production so far, is located immediately south of the old Alexandria ferry crossing on the east side of the Fraser River.

FRASER BEND FORMATION

The Miocene Fraser Bend Formation is the best exposed unit in the map area. Its horizontal beds form the walls of steep ravines (Photo 10) and undercut banks along the Fraser River, particularly between the city of Quesnel and the Big Bend to the north. The Fraser Bend Formation overlies beds of the Australian Creek Formation on an angular unconformity (Photo 7). This contact was seen in several places on the west bank of the Fraser River between Big Bend and Quesnel.

The formation comprises a coarse, basal conglomerate with overlying conglomerate, sandstone and claystone and is up to 150 metres thick. The basal, pebble to cobble conglomerate is known to carry placer gold and has been mined underground for gold on both sides of the Fraser River, north of its confluence with the Cottonwood River. It is considered a source of gold in Fraser River terraces downstream (Levson and Giles, 1993).

Overlying the basal conglomerate are cobble to granule conglomerates, sandstones and a few silt and clay layers which comprise the lower half of the formation. The upper half is mostly clay and silt beds with scattered sandy or gravelly layers. These clays have a bright yellow or brown colour and, to a lesser degree, are pale green and grey. The principal clay mineral has been identified as illite (Rouse and Mathews, 1979). Close to the top of the Fraser Bend Formation, in the Big Bend area, our work has identified a layer of white clay 2 metres thick (Photo 11), possibly useable for ceramic manufacturing.

The contact of the Fraser Bend Formation with the overlying Crownite Formation is rarely exposed, but has been observed on the west side of the Fraser River in the Big Bend area and approximately 3 kilometres south of the Crownite pit.

CROWNITE FORMATION

The Middle to Upper Miocene Crownite Formation is a layer of diatomaceous earth up to 12 metres thick. While it is an extensive unit and outcrops are scattered over the whole map area (Figure 3), the upper or lower contacts are only exposed in a very few places. The diatomite was formed by the accumulation of the silica skeletons of freshwater diatoms living in an extensive, shallow lake. In some outcrops, diatomite caps the Tertiary sequence.

Diatomite is white, light beige or light grey and has a low density. The top and bottom few metres are bedded, a few centimetres thick; the central part is more massive with beds 20 to 30 centimetres thick. A brown, massive clayey layer has been noted in many exposures (Photo 13). In the two most complete sections, the Crownite pit and a ravine to the south, this bed, described as volcanic ash, is approximately at the middle of the diatomite sequence.

The diatomite strata have been affected by slumping of landslide blocks (Photos 12, 14) throughout the study area (described below). These multiple vertical displacements, expose outcrops of diatomaceous earth at many elevations, resulting in estimated thicknesses by some authors of 45 to 65 metres (140 to 200 feet; Godfrey, 1963). After the development of the Crownite pit west of Quesnel, which facilitated a better understanding of the depositional environment the thickness of diatomite beds in the Quesnel area, where no erosion has taken place, is estimated to be 12 metres. The beds are contaminated by clay minerals and devitrified volcanic ash. The reported Al_2O_3 contents from different sites and stratigraphic intervals are between 6.45% and 15.92% with Fe_2O_3 analyses between 3 and 4% (McCammon, 1960). Clay content and contamination by

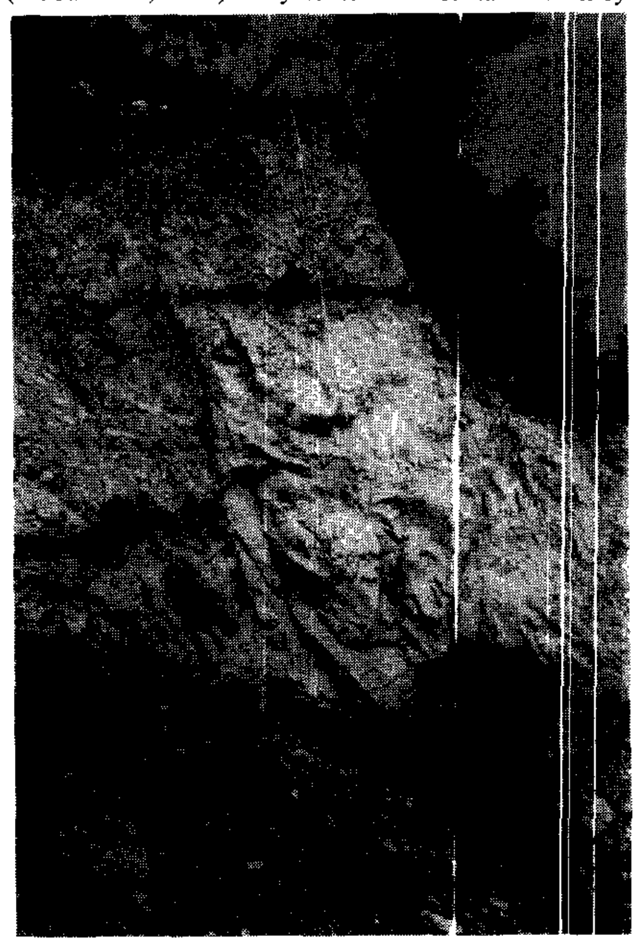


Photo 13. Crownite Formation diatomite. Note displacement of rusty (dark) volcanic ash layer

Photo 7. Australian Creek - Fraser Bend formations unconfomity, Big Bend area.

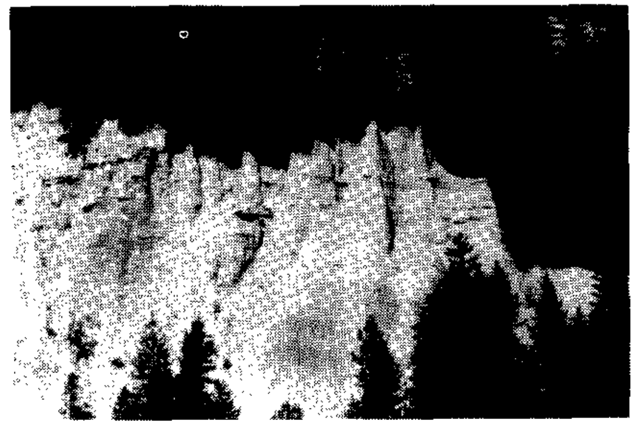


Photo 10. Hoodoo erosion of Fraser Bend Formation, Big Bend area.

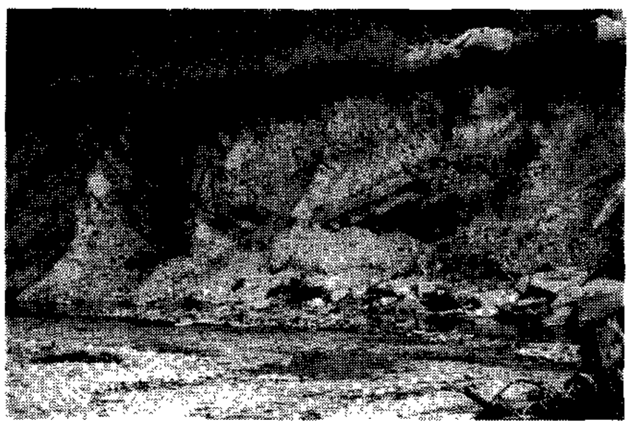


Photo 8. Australian Creek Formation with coal seam, Baker Creek, Quesnel.

Photo 11. Fraser Bend Formation, white ceramic clay bed, Big Bend area.

Photo 9. Partly burned coal seam with porcellanite zone, Australian Creek Formation near Alexandria ferry site.

Photo 12. Diatomite bed in recent slump, Big Bend area.

Photo 14. Diatomite bed exposed by recent slumping in the Buck Ridge area.

Photo 15. Basalt flow filling channel in Crownite Formation diatomite, Clayburn pit.

Photo 16. Recent sliding in glaciolacustrine silts, 'Big Slide' near Big Bend.

iron oxides are the main obstacles for higher value end-uses of Quesnel diatomite.

MIOCENE PLATEAU BASALT (CHILCOTIN GROUP EQUIVALENT)

An Upper Miocene basalt flow forms a solid cap over the softer underlying strata from Quesnel to Alexandria and south. The flow typically forms massive, columnar jointed cliffs and is found on hilltops and the broad, high plateaus west of the Fraser River. The basalt is black, and vesicular and uniformly fine grained. The unit is 5 to 10 metres thick at Pinnacles Park (Photo 1) increasing to 20 metres in the Narcosli area and southwards. In some places, the lowermost part of the flow is pillowed with or without palagonite breccia.

At the Clayburn pit (Figure 3), a flow channel has a strongly brecciated base that deformed and, in part, incorporated diatomite (Photo 15). This clearly demonstrates that some parts of the flow extended into lakes, ponds and muds that were diatomite rich. A rusty brown, unsorted pebble conglomerate, a few metres thick, is exposed below the basalt and conformably overlies diatomite at the Crownite pit. Elsewhere, this conglomerate was seen at scattered outcrops in the map area and may be discontinuous in its areal extent.

QUATERNARY

Most of the map area is covered by a mantle of Quaternary deposits, locally very thick. The top of the plateau west of the Fraser River has a Pleistocene basal till cover with irregularly distributed patches of gravel on top of it. Grooves, drumlins and striae are very common and indicate movement of glacial ice from south to north (Tipper, 1971).

The lower elevations are covered by a variety of sediments with very complex relations. They include waterlain till, varved lacustrine sediments and multiple generations of meltwater channels and corresponding sediments. All these features are well exposed by the Holocene erosion of the Fraser River and its tributaries.

A deep, filled Pleistocene channel has been documented to the east of the present Fraser River course (Rouse and Mathews, 1979). The glaciolacustrine sediments are widespread and often disrupted by recent mud flows and landslides in the map area. The prominent example is the "Big Slide" (Photo 16), north of Quesnel, that has an active sliding area of approximately 4 square kilometres.

FAULTING AND LANDSLIDES IN TERTIARY ROCKS

Poor bedrock exposure in the whole map area makes identification of faults very difficult. With the exception of Eocene volcanics in the Narcosli Creek area, outcrops of pre-Miocene rocks are restricted to a few isolated places precluding the possibility of observing breaks in the continuity of specific units. Tipper (1959, 1960) in his mapping of the 93B and 93G map sheets identified

Photo 17. Block slumping in the Fraser Bend Formation, Big Bend area. White ceramic clay bed at top of the sequence.

only three faults within our map area. According to Rouse and Mathews (1979), there has been no faulting which would have affected the Miocene rocks in the area of our study. This contrasts with the frequent vertical displacement of Miocene units from the Fraser Bend sediments to the Chilcotin Group basalts, as observed throughout the project area. Such vertical displacements can be seen as far as 5 kilometres to the west of the Fraser River channel.

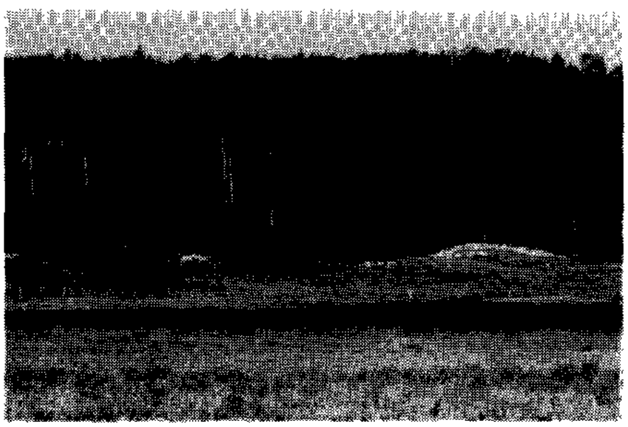


Photo 18. Drained and stabilized mudflow showing hummocky terrain with diatomite exposed (white), Buck Ridge area.

Block sliding is locally obvious. In the Big Bend area, for example, undercutting of near-vertical cliffs has triggered sliding of the Miocene sedimentary sequence towards the river in small blocks with many signs of recent movement. Such block slides are small in size, a few hundred metres in length, and extend only a few hundred metres from the river (Photo 17).

A much larger scale of sliding, however, has taken place in the southern part of the project area, between Narcosli Creek and the Fraser River. There, blocks, sometimes several kilometres long and up to 300 metres wide have slid towards the Fraser River and have vertical displacements of 1 or 2 to more than 10 metres. Quite often, a northerly trending, steeply dipping slide scar is the location of a poorly drained depression where the down-dropped block rests against the higher standing slice (Figure 4). Most of these slides seem to have stabilized and no indications of recent movements have been observed. However, the absence of fixed points may be obscuring the very slow process of creep which may be continuing. A geotechnical study in the urban area of Quesnel's east side, completed in 1977 and 1978, confirmed a relative displacement of 25 to 75 millimetres between two slide blocks over a period of one year. (M. Stepanek, personal communication, 1994).

It is not clear which beds within the Miocene sequence are the cause of block sliding. The failure surfaces are definitely deep seated and no seepage has been observed in the Miocene sequence. Although gravel and conglomerate beds, which could generate ground water pore pressures sufficient to trigger sliding, are common in the lower part of the Miocene Fraser Bend Formation, detachment may be occurring along the Oligocene-Miocene angular unconformity. This is in contrast to slides in the glaciolacustrine sediments, where numerous seepage horizons are clearly visible in exposed faces.

The lower benches of slide blocks are often covered by hummocky terrain, resulting from mudflows, now drained and stabilized (Photo 18). Such mudflows originated from upper blocks and led to the development of gullies that now drain the surrounding area (Figure 5).

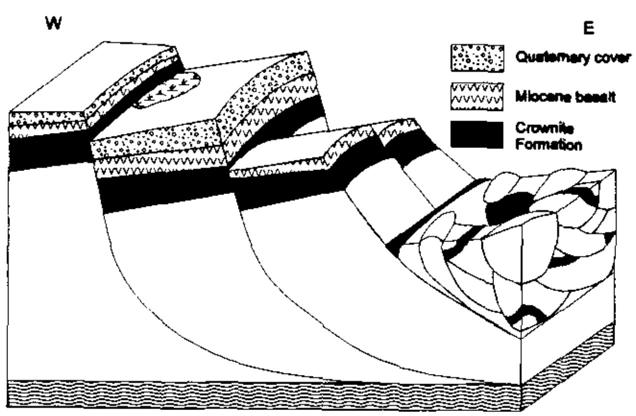


Figure 4. Block diagram of block sliding and slumping.

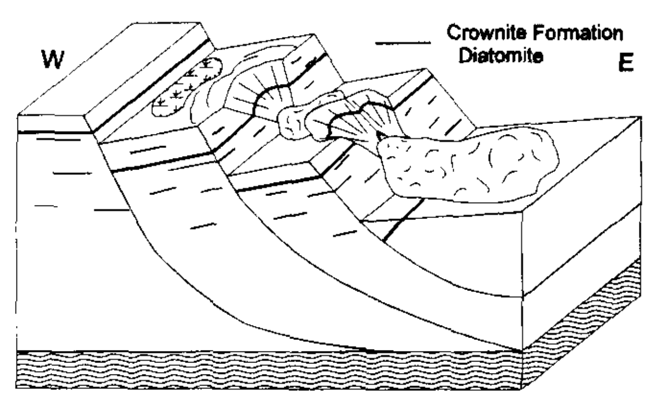


Figure 5. Block diagram of mud slides after block sliding. Short dashes are surface water seeps.

INDUSTRIAL MINERALS

DIATOMITE

Diatomite in the Quesnel area was first recognized by G.M. Dawson (1877), an early explorer. The first resource assessments were published by Reinecke (1920) and Eardley-Wilmot (1928). In 1937, Fairey and Cunliffe, a Vancouver company, started limited production of specialty ceramic products using diatomaceous earth from Quesnel as a raw material (Figure 3). This later expanded to manufacture of insulation brick and pozzolanic cement admixtures which continued until 1969. Its production came from Lot 6182 north of the Quesnel airport. Attempts to develop the resource in the Narcosli area (Buck Ridge) during the 1940s as a mineral filler or a filtration product did not succeed.

In 1963, Crownite Diatoms Ltd. of Calgary started to develop the deposit identified on Lot 906 on the west side of the Fraser River above Quesnel (Figure 3). The main products were anti-caking agents for fertilizer pellets and industrial and domestic absorbents. During intermittent operation and two ownership changes, considerable effort was made to develop a competitive, high value-added product by removing impurities like clay, calcium and magnesium sulphate from the crude diatomaceous earth. The process developed (Visman and Picard, 1969), for which Canadian Patent No. 890249 was issued in January 1972, succeeded in reducing clay contamination, measured by Al_2O_3 content, from 12.38% to only 4.8%. Such processing was never implemented in production and the operation on Lot 906 was permanently discontinued in 1984.

More recently, regular shipments of diatomite are made from a pit located on Lot 1615 at Buck Ridge, south of Quesnel, by Clayburn Industries Ltd. of Abbotsford, to manufacture insulation bricks.

NATURAL POZZOLAN

Three different types of pozzolanic materials from the Quesnel area have been marketed with some success. Both Fairey and Cunliffe and Crownite Diatoms Ltd. used the diatomaceous earth as pozzolan. Crownite Diatoms, however, recognized the pozzolan potential in ground porcellanite, also known locally as "red shale", the natural product of underground coal seam combustion. The pozzolan was used in a number of construction projects, particularly the W.A.C. Bennett dam (Carswell, 1966) on the Peace River at Hudson Hope. The porcellanite outcrops on the east bank of the Fraser River, south of the confluence with the Quesnel River and the site has been known as the Red Bluff. It is part of the Australian Creek Formation. Our mapping located a similar, previously unreported occurrence at the old Alexandria ferry site, on the east side of the river (Figure 3).

Another type of natural pozzolan was developed by a local company, Quesnel Red-Mix Cement Co. Ltd. Samples from a zone of andesite pumicite (Figure 3), part of the Eocene volcanic sequence in the Narcosli Creek area, were studied in 1964 by Construction Materials Section, Mines Branch, Department of Mines and Technical Surveys, in Ottawa (Malhotra and Zoldners, 1964). The results confirmed that the product meets ASTM and CSA specifications for pozzolan admixtures used in Portland cement. This type of natural pozzolan was produced from 1979 until 1984 and used in a number of construction projects in the Quesnel and Prince George areas.

CERAMIC CLAY

A bed of white clay, 2 metres thick, is exposed on the east side of the Fraser River, south of the Big Bend area (Figure 3). The clay bed is in the uppermost part of the Fraser Bend sediments and has been exposed by block slumping in a steep cliff above the river. The exposure is more than 100 metres long and the bed maintains its thickness and composition over the whole of the outcrop. The clay is being tested for its ceramic properties and preliminary results indicate it is probably suitable for stoneware type products (G Oprea, personal communication, 1984). The accessibility of this site is good and therefore the development potential, from a logistics point of view, is very good.

LANDSCAPE AGGREGATE

The porcellanite at Red Bluff has been used in the Quesnel area in limited amounts. The bright pink and red colours are very attractive and the material has been used for driveways, paths and roofing-chip aggregate

SUMMARY AND DISCUSSION

The 1994 map area is underlain by late Paleozoic phyllites of the Cache Creek Group and five Tertiary units: Eocene volcanics, Oligocene Australian Creek Formation, mid-Miocene Fraser Bend and Crownite Formation and Late Miocene plateau basalts. Mapping practically doubled the size and number of known diatomite occurrences. This observation suggests that the original diatomite deposition was widespread, extending from the northernmost showings in the Big Bend area all the way to the south near the old Alexandria ferry, probably in one large lake. The project also confirmed geologic resources of Eocene volcanics and burned, underground coal seams, porcellanite, of the Australian Creek Formation as sources of natural pozzolan

The deep weathering profile, several tens of metres, of Cache Creek rocks under the Miocene sediments, indicates a potential for residual clay deposits in similar geologic environments elsewhere. Beds of white clay suitable for ceramic wares may provide raw material for a local cottage industry. Similar clays are presently imported to British Columbia from Alberta and California.

ACKNOWLEDGMENTS

The authors wish to thank the many farmers in the mapping area for allowing entry to their properties and Mr. Tom Scuffi for providing the technical information from company files. Editorial comments by Brian Grant and John Newell are appreciated.

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NAZKO CINDER CONE AND A NEW PERLITE OCCURRENCE

By Z.D. Hora and K.D. Hancock

KEYWORDS: industrial minerals, Nazko cinder cone, Holocene volcanics, light-weight aggregate, lava rock, barbecue rock, volcanic glass, perlite

NAZKO CINDER CONE

Location: Lat. 52° 55' 45" Long. 123° 44' 00" 93G1/4. Cariboo Mining Division. Approximately 14 kilometres west of Nazko village, 75 kilometres west of Quesnel.

Access: Via the Michelle Creek forest service road and Baezaeko (Fishpot Lake) road.

Owner: Canada Pumice Corporation.

Operator: Canada Pumice Corporation

Commodities: Lightweight aggregate, lava rock, anti-skid sand, ornamental cinder aggregate.

GEOLOGY

The Nazko cinder cone is the most easterly volcanic centre in the Anahim volcanic belt. The edifice of this Holocene volcano is a product of three main volcanic events, one preglacial, one subglacial and one postglacial (Souther *et al*, 1987). The conical mound of the Nazko cone raises about 120 metres above the surrounding terrain and its circular base is approximately 1000 metres in diameter.

Two pyroclastic ejecta units comprise this composite cone (Figure 1). A conical mound some 100 metres high on the west side of the edifice is made of red basalt tuff-breccia. This unit predates the subaerial, crescent-shaped eastern rims of three craters and has been interpreted as of subglacial origin (Souther *et al*, 1987). Because of its attractive colour, material from this unit is of economic interest for a variety of granular cinder products.

A second unit forms much of the composite cone. It consists of fresh, black scoriaceous basalt tephra with irregular and round-shaped bombs up to 60 centimetres in diameter. On the surface, the black tephra weathers bright yellowish brown. A fine-grained member of this unit forms a gradually thinning eliptical blanket to the northeast of the cone. This blanket extends up to 8 kilometres east and northeast from the vents. According to Souther *et al*. (1987), the eruption which deposited the pyroclastic rocks of this second unit took place about 7200 years B.P. Material from this unit is also processed into general commercial products.

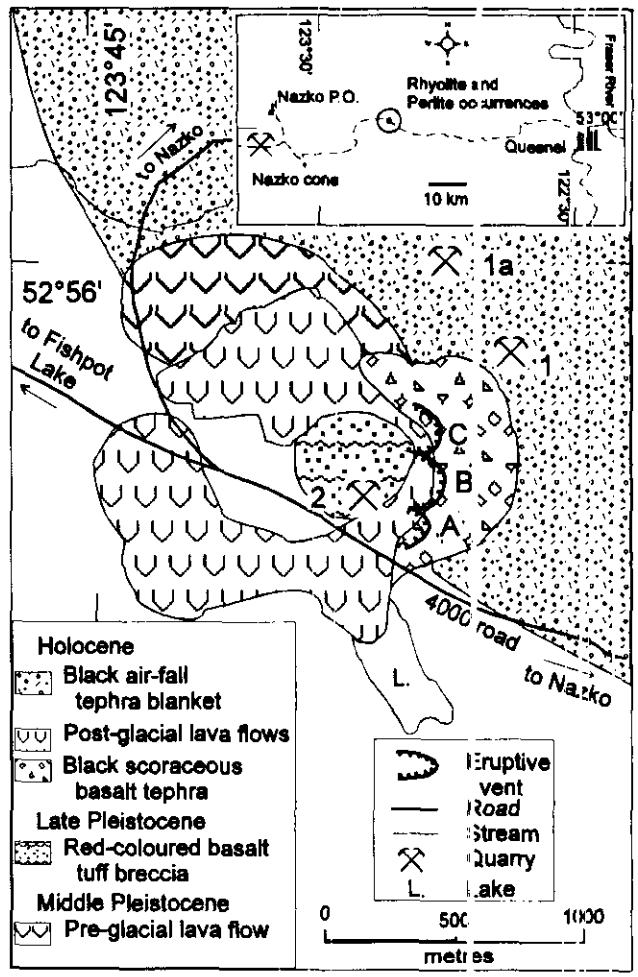

Figure 1. Location map and geology of the Nazko cone (after Souther *et al.*, 1987)

Two lava flows of different ages form part of the composite cone. A basal flow of subaerial basalt is exposed to the north. It predates the Wisconsinan glaciation and is extensively eroded. A K-Ar date of this basalt has been determined as 0.34±0.03 Ma.

The second flow unit comprises two separate lava streams that issued through narrow breaches on the west flank of the cone. These flows are a product of the same volcanic episode which resulted in accumulation of pyroclastics on the eastern flank of Nazko cone and the tephra blanket to the east.

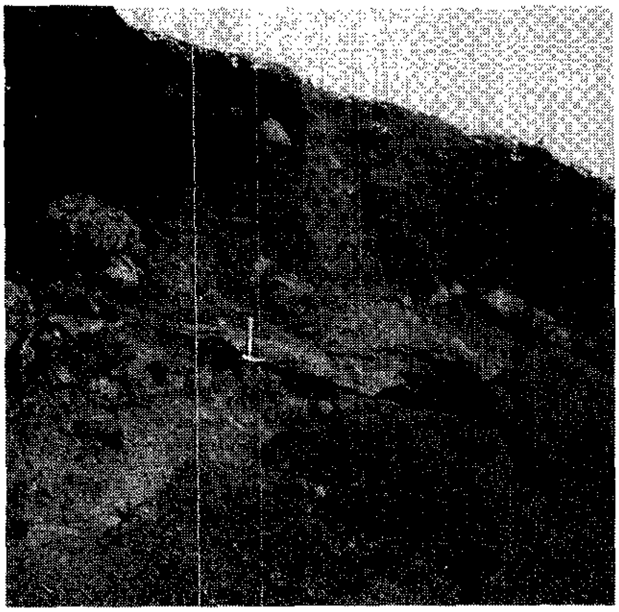

Photo 1. Unsorted nature of pyroclastic deposit. Black, scoriaceous basalt tephra, pit 1

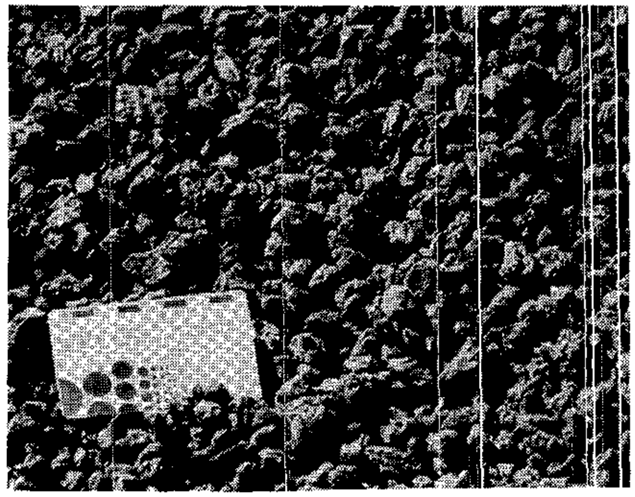

Photo 4. Sized red scoria - landscaping aggregate

Photo 2. View of pit 1a, opened in fine pyroclastic layer

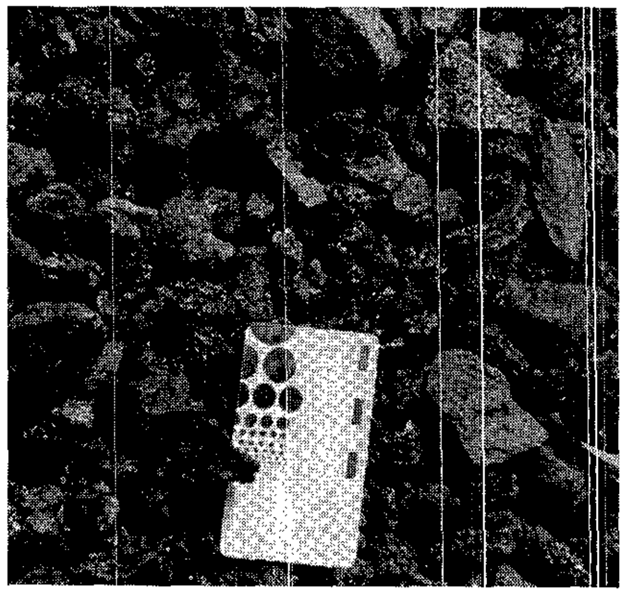

Photo 5. Sized black scoria - barbecue rock

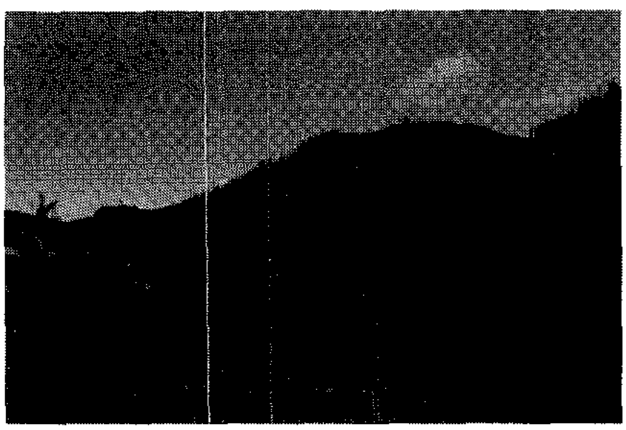

Photo 3. Subglacial mound of pyroclastic ejecta, source of the red cinder products

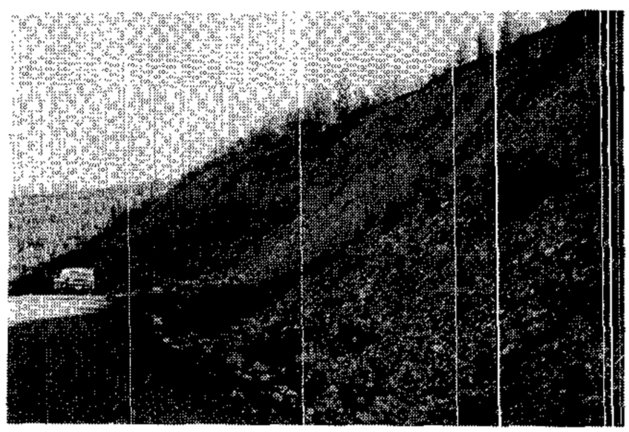

Photo 6. Glacial outwash face with abundant perlite boulders and cobbles.

PRODUCTION AND DEVELOPMENT

Canada Pumice Corporation has developed three production sites in the Nazko cone area. The first is a small pit at the north side of the toe of the volcanic mound (Photo 1). Because of a large number of volcanic bombs in the unsorted pyroclastic material, this source of black scoria is now abandoned and has been reclaimed. The company opened a new pit several hundred metres to the north, where there are no large bombs (Photo 2). On the south side of the Nazko cone, the company operates another pit as a source of red scoria (Photo 3).

Production equipment consists of a 2 by 3-metre, minus 10-centimetre grizzly, a Powerscreen double deck portable screen, a Cat 980B loader and a Cat D8 bulldozer. Typical production is about 115 cubic metres (150 cu. yards) per day with current annual production of 11 475 cubic metres (15 000 cu yard). Products are available in four screened sizes and also as oversize landscaping rocks. Most of the present production is used in decorative applications for landscaping (Photo 4), sand traps on golf courses and barbecue lava rock (Photo 5).

Other applications include anti-skid highway traction sand and light-weight aggregate. While both colours, black and red, are readily available, the greatest demand so far has been for red cinder products.

PERLITE

Location: Lat. 53° 01' 30" Long. 123° 12' 05" 93B/14. Cariboo Mining Division. Approximately 59 kilometres west of Quesnel.

Access: From Quesnel on Nazko road.

Commodities: Perlite, volcanic glass.

A previously unreported occurrence of perlite has been found during a cursory examination of large rhyolite outcrops and an adjacent bank of glacial outwash exposed in a cut on the road from Quesnel to Nazko (Photo 6).

While no bedrock outcrops containing volcanic glass are known in the area, abundant clasts of perlitic rock can be found throughout the outwash deposit. The large size of many of the perlite boulders (50 cm in diameter), low physical strength of the rock and proximity to a large exposure of Eocene rhyolites (Rouse and Mathews, 1988; Tipper, 1961), points to a nearby source most probably associated with the adjacent rhyolite outcrops.

The perlite rock is black to dark green, with microfractures resulting in platy, rod-like and isometric fragments. Four distinct types of volcanic glass were collected for expansion tests.

A sample of each of the four types was crushed to less than 1-centimetre size fragments, which were then placed under a propane torch flame for about 1 minute. All types expanded, increasing the volume of individual particles from approximately two to four times their original size.

The significance of this perlite occurrence is that it is the logistically best-located and accessible site in the British Columbia interior, and the authors believe that prospecting will locate the bedrock source of perlite rock in nearby Eocene rocks.

ACKNOWLEDGEMENTS

The authors thank Brian Wear for assisting with the visit to the Nazko property.

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NOTES

MINERAL POTENTIAL PROJECT - OVERVIEW

By Ward E. Kilby

Contribution to the Mineral Potential Project, funded in part by the Corporate Resource Inventory Initiative (CRII)

KEYWORDS: land-use planning, resource assessment, probabilistic estimates, Monte Carlo simulation, digital geology maps.

INTRODUCTION

The Mineral Potential project was initiated in 1992 to meet the need for current regional mineral potential information in regional and sub-regional land-use planning. These planning processes have the responsibility of making recommendations on protected areas, as described in the provincial Protected Areas Strategy (PAS). The goal of PAS, created in 1992, is to protect representative examples of the province's natural, recreational and cultural heritage features. A provincial target of 12% protection has been established; when PAS was announced, 6% of BC was considered protected. Mineral exploration and mining are not allowed in protected areas, hence decisions on which areas to protect need to fully account for mineral values.

Part of the mandate of the Commission on Resources and Environment (CORE) is to run regional land-use planning processes and to make recommendations to government on their findings. Initially, three regions, Vancouver Island, Cariboo-Chilcotin and the Kootenays, were selected for evaluation and land-use planning (Figure 1). Recommending protected areas is one of the more controversial issues in the CORE process.

To provide readily useable mineral resource information to this process, the land within each region was ranked with respect to its mineral potential using quantitative analysis. The CORE process necessitated the upgrading of all resource and cultural inventories in the province to facilitate informed land-use planning. This project is one of more than twenty inventory projects undertaken by seven ministries. The project is operated by the Geological Survey Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources and was designed to meet CORE's timetable. The project will complete the mineral potential assessment of the province within a four-year time frame and will meet the information needs of other land-use processes in addition to CORE's.

This paper provides an overview of the methodology used to assess the mineral potential and report on the progress of the project.

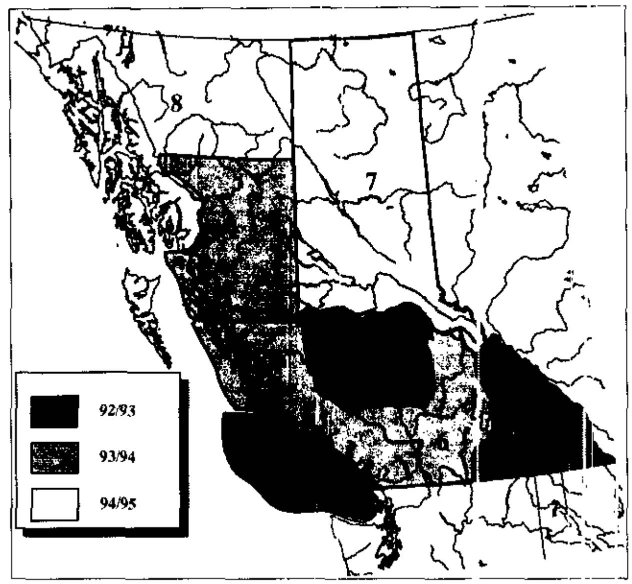

Figure 1. Mineral potential assessment regions; 1-Vancouver Island, 2- Cariboo-Chilcotin, 3- Kootenays, 4- Skeena-Nass, 5- Mid-Coast, 6- Thompson-Okanagan, 7- Northeast BC and 8- Northwest BC.

OBJECTIVES

Project objectives were three fold;

- Rank the land base of the province by its ability to support economic activity through mineral exploration and extraction.
- Produce results which are credible and understandable by all user groups, to assure the results of the analysis are used in the land-use planning process.
- Incorporate the expertise of the mining and exploration communities.

It was found that a straight forward relative ranking of the land base was more useful to decision makers than a measure such as gross-in-place dollar value of minerals in the ground. The primary concern with respect to mineral potential was, which land was the most and least important to the mining industry. The challenge was not to protect areas or not, but how to protect critical environmental and cultural values with a given percentage of a region's land base and with the least economic impact.

Mining industry representatives were participants in the regional based CORE planning processes. They were free to use whatever information they desired to represent their position. The analysis produced by the mineral potential project was one dataset available to industry representatives. To be useful and credible it was essential that the methodology used for this analysis was accepted by the mining industry and easily understandable by the other interests at the table. The use of factual historical data together with the opinions of recognized industry experts appeared to meet this criterion.

The mining and exploration industry is a major generator and repository of data related to the mineral endowment of the province. Individuals from industry were used as consultants to assist the Branch's mineral potential team prepare databases, compile geology and to provide quantitative estimates of future discovery potential.

METHODOLOGY

The assessment of mineral potential in this project takes two forms, a phase 1 and phase 2 analysis. In phase 1 historical information is used to rank the land base with respect to its mineral potential. The phase 2 analysis uses a combination of historical and subjective probability estimates by industry experts to achieve a ranking of the land base. The major steps in the analysis of a region are:

- Compile geological maps.
- Compile historical information.
- Delineate mineral assessment tracts.
- External review of geology and deposit data.
- Production of phase 1 analysis and map.
- Estimation of future deposit discovery potential.
- Production of phase 2 analysis and map.

The method is patterned after the three-part assessment methodology of the United States Geological Survey (Singer, 1993).

DATA COMPILATION

GEOLOGY AND MINERAL ASSESSMENT TRACTS

Accurate and current geological data are the framework on which all the analysis is built. The major component of this project is the compilation of the geology of the province at a scale of 1:250 000. Geologists familiar with each region produce the compilation by integrating all existing information with current geological theories. Much of the data used in the compilations was obtained from the Geological Survey of Canada and their contributions to the Project are acknowledged. The compiled geology is captured in digital form for subsequent analysis and distribution. The digital geological information has been made publicly available, as it is produced, by means of Open File series releases (Figure 2.; Bellefontaine and Alldrick, 1994; Schiarizza *et al.*, 1994; MacIntyre *et al.*, 1994; Höy *et al.*, 1994; Massey, 1994; Desjardins, 1994). To date the geology for five regions has been released.

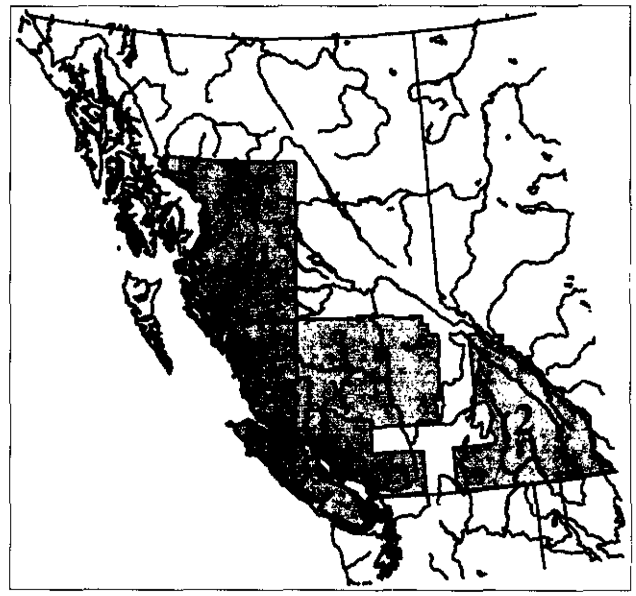

Figure 2. Areas of digital geology Open File releases; 1 - OF 1994-6, 2 - OF 1994-7, 3 - OF 1994-8, 4 - OF 1994-14 and 5 - OF 1994-17.

Upon completion of the geological compilation, the region is divided into mineral assessment tracts. These tracts are units in which the geology can be considered to be similar at a scale of 1:250 000. Tract boundaries are geological features such as faults or major contacts. Tract definitions reflect significant differences in lithology, structure and geological history, particularly where these are important to metallogeny. Once defined, these tracts become the base unit areas in which the assessments in phase 1 and phase 2 are performed (Figure 3). Articles in this volume describe in detail this effort in the various regions (Bellefontaine and Alldrick, 1995; Church, 1995; MacIntyre *et al.*, 1995; Massey, 1995).

HISTORICAL INFORMATION COMPILATION

Several large, well maintained databases describing the known mineral deposits of the province were available to the project. The Assessment Report Information System (ARIS) contains location information as well as the type and amount of exploration work performed on mineral deposits (Kalnins and Wilcox, 1994). Assessment work is reported annually so this database captures the distribution and intensity of exploration in the province. Exploration expenditure information since about 1950 is contained in this file. The existing database was augmented by compiling and digitally capturing the dollar amounts of work reported in many of the early reports. This information was captured for 15 000 of the 22 000 reports contained in the database. The dollar value of the exploration work recorded in each report was converted to 1986 dollars using the Canadian Consumer Price Index.

MINFILE is another database that was available for use by the project. It contains location and deposit information for about 11 000 mineral occurrence across the province (Jones and McPeek, 1992). Work under this project has

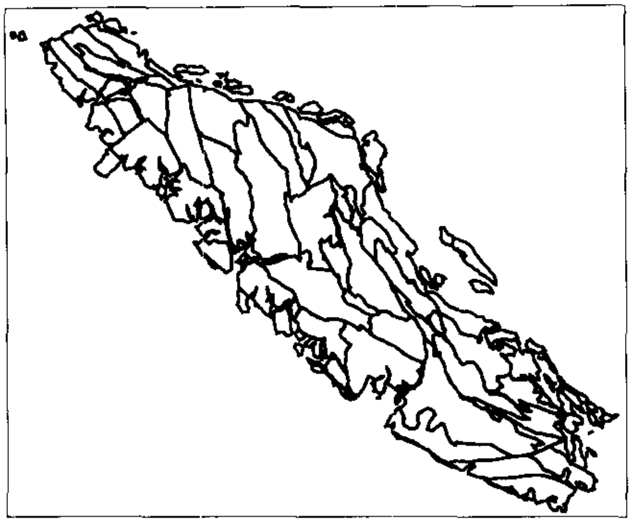

Figure 3. Display of the 59 mineral assessment tracts delineated for the Vancouver Island region

added deposit classification information to the file and significant effort was devoted to bringing reported reserve and resource information, as well as past production values, up-to-date. The value of remaining resources and past production for each deposit was calculated. Commodity prices were determined by using the average market value of the commodity for the years 1980 to 1989, reported in 1986 dollars.

A third important database dealing with the mineral resources of British Columbia is maintained by the Mineral Policy Branch. This database contains the reported production by commodity and year for each producer in the province. These data were valued as described above and correlated with the appropriate MINFILE occurrence to provide a geographic location.

Historical information describing the mining and exploration activity in the province was largely available in digital form prior to the initiation of the project. Some important information was added to these databases by the project and the required information from the databases was integrated and geographically referenced.

PHASE 1 ANALYSIS

Phase 1 analysis is the prediction of the relative future value of the land base by analysis of historical information. Four parameters were used in this analysis; value of past exploration, value of known resources, value of past production and number of discovered mineral occurrences. To date, only the six major metallic commodities; gold, silver, copper, molybdenum, lead and zinc have been used in this analysis. In the future, all metallic and industrial mineral commodities will be included in the phase 1 analysis.

Within each tract, the value of each of the four parameters was calculated. These parameter values were normalized by dividing them by the areas of the tracts. Tracts were then ranked by each normalized parameter and given an ordinal value related to the ranking. The ordinal values for each parameter range from 1, for the lowest ranking tract, to n, the number of tracts in the region, for the highest ranking tract. Each tract then had four ranking values, one for each of the parameters. These rankings were then multiplied by a weighting factor proportional to their perceived importance in predicting future value, and summed for a final ranking value.

The weighting factors used were; 25 for known resources, 10 for exploration expenditures and 5 for each of past production value and number of mineral occurrences. It was felt that discovered commodities in the ground was the most important indicator of future economic activity. To a lesser extent, the amount of exploration performed in a tract indicated where the exploration community, during the past 40 years, has felt the best ground is located. Value of past production and the number of mineral occurrences were given the least weighting but both are important as indicators of favourable geology.

The final ranking was used to order all tracts within a region from most to least potential. This type of analysis makes some very large assumptions and must be used with these assumptions in mind. To a large extent it assumes that new resources will be discovered near previously discovered resources. This assumption neglects the possibility that new types of deposits, completely unrelated to known deposits, may exist or that the importance (value) of commodities may change over time. The rankings are based on the market value of commodities. Market value may not be the best indicator of the value of a commodity to the province's socio-economic well being. In the future, mine-head value of commodities rather than the market will be used to get closer to the true value to the province of the commodities it produces. This is also how the provincial mineral statistics have traditionally been quoted.

PHASE 2 ANALYSIS

Phase 2 analysis evaluates both known resources and predicted future resources. The value of known resources is compiled from the literature and, as described above, was added to the MINFILE database. The amount of resources to be discovered in the future was obtained by soliciting probabilistic estimates from individuals with expertise in the area to be assessed or in the deposit types believed to exist in the area. The methodology used for these predictions is similar to the Three-part methodology of the United States Geological Survey (Singer, 1993).

In our methodology, tracts are based on geology rather than the possibility of a specific deposit type occurring, as in the Three-part methodology. For each combination of tract and possible deposit type, probabilistic estimates of the number of deposits to be discovered or proved in the future are made. These estimates are made individually by several experts for each combination of tract and deposit. No attempt to reach consensus between estimators is made as the range of thinking within the geological community is important.

The estimators were instructed to use the median deposit size and grade as the basis of their estimate. Grade and tonnage distribution curves, together with descriptive characteristics for each deposit type, were supplied to them. Where possible these curves were from British Columbia deposits, but in many cases there are insufficient deposits reported in the province to develop a meaningful curve and data from around the world were used. These world deposit grade and tonnage distributions were generously supplied by the United States Geological Survey (Grunsky, 1995; Cox and Singer, 1986). It is most important when using data from outside province, to assure that the relative economic importance of the deposit types remains true to the British Columbia situation. For this project a deposit is defined as a mineral occurrence which contains the same or more of a commodity than the smallest deposit reported in the associated grade and tonnage distributions. To make a probabilistic estimate for a particular deposit type in a tract, the estimator actually makes several estimates at different probability levels. The value reported for each of these estimates is the probability of at least a specified number of deposits being discovered or proved in the future. The first question estimators asks themselves when making an estimate is: "What is the chance of at least one more deposit of this type being discovered or proved in this tract?". This value is then recorded on a linear scale from 1 to 100% probability, with a "1" indicating at least one deposit. Estimators then ask the same question with respect to increasing numbers of deposits until they reach a number beyond which they feel there is no chance of that number of deposits being found in that tract in the future.

Each of the estimates are then run through the Mark 3 Monte Carlo Simulator to determine the amount of mineral commodity predicted by the estimate. The Mark 3 simulation program was developed by the USGS (Root *et al.*, 1992) and was generously provided to this project. Simply, the simulator combines the probability distribution of deposit discoveries provided by the estimators with the grade and tonnage probability distributions compiled from known deposits. The output from the simulator is the probability distribution of volume of the commodities associated with the deposit type.

As mentioned above, each estimate is put through the simulator individually. The results from multiple estimates of the same deposit type in the same tract are then combined and recorded. For each combination of deposit type and tract, the results at three probability levels are retained. The mean, maximum and minimum estimates from individual estimators at the 90, 50 and 10% probability levels are stored for each commodity included in the estimates for a given deposit type. Once all the deposit types for a tract had been simulated and the relevant values saved, the predicted amounts of each commodity are combined and given a dollar value. Finally the total dollar value of all the commodities with potential in the tract were combined to give nine values, the mean, maximum and minimum, at three probability levels (Figure 4).

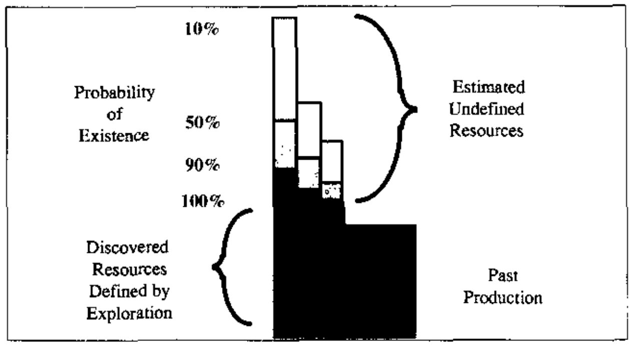

Figure 4. Graphic used to display the known and estimated resource value for each tract. The height of the bars is in dollars.

These estimated values of future discoveries, together with the value of the known resources in each tract, were used to rank the tracts within each region. The value used to rank the tracts was the value of the known resources plus the value of the mean of the estimates to the 50% probability level. Graphically displaying these values for all the tracts in a region allows easy visual comparison of the relative importance of each tract in a form useable by third parties (Figure 5).

To date, estimates have been made in an unstructured manner by experts from industry who donate their time to the project. The unstructured aspects relate to the process where the experts make estimates on the deposit type - tract combinations of their choosing. Using this format, some combinations of deposit types and tracts are missed. As the project has progressed, interest in participating on a voluntary basis has diminished. The most recent phase 2 analysis for Thompson-Okanagan (November 7-10, 1994) used industry experts as consultants and employed a structured format in which two to three estimators made individual estimates for each combination of deposit type and tract. In addition they made anonymous evaluations of each other's relevant expertise by assigning a weighting value to the other estimators.

RESULTS

Results of the mineral potential analysis have been used in three CORE regions, Vancouver Island, Cariboo-Chilcotin and Kootenay. The mineral potential is only one of at least twenty resource and cultural values incorporated into land-use decisions. They include values such as wildlife habitat, archeology sites and forest cover.

Recommendations for land-use on Vancouver Island and in the Cariboo-Chilcotin have be submitted by CORE to government and final decisions on land allocations were made in 1994. Government accepted the CORE recommendations in principle, however some boundary adjustments will be made. This boundary adjustment process is another point at which the mineral potential analysis is of use.

A comparison of the various land-use designations of the CORE recommendations with respect to the mineral po-

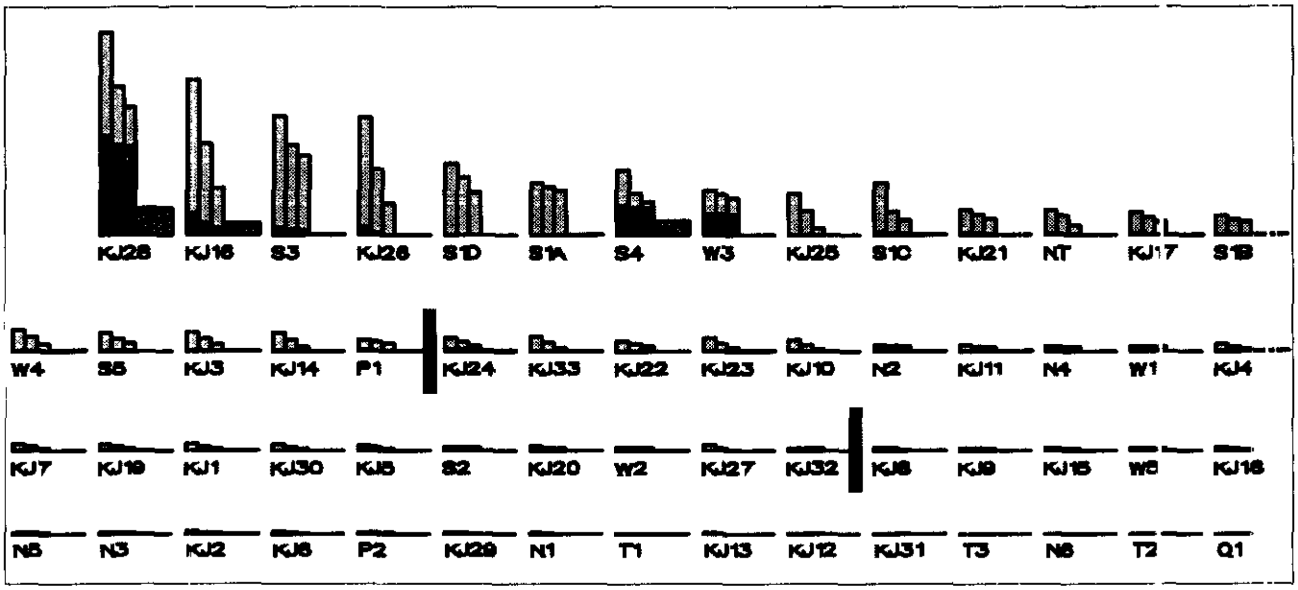

Figure 5. Graphic display of the known and estimated resource value in each tract in the Vancouver Island Region. The two vertical bars delimit the three mineral potential categories. Each contains one third of the land area in the region

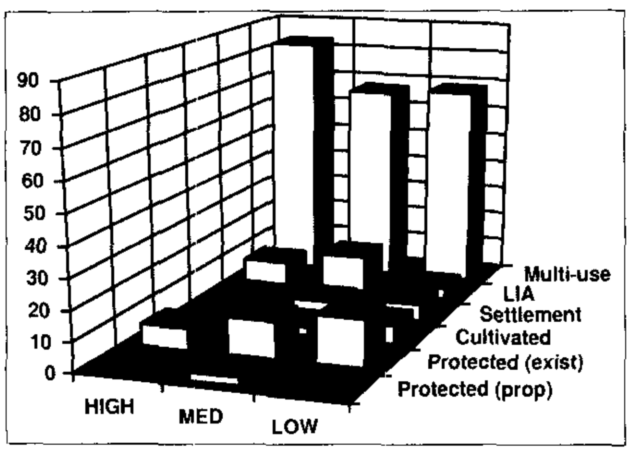

Figure 6. Graphic display showing the percent of each mineral potential category with respect to the land-use designations recommended by CORE for Vancouver Island. LIA= Low Intensity Area.

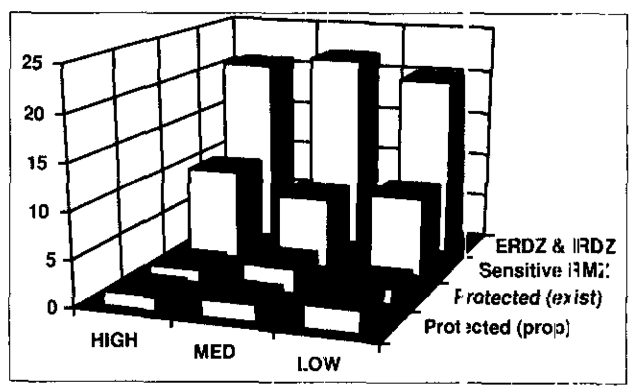

Figure 7. Graphic display showing the percent of each mineral potential category with respect to the land-use designations recommended by CORE for the Cariboo-Chilcotin. ERDZ= Enhanced Resource Development Zone; IRDZ = Intense Resource Development Zone; RMZ= Resource Management Zone.

tential values in each region was made. Figures 6 and 7 are graphical representations of the amount of land in each mineral potential category that CORE recommended for placement in the various land-use designations. The three mineral potential categories: high, medium and low, each contain one-third of the land area of a region. In both cases the proposed protected classification (no mining) contains less high-potential land than medium-potential land. In the Vancouver Island recommendations, more high mineral-potential land than medium-potential land was recommended for placement in land-use classifications which permit mining. The Cariboo-Chilcotin CORE recommendations show the same trend with more of the high mineral potential land being placed in "mining allowed" land designations than medium mineral potential land.

FUTURE

Geological compilation, phase 1 and phase 2 analysis will be completed for the whole province by 1996. Northwestern British Columbia, the last region to be evaluated, will be processed in 1995-1996.

Following the initial region-by-region compilation of geology, it is planned to merge all the geology into one seamless database. This digital database will then be available for a wide range of analysis and display purposes.

The mineral potential analysis currently uses monetary value of commodities to determine the relative importance between commodities and deposit types. The dollar value of *in situ* resources and estimated future resource discoveries may not accurately rank the importance of a tract with respect to the socio-economic well-being of the province. For example, the economic activity generated by a given value of a precious-metal resource will be less than the equivalent value of a bulk commodity. This is due to the greater amount of activity required in extracting, processing and transporting the bulk commodity.

The analysis is also based on the assumption that all commodities have a ready market. This assumption is definitely erroneous, but future markets are difficult to quantify. In general, precious metals and base metals have a ready market, with some price fluctuations, while some industrial minerals require extensive marketing.

The current analysis uses the monetary value of gross in-place resources, both discovered and undiscovered, to rank the land base. This is similar to the majority of mineral assessment processes. However, a more meaningful ranking for land-use planning would be based on the socio-economic impact of the resources in each tract, both discovered and undiscovered. Marketability, economic ripple effects, mine feasibilities and taxation structures must be determined for each deposit type to obtain this type of analysis. It is in this direction that mineral potential methodology is evolving.

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GRADE AND TONNAGE DATA FOR BRITISH COLUMBIA MINERAL DEPOSIT MODELS

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Contribution to the Mineral Potential Project, funded in part by the Corporate Resource Inventory Initiative (CRII)

KEYWORDS: mineral deposits, grade, tonnage, resource assessment

INTRODUCTION

The Mineral Potential Project currently being undertaken in British Columbia requires estimation of unknown mineral resources. The method of resource assessment known as the BC Mineral Resource Assessment Process [1993], is described by Kilby (1995, this volume) and in Grunsky *et al.* (1994). The method is based on the three-part assessment methodology developed by the United States Geological Survey (USGS) as documented in Singer (1975), Singer and Ovenshine (1979), Drew *et al.* (1986), Root *et al.* (1992) and Singer (1993). An essential component of predictive resource estimation is the creation of mineral deposit models and associated grade and tonnage data. In this study, resource estimation experts rely on geological and mineral deposit models to assist in their predictions. From the evaluation of models, quantitative estimation can be carried out on the basis of grades and tonnages of known deposits.

BACKGROUND OF MINERAL DEPOSIT GRADE AND TONNAGE DATA

It has been well established that resource estimation can be carried out using statistical procedures (cf. Allais, 1957; Harris *et al*, 1971; Whitney, 1975; Agterberg *et al.*, 1972). The use of grade and tonnage data was originally employed by Lasky (1950) who showed an inverse relationship between average grade and the log cumulative tonnage of porphyry copper deposits.

Estimation of resources generally involves a prediction on the size and grade of a mineral deposit. Such predictions are best based on knowledge of the frequencies of grades and tonnages that characterize such deposits. The distributions that comprise the grades and tonnages represent a stochastic model that can be viewed as probability density functions. Grade and tonnage models have the form of frequency distributions of size and average grades of well explored deposits for each type of mineral deposit model (Singer, 1993). The use of the compiled grade and tonnage data forms the basis for quantifying the predictive estimates. The BC Mineral Resource Assessment Process follows the same estimation technique as in the three-part assessments of the USGS, employing a Monte Carlo simulation using estimates of numbers of deposits and grade and tonnage distributions.

The compilation of information about mineral deposits is a crucial feature of resource estimation. The USGS has compiled extensive descriptions and characteristics for a wide range of mineral deposit types from global sources (Cox and Singer, 1986; Bliss, 1992). The models contain two main components; the descriptive features that characterize the deposits in terms of geology and tectonic setting, and grade and tonnage distributions which characterize the size and grades of known deposits from around the world. Singer (1993) describes the basic concepts in the three-part quantitative assessment methodology for undiscovered resources used by the USGS. The paper also describes the requirements for compiling and scrutinizing grade and tonnage data.

BRITISH COLUMBIA GRADE AND TONNAGE DATA

During the course of mineral deposit model selection for the mineral potential project, mineral deposit models from the USGS (Cox and Singer 1986) were reviewed. The review concluded that many of the USGS resource data sets were not suitable for describing the grade and tonnage of deposits that were likely to exist in British Columbia. In addition, many of the mineral deposit types in British Columbia were considered to be sufficiently unique to warrant distinctive descriptions together with grade and tonnage distributions. As a result, a compilation of mineral deposit models together with descriptions and grade and tonnage data was carried out (Lefebure *et al*, 1994; 1995, this volume). Geologists from the British Columbia Geological Survey Branch, the mining industry, the Geological Survey of Canada, and the USGS compiled deposit model descriptions for deposit types that are likely to exist in British Columbia. Grade and tonnage data were compiled by Stonehouse

Group consultants (Stonehouse Group, 1993) for 435 large deposits that were listed as producers, past producers, and those with proven reserves. Stonehouse used a classification scheme that was modified from Cox and Singer (1986). The classified deposits were subsequently reviewed against an alternative classification scheme developed for British Columbia deposits (Lefebure *et al.*, 1994, this volume). Both classifications, the modified USGS and the British Columbia classification scheme, were assigned to the mineral deposit data. At this time no studies have been carried out that detail the differences between USGS and British Columbia mineral deposit models.

The nature of deposit classification is to some extent subjective. Not all geologists can agree on classification designations for some deposit types. Through an iterative process, the deposits that were compiled by Stonehouse were classified and reclassified by geologists in the British Columbia Geological Survey Branch until a consensus was reached on most deposits. Deposits about which there was uncertainty or disagreement, were not classified and thus left out of the grade and tonnage curves.

In many cases there were too few deposits to adequately define a grade and tonnage profile or there were simply no data available. In these cases, we adopted the grade and tonnage distributions that were kindly provided by the USGS (Singer *et al.*, 1993). Singer has emphasized (Singer and Orris, 1994) that there are many serious pitfalls in the construction of grade and tonnage curves. In any resource assessment methodology that requires the use of such data the following requirements must be met:

- The geology of the tracts of ground being considered must be permissive for the deposit type.
- Grade and tonnage models must be consistent with the descriptive deposit models.
- Grade and tonnage models must be consistent with known deposits in the area being considered.
- The estimates of unknown deposits must be consistent with the grade and tonnage model.

GRADE AND TONNAGE DATA COMPILATION

Grade and tonnage data are compiled with the following assumptions:

- The deposit is correctly classified (*i.e.* no mixed deposit types).
- The grade and tonnage represent the complete *in situ* resource (production + reserves).
- The data represent grade and tonnage from a single deposit or a group of small deposits designated as a single deposit.
- The number of deposits that define a grade/tonnage curve are a reasonably complete representation of the resource.
- The grade represents the average grade for each commodity.
- The tonnage represents the tonnage of production plus reserves and resources.
- The grade and tonnage data are based on the lowest possible cutoff grade.

There are several sources of errors that create difficulty in constructing grade and tonnage curves as outlined by Singer (1993) and Singer and Orris (1994). These include:

- Mixed geological environments.
- Poorly known geology.
- Data recording errors.
- Mixed deposit/district data.
- Mixed mining methods.
- Incomplete production and resource estimates.

In addition to these errors Chung *et al.* (1992) have shown that in at least one case the construction of grade and tonnage curves is influenced by the timing of discoveries. A study of mercury deposits in California, in which the dates of discoveries were known, has shown that the largest deposits were discovered first. It follows from this that, for certain deposit types, if an area is incompletely explored, grade and tonnage curves may suggest a greater endowment than is actually present. However, this conclusion may not be universally accepted without thorough geological knowledge and a thorough history of exploration. There is an inherent bias in grade and tonnage data in that they represent only deposits that have been discovered and have been economically evaluated. Another bias in the creation of the data is that the information is knowledge and technology dependent.

If the knowledge of the geology associated with a particular class of mineral deposits changes it may result in an amalgamation or a division of deposits.

Other problems that create difficulty are:

- Grade and tonnage data that are not lognormal.
- Grade and tonnage data that have significant correlations. Most deposit models show little or no correlation between grade and tonnage (see Figure 1).
- Grade and tonnage data where groups of deposits form clusters within a particular mineral deposit model.
- The standard deviation for log-transformed data exceeds a value of 1.0.

The above criteria define standards for the creation of accurate and meaningful grade and tonnage data. The compilation and evaluation of the data attempt to meet all or most of these criteria. Once the data have been compiled, the evaluation of the actual grade and tonnage data requires several steps. An example given here is for calcalkalic porphyry copper deposits that occur in British Columbia. This deposit model is classified as Model L04 (Lefebure *et al.*, 1994) which incorporates USGS models 17, 20 and 21 (Cox and Singer, 1986). Table 1a summarizes the reserves data for the deposits used to characterize the grade and tonnage. The table is listed in increasing tonnage. Table 1b contains deposits that have been classified as calcalkalic porphyry copper deposits but do not fit well on the grade and tonnage curves. These deposits were excluded because the data provided for them were considered not to be a reasonable representation of the resource.

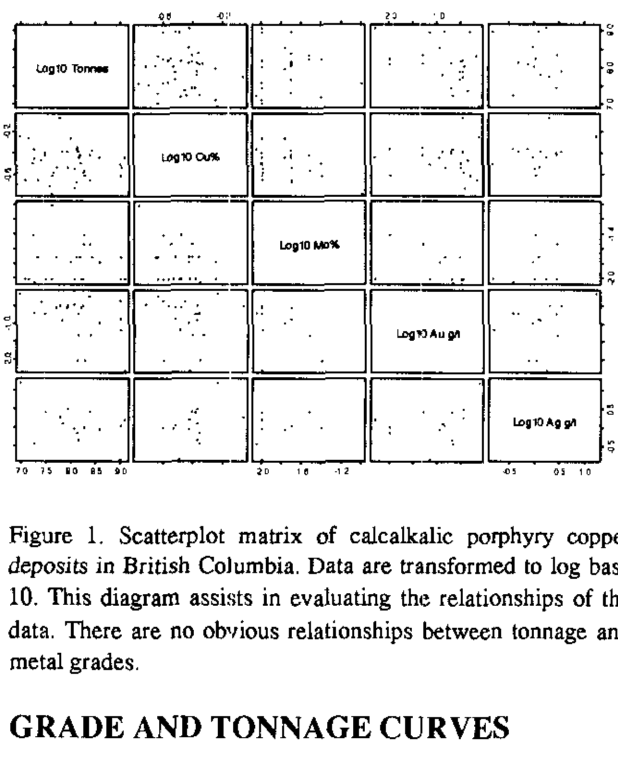

Figure 1. Scatterplot matrix of calcalkalic porphyry copper deposits in British Columbia. Data are transformed to log base 10. This diagram assists in evaluating the relationships of the data. There are no obvious relationships between tonnage and metal grades.

GRADE AND TONNAGE CURVES

Grade and tonnage curves graphically describe the distribution of tonnage and average deposit grades. The process of grade and tonnage curve construction involves the following steps:

- Plot the data are plotted as quantile-quantile plots (q-q plots).
- Plot the data as pairs plots (cf. Figure 1) to examine any possible associations or correlations.
- Calculate basic summary statistics on the data to check for non-normality (log transform) or high variances

Figure 1 shows a scatterplot matrix of the grade and tonnage data. These data have been transformed to log base 10. This plot is a graphically convenient way of examining interactions between the variables. In resource assessment procedures, the commodities and tonnages should be uncorrelated. The application of methods such as scatterplot matrices and regression methods can assist in testing the degree of correlation. From Figure 1 it can be seen that there is little or no correlation between any of the variables. This has been verified using regression methods.

A discussion on the use of the lognormal model is given by Harris (1984). The correct interpretation of the curves is important in applying them to resource assessment. They are plotted as the log (base 10) of grade or tonnage versus the proportion of curve (0-1). Although the distribution of tonnage and grades for metal deposits is generally log normal, this is not necessarily the case for industrial minerals (Singer and Orris, 1994).

Figure 2 shows cumulative probability plots for the porphyry copper grade and tonnage data. Each plot shows the ordered tonnage or grade for each deposit as a point. A theoretical log-normal curve is also plotted on the graph. The curve is derived from the mean and variance of the sample data. Each curve also shows three tie lines at 90, 50 and 10 percentile levels of the curves. The grade or tonnage that is shown at the 50 percentile level indicates the average or mean grade or tonnage for that particular deposit type. The figures can be interpreted as 50 % of the deposits will have a grade or tonnage less than this value, and 50 % of the deposits will have a grade or tonnage greater than this value.

In order to assess data that comprise the grade and tonnage information, various graphical procedures can be applied to test for atypical samples and examine the nature of the population distribution. The plots of Figure 3 show the log (base 10) of tonnage or grade of the deposits plotted against the quantiles of a normal distribution. Such plots can reveal atypical deposits or an unexpected trend in the data. Quantitative procedures can also be applied to determine which transformation best fits the data. Figures 3a and b show quantile-quantile plots for both the raw data and the log-transformed tonnage data. In Figure 3a the four largest deposits appear as outliers. Even after applying a log transform to the tonnage data these four deposits are still noticeably large and possibly atypical. Also, in Figure 3b, there is a change in the slope of the curve where deposit tonnages exceed 100 million tonnes. Such a change in slope suggests two distinct tonnage populations. The cause of

TABLE 1A
CALCALKALIC PORPHYRY COPPER DEPOSITS IN BRITISH COLUMBIA

Deposit	Tonnes (x1000)	Cu %	Mo %	Au g/t	Ag g/t
TASEKO	9,502	0.58	0	0 75	17
IDE - AM	11,481	0.23	0 01	NA	NA
KRAIN	14,000	0.56	0 01	NA	NA
OX LAKE	17,000	0.33	0.04	NA	NA
BIG ONION	18,000	0 36	0	NA	NA
NANIKA	18,144	0 44	0.009	0 21	0.38
REY	21,488	0 23	0.02	NA	NA
RED DOG	25,000	0.35	0	0 44	NA
EAGLE	30,000	0.41	0.01	0.2	2 71
GNAT PASS	30,000	0.39	0	NA	NA
SWAN	36,000	0 2	0	NA	NA
WHITING CREEK	40,000	0.17	0.1	NA	NA
DOROTHY	40,800	0.25	0.01	NA	NA
ANN	43,381	0.27	0	NA	NA
LOUISE LAKE	50,000	0.3	0.02	0 3	NA
KERR	60,000	0.86	0	0.34	2
GRANISLE	66,434	0 42	0	0.13	1.33
HI-MARS	82,000	0.3	0	0.3	NA
MORRISON	86,000	0.42	0	0.34	3 4
HUCKLEBERRY	100,000	0.56	0 017	NA	NA
GAMBIER ISLAND	114,000	0.29	0.01	NA	1
KEMESS NORTH	116,000	0.19	0	0.37	NA
HIGHMONT	125,000	0.22	0 02	NA	NA
BETHLEHEM	134,000	0.44	0	0 01	0.74
CATFACE	138,000	0.46	0	0 05	NA
BELL COPPER	143,000	0.42	0	0.2	0 48
POPLAR	144,000	0.37	0 02	NA	NA
O.K.	155,000	0 39	0.02	NA	NA
POISON MOUNTAIN	159,000	0.33	0.01	0.31	NA
HUSHAMU	173,000	0.27	0.01	0 34	NA
MAGGIE	181,000	0.28	0.03	NA	NA
BRENDA	183,000	0.25	0.04	0.01	1.06
KEMESS SOUTH	230,000	0.23	0	0.65	NA
BERG	238,000	0.39	0 03	0.05	2.84
JA	260,000	0.43	0.02	NA	NA
ISLAND COPPER	373,000	0.37	0.017	0.11	0 94
GIBRALTAR	965,000	0.32	0.01	0.07	0.15
FISH LAKE	976,000	0.25	0	0.48	NA
SCHAFT CREEK	1,000,000	0 3	0.02	0.14	1.2
HIGHLAND VALLEY COPPER	1,200,000	0.372	0.01	0.005	1.73

TABLE 1B
CALCALKALIC POPRHYRY COPPER DEPOSITS NOT USED IN GRADE AND TONNAGE CURVES

Deposit	Tonnes	Cu%	Mo%	Aug/t	Ag g/t
WIZ	294	1.26	0	NA	0.01
G.E.	540	0.27	0	NA	NA
VIMY	819	0 35	0	NA	NA

Note: NA= Missing Values (Data not available)

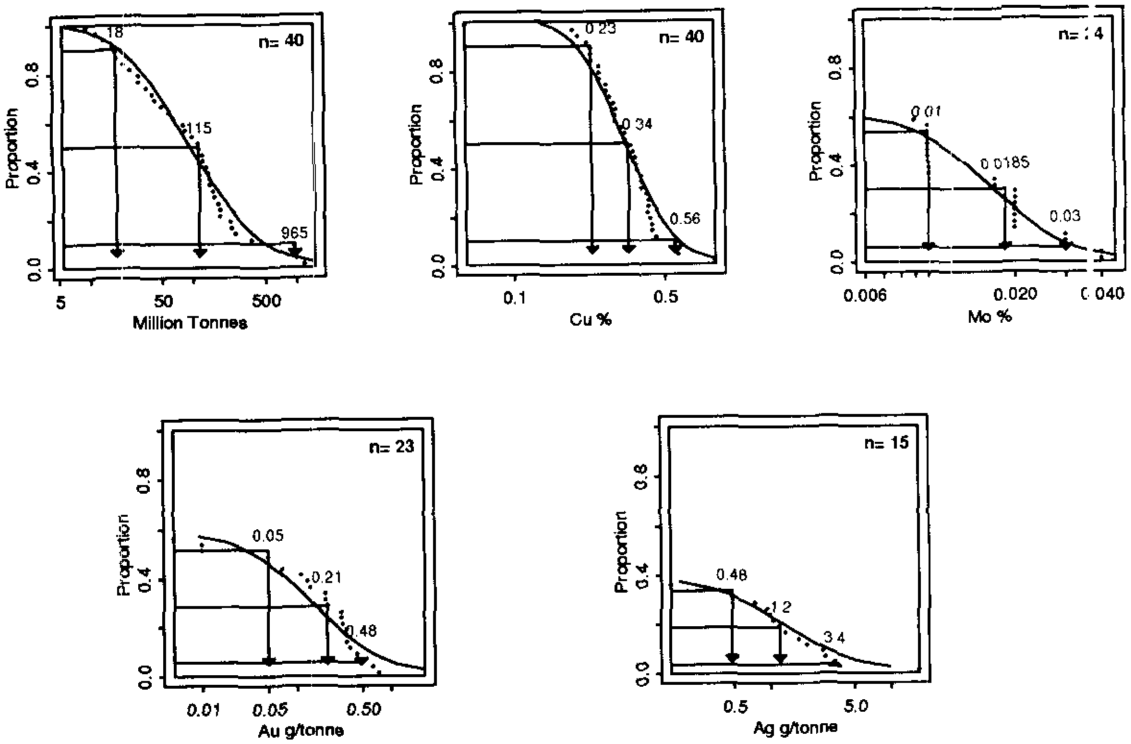

Figure 2: Grade and tonnage curves for British Columbia calcalkalic porphyry deposits.
Individual deposits are shown a dots. The curved line represents a lognormal curve fitted to the mean and variance of the logtransformed data. The tie lines on each graph represent the values of the tonnage or grade at the 90th, 50th, and 10th percentile. The intersection of the data and log-normal curve with the y-axis represents the proportion of data that are greater than zero and/or not missing data (NA in Table 1a). The number of data points for each commodity is shown in the upper right of each figure. No distinction is made between production and reserve data.

these two populations is not clearly understood. Figures 3c and d show quantile-quantile plots for copper. In this case the distinction between the untransformed and transformed data is less obvious. On closer examination however, it can be seen that the log-transformed data provide a better fit in the quantile-quantile plot. The copper data also displays four outliers which represent copper values greater than 0.5%. These data occur within the small to medium size deposits although there is no clear correlation between tonnage and copper grade as shown in Figure 1. The line of points in Figure 3d appears to be nearly a straight line. However, there is a slight change of curvature in the line at about log10 Cu = -0.4 (0.4%Cu) but it is not as nearly pronounced as the tonnage data in Figure 3b. Further study is required to investigate the possible bimodal nature of the calcalkalic porphyry copper deposits.

Finally, summary statistics can be applied to provide some numerical description of the data. These descriptions are best interpreted with the plots as described in Figures 1, 2 and 3. Table 2 shows summary statistics for the grades and tonnages of the porphyry copper data.

CONCLUDING REMARKS

The mineral potential project requires assessments for a wide range of mineral deposit types. For several deposit types, grade and tonnage data have been constructed to meet the requirements for quantitative resource assessment. As outlined above, there are many considerations required in the construction of grade and tonnage tables and curves. With these considerations in mind, mineral deposit resource data can be compiled to meet the requirements of the British Columbia Resource Assessment Process.

For many mineral deposit models, there are an inadequate number of deposits for the construction of grade and tonnage curves. In these cases, and where appropriate, deposit model descriptions and grade and tonnage curves from the USGS have been used. In some cases there are deposit profiles for which there are no grade and tonnage data available. In these special cases, mineral deposit experts were asked to provide examples of expected grades and tonnages, from which curves could be constructed and used in situations where estimates are required.

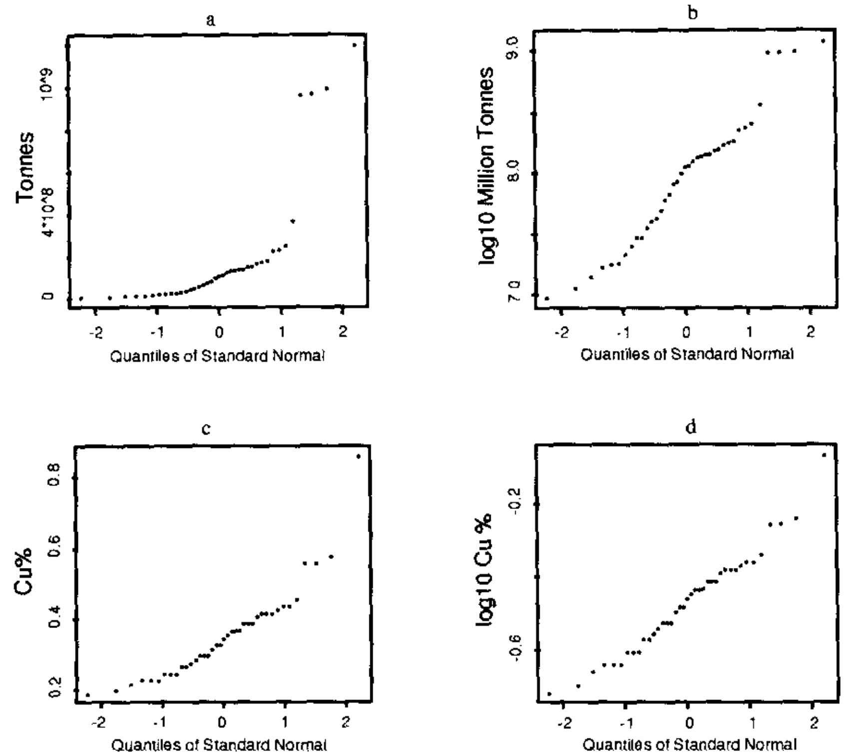

Figure 3: Quantile-quantile plots of British Columbia calcalkalic porphyry copper deposits.. Deposit tonnage and copper grades are displayed as raw untransformed data and as log-transformed values. The use of quantile-quantile plots graphically displays the distributional nature of the data. The tonnage data displayed in raw form (a) show a marked positive skewness. The log-transformed tonnage data (b) display characteristics that are more typical of a normally distributed set of data. Note the 4 outliers in (b). The copper data show a small positive skewness in the raw state (c). This skewness is absent in the log-transformed state (d).

TABLE 2
SUMMARY STATISTICS FOR BRITISH COLUMBIA CALCALKALIC PORPHYRY COPPER DEPOSITS.

	Tonnes	Cu%	Mo%	Au g/t	Ag g/t
Minimum	6.98	-0.77	-2.05	-2.3	-0.82
1st Quartile	7.54	-0.58	-0.2	-1.06	-0.08
Median	8.03	-0.47	-1.73	-0.68	0.07
Mean	7.95	-0.47	-1.76	-0.84	0.11
3rd Quartile	8.24	-0.38	-1.7	-0.47	0.37
Maximum	9.08	-0.07	-1	-0.12	1.23
Variance	0.3	0.02	0.07	0.36	0.22
NA's	0	0	16	17	25

Note: All data transformed to log (base 10)
NA= Missing Values (Data not available)

The compilation, description and refinement of grade and tonnage data is being carried out for all deposit models for which data are available in British Columbia. The resulting models will provide a realistic basis for quantitative resource estimation procedures that form a core part of the British Columbia Resource Assessment Process.

ACKNOWLEDGMENTS

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NOTES

MINERAL POTENTIAL OF THE OKANAGAN-SIMILKAMEEN-BOUNDARY AREA (82E, 82L/SE, SW, 92H/SE, NE)

By B.N. Church

Contribution to the Mineral Potential Project, funded in part by the Corporate Resource Inventory Initiative (CRII)

KEYWORDS: Okanagan, Similkameen, Boundary, mineral potential, tracts

INTRODUCTION

This report describes the preliminary phase of the mineral potential evaluation of the Okanagan-Similkameen-Boundary area in the southeast part of the Thompson-Okanagan region of south-central British Columbia. This is part of a province-wide study initiated by the B.C. Ministry of Energy, Mines and Petroleum Resources in May 1992 to provide accurate and credible information to landuse planning processes.

The Okanagan-Similkameen-Boundary area is part of a larger well-mineralized region of complex geology that has good potential for new mineral discoveries. This report attempts to define the areas (mineral assessment tracts) that may be favourable for future mineral development. These areas are the basic units for subsequent qualitative and quantitative mineral potential evaluations.

The evaluation process has two phases. Phase 1 ranks the tracts according to their mineral potential based on historic data. Phase 2 uses predictive methods based on the known and potential resource inventory. The steps in this process are (Kilby, 1994, personal communication); Hoy *et al.*, 1994; Church and Kilby, 1994):

(1) Geological compilation at a scale of 1:250 000.
(2) Define mineral assessment tracts.
(3) Compile mineral deposit data.
(4) Review of geology and mineral inventory data by industry geoscientists.
(5) Phase 1 of the mineral potential assessment.
(6) Estimate the mineral potential of undiscovered deposits in the tracts.
(7) Phase 2 of the mineral potential assessment.

These evaluations are scheduled for completion in 1995.

HISTORY

The Okanagan-Similkameen-Boundary area includes the southeast part of the Thompson-Okanagan planning district, one of several designated planning districts in British Columbia (Figure 1). It corresponds in part with the "Okanagan-Shuswap Region" that was the focus of a broad based economic study sponsored by the British Columbia government in 1971.

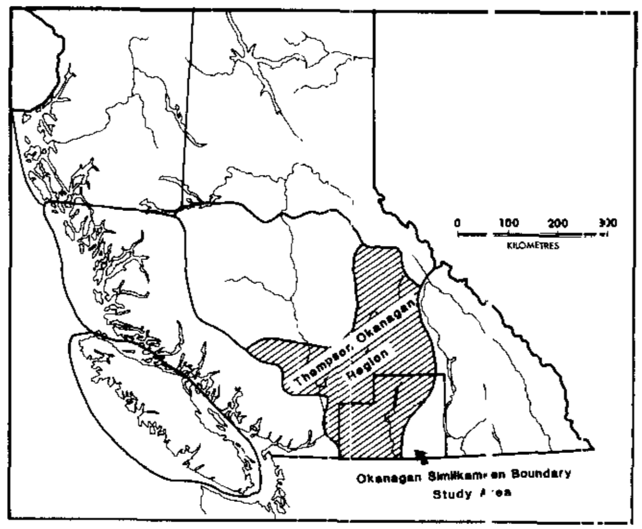

Figure 1. The Okanagan-Similkameen-Boundary study area, southeastern part of the Thompson-Okanagan planning district.

The first comprehensive evaluations of the geology and mineral deposits of the region were by Cairnes (1937), Rice (1947) and Jones (1959). From these studies it was clear that some geological units are mineralized and others are relatively barren. It is also apparent that many types of mineral deposits occur in the region and that each type tends to cluster, forming mineralized tracts or distinctive areas constituting mining camps.

Mineral Deposit Land Use (MDLU) maps were developed in the period 1969 to 1978 at a scale of 1:250 000 to cover most of the province (McCartney *et al.* 1974). This was the first step in estimating mineral potential. The MDLU maps classified areas into five categories, according to mineral exploration potential, ranging from 1, the highest, to 5, the lowest. This classification was based on the frequency of mineral occurrences and the geological environment of the area. The various types of deposits were indicated and metal producers were labelled according to size. A review of the MDLU program by Legun and Matheson (1991) showed that the maps were quite successful. Indeed most new discoveries are within the delineated high-potential areas 1 and 2. In glacial drift covered or unmapped areas some deposits undoubtedly remain undetected.

Figure 2. Geology of the Okanagan-Similkameen-Boundary area showing the main granitic batholiths and plutons.

THE GEOLOGICAL MAP

The area covered by this study encompasses the Penticton (82E), Vernon (82L, south half) and Princeton (92H, east half) quadrangles - a total area of about 34 000 square kilometres (Figure 2). Compilation of the geology is based mainly on the publications of Tempelman Kluit (1989) for the Penticton area, Okulitch (1978, 1991) for the Vernon area, Monger (1989) for the Princeton area, the Tectonic Assemblage Map of the Canadian Cordillera by Wheeler and McFeely (1991) and the contributions of more than 90 other authors.

The Okanagan-Similkameen region consists principally of accreted Mesozoic oceanic arc (Pacific plate) terranes in the western part (Nicola Group) and Proterozoic-Paleozoic pericratonic (North American plate) rocks to the east (Monashee-Shuswap Complex). The major boundary between these areas is the Okanagan fault system. The rocks are overprinted by several episodes of metamorphism related to the intrusion of numerous Triassic to Tertiary plutons. Tertiary graben and half-graben (late orogenic) structures infilled with rocks of the Penticton, Princeton and Kamloops groups are associated with the Okanagan fault system and smaller rifts in the Princeton and Kettle River areas.

There are 54 distinctive lithological units on the map, half of which are bedded rocks and half, igneous intrusions. The late Paleozoic and younger part of the stratigraphic column is well represented with an average of two or three units for each epoch; the older rocks are not as readily subdivided because of the scarcity of fossils and the alteration of primary structures by regional metamorphism. The intrusive rocks are mostly Triassic or Jurassic age; a few are Paleozoic, and about one third are Cretaceous or Early Tertiary.

The prospecting philosophy for the region proposed by Cairnes (1937) holds that intrusive rocks are the prime source of metallic mineralization (a philosophy that remains valid for most of the important metal deposits in the area). Corollaries to this are that the small intrusive bodies are favourable locations for ore deposits as are roof pendants in the larger intrusions. Bodies of diorite, quartz diorite and alkaline rocks are more favourable for mineralization than bodies of granite and granodiorite.

MINERAL ASSESSMENT TRACTS

Garnett (1971) indicated high priority areas (tracts) of mineral potential for the Okanagan-Similkameen area based on gross lithology, age and structural information. For example, the Nicola Group (Triassic-Jurassic age) and subjacent feeder intrusions form large tracts in the Princeton and Vernon areas especially favourable for mineral exploration, whereas the equally large areas underlain by Tertiary rocks and the Shuswap Metamorphic Complex in the Penticton area have conspicuously fewer mineral occurrences.

In this study the concept of a geological tract is refined somewhat and becomes the basis for more detailed evaluation. A tract is a non-political land unit (defined at a scale of 1:250 000). It is underlain by a an array of variously mineralized geological formations in a structural panel with clear lithological boundaries such as faults or intrusive contacts. A total of 48 tracts have been delineated in the Okanagan-Similkameen-Boundary area (Figure 3, Table 1). Each tract is given a local name and distinctive symbol (*e.g.* "P1h" for Princeton). The tracts range in size from about 30 square kilometres for the Tulameen basin (P2h) to 1560 square kilometres for the Okanagan Highlands (M2). The number of geological units in each tract varies from one (the Anarchist Group) in the Bridesville tract (AN1), to five units in the Lambly Creek tract (H1).

The ranking of tracts is useful to economists and land-use decision makers. Garnett (1971) used a qualitative method of ranking. He chose four ranking levels - (1) areas with currently producing mines, (2) areas of high potential for future mineral production, (3) areas with a geological setting favourable for the discovery of new mineral deposits, (4) areas of uncertain mineral potential with only a few scattered mineral occurrences.

The determination of ranking by Kilby (1994, *personal communication*) begins with the following data:

- Estimated value of known mineral reserves.
- Historical exploration expenditures.
- Value of past production.
- Number of mineral occurrences.

These data are then weighted according to ability to predict sustainable mineral exploration and development.

The mining camps and mineralized tracts are patterned, in Figure 3 of this report, such that increasing pattern density is relative to increasing intensity of mineralization and mineral potential. 'Very high' ranking results from the combination of major mineral production, significant expenditures on exploration and a high frequency of mineral occurrences that is typical of the principal mining areas such as the Hedley camp (noted for gold production), the Beaverdell camp (silver), the Greenwood camp (copper, gold, silver) the Copper Mountain camp (copper), and the Tulameen basin (coal). 'High' ranking is typical of the lesser mining and prospecting areas such the copper deposits in the Axe-Cincinnati belt in the Aspen Grove area, Dusty Mac (gold and silver) in the Penticton area, Chaput (silver, lead and zinc) near Vernon, and the Hydraulic Lake - Blizzard area (uranium). 'Moderate' ranking areas are characterized by favourable geology but negligible mineral production and only scattered mineral occurrences, such as the disseminated copper and molybdenum prospects associated with the Bromley batholith, and the platinum and chromite showings associated with the Tulameen Ultramafic Complex.

Figure 4 shows the distribution of mineral occurrences and the principal mines in the study area.

RESOURCES

The mineral resources of the area are metallic minerals, industrial minerals and coal - of which the first

Figure 3. Mineral assessment tracts (mining camps and mineralized tracts patterned).

TABLE 1. DESCRIPTION OF MINERAL ASSESSMENT TRACTS

Tract	Tract Name	Units*	Resources	Tract	Tract Name	Units*	Resources
AP	Keremeos	Apex Mountain Group, Cahill (South) pluton, Penticton Group	copper, molybdenum, gold, silver	N2	Coalmont	Nicola Group	veins
AN1	Bridesville	Anarchist Group	podiform chromite	N3	Similkameen Falls	Nicola Group	veins
AN2	McKinney	Anarchist Group	gold quartz veins	N4	Hedley	Nicola Group, Cahill Creek pluton, Sl well Pekens Group, Hedley Intrusions	garnet and gold skarns
B1	Bromley	Bromley pluton, Nicola Group	veins	N5	Aspen Grove	Nicola Group, Allison Lake pluton, Chilcotin Group, Spences Bridge Group,	copper, veins
BR	Greenwood	Brooklyn Group, Attwood Group, Knob Hill Group, Greenwood pluton, Penticton Group	copper gold skarns, polymetallic veins, copper porphyries	N6	Cherryville	Nicola Group, Harper Ranch Group, Chilcotin Group	polymetallic veins
CM	Copper Mountain	Copper Mountain stock, Nicola Group	alkaline porphry copper	N7	Lumby	Nicola Group, Harper Ranch Group, Kamloops Group, Nelson Plutonic Complex, Silver Creek Formation	polymetallic veins
CS	Cathedral	Cathedral Lakes pluton, Similkameen batholith		N8	Vernon	Nicola Group, Harper Ranch Group, Kamloops Group	gypsum and granite quarries
C1	Christina Lake	*Coryell intrusions, Nelson Plutonic* Complex, Valhalla intrusions, Mt Roberts Group	polymetallic skarns, veins	O1	Trout Creek	Osprey Lake batholith, Summers Creek pluton	granite quarries
C2	Kettle River	Ladybird granite, Coryell intrusions, Nelson Plutonic Complex, Penticton Group		OK1	Vaseaux	Okanagan batholith, Valhalla intrusions, Nelson Plutonic Complex, Coryell intrusions, Monashee gneiss	veins
E1	*Granite Mountain*	*Eagle Plutonic Complex*	*veins*	*OK2*	*Isintok*	*Okanagan intrusions, Penticton Group*	*uranium, veins*
FR	Franklin	Harper Ranch Group, Coryell intrusions	polymetallic veins	PN	Pennask	Pennask batholith, Nicola Group, Penticton Group	copper, molybdenum porphyries
H1	Lambly Creek	Harper Ranch Group, Chapperon Group, Terrace Creek batholith, Penticton Group, Lambly Creek basalt	veins	P1e	Penticton	Penticton Group	epithermal gold-silver veins
J1	Skagit	Jackass Mountain Group, Dewdney Creek Formation, Ladner Group		P2e	Rock Creek	Penticton Group, Coryell intrusions, Knob Hill Group, Brooklyn Group, Anarchist Group	epithermal gold-silver veins
K1	Cawston	Kobau Group, Similkameen batholith, Nelson Plutonic Complex, Fairview intrusions, Apex Mountain Group	silver quartz-carbonate veins, nepheline syenite, skarn copper, quartz	P3e	Kelowna	Penticton Group, Terrace Creek batholith, Nicola Group, Lambly Creek basalt	veins
K01	Fosthall	Kootenay assemblage, Fosthall intrusions, Nicola Group	lead, zinc	P0h	Princeton I	Princeton Group	zeolites
K02	Sugar Lake	Kootenay assemblage, Harper Ranch Group, Nelson intrusions	veins	P1h	Princeton II	Princeton Group, Nicola Group	coal
LD	*Trapping Creek*	Vahalla intrusion, Monashee gneiss, Chilcotin basalt	*uranium*	*P2h*	*Tulameen I*	*Princeton Group, Chilcotin Group*	coal, kaolinite, bentonite
M1	Damfino	Nelson Plutonic Complex, Monashee gneiss	veins	PS	Manning	Pasayten Group	
M2	Okanagan	Shuswap Complex, Okanagan batholith	granite quarries	S1	Ashnola	Spences Bridge Group	copper, zinc, veins
M3	Grand Forks	Grand Forks gneiss, Tertiary intrusions	uranium pegmatites	S2	Thalia	Spences Bridge Group, Otter intrusions, Princeton Group, Nicola Group	veins
M4	Osoyoos	Vaseaux gneiss, Nelson Plutonic Complex, Anarchist Group	veins	T1h	Tulameen II	Tulameen Ultramafic Complex, Nicola Group	chromite, platinum, dunite
M5	Highlands	Shuswap Complex, Chilcotin Group, Nelson Plutonic Complex, Penticton Group	uranium, granite	TI1	Terrace	Terrace Creek batholith, Penticton Group, Harper Ranch Group, Coryell intrusions	gold quartz veins
NO	Lightning Peak	Harper Ranch Group, Valhalla intrusions, Nelson Plutonic Complex	polymetallic veins, skarns	V	Verde Creek	Verde Creek pluton, Princeton Group, Spences Bridge Group	veins
N1	Beaverdell	Nelson Plutonic Complex, Anarchist Group, Penticton Group	silver-bearing quartz-carbonate veins	VH	Edgewood	Valhalla intrusions, Nelson Plutonic Complex, Monashee gneiss	

**Formations in column three are given in order of importance*

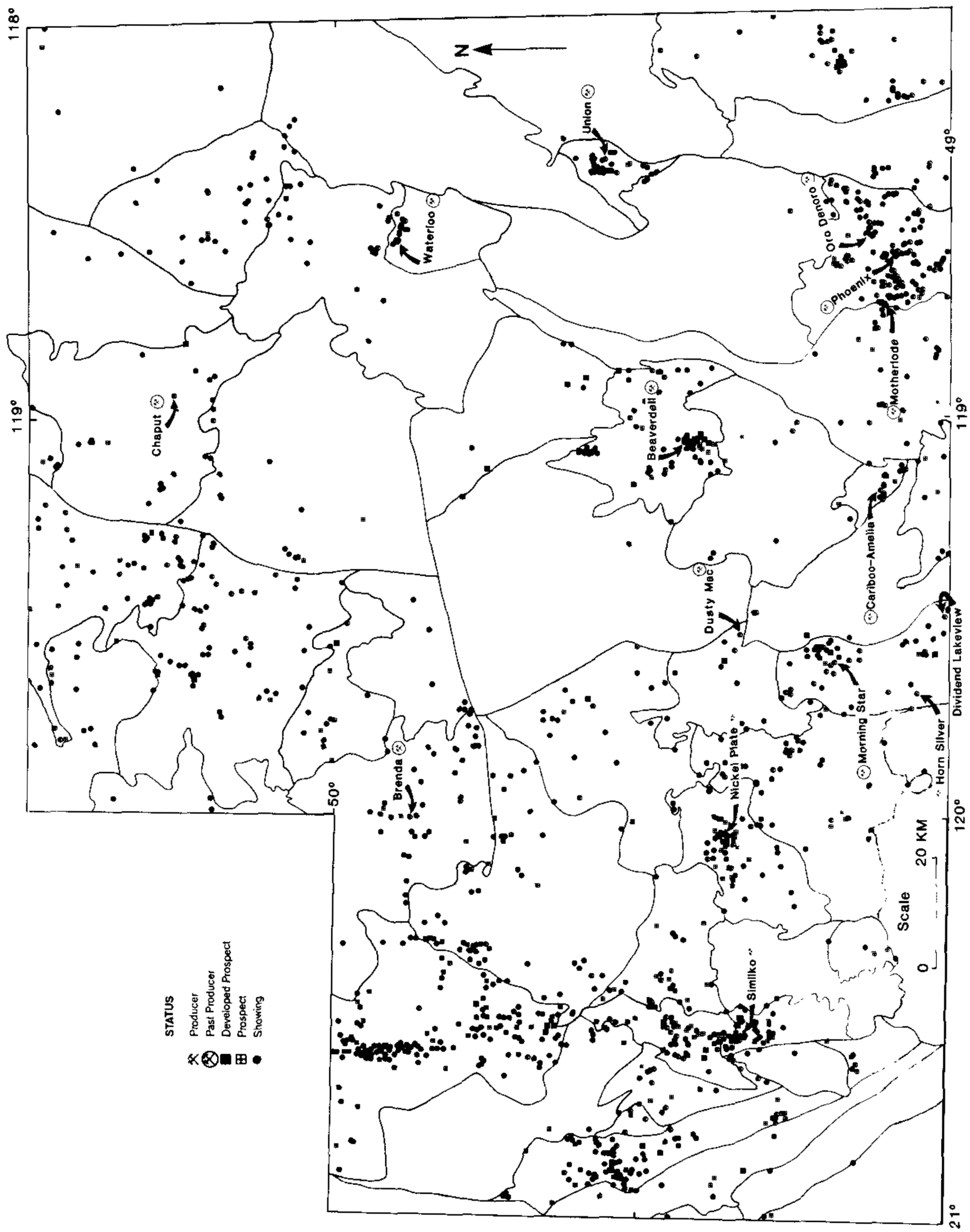

Figure 4. Location of principal mines and mineral occurrences.

is the most important. The principal metals are gold, silver, copper, lead and zinc (Figure 5). Gold is generally associated with silver; copper with molybdenum; and silver with lead and zinc. These metal combinations are common world-wide associations.

GOLD CAMPS

Most precious metal occurrences are in the southern part of the study area (Figure 5B). Gold clusters mainly in the Hedley and Greenwood camps in the Similkameen (southwest) and Boundary (southeast) areas, respectively.

The Hedley camp, which includes the Nickel Plate and adjoining Hedley Mascot mines, is one of the principal mining districts in British Columbia. Between 1904 and 1955 the Nickel Plate alone produced almost 49 tonnes of gold from underground workings. In 1987 Corona Corporation (formerly Mascot Gold Mines Ltd.) reopened the mine as a 2450 tonnes per day open-pit operation with ore reserves of 5.1 million tonnes averaging 2.98 grams per tonne gold. The gold is intimately associated with arsenopyrite and bismuth tellurides and hosted by pyroxene-rich skarn formed as a result of the intrusion of Hedley dioritic sills and dikes into Nicola limestone and siltstone (Ray and Dawson, 1994).

Camp McKinney is the most important of several mining areas where gold-bearing quartz veins are the main type of deposit. The Cariboo-Amelia mine, the largest producer in the camp, is recorded as having yielded over a million dollars in gold from 1895 to 1903 inclusive. It seems probable that further discoveries of note will be made in the area, however, the old workings are collapsed and there is little information to guide modern exploration other than to note that the hostrocks are assigned to the Anarchist Group (Cairnes, 1937).

The Fairview camp closely resembles Camp McKinney. The ore deposits are erratic quartz veins (with some sulphide mineralization) in schistose Kobau Group cut by Oliver and Fairview granitic stocks (Mader *et al.* (1989). Among the numerous properties in the area, only the Morning Star and Stemwinder mines had significant production. In the period 1898 to 1949 inclusive these deposits yielded 0.5 tonne of gold and 5.2 tonnes of silver. It is interesting to note that although the principal veins were more than 600 metres long, underground development was carried to depths of less than 100 metres. It may be that technological advances will allow deeper exploration and additional future production from these properties.

The Dusty Mac mine was distinctive in that it was an open-pit operation on a Tertiary quartz breccia - epithermal vein system. Gold, silver and a small amount of sulphides occur in a silicified lens on a gently dipping fault zone in the Penticton Group (Church, 1973). Production for the period 1969 to 1976 amounted to 10.5 tonnes of silver, 0.6 tonne of gold and minor copper and zinc.

SILVER CAMPS

The Beaverdell camp is centred on a quartz-carbonate vein system (Figures 4 and 5B) that was a continuous producer of silver, gold, lead and zinc from 1913 to 1991. The Sally property was the principal producer prior to 1911; this was followed by the Wellington and Rob Roy from 1919 to 1925. The Highland Bell mine, an amalgamation of properties including the Bell and Highland Lass, achieved a total production from 1913 to 1990 of 1074.3 tonnes of silver, 0.519 tonne of gold, 11.6 tonnes of lead and 13.9 tonnes of zinc. The ore occurs in veins and fractures in altered granodiorites and granites of the West Kettle batholith near the contact with the Permo-Carboniferous Anarchist Group.

The Horn Silver (Utica) mine is known for significant silver and minor gold, lead and zinc production (like the mines in the Beaverdell area). The principal deposit is a faulted, gently dipping, sulphide-bearing quartz-carbonate vein system. The hostrock is an altered phase of the Kruger syenite that is a border facies of the Middle Jurassic Similkameen batholith. Production from this mine for the period 1915 to 1968 was 127.2 tonnes of silver, 0.3 tonne of gold, 0.3 tonne of lead and 0.4 tonne of zinc.

COPPER CAMPS

The Copper Mountain camp is a prime copper, gold and silver producer. The Copper Mountain (Similco) and Ingerbelle mines account for most of the production from 33 localities in the area for which there are records of copper shipments. Orebodies in the camp occur principally in Nicola volcanic rocks peripheral to the Copper Mountain stock. The orebodies are skarns transitional to porphyry types, developed both by underground and open pit mining methods. Localization and concentration of sulphides is largely controlled by a north-trending fracture system (Preto, 1972). Production from the Copper Mountain mine for the period 1903 to 1990 amounted to 543 382 tonnes of copper, 12.5 tonnes of gold and 230.7 tonnes of silver; production from the Ingerbelle mine for the period 1972 to 1979 is recorded as 156 628 tonnes of copper, 7.3 tonnes of gold and 29.3 tonnes of silver (MINFILE).

The Brenda mine was the most significant large-tonnage low-grade mining operation in the region. The mine is underlain by border phases of the Pennask batholith just east of a large pendant of Nicola Group rocks. The mineralization is porphyry type consisting of a reticulation of sulphide-bearing quartz-carbonate veinlets in altered quartz diorite and porphyritic granodiorite (Carr, 1968). Total production from this deposit in the period 1970 to 1990 was 2.3 tonnes of gold, 148 tonnes of silver, 276 227 tonnes of copper and 67 929 tonnes of molybdenum.

The Greenwood mining camp is a world-class copper-gold-silver producer. The Phoenix, Motherlode and Oro Denoro mines, the largest of 26 producers in the

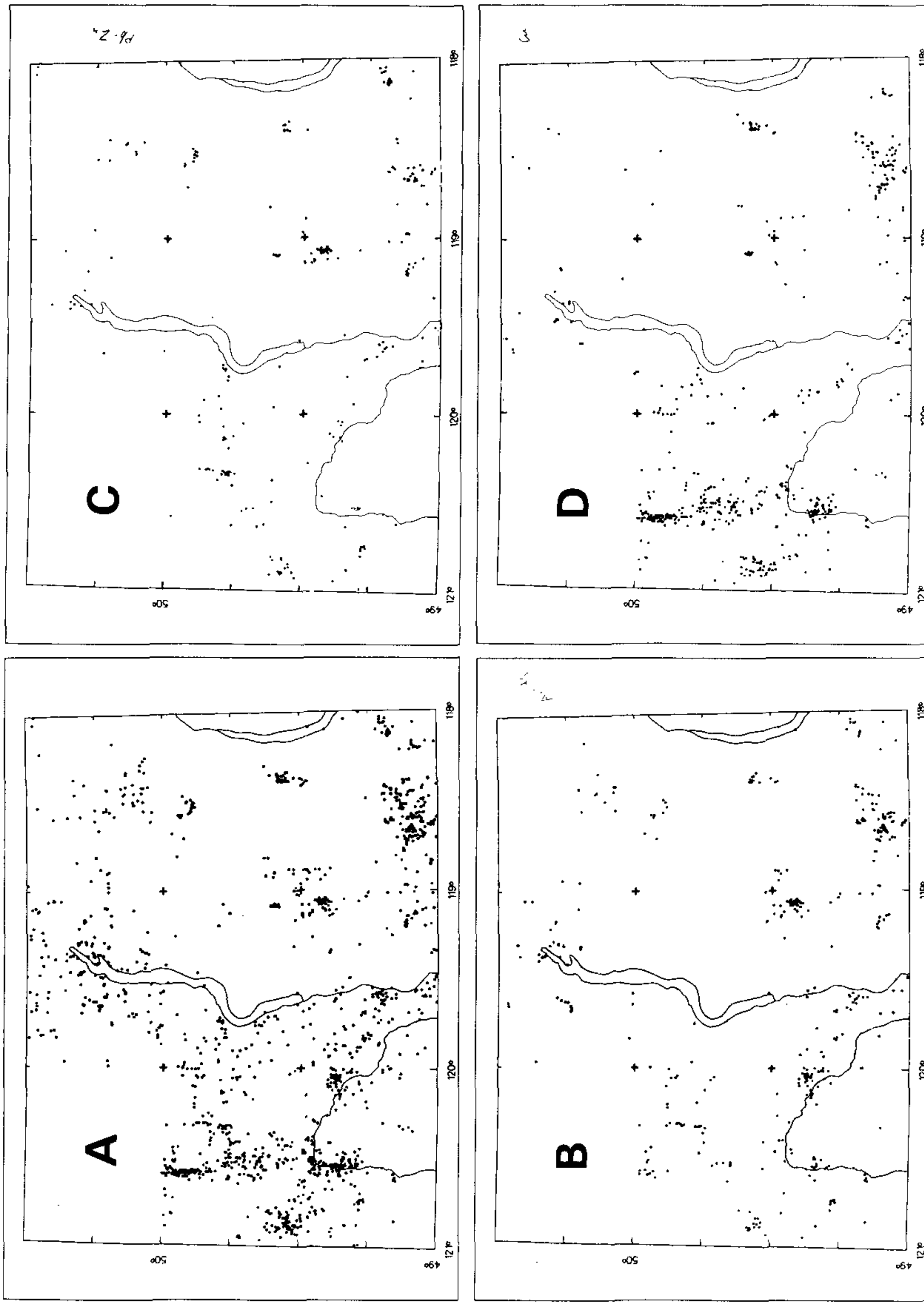

Figure 5. Distribution of mineral occurrences (A); showing gold and silver (B); lead and zinc (C) and copper (D).

area, are copper skarn deposits developed in Triassic limestone. To a lesser extent production has been derived from gold and silver-bearing quartz veins containing a minor amount of lead and zinc. Total production from the camp is 32 044 173 tonnes of ore that yielded 38.3 tonnes of gold, 283.1 tonnes of silver, 270 945 tonnes of copper, 966 tonnes of lead and 329 tonnes of zinc (Church 1986).

LEAD-ZINC (SILVER) CAMPS

The Franklin camp is comprised of about 25 mineral occurrences in Anarchist volcanic and metasedimentary rocks (Drysdale, 1915). These are principally skarn deposits related to the Nelson and Valhalla granitic plutons, veins and segregations in the multiphase Averill alkali complex and polymetallic veins related to Tertiary faulting. The Union mine is the largest producer in the area. During the period 1913 to 1946 this mine produced 1.7 tonnes of gold, 42.9 tonnes of silver, 12.7 tonnes of copper, 168.5 tonnes of lead and 299.5 tonnes of zinc.

The Lightning Peak mining camp consists of polymetallic vein systems and skarns. The area is underlain by remnants of metavolcanic and metasedimentary rocks of the Anarchist Group which have been intruded by Nelson granitic stocks (Cairnes, 1931). The area has witnessed intermittent production from 1903 to 1983. The Waterloo mine, the largest operation, has produced 2.6 kilograms of gold, 1586 kilograms of silver, 5 kilograms of copper, 14 tonnes of lead and 37 tonnes of zinc.

The Chaput mine worked a polymetallic quartz vein system in folded Nicola metasedimentary rocks near a small Cretaceous granodiorite stock. Production from this mine for the period 1968 to 1976 was 1.7 tonnes of silver, 72.2 tonnes of lead and 50.8 tonnes of zinc.

The Skookum occurrence is similar to Chaput but smaller. Polymetallic quartz veins are developed in Nicola volcanic and metasedimentary rocks. Production from this deposit for the period 1936 to 1969 amounted to 84.4 kilograms of silver, 1.2 kilograms of gold, 45 kilograms of copper and 3.15 kilograms of lead.

The Dividend-Lakeview mine is a significant polymetallic skarn deposit developed in micaceous quartzite, chlorite schist, limestone and greenstone units of the Kobau Group near the margin of the Osoyoos batholith. From 1907 to 1939 a total of 0.5 tonne of gold, 0.088 tonne of silver, 73 tonnes of copper, 71 tonnes of lead and 71 kilograms of zinc were produced (Ettlinger and Ray, 1989).

OTHER COMMODITIES

Other important mineral commodities in the region include coal, uranium, dolomite, gypsum, silica and granite.

The principal coal mines worked major deposits in the Princeton and Tulameen basins. The product was soft thermal coal from the limnic sedimentary formations of the Princeton Group. Numerous small mines in the Princeton area began production in 1910 and continued through 1961 producing 1.6 million tonnes of coal. Production from the nearby Tulameen deposit occurred intermittently between 1915 and 1957, yielding more than 2.6 million tonnes (Matheson *et al.*, *1994)*.

The Dolo claim near Rock Creek is a notable local source of dolomite. This is a pod, estimated to contain 15.4 million tonnes of fine-grained white dolomite, occurring in hornblende gneiss and schist of the Anarchist Group. Total production from this property for the period 1972 to 1988 is reported to be 60 000 tonnes (Fischl, 1992).

The Gypo silica deposit at Oliver was first explored in 1926. The deposit is a large quartz lens in a porphyritic phase of the Oliver granite. Mining operations were intermittent at first then continuous from 1953 to 1968. Initially the quartz was shipped for smelter flux. Total production to the end of 1968 is estimated to be approximately 600 000 tonnes (Foye, 1987).

The Falkland gypsum deposits occur as a series of lenses in a succession of sheared Harper Ranch tuffs and argillites. The main period of mining was from 1926 to 1956 during which time 1.125 million tonnes of gypsum was produced (Butrenchuk, 1991).

Granite has been produced at several localities in the Okanagan-Similkameen region; there was significant demand for granite throughout Brish Columbia from 1911 to 1916, and 1952 and 1966. In the Vernon area a few hundred cubic metres of granite was shipped from the Lefroy quarry (1910-1912) near Okanagan Landing on the east side of Okanagan Lake and subsequently (until 1950) from the larger Vernon Granite and Marble Works quarry a few kilometres to the south (Carr, 1955). In the Kelowna area about 50 tonnes of granite has been quarried (1972 to recent) from the Starr claims on Little White Mountain. This is the 'Pacific Pearl' grey granite from the Late Cretaceous to Early Tertiary Okanagan batholith (Z.D. Hora, personal communications. 1993). There is a new quarry on the Dobo claims located about 40 kilometres west of Summerland. Here, a few hundred tonnes of 'Pacific Rose' red granite has recently been quarried from the Middle Jurassic Osprey Lake batholith. The Beaverdell granite has yielded about 90 tonnes of pink porphyry from a Tertiary stock (located 12 kilometres south of Beaverdell on Highway 33).

Basal uranium deposits occur at Hydraulic Lake, east of Kelowna and on the Blizzard property northeast of Beaverdell - the latter being the more important occurrence. At Blizzard the uranium is found in basal conglomerate, sandstone and shale below Chilcotin basalt lava flows. Basement rocks include Nelson and Valhalla granitic rocks and some Tertiary volcanics assigned to the Penticton Group. The ore reserves are estimated to be 2.2 million tonnes grading 0.182% uranium (Canadian Mining Journal, April 1979).

CONCLUSIONS

The Okanagan-Similkameen-Bounary district is part of a broad, well mineralized region in south-central British Columbia. The district is actually a quilt of mining camps and less favourably endowed mineralized tracts. Examples of areas with high mineral potential must include the Copper Mountain and Hedley camps that are currently active and record major precious and base metal production. Areas with high to intermediate potential are underlain by some of the large granitic batholiths such as the Osprey Lake and Pennask bodies that locally feature large, low-grade metal deposits (*e.g.* the Brenda porphyry). Coal deposits in the Tulameen and Princeton basins also have important potential. These basins retain major coal reserves for future exploitation. The production of industrial minerals and building stone from the district is commonly from areas not otherwise mineralized and having low potential for metal deposits - granite quarries, for example, are mostly free of quartz veins, alteration and sulphide mineralization.

This report describes the preliminary phase in assessing the mineral potential of the district - geological compilation, tract selection and ranking. The final phase in this process will employ subjective probability methods to estimate the unknown resource in each tract by drawing upon government and industry expertise in mineral commodities and local geology. In this process the writer is cognizant that mineable reserves increase with increases in commodity prices, improved infrastructure such as access to mining sites and new technology that makes it possible to produce economically from areas that could not be mined previously. Reserves are reduced by ongoing production, decreases in commodity prices, increases in mining or transportation costs, increased availability of substitute products, increased taxation or government regulations that restrict production.

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THE VANCOUVER ISLAND MINERAL POTENTIAL PROJECT (92B, C, E, F, G, K, L AND 102I)

By Nick W. D. Massey

Contribution to the Mineral Potential Project, funded in part by the Corporate Resource Inventory Initiative (CRII)

KEYWORDS: Mineral potential, Vancouver Island, land use, C.O.R.E.

INTRODUCTION

The Vancouver Island project was the first of the British Columbia mineral potential projects, being launched in June 1992. It was the test bed on which the methodology described by Kilby (1995, this volume) was developed.

The project area included Vancouver Island, the Gulf Islands and those parts of the mainland which are underlain by clearly identifiable Wrangellian stratigraphy. This area includes Texada and Lasqueti islands although they were not considered part of the Commission on Resorces and Environment's (CORE) Vancouver Island planning process. The area has a long history of mineral exploration and exploitation dating from the discovery of coal near Fort Rupert in 1848. Over 1300 mineral occurences are recorded in MINFILE and more than 1900 assessment reports have been filed since 1947. At present, four mines are operating on Vancouver Island - Island Copper (Cu,Ag, Mo, Au), Myra Falls (Cu, Zn, Ag, Au, Pb), Benson Lake (limestone) and Quinsam (coal) and three limestone quarries are operating on Texada Island - Blubber Bay, Gillies Bay and Imperial.

PHASE 1

The geology of the Island was compiled at 1:100 000-scale during the period from June to October 1992. Data were derived from a variety of sources including published maps and reports, theses and assessment reports (see Data Sources, below). The line work was digitized into the GIS and all polygons tagged as compilation progressed. The complete digital data were released in 1994 (Massey *et al.*, 1994).

The project area has been divided into 59 tracts (Figure 1). The tracts reflect significant differences in lithologies, structure and geological history, particularly where these are important to metallogeny, for example the Leech River Complex, the Sicker Group uplift areas and the Nanaimo Group. Where necessary, large lithologically determined tracts were subdivided, in order to have more convenient and more equal sized tracts. Tract definition made use of geological features, such as major faults or contacts, where possible. The tracts vary in size from 2138 to 215 677 hectares, averaging 58 368 hectares.

The number of mineral occurrences, the value of known resources in the ground, the value of exploration expenditures (as recorded or allowed in assessment reports) and the value of past production were compiled for each tract (Table 1, Figure 2). Tracts were then ranked and aggregated by area into three groups of highest, medium and lowest mineral potential, each category comprising approximately one third of the total project area (Figure 3). The results of this analysis were presented for use of the Vancouver Island CORE process and also displayed at Cordilleran Roundup 1993.

The highest ranked tracts include those underlain by or containing significant Sicker Group (*e.g.* the Cowichan and Buttle Lake uplifts), Tertiary intrusions (Zeballos, Mount Washington), Leech River Complex, Upper Triassic limestones (Texada and Quadra islands, Alice Lake) or Bonanza Group volcanics (Pemberton Hills). The lowest ranked areas occur in the east-central part of the Island and along the west coast fringe. They include the areas underlain by the Nanaimo Group which have significant coal and coalbed methane potential not considered in this analysis, but included in a separate energy study.

PHASE 2

The Phase 2 analysis was initiated with a workshop for potential expert estimators held on March 8, 1993 in Victoria. Attendees were drawn from industry, Ministry of Energy, Mines and Petroleum Resources and the Geological Survey of Canada. As a result, seventeen experts made 1127 separate estimations. The resultant value of estimated resources was used to re-rank the tracts (Table 1, Figure 4) and regroup them into the highest, medium and lowest categories (Figure 5).

As in phase 1, the highest ranked tracts include those containing Sicker Group, Tertiary intrusions, Leech River Complex, Upper Triassic limestones and Bonanza Group volcanics. Lowest ranked tracts include those dominated by Nanaimo Group sediments, Karmutsen Formation basalts, or Tertiary rocks along the western edge of the Island.

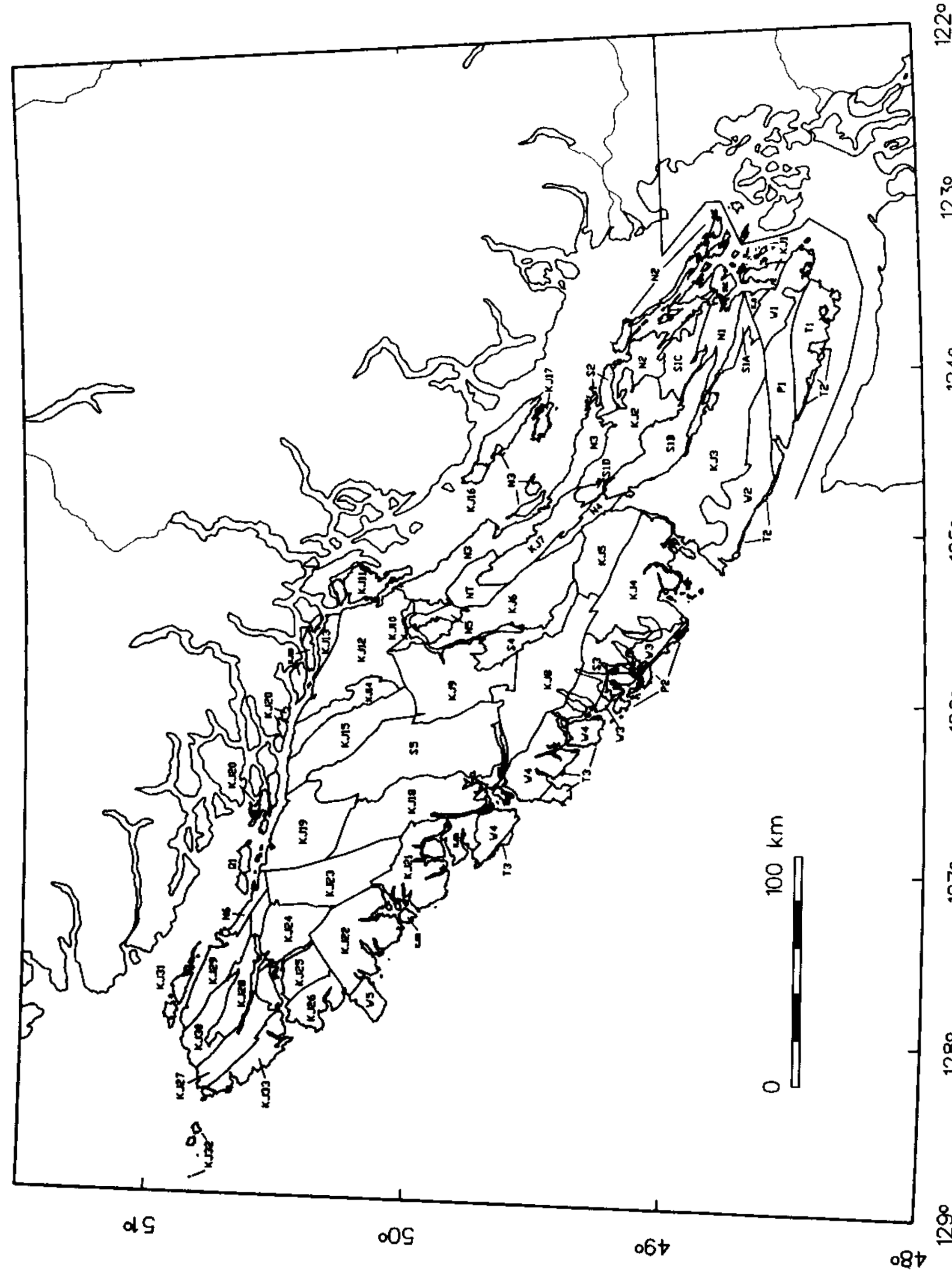

Figure 1. Mineral land assessment tracts for the Vancouver Island project.

TABLE 1: SUMMARY OF DATA FOR VANCOUVER ISLAND TRACTS

Tract Code*	Tract Name	Area ha	Number of MINFILE Occurrences	Value of Known Mineral Inventory $ (1986)	Exploration Expenditures $ (1986)	Value of Past Production $ (1986)	Phase 1 Ranking	Estimated Value of Future Resources $ (1986)/ha	Phase 2 Ranking
KJ28	Pemberton Hills	46,200	50	6,657,910,620	9,631,090	2,081,787,998	1	252,[illegible]85	1
KJ16	North Texada	5,602	70	54,933,062	1,732,992	113,567,236	2	154,[illegible]90	2
S3	Bedwell Sound	55,178	36	30,405,508	471,768	632,186	16	152,[illegible]59	3
KJ26	Le Mare Lake	34,020	11	-	231,368	-	36	111,[illegible]78	4
S1D	Summit	8,109	8	-	61,957	-	30	97,[illegible]56	5
S1A	Koksilah	17,411	19	-	121,935	61,422	20	81,[illegible]91	6
S4	Buttle Lake	46,308	24	2,126,554,822	1,103,477	1,132,377,838	3	70,[illegible]73	7
W3	Clayoquot	32,233	15	1,130,122,000	403,435	-	9	69,[illegible]19	8
KJ25	Klootchlimmis Inlet	41,582	19	11,665,192	930,019	8,741,835	8	41,[illegible]24	9
S1C	Saltspring-Chipman	52,644	43	138,918,904	3,936,089	40,073,253	5	40,[illegible]43	10
KJ21	Esperanza Inlet	99,850	49	156,784,342	420,995	111,351,289	11	35,[illegible]26	11
NT	Mount Washington	31,671	16	52,430,107	2,897,464	9,748,543	4	32,[illegible]40	12
KJ17	Texada-Lasqueti	30,385	37	-	708,592	280,608	18	30,[illegible]52	13
S1B	North Cowichan	77,124	86	29,270,629	6,185,907	2,138,836	6	26,[illegible]66	14
W4	Nootka-Flores	119,892	34	68,948,530	1,069,007	2,669,098	15	25,[illegible]06	15
S5	Schoen-Muchalat	197,550	10	-	428,819	-	46	22,[illegible]08	16
KJ3	Nitinat River	215,677	97	-	2,259,318	13,217,224	19	22,[illegible]54	17
KJ14	White River	38,895	4	5,440,033	50,437	-	50	19,[illegible]33	18
P1	Leech River	64,006	27	5,853,231	1,945,267	334,868	13	17,[illegible]57	19
KJ24	Alice Lake	52,545	40	149,154,000	413,696	126,317,956	7	16,[illegible]65	20
KJ33	Winter Harbour - Cape Scott	38,670	1	-	12,333	-	54	15,[illegible]89	21
KJ22	Ououkinsh Inlet	97,963	29	-	1,159,749	-	32	13,[illegible]92	22
KJ23	Karmutzen Range	98,761	36	-	580,252	3,136,738	23	13,[illegible]05	23
KJ10	Upper Quinsam Lake	17,668	10	-	82,002	4,038	22	11,[illegible]37	24
N2	Nanaimo	78,371	48	-	167,132	-	37	9,[illegible]90	25
KJ11	Quadra Island	26,984	57	9,876,094	326,898	692,996	10	9,[illegible]30	26
N4	Alberni Valley	20,864	5	-	60,122	-	43	8,[illegible]18	27
W1	Victoria-Shawnigan	46,079	16	-	17,505	-	47	8,[illegible]59	28
KJ4	*Kennedy Lake*	*131,617*	*104*	*50,419,732*	1,655,057	681,424	14	8,[illegible]31	29
KJ7	Beaufort Range	57,754	8	-	67,435	-	48	7,[illegible]88	30
KJ19	Bonanza Lake	93,460	31	14,999,388	953,740	218,570	17	7,[illegible]20	31
KJ1	Saanich	16,609	6	-	-	-	61	7,[illegible]08	32
KJ30	Nahwitti Lake	35,827	18	-	758,516	-	25	6,[illegible]54	33
KJ5	Sproat Lake	66,052	29	-	1,443,637	-	24	6,481	34
S2	Nanoose Arch	12,002	7	-	85,579	-	31	6,106	35
KJ20	North Johnson Strait	16,295	10	-	29,832	-	40	6,[illegible]35	36
W2	Bamfield-Renfrew	95,627	23	45,981,324	249,201	-	42	5,[illegible]32	37
KJ27	San Josef River	43,224	9	-	784,337	-	34	5,134	38
KJ32	Scott Islands	2,138	0	-	-	-	59	4,732	39
KJ8	Moyeha River	137,044	36	-	452,996	3,242,193	28	3,[illegible]93	40
KJ9	North Strathcona	118,352	9	-	210,040	26,331	39	3,[illegible]61	41
KJ15	Adam River	85,176	12	-	550,340	-	38	3,735	42
W5	Brooks Peninsula	15,514	1	-	-	-	55	3,690	43
KJ18	Woss Lake	113,859	29	2,059,184	444,917	8,413,906	27	3,672	44
N5	Quinsam	12,858	2	-	22,260	-	44	3,663	45
N3	Comox	121,326	9	-	5,835	-	53	3,478	46
KJ2	Nanaimo Lakes	85,732	29	-	1,466,324	8,949	21	3,387	47
KJ6	East Strathcona	111,440	12	-	214,791	-	45	3,234	48
P2	Pacific Rim	11,470	5	-	27,874	311,228	29	3,103	49
KJ29	Georgie Lake	46,469	14	-	446,064	-	35	2,072	50
N1	Duncan	48,741	9	-	1,324,981	-	26	1,858	51
T1	Sooke-Renfrew	59,489	28	37,417,380	337,038	27,810,381	12	1,202	52
KJ13	Rock Bay	29,081	3	-	10,803	-	52	1,138	53
KJ12	Salmon River	133,974	14	-	126,992	1,859	41	912	54
KJ31	Nigei	11,222	0	-	-	-	58	901	55
T3	Hesquiat	10,272	1	-	-	-	56	449	56
N6	Suquash	11,992	2	-	10,155	-	49	432	57
T2	Juan de Fuca Strait	9,254	1	-	119,644	-	33	210	58
Q1	Malcolm Island	8,665	0	-	-	-	57	-	59

* letters in tract code designate dominant geological unit as follows:

Q: Quaternary
N: Nanaimo Group
P: Pacific Rim Terrane
W: West Coast Complex

T: Tertiary Carmanagh Group or Matchosin Complex
KJ: Vancouver and Bonanza Groups, Island Plutonic Suite
S: Sicker and Buttle Lake Groups

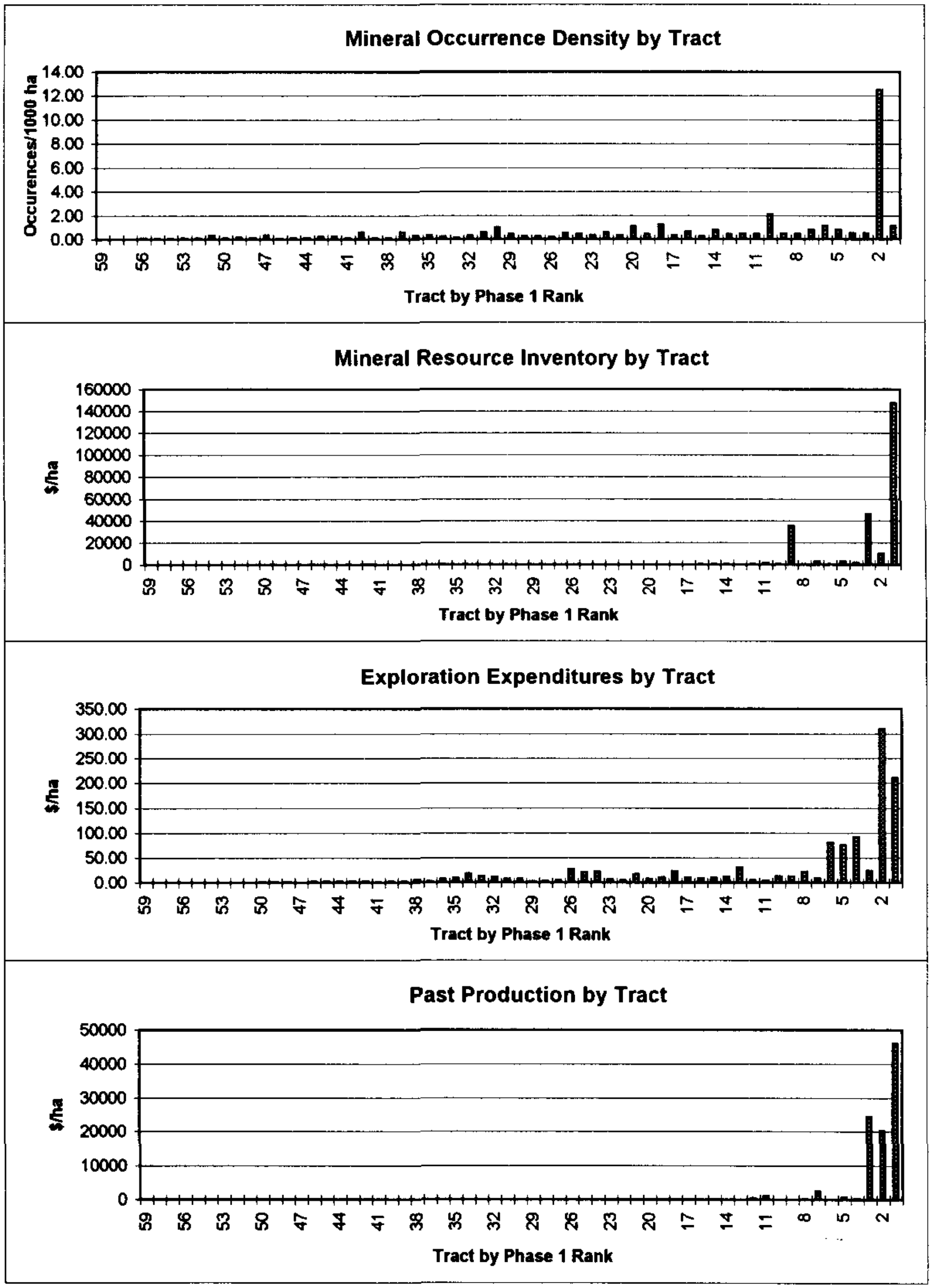

Figure 2. Ranges of data used in the phase 1 evaluation. The tracts are ordered from lowest (59) to highest (1), see Table 1.

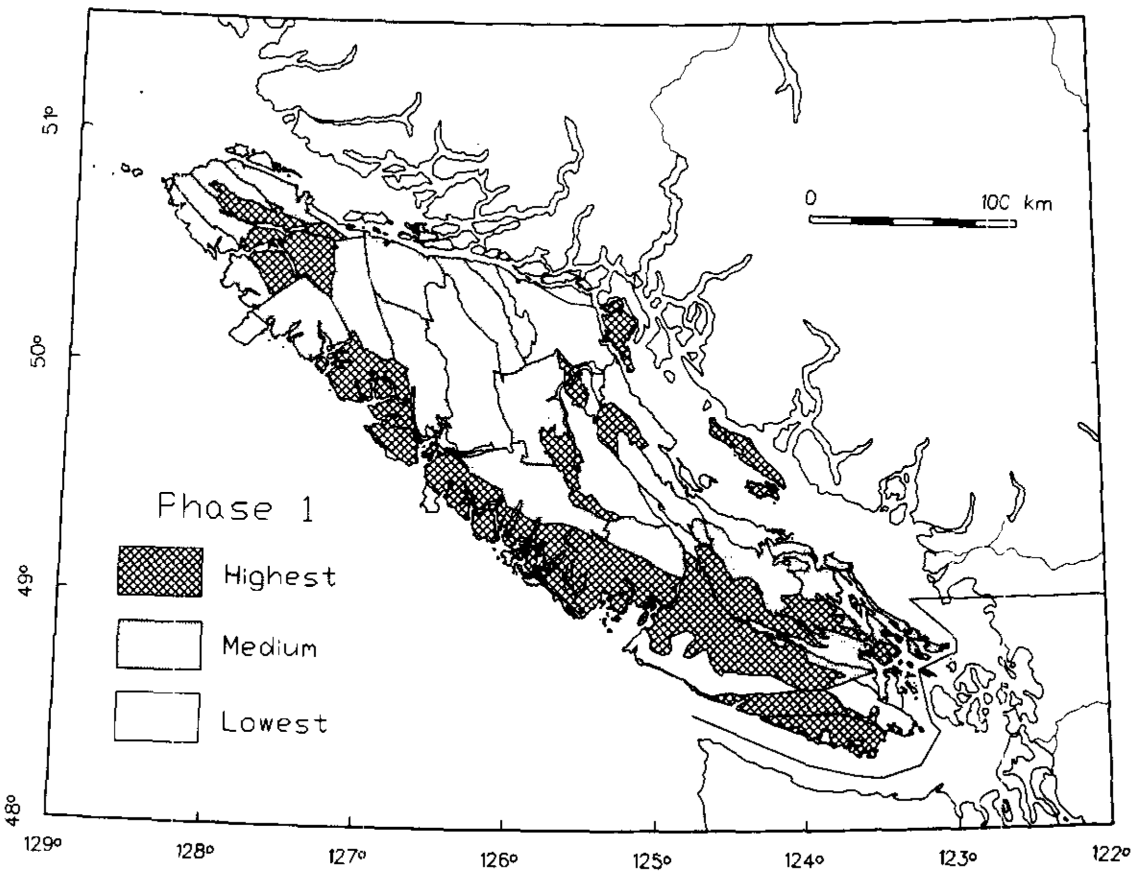

Figure 3. Distribution of phase 1 mineral potential categories. lowest tracts include those ranked 40 - 59; medium 20 - 39; highest 1 - 19

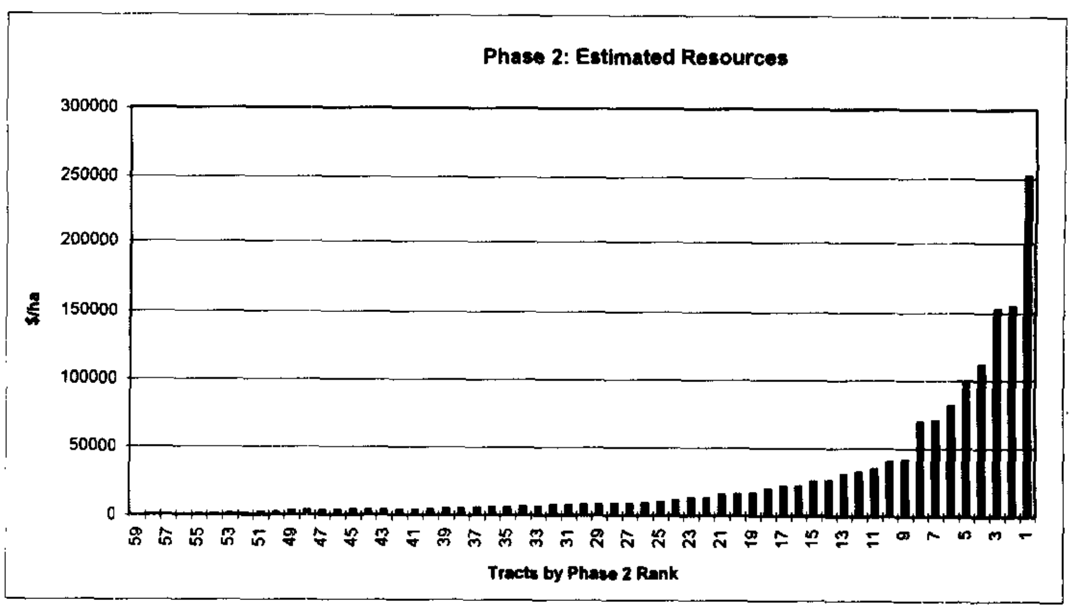

Figure 4. Range of phase 2 values ($/ha) for tracts in the Vancouver Island project area.

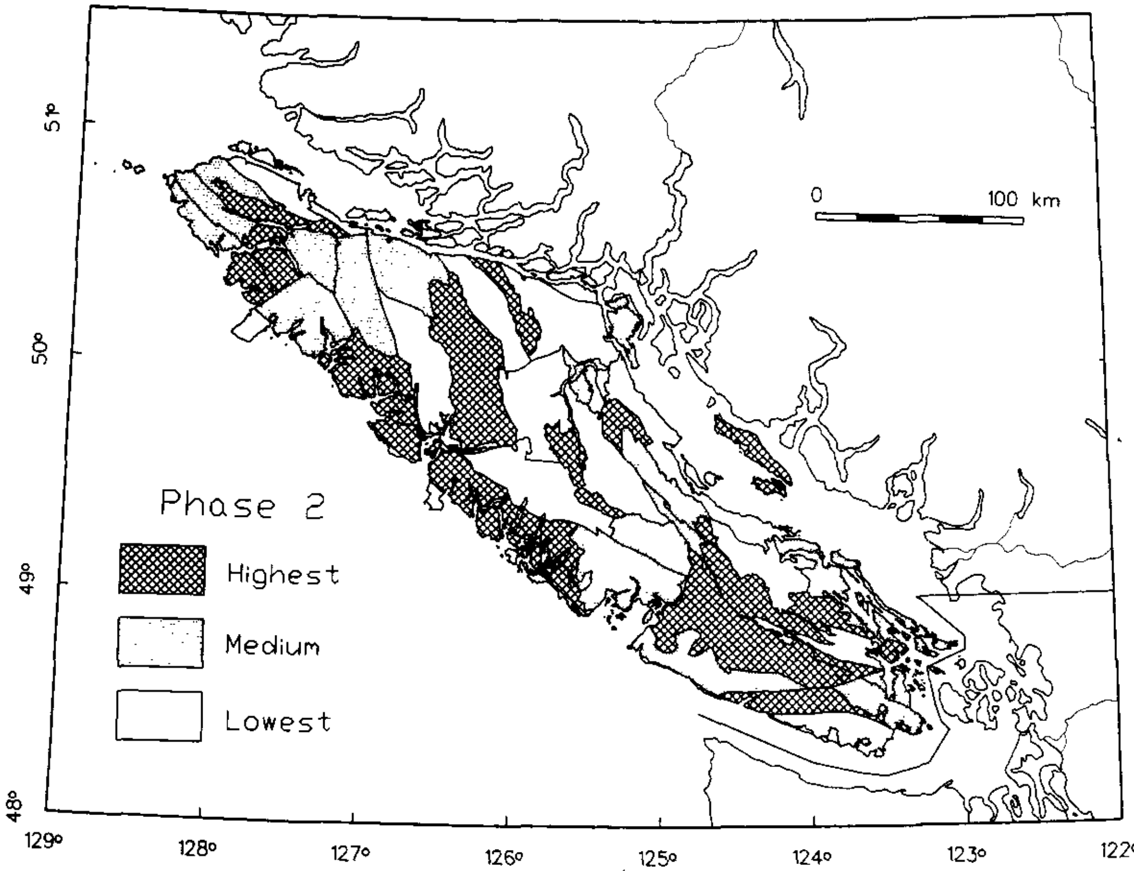

Figure 5. Distribution of phase 2 mineral potential categories. lowest tracts include those ranked 40 - 59; medium 20 - 39; highest 1 - 19.

COMPARISON OF PHASE 1 AND PHASE 2 RESULTS.

The addition of the estimated undiscovered resouces in phase 2, coupled with the consideration of a larger list of commodities than phase 1, may be expected to have an effect on the results of the mineral potential analysis. Despite the different methods used, the two phases of the study both express their findings as a relative ranking of the 59 tracts. The results of the two phases can thus be directly compared by looking at the relative rankings for individual tracts to see if any of them show significant changes.

Comparison of Figures 3 and 5 show many tracts fall in the same categories. However, several tracts have changed; the most startling being the Sooke-Renfrew area of southern Vancouver Island which dropped from highest to lowest categories, and the Schoen-Muchalat area which moved up from lowest to highest categories. It is easier, however, to compare the results of the two phases by plotting a histogram of the changes in relative rankings (Figure 6). Changes in relative ranking are generally not large and do not have a major impact on the final outcome. However, some tracts have moved more than 20 places in the ranked list, some upwards, some downwards.

Significantly, those tracts that have a large decrease in relative ranking occur in southern Vancouver Island. Here access and past exploration have been good and these tracts have good historical databases, consequently scoring high in phase 1. However, they are considered by the experts to have a poor potential for finding new resources and score much lower in the phase 2

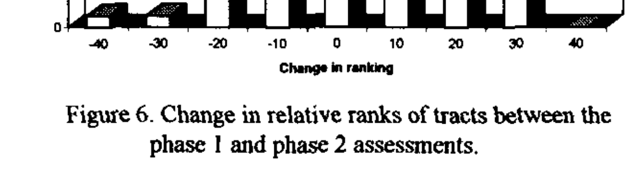

Figure 6. Change in relative ranks of tracts between the phase 1 and phase 2 assessments.

assessment. In contrast, areas in Northern Vancouver Island have poorer accessibility and have been less well explored in the past. However, they are underlain by geology that is very favourable to the discovery of more resources in the future, or contain resources such as magnetite skarns, excluded from the phase 1 process. These tracts thus ranked much higher in phase 2.

LAND USE RECOMMENDATIONS AND MINERAL POTENTIAL

The establishment of the Commission on Resources and Environment provided the major stimulus to the Branch's re-evaluation of the regional mineral potential of British Columbia. As such, the Commission's initial planning areas and timetable were the major influence on choice of areas of study and scheduling of geological compilation and data analysis.

As they were completed, the results of the mineral potential analyses were presented to the government Technical Working Group supporting the CORE process. They were incorporated into a GIS, along with other biophysical and cultural data sets. The final GIS model consisted of 26 groups of data divided into 114 layers. The mineral potential data formed one of these layers, with the energy potential and mineral tenure as separate, complementary layers. The attribute data accompanying the tract polygons comprises not only the tract rankings from both phases but all the supporting data behind those rankings, for example, the numbers of mineral occurrences recorded in the MINFILE database, exploration expenditures, etc.

After assembling the data, the Technical Working Group produced hard copy maps at 1:250 000-scale for each of the biophysical themes. Copies of these maps were then distributed to each sector at the Vancouver Island CORE Table for their use during deliberations. Separate maps were produced for minerals, energy and mineral tenure. Computers, loaded with the GIS data model, were also available during Table meetings to allow for interactive viewing and comparison of datasets.

It is almost impossible to evaluate how effective the mineral potential data were during the CORE Table deliberations due to the complex sociopolitical nature of that process and its failure to reach a concensus by the deadline date set by CORE. Anecdotal evidence confirms that the data were presented to all sectors, were available and consulted during meetings, and used in the evaluation of the various proposed land-use scenarios. It is easier, and maybe more useful, to evaluate the government's final land-use plan, based on the recommendations of the Commissioner, and their effect on mineral exploitation on Vancouver Island.

Table 2 summarizes the recommended land use subdivisions and the aggregate areas and proportions of each designation which fall in tracts of high, medium or low mineral potential from the phase 2 analysis. The areas are based on the preliminary recommended boundaries. These boundaries are presently being reviewed and a few will be the subject of major revisions. Comparing these spectra of mineral potential in the various categories suggests that the land available to exploration and mining (total multi-resource and low intensity areas) contains proportionally more high-value ground, and less low-value ground, than the lands to be protected.

However, this is a fairly simplistic analysis and looking at the data in more detail does point out some areas of possible concern. The proposed protected areas have significantly more medium-value ground compared to the rest of Vancouver Island. Also the regionally significant lands, which will have stricter review of work proposals, are dominated by high and medium-value

TABLE 2: MINERAL POTENTIAL OF RECOMMENDED LAND USE CATEGORIES

	HIGH		MEDIUM		LOW		TOTAL	
	ha	%	ha	%	ha	%	ha	%
Existing Protected Areas	75680	22.33	107843	31.82	155362	45.85	338885	10.31
Proposed Protected Areas	20069	22.29	53378	59.29	16583	18.42	90030	2.74
Multi-resource Lands	1002710	41.99	710029	29.74	675062	28.27	2387801	72.62
Low Intensity Areas	97483	36.16	132048	48.99	40035	14.85	269566	8.20
Cultivation	4929	5.11	26823	27.82	64653	67.06	96405	2.93
Settlement	10276	9.74	36728	34.81	58516	55.45	105520	3.21
Total Vancouver Island	1211147	36.83	1066849	32.44	1010211	30.72	3288207	100.00
Total Multi-resource + LIAs	1100193	41.40	842077	31.69	715097	26.91	2657367	80.82
Total Protected	95749	22.32	161221	37.59	171945	40.09	428915	13.04

ground.

To a large extent this reflects the somewhat arbitrary nature of the subdivision of the high-medium-low lands and the nonlinear range of values for the tracts (Figure 4). The arithmetic average mineral value of land for Vancouver Island is approximately $20 000 per hectare. However, tracts with values greater than this make up only 31.5% of the Island and would all be ranked as high potential. Thus all the medium and low-potential land has values less than the arithmetic average. The median value, that is the value exceeded by tracts that make up 50% of the area of Vancouver Island, is lower at $8000 per hectare. A significant jump in value occurs at about $50 000 per hectare, but tracts exceeding this value constitute only 7% of Vancouver Island. The values of $8000, $20 000 and $50 000 per hectare may be better benchmarks to use in evaluating the impact of land-use decisions.

Perhaps a more informative way to review the land use decisions is to consider the range of values for the various parcels of land designated as protected or low intensity and how they compare to each other and to the full range of values for the tracts. In order to carry this out, the phase 2 value has been calculated for each area designated as presently protected (EPA), proposed protected (CPA) or low intensity (LIA). Where a designated area is wholly contained within a single tract, it assumed the same ranking as that tract. Where it straddles more than one tract, an area calculation was made for the proportions of the study area within each tract, and those values used as weightings to the tract rankings to determine a fractional rank. These values were then added to determine a total rank for the area. Only the on-land portions of the areas were included as the mineral potential of marine areas has not yet been determined. Figures 7, 8 and 9 display the phase 2 values and areas of the existing protected areas, proposed protected areas and low intensity areas, respectively. The areas were also aggregated by tract and compared to the phase 2 tract values in Figures 10 to 12.

The existing protected lands show a range of values from $1000 to $150 000 per hectare (Figure 7). However, the areas of the higher value parks are small, a total of 6133.9 hectares with values over $50 000 per hectare. Strathcona Park with a weighted average value of $15 298 per hectare accounts for 71.4% of the total existing protected area. The distribution by tract (Figure 10) shows most of the land to be in the lowest value tracts, but a significant area in the higher tracts (21.9% in tracts over $20 000 per hectare, 13.6% over $50 000 per hectare). Most of this, however, is in tract S4, Buttle Lake, the most significant part of which is not actually alienated, falling within the Westmin Myra Falls mining lease.

The proposed protected lands (Figure 8) range in value from $900 to $41 500 per hectare, comparable to the existing protected areas. None have weighted values above $50 000 per hectare, and seven parcels, comprising 21.4% of the total CPA, have values over $20 000 per hectare. The largest of these parcels will warrant more

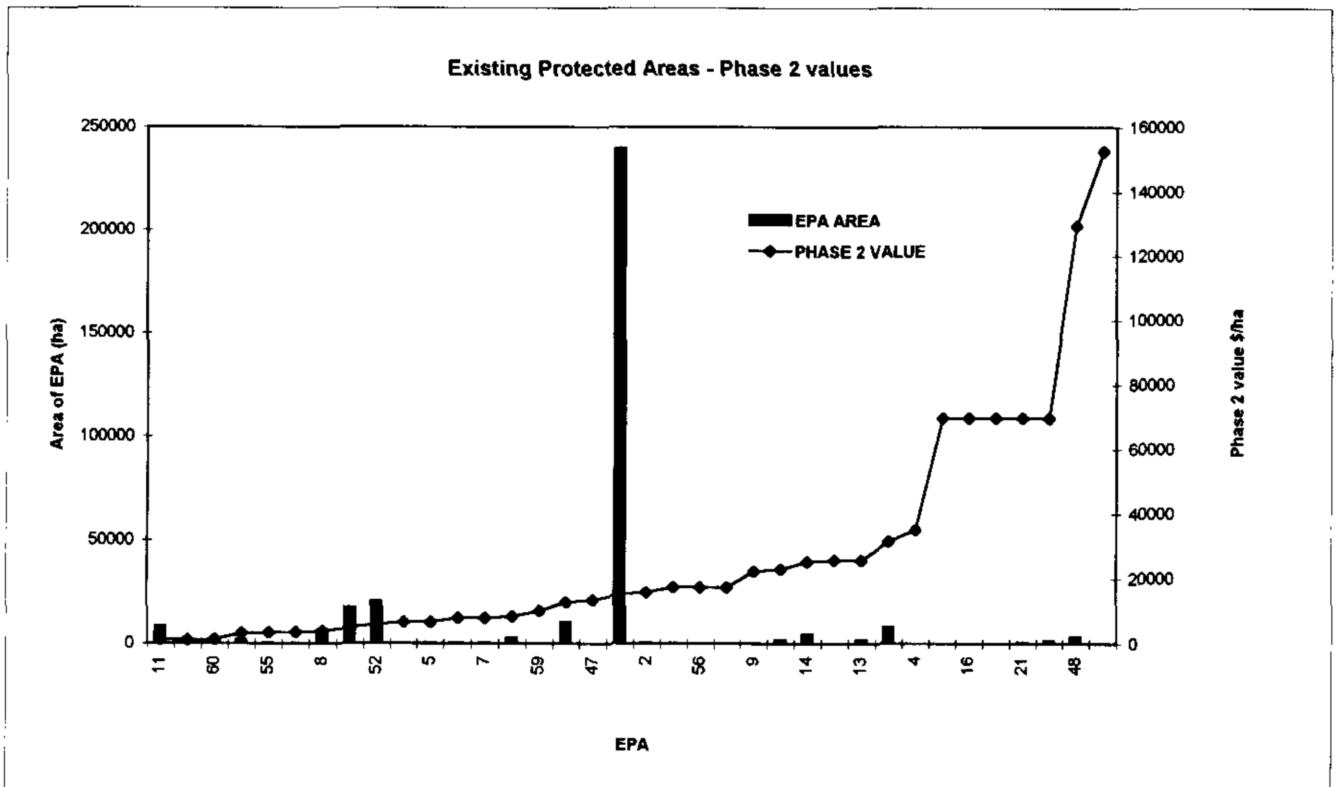

Figure 7. Phase 2 values for existing protected areas, Vancouver Island CORE region.

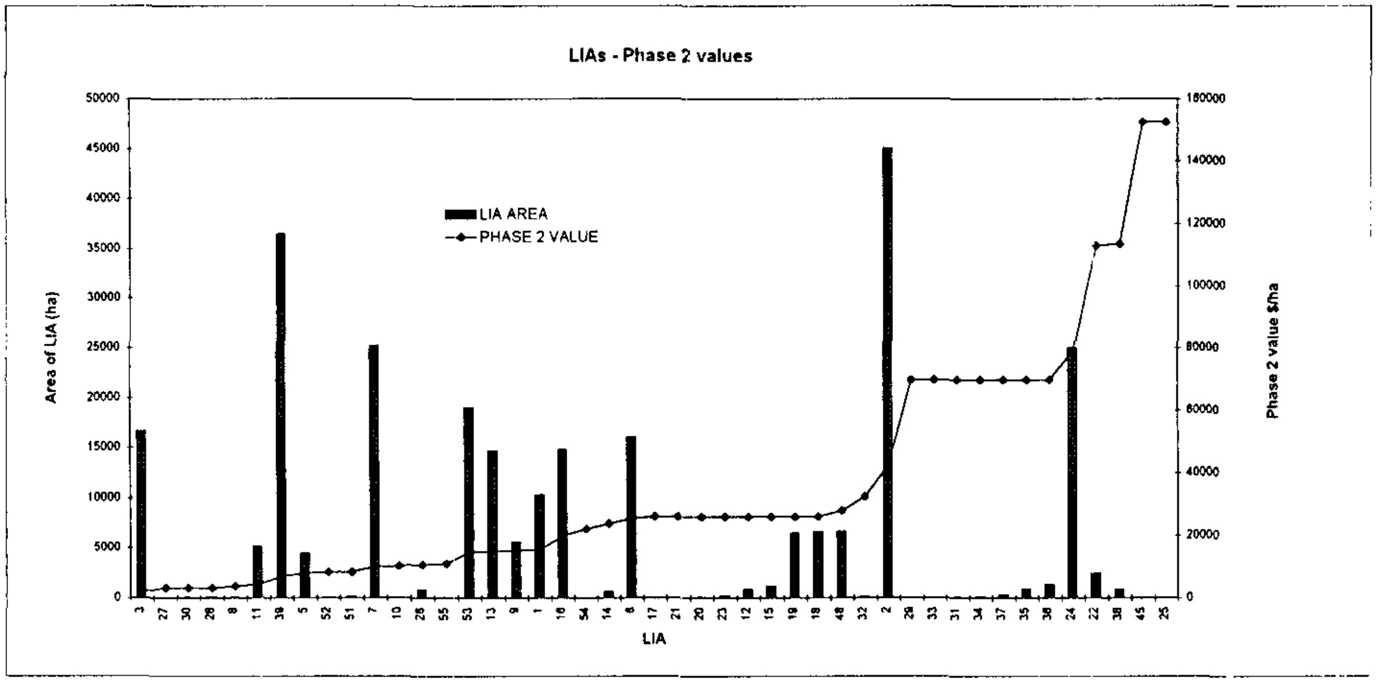

Figure 8. Phase 2 values for proposed protected areas, Vancouver Island CORE region.

detailed analysis to determine the local impact of alienation and possible boundary changes. The distribution by tract (Figure 11) shows most of the proposed protected land to be in tracts with values below the median of $8000 per hectare.

The low intensity areas (Figure 9) are very variable in size (<2 to 45 000 hectares) and weighted value ($2000 - $150 000 per hectare). The largest of these parcels are directly comparable in size to some tracts and warrant more detailed evaluation than given here. There is more high-value land in this category than in the protected lands, although it is concentrated in a few very large parcels. The distribution by tract (Figure 12) shows most (68%) of the LIA to be in tracts with values above the median of $8000 per hectare, 35% above $20 000 and 13% above $50 000. Although these percentages are higher than those for Vancouver Island as a whole, they are not significantly different to the range of values in the 80% of the island available to multi-resource use (the population from which the LIAs are drawn) suggesting that the designation of LIAs has been essentially mineral neutral.

Protected and alienated lands on Vancouver Island are disproportionately drawn from areas considered to be of lower value. The designation of LIAs, however, appears to have been mineral neutral, being based on other values. On the sub-regional scale, the designation and boundaries of land use areas are undergoing detailed review by government agencies. The above information is being considered in that review.

DATA SOURCES USED IN GEOLOGICAL COMPILATION

This list contains all published and unpublished, data used in the compilation of the geology of Vancouver Island. Numerous assessment reports were also consulted providing data supporting or enhancing the listed sources. Aeromagnetic maps at 1:50 000 scale are available for the whole project area and were utilized, though they are not included in the listing.

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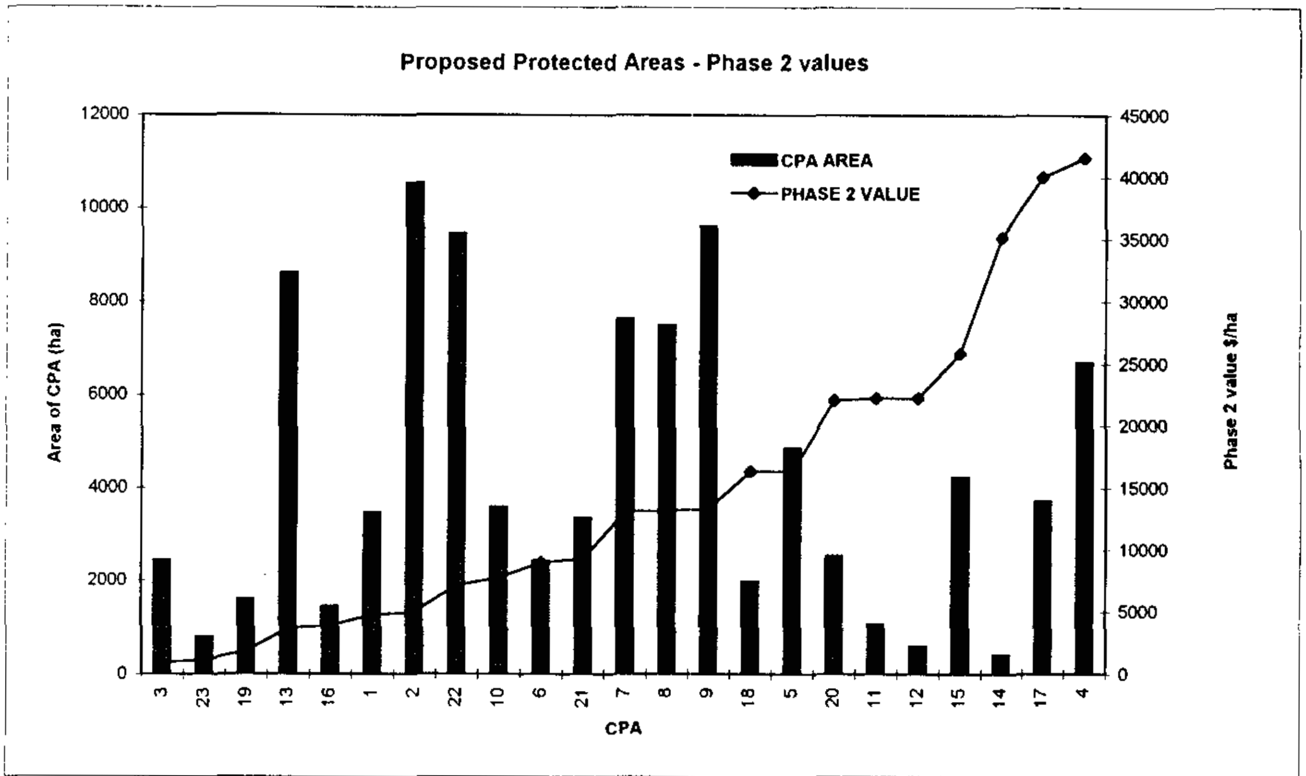

Figure 9. Phase 2 values for low intensity areas, Vancouver Island CORE region.

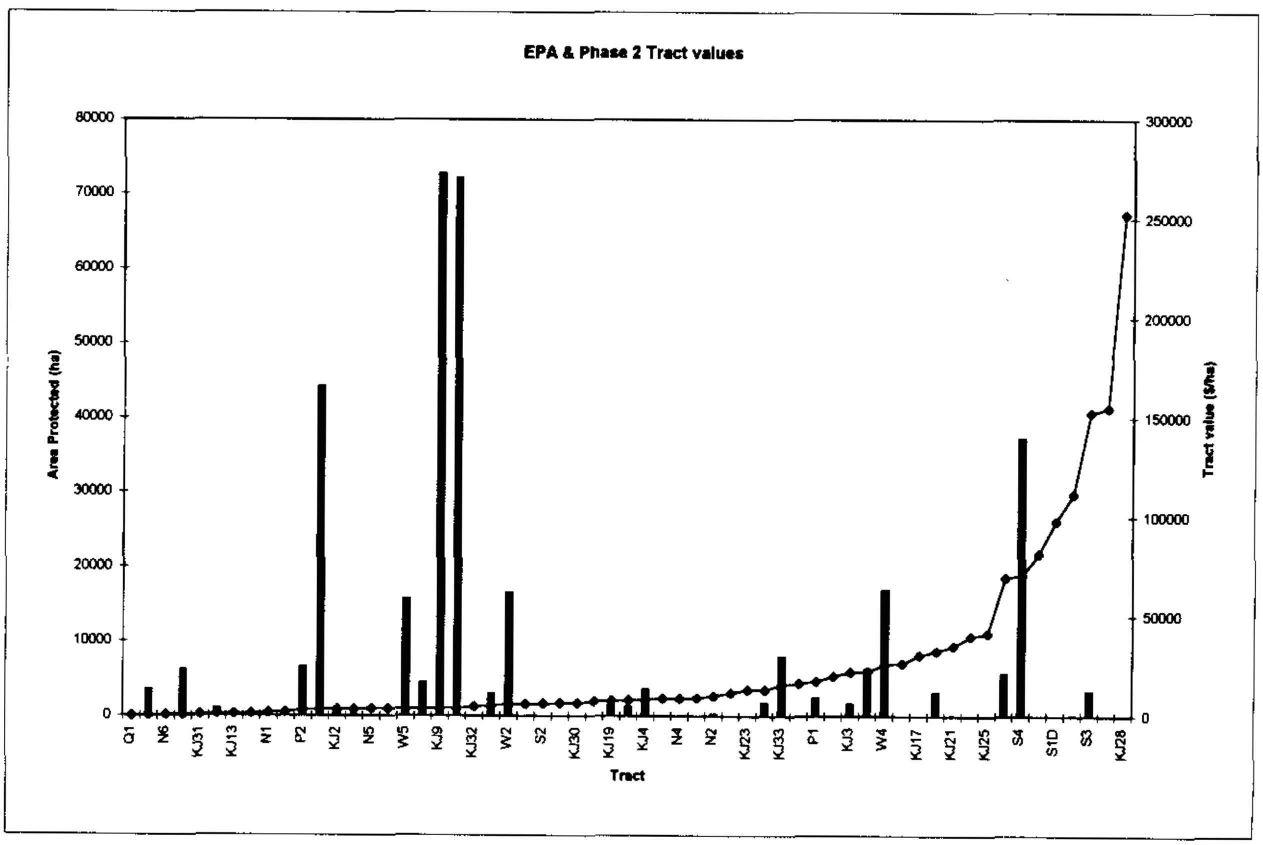

Figure 10. Existing protected areas and phase 2 tract values, Vancouver Island CORE region.

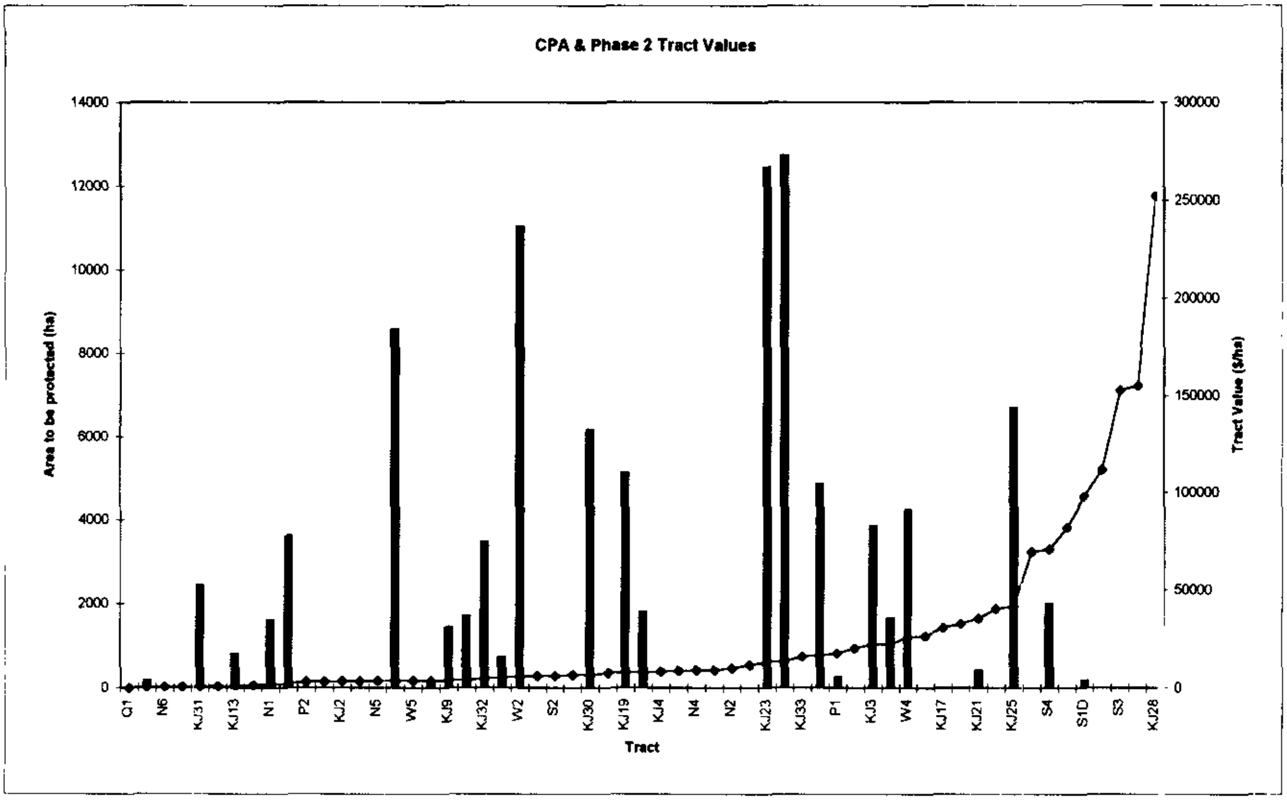

Figure 11. Proposed protected areas and phase 2 tract values, Vancouver Island CORE region.

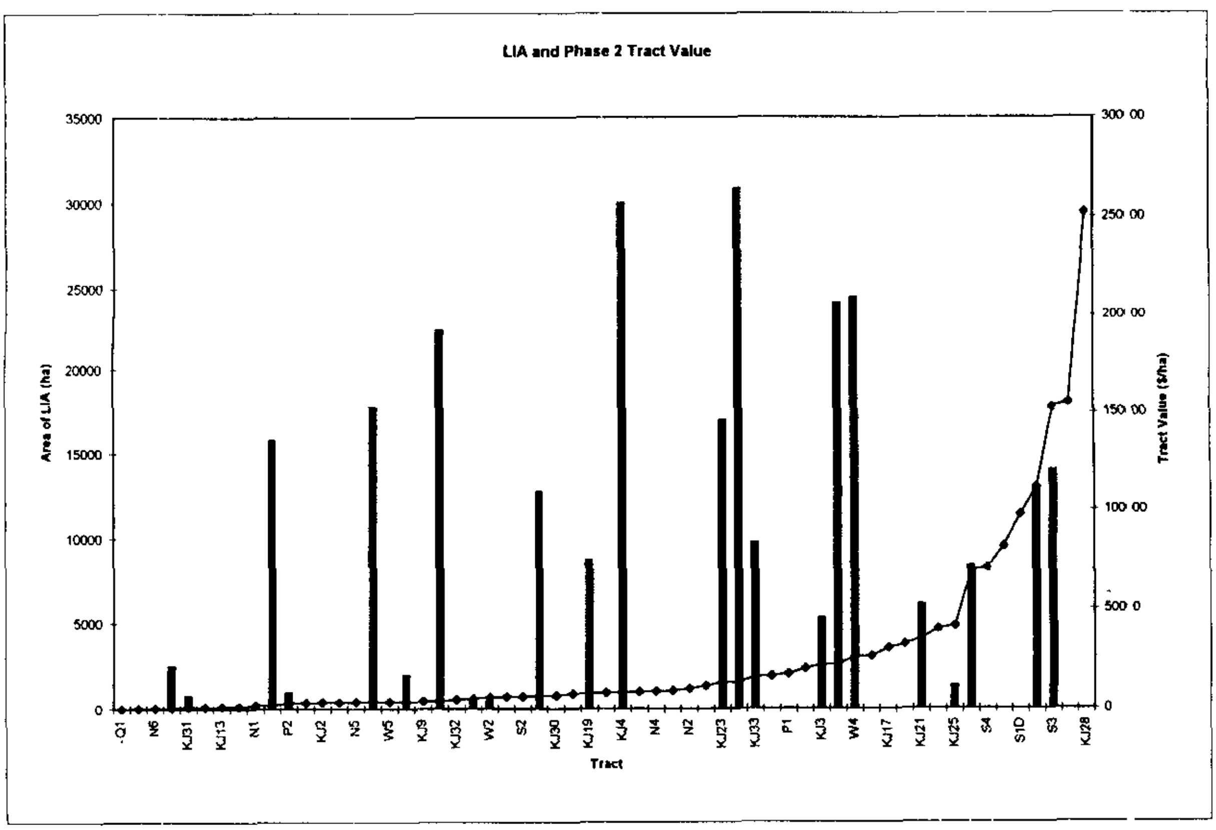

Figure 12. Low intensity areas and phase 2 tract values, Vancouver Island CORE region.

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The author would like to acknowledge the important contributions of Pat Desjardins and Eric Grunsky in digitizing, editing and re-editing maps during the lifetime of the project. The expert estimators were crucial and fundamental to the success of phase 2 and their contribution cannot be adequately acknowledged. Gregg Stewart and Graeme McLaren made invaluable contributions to the analysis of land use decisions.

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NOTES

HIGHLIGHTS OF THE MID-COAST MINERAL POTENTIAL PROJECT (92F, G, H, J, K, L, M, N, 93D, 102P, 103A)

By Kim A. Bellefontaine and Dani J. Alldrick

Contribution to the Mineral Potential Project, funded in part by the Corporate Resource Inventory Initiative (CRII)

KEYWORDS: Mineral potential, Mid-Coast, southwest British Columbia, mineral assessment tract

INTRODUCTION

The mineral potential program was designed and implemented by the British Columbia Ministry of Energy, Mines and Petroleum Resources in response to a need for accurate and credible information for land-use planning. As part of that program, the Mid-Coast project was established to evaluate the mineral potential of southwestern British Columbia. This paper gives a geological overview for the Mid-Coast region and describes the results of phase 1 mineral potential analysis.

LOCATION

The Mid-Coast project is one of seven areas being studied (Figure 1). Other project areas include Vancouver Island (Massey, 1995, this volume), Cariboo-Chilcotin, Kootenay, Thompson-Okanagan (Church, 1995, this volume), Skeena-Nass (MacIntyre *et al.*, 1995, this volume) and the currently running Northeast project. The remaining northwest corner of the province is slated for compilation and evaluation in 1995-1996.

The Mid-Coast project covers 76 660 square kilometres of southwestern British Columbia. Its limits contain abundant low-lying islands and marine channels of the western coastal lowlands. Eastward, the topography rises abruptly to encompass the rugged ice-capped terrain of the Coast Mountains. Population centres within the limits of the study area include the city of Vancouver in the south and the northern coastal town of Bella Coola. The project area covers all of NTS map sheets 92M, 93D, 102P and 103A and parts of 92G, F, H, J, K, L, M, N (Figure 2).

PROCESS AND PRODUCTS

The mineral potential evaluation process involves numerous steps. Specific aspects of the approach adopted by the Geological Survey Branch are detailed in the mineral potential overview paper by Kilby (1995, this volume). Briefly the process involves:

- Geological compilation at a scale of 1:250 000.
- Delineation of mineral assessment tracts.
- Compilation of mineral deposit data.
- Review of geology by experts.
- Phase 1 mineral potential analysis.
- Estimations of undiscovered mineral deposits by industry experts.
- Phase 2 mineral potential analysis.

Figure 1. The Mid-Coast mineral potential project (1) is one of seven areas selected for study. Other areas are Vancouver Island (2), Cariboo-Chilcotin (3), Thompson-Okanagan (4), Kootenay (5), Skeena-Nass (6) and the currently running Northeast project (7).

Resources dedicated to the Mid-Coast project included the assignment of two full-time geologists to geological compilation. Compilation of the map sheets was completed in approximately 8 months. Project milestones included two map review sessions and two expert workshops each held in Vancouver and Smithers. These workshops reported to industry and government experts on the geology of the Mid-Coast region and the mineral potential evaluation process. After peer review and editing of the maps, the data were digitized and entered into the Terrasoft GIS system. This work took approximately 4 person-months to complete. The digital format of the geological compilation is GIS compatible and was released as Open File 1994-17 (Bellefontaine

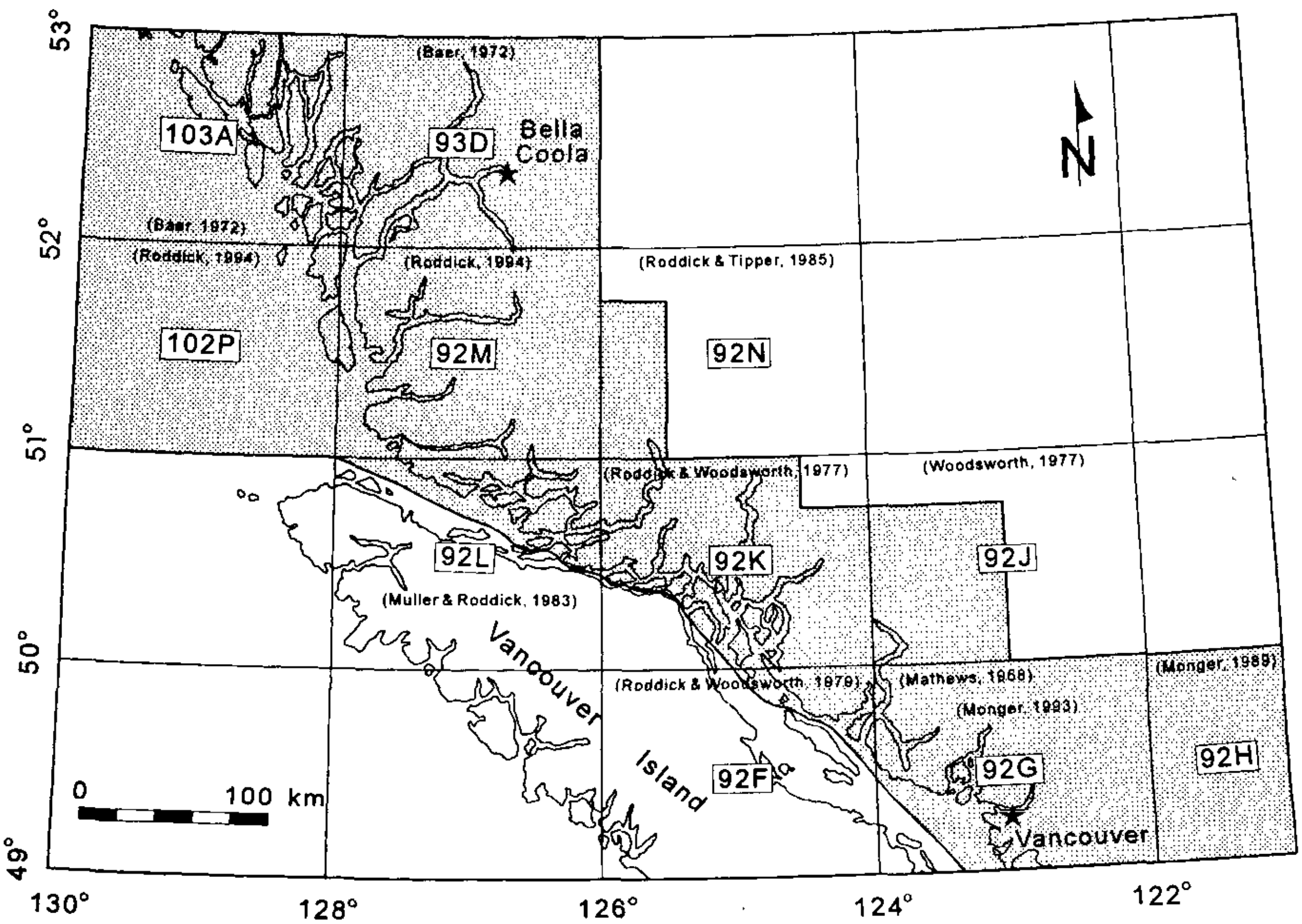

Figure 2. Location of the Mid-Coast mineral potential project detailing the NTS map sheets included in the study. References pertain to the main source of geological data for individual map sheets, mostly at 1:250 000 scale.

and Alldrick, 1994). Figure 3 shows the time line and current products of the Mid-Coast project.

SOURCES OF INFORMATION

All available published and unpublished data were incorporated in the geological compilation. Figure 2 shows the largest scale geological base maps available for the region; almost all are Geological Survey of Canada publications at a scale of 1:250 000. This information was complimented with data from approximately 40 papers, memoirs, bulletins and maps produced by the Geological Survey of Canada, a dozen Ministry of Energy, Mines and Petroleum Resources publications, 110 assessment reports, 20 journaled articles, and four theses. A complete listing of data sources used in compilation is provided in Bellefontaine and Alldrick (1994). The resulting compilation and interpretations have been refined by the expert reviews of Jim Roddick, Glenn Woodsworth, Jim Monger, Peter van der Heyden and Murray Journeay of the Geological Survey of Canada.

Compared to other regions of study, the Mid-Coast yielded a smaller amount of information, especially in the north. This is due lack of access, steep topography, large glacial masses and dense coastal forest which all contribute to the paucity of data. This is well represented in Figures 4a and b which display the location of mineral occurrences recorded in MINFILE and assessment reports in the project area. Exploration activity has clearly been focused in the southern parts of the region where access and infrastructure are better. Consequently the geological database is larger and more complete (*i.e.*, RGS and aeromagnetic coverage).

GEOLOGICAL COMPILATION

Due to the complexity of the geology and the large size of the Mid-Coast project area, the geological setting will be discussed only in very broad terms. A geological map of the project area is not included with this paper due to the difficulty of reproducing the data at page scale. Readers are referred to Bellefontaine and Alldrick (1994) for the most up-to-date geological compilation and detailed lithologic descriptions. The terrane map (Wheeler *et al.*, 1991) and tectonic assemblage map (Wheeler and McFeely, 1991) are ideal for obtaining an overview of the tectonic framework of the area.

The rocks of the Mid-Coast region record the Late Jurassic to Cretaceous subduction and accretion of two composite terranes; the Insular and Intermontane superterranes. The resulting plutonic and metamorphic welt occupies the core of the study area and is comprised of the Coast Plutonic Complex and the Central Gneiss Complex respectively. Strata belonging to pre-collisional terranes are often preserved as interpluton septa and roof pendants. Many of the pendants cannot be definitely correlated with their parent terranes due to the complexity of deformation and degree of metamorphism.

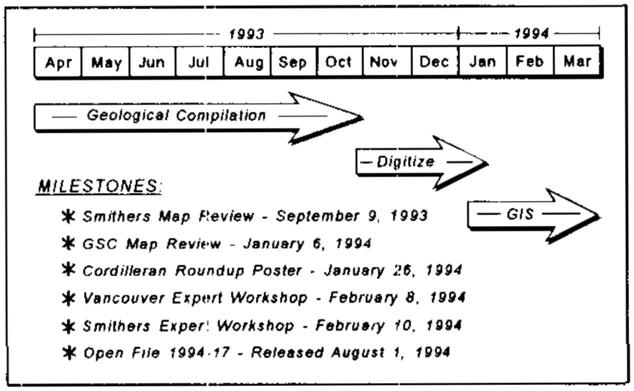

Figure 3. Time-line of the Mid-Coast mineral potential project detailing milestones and current products.

Fragments of eleven terranes exist in the Mid-Coast area. Volcanic arc assemblages occur in both the Insular and Intermontane belts and comprise segments of Paleozoic Chilliwack, Paleozoic and Mesozoic Wrangell, Triassic Cadwallader and Quesnel, and Jurassic Stikine and Harrison Lake terranes. The Paleozoic Alexander Terrane, located in the Insular Belt, comprises a variety of geologic environments including arc, back-arc and rift settings. Metamorphosed continental shelf strata of probable Proterozoic and Paleozoic age are represented by the ill-defined Nisling Terrane and make up a large part of the Central Gneiss Complex. Paleozoic to Mesozoic oceanic crust, accretionary prism and associated sedimentary rocks are restricted to the Intermontane Belt and include the Shuksan and Bridge River terranes. The intrusive rocks of the Coast Plutonic Complex stitch these terranes together and include pre-, syn- and post-deformational plutons. Recent work in the southern Coast Belt has demonstrated that the intrusive rocks fall into broad belts of similar age (Monger, 1993; Monger and McNicoll, 1993; Friedman and Armstrong, 1990). The main pulses of plutonism occurred during the late Middle Jurassic, Late Jurassic, Jura-Cretaceous, and Middle Cretaceous. Subsequent Late Cretaceous and Tertiary intrusions form discreet bodies in the eastern areas of the Coast Belt.

During the accretionary process the Cretaceous Gambier volcanic arc formed on top of the Insular, Coast and Intermontane belts. The Georgia Basin, and its largest component, the sedimentary Nanaimo Group, also formed an overlap assemblage. It contains material eroded from both the Insular and Coast belts. Other major groups of Cenozoic rocks include the Tertiary Chilcotin plateau basalts, the Tertiary to Quaternary Anahim plume volcanics and the Quaternary to Recent Garibaldi arc system. In this study the geology of the Mid-Coast region has been subdivided into 144 distinct lithologic units (Bellefontaine and Alldrick, 1994); 82 are layered and 62 are intrusive.

Large-scale structural features, reflecting a variety of tectonic regimes, are abundant in the project area. Contractional faults and imbricate thrust systems are related to deformation in the Northwest Cascade system and the Coast Mountains. Northeast-verging thrust faults include the Sheemahant thrust, the Ashlu Creek fault zone and the Chuwanten fault. The Thomas Creek fault zone, the Menzies Point shear zone, the Fire Creek thrust and the Shuksan thrust are all southwest-directed structures. Large right-lateral transcurrent fault systems were superimposed during the Cretaceous and Tertiary and include the Harrison Lake shear zone and the many strands of the Fraser fault system. Northeast-striking structures such as the Vedder, Sumas and Coquihalla faults are located in the southernmost parts of the study area and were active during the Tertiary Additional crustal-scale faults and lineaments include the Grenville Channel fault, the Principe-Laredo lineament and the Work Channel lineament. Other newly recognized, unnamed regional-scale structures have also been identified as a result of this compilation work.

There is a very strong northwest-trending structural grain that extends through the Mid-Coast area. Although the voluminous intrusions of the Coast Plutonic Complex tend to mask much of the pre-accretionary geology, this study has shown that many of the terranes maintain their integrity toward the northwest. This has strong implications for the mineral potential of the northern Mid-Coast area.

DELINEATION OF TRACTS

Mineral assessment tracts are areas of land containing similar internal bedrock geology. For comparative purposes it is essential that these units be of similar size. Large deviations in tract size may result in unrealistic high and low rankings of mineral potential. Tract boundaries are non-political and non-geographic and are usually defined by regional-scale faults and terrane boundaries.

Sixty-one mineral assessment tracts were delineated for the Mid-Coast region (Figure 5). The average tract size is 125 640 hectares. The smallest tract is Silverthrone Mountain (G-1) with an area of 28 846 hectares. The Bella Coola tract (GA-6) is the largest at 340 866 hectares. The main lithologic units in each tract are listed in Table 1.

RESOURCES

Known resources in the Mid-Coast region are listed in Table 2. Some of the most important commodities in

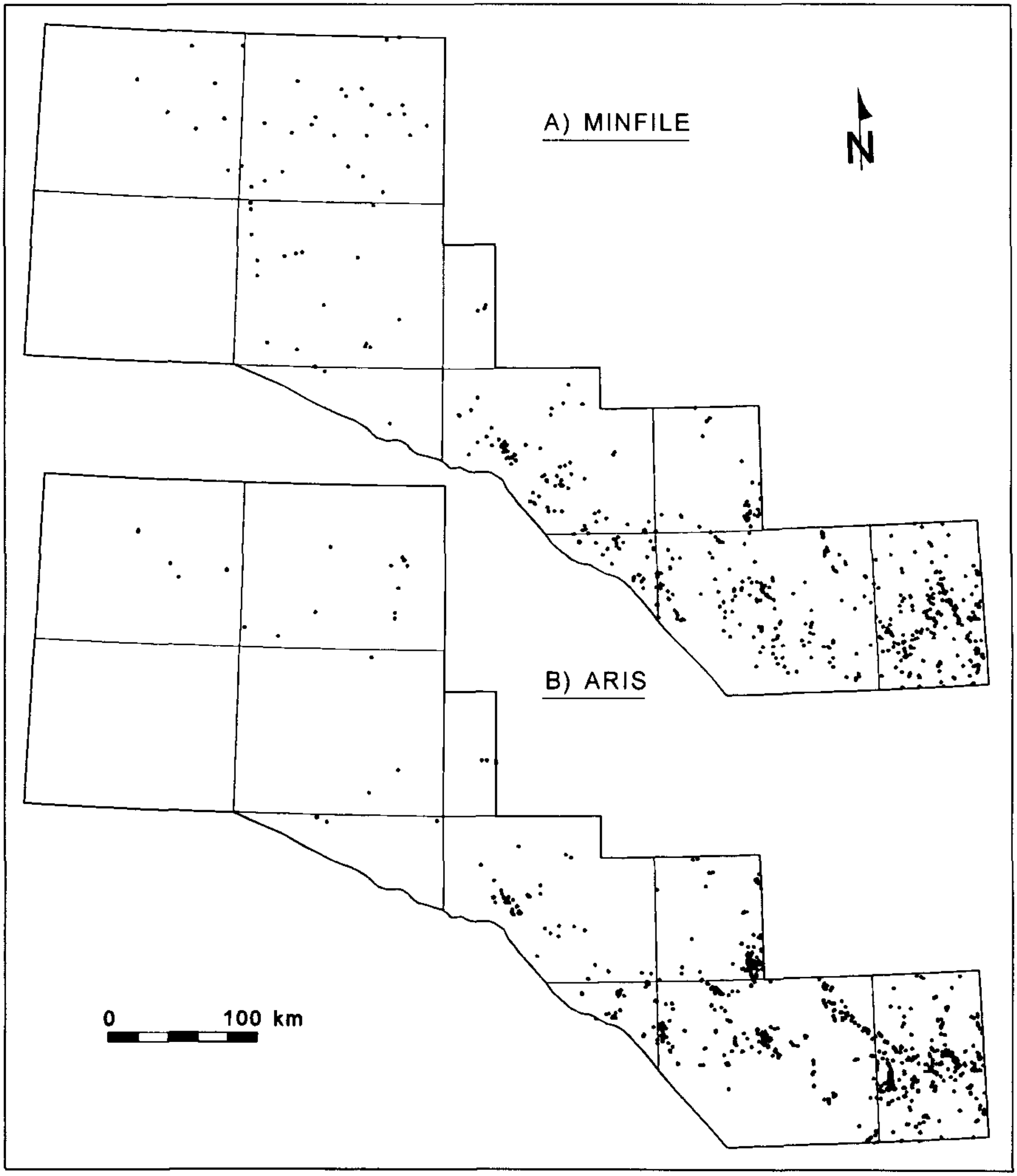

Figure 4. Exploration activity in the Mid-Coast region has clearly focused on areas close to the Lower Mainland. Map A shows the distribution of 600 mineral occurrences in the project area; 83% fall within 200 kilometres of Vancouver. Map B displays the distribution of 1112 assessment reports for the same region; 92% of the reports have been filed within a 200-kilometre radius of Vancouver.

the project area include copper, gold, lead, zinc, silver and molybdenum. The majority of the metallic mineral deposits occur in volcanic terranes often associated with large-scale structures. In general, the mineral potential of the layered rocks is higher than the bulk of the intrusives in the Coast Plutonic Complex.

The project area has been host to many notable past producers. Mining of copper, zinc, silver and gold at the

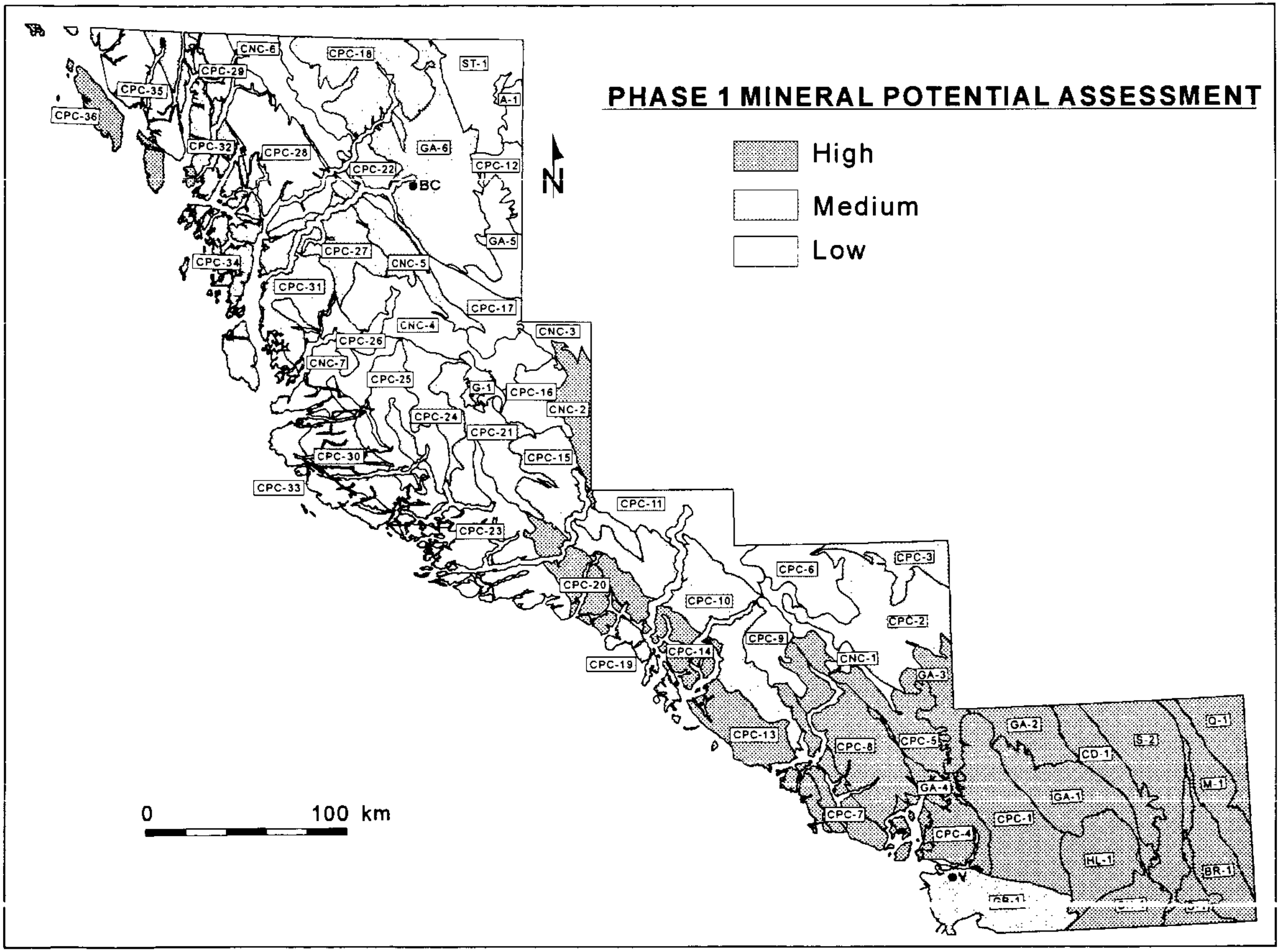

Figure 5. Map showing the 61 mineral assessment tracts of the Mid-Coast region and the results of the phase 1 analysis. The land base is divided equally by total area into high, medium and low mineral potential categories.

TABLE 1. TECTONIC AND LITHOLOGIC COMPONENTS OF MINERAL ASSESSMENT TRACTS

TRACT ID	TRACT NAME	MAIN LITHOLOGICAL UNITS	TECTONIC ELEMENT
GA-4	Britannia	Garibaldi volcanics, Gambier Gp, Coast Plutonic Suite	Tertiary overlap, Mesozoic overlap, Coast Plutonic Complex
M-1	Manning	Princeton Gp, Pasayten Gp, Jackass Mtn. Gp, Thunder Lake sequence, Ladner Gp, Dewdney Ck. Fm, Spider Peak Fm, Mount Lytton Cpx, Bridge River Cpx, Coast Plutonic Suite	Tertiary overlap, Methow, Quesnel, Bridge River, Coast Plutonic Complex
HL-1	Harrison Lake	Unknown metamorphics, Kent Fm, Billhook Creek Fm, Harrison Lake Fm, Camp Cove Fm, Coast Plutonic Suite	Unknown, Harrison Lake, Coast Plutonic Complex
GA-3	Northair	Garibaldi volcanics, Gambier Gp, Cadwallader Gp?, Coast Plutonic Suite	Tertiary overlap, Mesozoic overlap, Cadwallader?, Coast Plutonic Complex
S-2	Spuzzum	Shuksan schist, Hornet Creek gneiss, Chilliwack Gp, Bridge River Cpx, Yellow Aster Cpx, Mt. Barr batholith, Scuzzy pluton, Spuzzum pluton, Coast Plutonic Suite	Shuksan, Bridge River, Chilliwack, Coast Plutonic Complex
GA-1	Mount Clarke	Garibaldi volcanics, Gambier Gp, Coast Plutonic Suite	Tertiary overlap, Mesozoic overlap, Coast Plutonic Complex
CPC-20	Loughborough Inlet	Karmutsen Fm, Quatsino Fm, Coast Plutonic Suite	Wrangellia, Coast Plutonic Complex
CPC-13	Powell River	Nanaimo Gp, Karmutsen Fm, Quatsino Fm, Coast Plutonic Suite	Geogia Basin stratigraphy, Wrangellia, Coast Plutonic Complex
CPC-5	Cloudburst	Garibaldi volcanics, gneiss, Cloudburst pluton, Coast Plutonic Suite	Tertiary overlap, Central Gneiss Cpx, Coast Plutonic Complex
CPC-4	Cypress Bowl	Unknown metamorphics, Nanaimo Gp, Gambier Gp, Bowen Island Gp, Coast Plutonic Suite	Unknown, Georgia Basin stratigraphy, Mesozoic overlap, Wrangellia, Coast Plutonic Complex
S-1	Chilliwack	Skagit Fm, Princeton Gp, Custer gneiss, Shuksan schist, Chilliwack Gp, Bridge River Cpx, Coast Plutonic Suite,	Tertiary overlap, Shuksan, Chilliwack, Bridge River, Coast Plutonic Complex
Q-1	Spences Bridge	Coquihalla Fm, Princeton Gp, Spences Bridge Gp, Nicola Gp, Eagle Plutonic Cpx, Mt. Lytton Cpx, Coast Plutonic Suite	Tertiary overlap, Quesnel, Coast Plutonic Complex
GA-2	Fire Lake	Gambier Gp, Mt. Clarke pluton, Thomas Lake pluton, Pemberton diorite, Coast Plutonic Suite	Mesozoic overlap, Coast Plutonic Complex
CPC-7	Bowen Island	Bowen Island Gp, Karmutsen Fm, Quatsino Fm?, Coast Plutonic Suite	Wrangellia, Coast Plutonic Complex
CH-1	Bridal Falls	Princeton Gp, Slollicum schist, Gambier Gp?, Kent Fm, Cultus Fm, Chilliwack Gp, Vedder Cpx, Bridge River Cpx, Cogburn schist	Tertiary overlap, Cadwallader, Mesozoic overlap, Harrison Lake, Chilliwack, Bridge River
BR-1	Hozameen	Hozameen Cpx, Bridge River Cpx, Coast Plutonic Suite	Bridge River, Coast Plutonic Complex
CD-1	Breakenridge	Breakenridge gneiss, Shuksan schist, Slollicum schist, Bridge River Cpx, Cogburn schist, Chilliwack Gp, Mt. Mason pluton, Coast Plutonic Suite	Mesozoic overlap, Shuksan, Cadwallader, Bridge River, Chilliwack, Coast Plutonic Complex
CNC-2	Klinaklini River	Tertiary volcanics, metamorphics, gneiss, Coast Plutonic Suite	Tertiary overlap, Stikinia?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-14	Bute Inlet	Cretaceous volcanics, Karmutsen Fm, West Redonda pluton, Coast Plutonic Suite	Mesozoic overlap, Wrangellia, Coast Plutonic Complex
CPC-1	Pitt Lake	Garibaldi volcanics, unknown metamorphics, Gambier Gp, Coast Plutonic Suite	Tertiary overlap, Unknown, Mesozoic overlap, Coast Plutonic Complex
CPC-36	Aristazabal Island	Lake Island Fm, metasediments and metavolcanics, Coast Plutonic Suite	Tertiary overlap, Alexander, Coast Plutonic Complex
CPC-8	Jervis Inlet	Gambier Gp, Coast Plutonic Suite	Mesozoic overlap, Coast Plutonic Complex
CPC-33	Cape Caution	Karmutsen Fm, Paleozoic volcanic and sedimentary rocks, Coast Plutonic Suite	Wrangellia, Coast Plutonic Complex
GA-6	Bella Coola	Gambier Gp, Coast Plutonic Suite	Mesozoic overlap, Coast Plutonic Complex
CPC-19	Surge Narrows	Karmutsen Fm, Bonanza Gp, Harbledown Fm, Coast Plutonic Suite	Wrangellia, Coast Plutonic Complex
CPC-3	Sampson-Delilah	Garibaldi volcanics, Gambier Gp, Cadwallader Gp, gneiss, metamorphics	Tertiary overlap, Mesozoic overlap, Cadwallader, Central Gneiss Cpx, Stikinia?
CPC-10	Toba Inlet	Gambier Gp, Karmutsen Fm, metamorphics, gneiss, Paradise River pluton, Goat Lake pluton, Coast Plutonic Suite	Mesozoic overlap, Wrangellia, Stikinia?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-30	Seymour Inlet	Paleozoic volcanic and sedimentary rocks, Coast Plutonic Suite	Wrangellia, Coast Plutonic Complex
CPC-2	Meagher Creek	Garibaldi volcanics, Gambier Gp, gneiss, Coast Plutonic Suite	Tertiary overlap, Mesozoic overlap, Central Gneiss Cpx, Coast Plutonic Complex
CPC-27	Kwatna River	Tertiary volcanics, metasediments and metavolcanics, Coast Plutonic Suite	Tertiary overlap, Alexander, Coast Plutonic Complex
CPC-32	Roderick Island	Lake Island Fm, metasediments and metavolcanics, Coast Plutonic Suite	Tertiary overlap, Alexander, Coast Plutonic Complex
CPC-31	Namu	Metasediments and metavolcanics, Coast Plutonic Suite	Alexander, Coast Plutonic Complex
CPC-24	Wakeman River	Metamorphics, gneiss, Coast Plutonic Suite	Stikinia?, Central Gneiss, Cpx, Coast Plutonic Complex
CPC-15	Knight Inlet	Tertiary volcanics, metamorphics, gneiss, Coast Plutonic Suite	Tertiary overlap, Central Gneiss Cpx, Stikinia?, Coast Plutonic Complex

TECTONIC AND LITHOLOGIC COMPONENTS OF MINERAL ASSESSMENT TRACTS

TRACT ID	TRACT NAME	MAIN LITHOLOGICAL UNITS	TECTONIC ELEMENT
CPC-34	Bella Bella	Lake Island Fm, Bella Bella Fm, metasediments and metavolcanics, Coast Plutonic Suite	Tertiary overlap, Alexander, Coast Plutonic Complex
CNC-5	South Bentick Arm	Metamorphics, gneiss, Coast Plutonic Suite	Nisling?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-18	Kimsquit	Gambier Gp, Gamsby Cpx, metamorphics, gneiss, Coast Plutonic Suite	Mesozoic overlap, Stikinia, Nisling?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-21	Kingcome River	Garibaldi volcanics, gneiss, Coast Plutonic Suite	Tertiary overlap, Central Gneiss Cpx, Coast Plutonic Complex
GB-1	Vancouver	Point Grey eruptives, Kitsilano Fm, Nanaimo Gp, Coast Plutonic Suite	Georgia Basin stratigraphy, Coast Plutonic Complex
CNC-7	Rivers Inlet	Paleozoic volcanic and sedimentary rocks, metamorphics, gneiss, Coast Plutonic Suite	Wrangellia, Stikinia?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-22	Tezwa River	Gambier Gp, metamorphics, gneiss, Coast Plutonic Suite	Mesozoic overlap, Nisling?, Central Gneiss Cpx, Coast Plutonic Complex
CNC-6	Nascall River	Metamorphics, gneiss, Coast Plutonic Suite	Nisling?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-12	Atnarko	Chilcotin Gp, Gambier Gp, Coast Plutonic Suite	Tertiary overlap, Mesozoic overlap, Coast Plutonic Complex
ST-1	Tweedsmuir	Chilcotin Gp, Gambier Gp, Smithers Fm, Hazelton Fm, Coast Plutonic Suite	Tertiary overlap, Mesozoic overlap, Stikinia, Coast Plutonic Complex
CPC-11	Superb Mountain	Tertiary volcanics, metamorphics, gneiss, Coast Plutonic Suite	Tertiary overlap, Stikinia?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-28	Ocean Falls	Metasediments and metavolcanics, metamorphics, gneiss, Coast Plutonic Suite	Alexander, Nisling?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-23	Gilford Island	Paleozoic volcanic and sedimentary rocks, gneiss, Coast Plutonic Suite	Wrangellia, Central Gneiss Cpx, Coast Plutonic Complex
CPC-9	Big Julie	Big Julie pluton	Coast Plutonic Complex
CNC-3	Knot Creek	Metamorphics, gneiss, Coast Plutonic Suite	Stikinia?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-26	Amback	Coast Plutonic Suite	Coast Plutonic Complex
G-1	Silverthrone Mtn.	Garibaldi volcanics, metamorphics, gneiss, Coast Plutonic Suite	Tertiary overlap, Stikinia, Central Gneiss Cpx, Coast Plutonic Complex
CPC-6	Clendenning	Coast Plutonic Suite	Coast Plutonic Complex
CPC-29	Sheep Passage	Metasediments and metavolcanics, Coast Plutonic Suite	Alexander, Coast Plutonic Complex
A-1	Anahim	Anahim volcanics, Chilcotin Gp, Coast Plutonic Suite	Tertiary overlap, Coast Plutonic Complex
CPC-16	Tumult Glacier	Garibaldi volcanics, gneiss, Coast Plutonic Suite	Tertiary overlap, Central Gneiss Cpx, Coast Plutonic Complex
CPC-25	Doos Creek	Gneiss, Coast Plutonic Suite	Central Gneiss Cpx, Coast Plutonic Complex
CNC-1	Princess Louisa	Gneiss, Coast Plutonic Suite	Central Gneiss Cpx, Coast Plutonic Complex
GA-5	Monarch	Gambier Gp, Coast Plutonic Suite	Mesozoic overlap, Coast Plutonic Complex
CPC-35	Princess Royal	Metasediments and metavolcanics, Coast Plutonic Suite	Alexander, Coast Plutonic Complex
CNC-4	Owikeno Lake	Garibaldi volcanics, metamorphics, gneiss, Coast Plutonic Suite	Tertiary overlap, Stikinia?, Central Gneiss Cpx, Coast Plutonic Complex
CPC-17	Sheemahant River	Sheemahant thrust zone, Coast Plutonic Suite	Coast Plutonic Complex

Tectonic elements listed are terranes unless otherwise stated. The tract identification label is based on the most abundant tectonic or lithologic component of the tract. Abbreviations: GA-Gambier, M-Methow, HL-Harrison Lake, S-Shuksan, CPC-Coast Plutonic Complex, Q-Quesnel, CH-Chilliwack, BR-Bridge River, CD-Cadwallader, CNC-Central Gneiss Complex, GB-Georgia Basin, ST-Stikine, G-Garibaldi, A-Anahim, Fm-Formation, Gp-Group, Cpx-Complex.

historic Britannia mine lasted more than 70 years. The Carolin and Aurum mines, located along the East Hozameen fault, produced gold and silver intermittently between 1928 and 1984. The Northair mine, located near the town of Whistler, mined gold, silver, lead and zinc from veins between the years of 1974 and 1982.

In addition to past production and known resources, the Mid-Coast region has potential for future discoveries of numerous types of mineral deposits. Volcanic rocks of the Wrangell, Alexander, Stikine, Harrison Lake and Quesnel terranes and the Gambier Group have potential for hosting porphyries, volcanogenic massive sulphide deposits, skarns, epithermal systems and other vein types. Quaternary volcanics of the Anahim and Garibaldi chains have geothermal potential. Oceanic rocks of the Bridge River and Shuksan terranes may host mesothermal gold veins, gabbroic nickel-copper, Cyprus-type massive sulphide deposits, podiform chromite, talc, asbestos and other industrial minerals. The Coast Plutonic Complex has the potential to host numerous types of industrial minerals, porphyry deposits and veins.

MINERAL POTENTIAL RESULTS

One of the primary goals of the mineral potential project is to predict the future mineral potential of the land base. This is accomplished by a two-phase analysis which ranks the tracts within a study area relative to each other. The phase 1 analysis ranks the land using factual, historical information. It deals only with six major metallic commodities: gold, silver, lead, zinc, copper and molybdenum. Phase 2 predicts the future mineral potential of an area by using probabilistic estimates of undiscovered resources made by experts. It involves additional metallic and nonmetallic commodities including industrial minerals.

TABLE 2. MINERAL RESOURCES IN MID-COAST AREA

TRACT ID	COMMODITIES	DEPOSIT TYPE	DEPOSIT NAME
GA-4	Cu, Zn, Pb, Ag, Au, Cd	Kuroko VMS	Britannia
	Cu, Mo	Porphyry	Gambier Island
	Cu, Zn, Pb, Ag	Polymetallic veins	McVicar
M-1	Au, Ag, Cu, Zn	Gold-quartz veins	Carolin
	Ag, Pb, Zn, Cu, Au, Sb	Polymetallic veins	Treasure Mtn.
	Cu, Au, Ag, Zn, Pb, Mo, U	Porphyry	Giant Copper
HL-1	Zn, Cu, Ag, Au, Pb	Kuroko VMS	Seneca
GA-3	Au, Ag, Pb, Zn, Cu, Cd	Polymetallic veins	Northair
	Au, Ag, Pb, Zn, Cu, Cd	Polymetallic veins	Silver Tunnel
	Ag, Au, Pb, Zn, Cu	Polymetallic veins	Tedi
S-2	Mo, Cu, W, Bi	Porphyry	Gem
	Ni, Cu, Co, Au, Ag, Cr, Pt	Gabbroic Ni-Cu	Pride of Emory
	Ni, Cu	Gabbroic Ni-Cu	Victor
GA-1	Au, Ag, Cu, Zn, Pb, Mo, W	Shear hosted veins	Harrison Gold
	Au, Ag, Cu	Porphyry	Doctor's Point
CPC-20	Au, Ag, Pb, Zn, Cu	Gold-quartz veins	Doratha Morton
	Au, Ag, Cu	Gold-quartz veins	Alexandria
CPC-13	Cu, Mo	Porphyry	O.K.
	Ka, Ge, Ga, In, Cy	Industrial minerals	Lang Bay
	Cu, Mo	Porphyry	Hi-Mars
CPC-5	Au, Ag, Cu, Zn, W	Polymetallic veins	Ashlu
CPC-4	Zn, Ag, Pb	Zn-Pb skarn	Lynn Creek
CPC-30	Fe, Ti, V, Ag	Magmatic magnetite	Wigwam

Commodity abbreviations are: Au-gold, Ag-silver, Bi-bismuth, Cu-copper, Cd-cadmium, Co-cobalt, Cr-chromium, Cy-clay, Fe-iron, Ga-gallium, Ge-germanium, In-indium, Ka-kaolinite, Mo-molybdenum, Ni-nickel, Pb-lead, Pt-platinum, Sb-antimony, Ti-titanium, U-uranium, V-vanadium, W-tungsten, Zn-zinc.

PHASE 1

The phase 1 analysis is a representation of mineral potential based on historical data. Factors such as the number of mineral occurrences recorded in MINFILE, the value of past production, the value of known resources and the amount spent on exploration (from ARIS files) are ranked for each tract. The MINFILE rank is calculated on a per hectare basis. These rank values are weighted to produce the total rank for each mineral assessment tract. A weight of 25 is given to known resources, past exploration work is factored by 10 and the number of mineral occurrences and past production are multiplied by 5 (Kilby, 1995, this volume). Table 3 presents the results of the phase 1 mineral potential analysis for the 61 tracts in the Mid-Coast region arranged from highest to lowest rank.

Figure 5 shows the distribution of mineral assessment tracts with the land base divided into thirds and placed into high, medium and low categories. Readers are reminded that the tracts are ranked relative to each other and that comparisons with tracts in other project areas are not valid. A tract marked "low" mineral potential in Figure 5 means it has lower potential compared to other tracts in the Mid-Coast area. It does not mean the tract has no mineral potential.

Twenty-two tracts in the Mid-Coast area are ranked high potential (Table 3). All but two are located within 200 kilometres of the city of Vancouver. Approximately half of the tracts have well known past-producing mines including Britannia (GA-4), Northair (GA-3), Carolin (M-1) and Treasure Mountain (M-1). All of the currently known resources (for the six metals included in the study) are also located in these high-potential tracts (*i.e.*, Seneca, Harrison Gold, Gambier Island, O.K.; see Table 2). The two anomalous tracts in the northern part of the study area are Klinaklini River (CNC-2) and Aristazabul Island (CPC-36). The Klinaklini River tract ranks high based solely on three occurrences and the value of exploration work conducted on the Hoodoo North and Hoodoo South properties. The Aristazabul Island tract contains three mineral occurrences and has recorded exploration expenditures of approximately $130 000. Both of these tracts have lower topography and easier access compared to most of the northern part of the study area.

All of the mineral assessment tracts ranked as medium contain mineral occurrences or have exploration expenditures recorded for them (Table 3). There are 17 tracts that fit within this category; with the exception of the Vancouver tract (GB-1) they all lie outside the Lower Mainland.

There are 22 tracts in the Mid-Coast area that fit into land base designated as low mineral potential. Fourteen of these are assigned an overall rank of zero based on the number of showings and recorded work. Most are in the northern parts of the project area and all show a strong correlation with the highest topography and the least accessibility.

PHASE 2

Expert estimations for the phase 2 mineral potential analysis have been conducted for the Mid-Coast project area. Preliminary results have yet to be evaluated. In other project areas the phase 2 analysis has not significantly changed the ranking of the land.

TABLE 3. RESULTS OF PHASE 1 MINERAL POTENTIAL ANALYSIS FOR MID-COAST PROJECT

Status	Tract ID	Tract Name	Area (Hectares)	No. of MINFILE	MINFILE Rank	Resource Value	Resource Rank	ARIS Value	ARIS Rank	Production Value	Production Rank	Total Rank
HIGH	GA-4	Britannia	53165	33	58	743729157	61	3285062	61	1285576201	61	2730
	M-1	Manning	110325	118	61	176387535	59	4900942	60	20182068	59	2675
	HL-1	Harrison Lake	135193	44	56	97785036	57	3356463	58	36919	54	2555
	GA-3	Northair	89111	18	47	37957746	54	2239167	59	93052360	60	2475
	S-2	Spuzzum	215969	67	54	176101740	58	1128227	46	22946240	58	2470
	GA-1	Mt. Clarke	160102	16	43	106355200	56	2771951	57	420126	55	2460
	CPC-20	Loughborough Inlet	97937	27	52	6826199	52	1552022	56	2236677	57	2405
	CPC-13	*Powell River*	*145260*	*37*	*51*	*1627180000*	*60*	*2264256*	*55*	*0*	*0*	*2305*
	CPC-5	Cloudburst	132513	14	44	11302775	53	588447	44	2732355	56	2265
	CPC-4	Cypress Bowl	86713	15	45	50620830	55	119050	38	0	0	1980
	S-1	Chilliwack	63299	47	60	0	0	627004	51	0	0	810
	Q-1	Spences Bridge	98478	32	55	0	0	1250513	53	0	0	805
	GA-2	Fire Lake	86824	18	49	0	0	1140810	54	0	0	785
	BR-1	Hozameen	109067	68	59	0	0	667993	47	0	0	765
	CH-1	Bridal Falls	84186	33	57	0	0	597225	48	0	0	765
	CPC-7	Bowen Island	104609	31	53	0	0	971728	50	0	0	765
	CD-1	Breakenridge	108440	23	50	0	0	843063	49	0	0	740
	CNC-2	Klinaklini River	85293	3	34	0	0	882907	52	0	0	690
	CPC-14	Bute Inlet	99458	19	46	0	0	503341	45	0	0	680
	CPC-1	Pitt Lake	232841	23	42	0	0	428877	41	0	0	620
	CPC-8	Jervis Inlet	209880	15	40	0	0	312183	39	0	0	590
	CPC-36	Aristazabal Island	73408	3	38	0	0	129685	40	0	0	590
MEDIUM	GA-6	Bella Coola	340866	9	31	0	0	674013	42	0	0	575
	CPC-33	Cape Caution	81895	2	29	0	0	226491	43	0	0	575
	CPC-19	Surge Narrows	43449	9	48	0	0	23506	33	0	0	570
	CPC-3	Sampson-Delilah	78274	3	36	0	0	74719	36	0	0	540
	CPC-10	Toba Inlet	299455	11	35	0	0	225844	34	0	0	515
	CPC-30	Seymour Inlet	155835	6	37	0	0	74452	32	0	0	505
	CPC-2	Meagher Creek	260635	5	25	0	0	226065	35	0	0	475
	CPC-32	Roderick Island	144915	4	32	0	0	33219	30	0	0	460
	CPC-27	Kwatna River	109800	1	18	0	0	136360	37	0	0	460
	CPC-31	Namu	134289	3	27	0	0	14845	28	0	0	415
	CPC-24	Wakeman River	89064	2	28	0	0	9840	27	0	0	410
	CPC-15	Knight Inlet	146135	1	16	0	0	40063	31	0	0	390
	CPC-34	Bella Bella	127358	2	24	0	0	6906	26	0	0	380
	CNC-5	South Bentick Arm	102384	1	20	0	0	5309	25	0	0	350
	CPC-18	Kimsquit	214607	2	19	0	0	2242	24	0	0	335
	CPC-21	Kingcome River	167285	0	0	0	0	20180	29	0	0	290
	GB-1	Vancouver	175981	17	41	0	0	0	0	0	0	205
LOW	CNC-7	Rivers Inlet	155953	8	39	0	0	0	0	0	0	195
	CPC-22	Tezwa River	104739	3	33	0	0	0	0	0	0	165
	CNC-6	Nascall River	117034	3	30	0	0	0	0	0	0	150
	CPC-12	Atnarko	51769	1	26	0	0	0	0	0	0	130
	ST-1	Tweedsmuir	154585	2	23	0	0	0	0	0	0	115
	CPC-11	Superb Mountain	173371	2	22	0	0	0	0	0	0	110
	CPC-28	Ocean Falls	191301	2	21	0	0	0	0	0	0	105
	CPC-23	Gilford Island	236071	2	17	0	0	0	0	0	0	85
	CPC-9	Big Julie	73306	0	0	0	0	0	0	0	0	0
	CNC-3	Knot Creek	44786	0	0	0	0	0	0	0	0	0
	CPC-26	Amback	35616	0	0	0	0	0	0	0	0	0
	G-1	Silverthrone Mtn.	28846	0	0	0	0	0	0	0	0	0
	CPC-6	Clendenning	118636	0	0	0	0	0	0	0	0	0
	CPC-29	Sheep Passage	60268	0	0	0	0	0	0	0	0	0
	A-1	Anahim	33591	0	0	0	0	0	0	0	0	0
	CPC-16	Tumult Glacier	79608	0	0	0	0	0	0	0	0	0
	CPC-25	Doos Creek	159214	0	0	0	0	0	0	0	0	0
	CNC-1	Princess Louisa	58549	0	0	0	0	0	0	0	0	0
	GA-5	Monarch	92540	0	0	0	0	0	0	0	0	0
	CPC-35	Princess Royal	137053	0	0	0	0	0	0	0	0	0
	CNC-4	Owikeno Lake	205392	0	0	0	0	0	0	0	0	0
	CPC-17	Sheemahant River	97506	0	0	0	0	0	0	0	0	0

Tracts are arranged from highest to lowest total rank of mineral potential. Values for resources, production and exploration expenditures (ARIS) are in 1986 dollars. The rank of known resources is given a weight of 25, the rank of past work is factored by 10 and MINFILE and past-production ranks are multiplied by 5. The sum of these four ranks yields the total rank for each tract. One third of the total land base (by area) is placed in high, medium and low mineral potential categories.

DISCUSSION

Historically, exploration and research have been focused in the southern areas of the Mid-Coast region. Geological compilation (Bellefontaine and Alldrick, 1994) has demonstrated that many of the terranes maintain their integrity even through abundant intrusive rocks of the Coast Belt. This suggests that rock units in the northern areas should have similar mineral potential to their southern counterparts. However, due to the lack of recorded exploration and the paucity of data in the northern areas, most of the southern Mid-Coast region ranks high in the phase 1 mineral potential analysis.

Ideally, estimations by experts for the phase 2 analysis should capture a wide range of thinking on the future mineral potential of this little known region of the province. Although phase 2 has not significantly changed the ranks of tracts in other study areas, in no region has the lack of available expertise for estimations been as large as in the Mid-Coast project area.

There are approximately 600 mineral occurrences in the Mid-Coast region; 80% of them occur within 200 kilometres of Vancouver. Similarly, there are 101 present or past producers in the project area; 83% are located within 200 kilometres of Vancouver. The northward geological continuity and lack of previous exploration work in the northern part of the Mid-Coast area highlights the potential for exploration opportunities.

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MINERAL POTENTIAL ASSESSMENT OF THE SKEENA-NASS AREA

(93E, L,M, 94D, 103G, H, I, J, P, 104A, B)

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KEYWORDS: mineral potential, Skeena, Nass, mining history, compilation, mineral assessment tracts, digital data, exploration expenditures, past production, mineral inventory, mineral occurrences.

INTRODUCTION

The Skeena-Nass project is one of seven projects comprising the Mineral Potential Initiative (Figure 1). Other areas include Vancouver Island, Cariboo-Chilcotin, Thompson-Okanagan, Kootenay, Mid-Coast and Northeast B.C. The final project, Northwest B.C., will be started in 1995. The main purpose of these projects is to produce a new series of high quality, digital mineral potential maps that can be used for land-use planning.

This report describes the general geology and mineral resources of the Skeena-Nass area and the results of the phase 1 mineral potential evaluation. An overview of the Mineral Potential Initiative, including methodology used for the phase 1 and phase 2 mineral potential assessments, is described elsewhere in this volume (Kilby, 1995).

LOCATION

The Skeena-Nass area is situated in west-central British Columbia between latitudes 53° and 57° North and longitudes 126° and 132° West (Figure 2). The project name is derived from the Skeena and Nass rivers which drain the area. The study area includes the 1:250 000-scale NTS map sheets 93E, 93L, 93M, 94D, 103G, 103H, 103I, 103J, 103P, 104A and 104B (Figure 1). The total land area is approximately 1 244 000 hectares. Major towns in the area include Prince Rupert, Kitimat, Terrace, Stewart, Hazelton, Smithers and Houston. The principle transportation routes through the area are Highway 16, Highway 37 and the Canadian National Railway.

MINING AND EXPLORATION HISTORY

The mining and exploration history of the Skeena-Nass area can be divided into three phases. The initial phase coincided with the first major influx of European fortune seekers to northwestern North America in 1889 as a result of the Klondike gold rush. A second phase was driven by mineral requirements for the Second World War. The third phase spans the period from 1965 to the early 1980s when large-tonnage porphyry deposits were the main exploration target. In recent years deposits containing gold have been the main exploration targets with several new discoveries made in the Stewart mining camp.

Figure 1. Location of the Skeena-Nass project (6) and the Mid-Coast (1), Vancouver Island (2), Cariboo-Chilcotin (3), Thompson-Okanagan (4), Kootenay (5) and Northeast (7) mineral potential projects.

The Skeena-Nass area is one of the most richly endowed parts of the province for mineral resources with 1954 mineral occurrences recorded in the MINFILE database for this area. This represents approximately 20% of the total number of occurrences in the province. Most of the occurrences contain base and/or precious metals. Of these, there are 165 past-producing mines and three current producers. The total value of past production is $7.13 billion. In-ground reserves are valued at $27.14 billion. Total exploration expenditures are estimated at $133.67 million. These values are in 1986 Canadian dollars and were derived from data in the MINFILE and ARIS databases and from historical mining records.

Mineral occurrences within the study area cluster into specific camps as shown in Figure 2. These camps reflect the presence of important controls to mineral accumulation, for example the presence of high-level intrusions or major fracture systems. The highest incidence of deposits is clearly within the continental and island arc volcanic rocks and include a variety of deposit types genetically associated with arc development. These

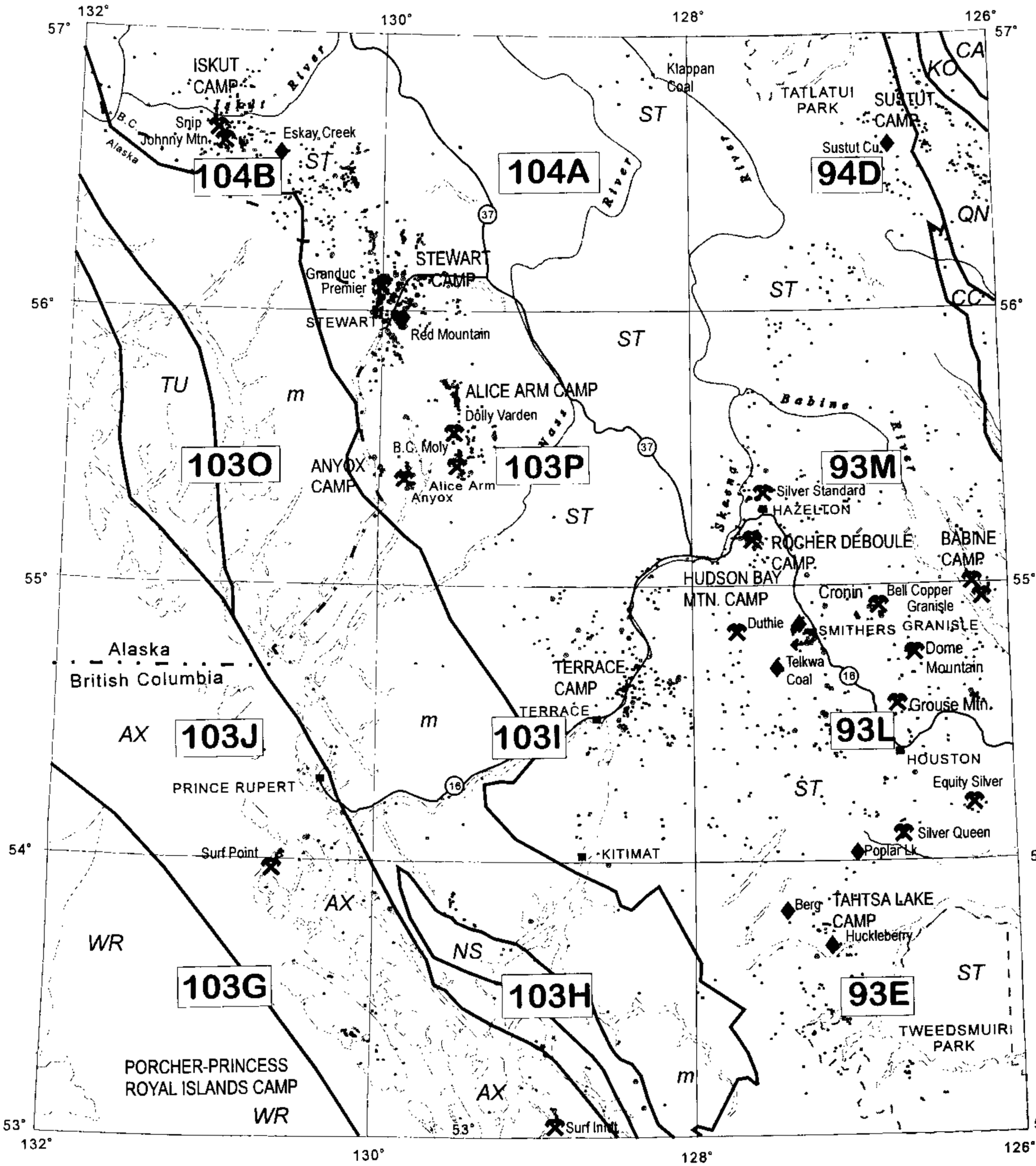

Figure 2. The Skeena-Nass project area showing NTS map sheets, major towns and transportation routes, location of mining camps and terrane boundaries. Terranes shown are Wrangellia (WR), Alexander (AX), Nisling (NS), Taku (Tu), metamorphic and plutonic rocks of the Coast Plutonic complex (m), Stikinia (ST), Cache Creek (CC), Quesnellia (QN), Kootenay (KO) and Cassiar (CA). Diamonds represent major prospects, crossed pick and shovels represent past and current producers.

TABLE 1. MAJOR DEPOSIT TYPES

Deposit Type	*Examples*
Porphyry Cu-Mo	Kitsault
	Ajax
	Hudson Bay Mtn.
	Bell
	Granisle
	Huckleberry
	Berg
	Poplar Lake
	Kerr
VMS - Besshi	Ecstall
	Anyox
	Granduc
	Eskay
Basalt hosted Cu	Sustut Copper
Epithermal Veins	Equity
	Premier
Mesothermal Veins	Dome Mtn.
	Snip
	Red Mountain
	Surf Inlet
	Surf Point
Skarns	Yreka
	Silverado
Coal	Klappan
	Telkwa

are epithermal and mesothermal veins, porphyry copper and molybdenum deposits, massive sulphide deposits, skarns and basalt-hosted copper deposits. In addition, the area has important coal resources at Klappan and Telkwa. Table 1 lists major deposit types found in the area.

GEOLOGIC FRAMEWORK

The Skeena-Nass area is part of the North American Cordillera, a broad belt of deformed igneous, metamorphic and sedimentary rocks that extends from Mexico to Alaska. The Cordillera is divisible into a number of distinct geologic terranes, many of which were accreted to the edge of the North American continent in Mesozoic time. The study area includes rocks of Wrangellia (WR), Alexander terrane (AX), Nisling terrane (NS), undivided metamorphic rocks of the Coast Belt (m), Stikinia (ST), Cache Creek terrane (CC) and Quesnellia (QN). Pericratonic and displaced continental margin rocks of ancestral North America (Kootenay and Cassiar terranes) are only found in the extreme northeast corner of the area.

A detailed discussion of the geology of the area is beyond the scope of this report. The reader is referred to published maps and reports of the Geological Survey of Canada and the British Columbia Geological Survey Branch for more geologic information. A list of selected references is included with this report.

MINERAL POTENTIAL EVALUATION

The Skeena-Nass mineral potential project was started in April 1993. Don MacIntyre, Chris Ash and Jim Britton were assigned responsibility for the geologic compilation and digital data capture; Ward Kilby and Eric Grunsky did the phase 1 and phase 2 assessments.

The key stages in the evaluation process are summarized in Figure 3. The evaluation involved compilation of geologic maps at 1:100 000 scale, selection of tracts based on geology, and evaluation of the potential of each of these tracts. The evaluation of mineral potential involves two phases, one based on historical data (phase 1) and one using probabilistic determinations based on expert assessments (phase 2). The methodologies used for assessing the mineral potential of the Skeena-Nass area are similar to those used in the Mid-Coast (Bellefontaine and Alldrick, 1995, this volume), Vancouver Island (Massey, 1995, this volume) and Thompson-Okanagan (Church, 1995, this volume) projects.

GEOLOGICAL COMPILATION

The bulk of the evaluation process involved researching, compiling and digitizing the geology of the study area to produce an up-to-date digital geological database. Mineral tracts were defined using this database. Geological compilation data for the project was released as GIS-compatible digital files in February, 1994 (MacIntyre *et al.*, 1994)

The data used for the geological compilation were obtained from existing published and unpublished sources as summarized in the list of references at the end of this report. Geological data are primarily from memoirs, papers and open file maps published by the Geological Survey of Canada, bulletins, papers, open file and preliminary maps published by the British Columbia Geological Survey, university theses and journal publications. In addition, discussions with many individuals currently or previously involved in research or exploration in the region proved invaluable.

The primary source of geological data for the mineral potential project is the 1:250 000-scale geological maps produced by the Geological Survey of Canada. They have published maps at this scale for each of the NTS map sheets covering the study area. Unfortunately there is considerable variation in the vintage and detail of mapping and this poses problems in correlating geological units across map boundaries. However, for some areas, in particular the Coast Belt and in large part the Bowser Basin, these maps are the only source of geological information.

The British Columbia Geological Survey Branch has mapped selected areas within the study area at 1:50 000 and 1:100 000 scale. Most of this mapping is recent and covers areas of known mineral potential such as the Stewart, Smithers and Whitesail regions. In most cases, the amount of detailed geologic information contained on

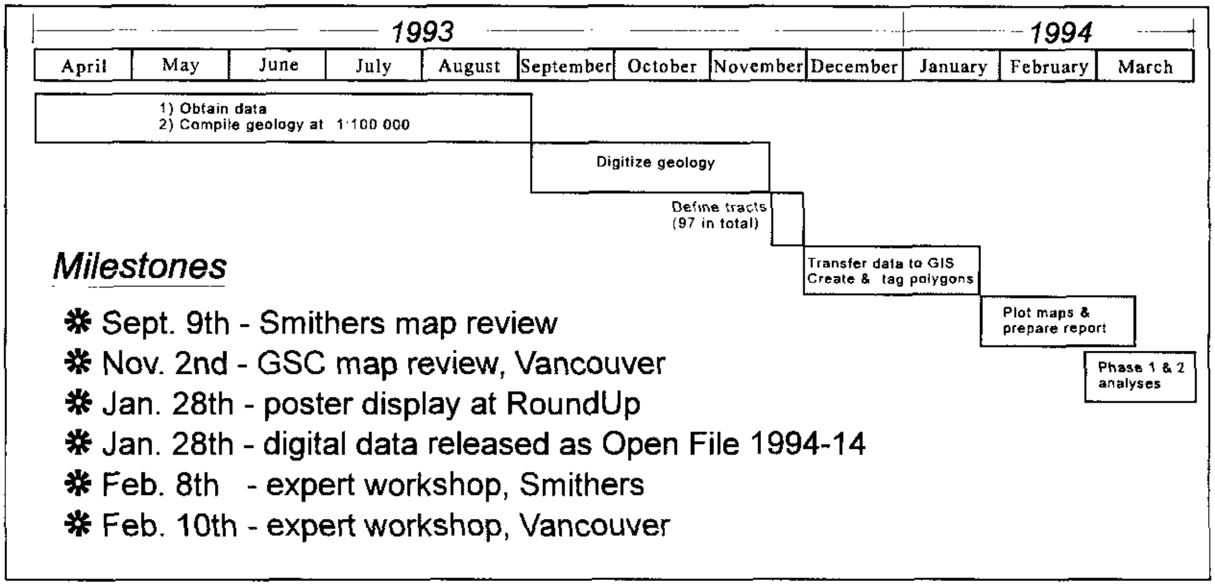

Figure 3. Time line for the Skeena-Nass project showing project milestones.

these maps was too great for a 1:250 000-scale compilation and some generalization was required.

In recent years the Mineral Deposit Research Unit (MDRU) at the University of British Columbia has conducted detailed mapping in selected mineral camps. In the study area, MDRU has produced maps for parts of the economically important Iskut River camp.

As of September 1994, there were a total of 1995 reports filed for assessment within the study area. Many of these reports contain good quality geological maps. Unfortunately most of the assessment report maps are between 1:500 and 1:5 000 scale and cover a very small area on a 1:250 000 scale map.

DATA CAPTURE

The first step for the compilation team was to compile the geology of the area onto mylar overlays registered to 1:100 000 scale topographic base maps. These base maps were generated from digital 1:250 000 scale, restructured topographic maps produced by the Ministry of Environment, Lands and Parks. In order to compile at 1:100 000 it was necessary to divide each 1:250 000 scale map area into four quadrants. A total of 38 maps were required to cover the study area.

The manuscript geology maps were digitized using AutoCad Release 12. AutoCad was used because it supports many digitizing functions which are not found in other CAD (Computer Assisted Drafting) or GIS (Geographic Information System) software packages. A digitizing strategy was used that ensured polygon closure, a key requirement if digital data are to be used in a GIS. Lines that formed polygon boundaries were placed on different layers from lines not forming boundaries. This greatly reduced the amount of editing required when the data were converted to Terrasoft GIS format.

After the maps were digitized and edited, the digital data was exported in DXF format and imported into Terrasoft using a DXF translation routine. Terrasoft was used to clean up linework, build a topology and link geology polygons to an associated attribute table. The GIS created a total of 5350 polygons, each of which was given a unique identification number by the system. Geology tags were entered manually for each of the polygons using the GIS tagging routines.

TRACT SELECTION

Mineral tracts were defined on the basis of geology and known mineral occurrence distribution. Typically, tract boundaries are defined by geological contacts - either stratigraphic or tectonic. However, in a number of cases it was necessary to place tract boundaries arbitrarily through areas of similar geology in order to reduce the size of a tract. This was particularly true for parts of the Coast Plutonic Complex and Bowser Basin.

The geological compilation maps were used as a basis for dividing the Skeena-Nass area into 97 mineral tracts (Figure 4). Individual tracts were assigned a sequential identification code based on the dominant lithostratigraphic unit within the tract (JH - Hazelton Group, CC - Cache Creek, ST - Stikine Assemblage; CP - Coast Plutonic Complex; KK - Kasalka Group; KS - Skeena Group; JB - Bowser Lake Group; PL - Lay Range Assemblage; PI - Ingenika Group; TA - Takla Group; TV - Tertiary volcanics). A list of mineral assessment tracts in order of phase 1 ranking and showing tract identification code, tract name, area in hectares, number of mineral occurrences, value of mineral inventory, total exploration expenditures, value of past production and weighted phase 1 score for each tract, is presented in Table 2.

TABLE 2. SKEENA-NASS MINERAL ASSESSMENT TRACTS - PHASE 1 DATA

Potential Class	Rel. Rank	Tract ID	Tract Name	Area (hectares)	No of Minfile Occ	Mineral Inventory Value (1986 $)	Exploration Expenditures (1986 $)	Past Production Value (1986 $)	Weighted Phase 1 Score
HIGH POTENTIAL (33.08% of Total Area)	1	JH30	Brucejack Lake	153,982	125	8,405,910,986	19,742,757	394,193,930	4,285
	2	JH26	Alice Arm	105,619	129	2,447,448,370	5,277,323	405,426,070	4,175
	3	JH17	Hudson Bay Mtn.	35,318	50	1,241,736,544	765,033	19,177,668	4,085
	4	JH20	Newman Peninsula	84,265	19	1,957,608,942	2,476,771	1,131,845.272	4,040
	5	JH7	Tahtsa Reach	88,702	43	1,333,121,472	3,440,404	1,825 758	4,020
	6	JH29	Mount Dilworth	82,903	207	293,221,116	5,509,563	2,653,869 595	4,010
	7	JH16	Babine Range	63,037	39	229,493,710	4,335,920	4,414.286	4,005
	8	KK3	Poplar Lake	126,550	27	2,269,096,270	6,372,581	20,549.912	3,995
	9	JH31	Snippaker Creek	126,129	103	419,923,603	17,983,159	80,469 822	3,960
	10	JH25	Hastings Arm	143,526	50	1,322,569,659	2,899,007	1,409,341 250	3,915
	11	JH8	Mt. Ney	40,115	4	2,364,400,000	1,288,001	-	3,560
	12	TV4	Goosly Lake	130,523	8	153,931,000	5,005,989	739,300 933	3,425
	13	TA3	McConnell Range	125,274	83	449,000,000	2,811,832	-	3,410
	14	JH28	Mount Pattullo	147,466	80	439,430,784	6,194,186	-	3,400
	15	JH13	Grouse Mountain	73,557	31	43,404,114	1,782,282	5,766	3,385
	16	TA2	Sustut Peak	143,368	41	1,112,500,000	1,734,042	-	3,330
	17	JB3	Mt. Thornlinson	60,163	8	213,896,800	1,031,644	-	3,185
	18	JH14	Matzehtzel Mtn.	69,361	15	18,228,600	1,618,267	15,131	3,165
	19	CP11	Pitt Island	254,031	24	368,182,584	1,161,970	16,738,484	3,135
	20	CP7	Ecstall Lake	119,967	21	243,040,500	2,235,433	-	3,095
	21	CP10	Banks Island	113,185	38	110,966,171	3,158,283	-	3,070
	22	KK1	Red Bird Mtn	62,547	10	474,980,000	297,502	-	3,030
	23	JH22	Trail Peak	74,232	8	179,550,000	770,969	-	2,990
	24	KK5	*Rocher Déboulé*	76,687	35	8,091,460	607,769	7,735,236	2,975
	25	JH6	Troitsa Peak	41,327	7	34,761,230	1,297,745	-	2,955
	26	JB2	Nine Mile Mtn.	77,342	25	3,726,600	683,832	214,731	2,895
	27	CP5	Gil Island	87,287	12	9,942,387	604,882	163,424,225	2,845
	28	JH21	Netalzul Mtn.	73,151	19	3,104,163	645,726	87,478	2,835
	29	JH9	Monce Lake	152,830	16	144,727,746	2,452,547	-	2,820
	30	KS5	Smithers Landing	40,174	3	63,029,662	281,500	-	2,770
	31	JH10	Howson Range	153,085	33	153,901,000	976,526	-	2,735
	32	PL1	*Ingenika River*	44,476	8	7,938,000	1,024,012	-	2,690
	33	JB8	Sicintine Range	140,890	17	58,000,000	1,263,914	-	2,660
	34	KS3	Bulkley Valley	77,153	10	15,264,000	136,500	53,163	2,640
	35	JH24	Driftwood Range	93,208	15	32,040,000	729,747	-	2,605
	36	ST3	Iskut Mountain	288,992	34	91,014,856	2,948,979	-	2,600
	37	JH19	Zymoetz River	216,738	98	67,542,746	908,603	-	2,545
	38	KS4	Ashman Ridge	127,979	7	166,140,000	321,215	-	2,530
MEDIUM POTENTIAL (33.11% of Total Area)	39	CP3	Kemano River	102,900	5	129,195,000	311,496	-	2,520
	40	*CP4*	*Gribbell Island*	*196,343*	*14*	*14,642,380*	*450,140*	*12,262*	*2,485*
	41	CP1	Kimsquit River	149,912	9	51,029,861	203,022	-	2,180
	42	KS7	Kispiox River	65,343	34	-	385,341	78,268,471	1,425
	43	ST2	Newmont Lake	124,667	27	-	6,951,743	-	1,285
	44	JH12	Telkwa Range	75,662	34	-	952,964	-	1,155
	45	CP18	Terrace	84,761	37	-	981,137	-	1,130
	46	ST1	Fulton River	39,303	11	-	333,769	-	1,000
	47	JH15	Baboon Lake	82,601	10	-	907,373	-	990
	48	*JB1*	*Kitsumkalum Lake*	*239,482*	*55*	-	*1,613,738*	-	*915*
	49	KS11	Nilkitkwa River	41,815	1	-	584,861	-	880
	50	KS6	Skeena Crossing	88,639	29	-	346,944	-	870
	51	JH11	Houston Tommy Crk.	31,835	2	-	322,148	-	865
	52	JH5	Shelford Hills	77,768	3	-	800,720	-	850
	53	JB4	Atna Range	82,065	16	-	345,818	-	835
	54	KK2	Kasalka Range	59,580	4	-	468,639	-	810
	55	CC1	Axelgold Peak	20,683	2	-	83,698	-	740
	56	*CP20*	*Dundas Island*	*98,503*	*30*	-	*135,411*	-	*720*
	57	KS2	Round Lake	48,361	1	-	363,156	-	710
	58	CP12	Dala River	234,289	19	-	820,991	-	690
	59	JH3	Pondosy Lake	61,569	15	-	41,653	-	670
	60	JH27	Sikanni Range	114,295	9	-	206,292	-	615
	61	JH18	Telkwa River	71,838	6	-	123,110	-	610
	62	JH23	Bait Range	84,191	7	-	51,894	-	535
	63	KK4	Harold Price Creek	51,641	2	-	77,972	-	525
	64	KT2	Thutade Lake	117,111	2	-	221,421	-	515
	65	TV5	Maxan Lake	95,944	1	-	271,826	-	515
	66	JB12	Oweegee Peak	531,231	4	-	1,156,091	-	465
	67	TV3	Wisteria	122,784	0	-	445,590	-	460
	68	KS1	Thautil River	70,950	4	-	30,616	-	440
	69	CP22	Observatory Inlet	341,353	5	-	199,317	-	380
	70	JH1	Oppy Lake	52,438	2	-	5,517	-	365
	71	CP2	Kitlope River	290,135	6	-	64,138	-	355
	72	CP17	Mount Morris	*94,457*	1	-	*54,770*	-	*350*
	73	KS9	Nilkitkwa Lake	73,618	0	-	102,467	-	340
LOW POTENTIAL (33.80% of Total Area)	74	JB5	Hazelton Mountain	399,414	6	-	90,175	-	335
	75	TV2	Chelaslie River	80,987	0	-	110,807	-	320
	76	KS10	Takla Lake	107,864	1	-	25,000	-	315
	77	CP8	Foch Lake	128,072	2	-	2,827	-	290
	78	KS8	Gunanoot Lake	99,753	0	-	57,963	-	270
	79	JB10	Lipsconesit Mountain	958,829	2	-	183,662	-	260
	80	CP16	Kateen River	233,277	2	-	5,921	-	250
	81	JB7	Kispiox Range	288,960	1	-	28,038	-	245
	82	CP19	Work Channel	52,157	4	-	-	-	230
	83	JH2	Butler Peak	41,006	3	-	-	-	220
	84	TA1	Mesilinka River	30,388	1	-	-	-	160
	85	JB11	Devils Claw	244,250	8	-	-	-	155
	86	CP21	Khutzeymateen	35,888	1	-	-	-	150
	87	CP6	Ecstall River	208,830	5	-	-	-	145
	88	CP15	Quottoon Inlet	128,082	2	-	-	-	115
	89	CP9	Crab Lake	195,024	3	-	-	-	110
	90	KT1	Connelly Range	163,040	2	-	-	-	95
	91	CP13	Alastair Lake	102,880	1	-	-	-	80
	92	JB6	Swan Lake	224,951	1	-	-	-	60
	93	JB9	Mosque River	146,830	0	-	-	-	-
	94	JH4	Quanchus Range	166,912	0	-	-	-	-
	95	TV1	St. Thomas River	82,190	0	-	-	-	-
	96	CP14	Mount Salvus	33,781	0	-	-	-	-
	97	PI1	Tucha Range	51,187	0	-	-	-	-
				12,438,760	1954	27,145,732,316	133,696,593	7,126,969,443	157,770

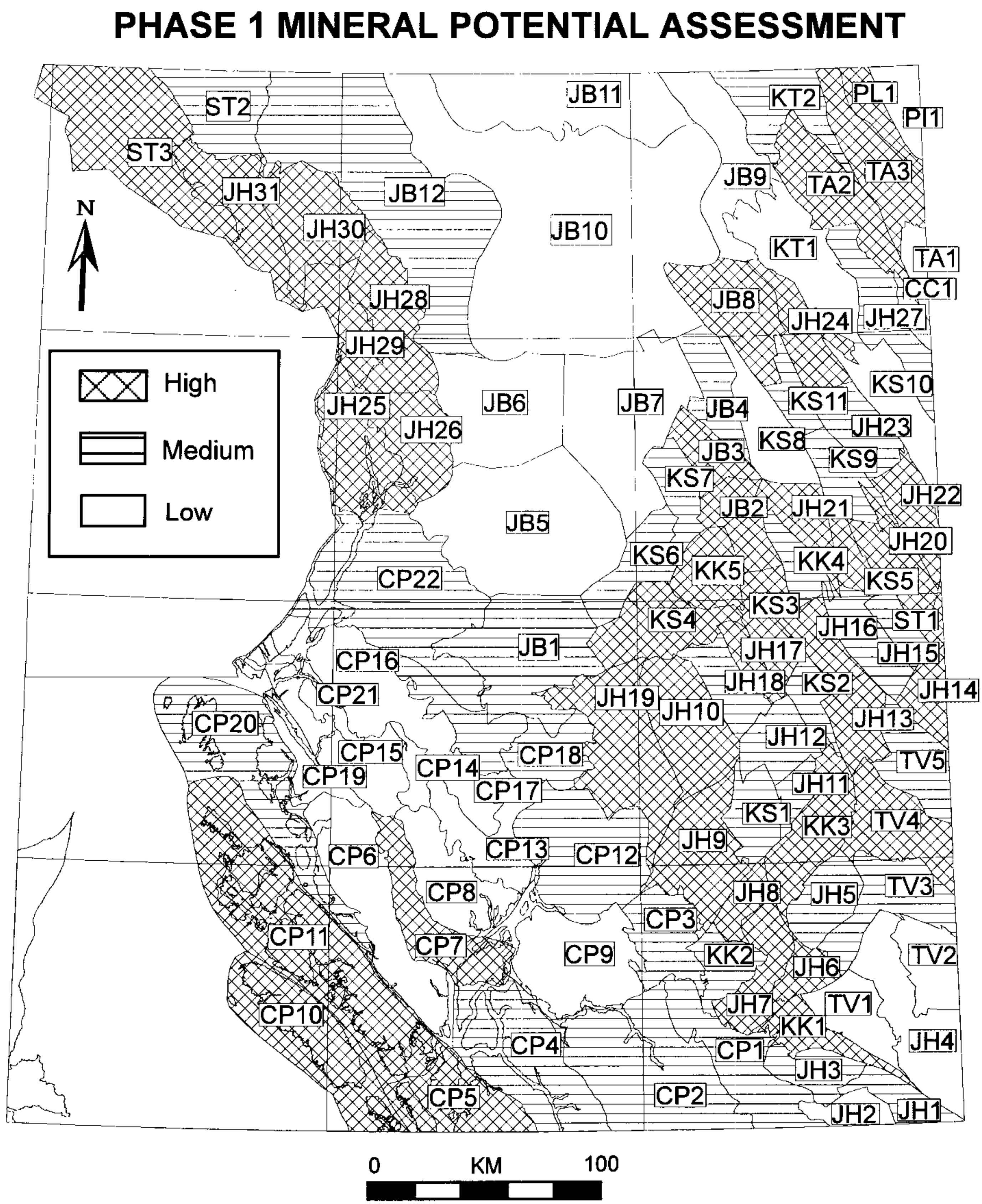

Figure 4. Skeena-Nass mineral assessment tracts showing tracts ranked high, medium and low in the phase 1 assessment.

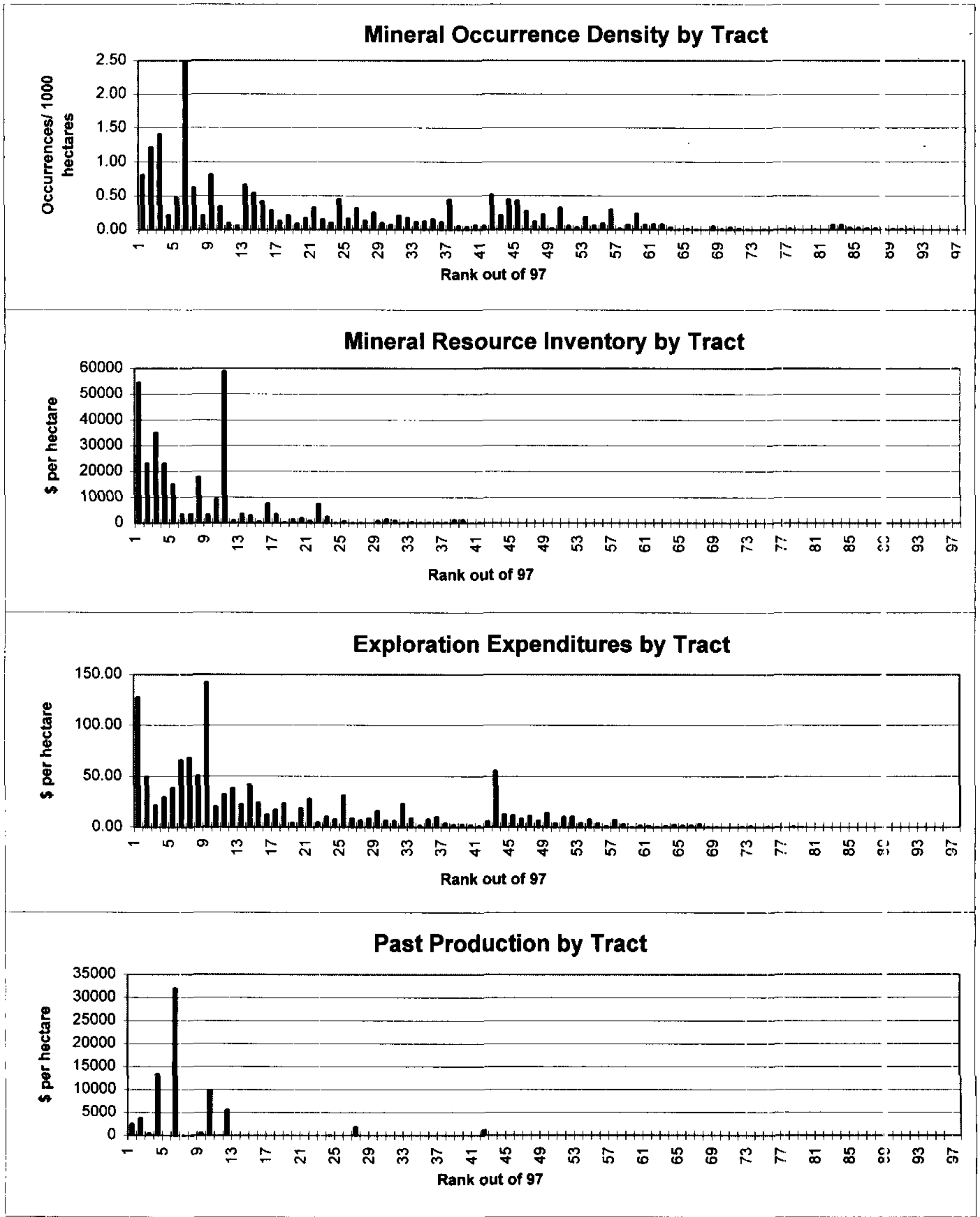

Figure 5. Bar graphs of phase 1 mineral assessment data normalized to tract area and ordered by rank.

PHASE 1

The phase 1 mineral potential assessment is based on the mineral occurrence density, value of past production, previous exploration expenditures and value of known in-ground "reserves" for each tract as described elsewhere in this volume (Kilby, 1995). The score shown in Table 2 is calculated by ranking each tract according to these factors relative to tract area, and then applying a weighting factor to the resultant ranks and adding the results. The weighting factors are 25 for known resources, 10 for past exploration work and 5 for number of mineral occurrences and past production. The tracts are then given a rank from 1 to 97, with 1 being highest potential and 97 lowest. The per hectare values calculated for each tract and arranged by rank out of 97 are shown graphically in Figure 5. This ranking is specific to the project area only and does not relate to ranks assigned in adjacent areas (*e.g.* Mid-Coast). Tracts ranked low in the Skeena-Nass area may still have significantly higher mineral potential than those in adjacent areas that are not as well endowed with mineral deposits. A low rank does not imply no mineral potential, only relatively low potential by comparision with other tracts in the project area.

After a phase 1 ranking has been determined, the tracts are then divided into groups representing high, medium and low potential based on cumulative area. In this way tracts representing the top 33.08 % of the area (4 115 143 ha) are assigned to the high potential category, the next 33.11 % (4 119 066 ha) are considered medium potential and the bottom 33.80 % (4 204 551 ha) are considered to have low potential (Table 2).

Figure 4 shows the distribution of tracts in the area with a shading pattern reflecting high, medium and low potential. The highest ranked tract (JH30) is in the Stewart area and contains the Eskay Creek deposit; the lowest ranked tract (PI1) is in the extreme northeast corner and is underlain by unmineralized Proterozoic rocks. In general, tracts containing volcanic rocks of Triassic, Jurassic and Cretaceous age are ranked medium and high while those containing successor basin sedimentary rocks (Bowser Lake Group) or large unmineralized plutons such as those of the Coast Plutonic Complex are ranked low.

PHASE 2

The phase 2 estimation process is designed to identify tracts with potential for undiscovered mineral deposits. The estimates are done by experts with personal knowledge of the area, and, when combined with the phase 1 results give an overall ranking for the mineral potential of a given tract. The phase 2 estimates take into account previous levels of exploration and current deposit models that may not have been the focus of previous exploration efforts. In this way, tracts with favourable geology but no known production or reserves can often be ranked higher than tracts which are considered to be well explored and to have less potential for new discoveries.

Expert estimation for the phase 2 mineral potential assessment were completed for the Skeena-Nass project in February, 1994. Unfortunately, the number of estimators participating in the process was relatively low. Consequently, not all tracts and deposit types were considered by the estimators and it may be necessary to conduct a new set of estimates using a revised methodology.

DISCUSSION

The phase 1 rankings clearly reflect the weighting criteria used to score the tracts. Well explored areas with known reserves and historical production are the top ranked tracts; tracts with no known occurrences and no previous exploration or production history score very low. Tract size can also be important because scores are based on per hectare values not total values. A small tract with numerous occurrences and historical reserves will score higher than larger tracts with similar values.

A complete assessment of the mineral potential of the Skeena-Nass area must await completion of the phase 2 assessment. Although useful as a guide to areas of favourable mineral endowment, the phase 1 assessment does not by itself, address the potential for undiscovered deposits. This information is required before a final mineral potential map and report can be produced for the project.

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BRITISH COLUMBIA MINERAL DEPOSIT PROFILES

By David V. Lefebure, Dani J. Alldrick, George J. Simandl and Gerald E. Ray

KEYWORDS: economic geology, mineral deposits, mineral potential, models, British Columbia, metallic, industrial minerals, coal, gemstones, gold skarn.

INTRODUCTION

The British Columbia Geological Survey Branch started a mineral potential assessment in 1992 utilizing deposit models for defining and characterizing mineral and coal deposits which exist, or for which favourable geological environments could exist, in the province. The current methodology for this resource assessment process is described by Grunsky *et al.* (1994), Kilby (1995, this volume) and Grunsky (1995, this volume). A fundamental part of this process is compilation of information about mineral deposits including descriptions, classification and resource data. The resulting deposit models are being used to classify known deposits and occurrences, to guide experts in their identification of possible undiscovered mineral deposits, and to group deposits to allow compilation of representative grade and tonnage data.

The Branch initially relied on mineral deposit models published by the United States Geological Survey (USGS) and Geological Survey of Canada (GSC). However, it became apparent that some models needed revision and that there are British Columbia deposit types lacking published models. This work is proceeding using the Branch's considerable in-house expertise (McMillan *et al.*, 1991) with assistance from economic geologists of the GSC, USGS and industry.

These revised deposit models are called 'deposit profiles' to distinguish them from the USGS 'deposit models' and to underline their relationship to the province's mineral occurrence database (MINFILE). The profiles will provide geologists and prospectors with a reference guide to deposits with which they may have little familiarity. In some cases they may encourage consideration of new exploration targets within the province.

BACKGROUND

> *"An ore deposit model is a conceptual and/or empirical standard, embodying both the descriptive features of the deposit type, and an explanation of these features in terms of geological processes."*
>
> Hodgson, 1993

In recent years there has been considerable discussion of the importance of deposit models and their relevance to exploration (Cox, 1993). One of the points underscored by this debate is that while models are an extremely useful method of organizing data, they may lead to over simplification of complex natural phenomena. This may result in failure to consider relevant data which do not fit the model. It is important to remember that any model has limitations, particularly those attempting to portray the essential features of natural phenomena.

Interactions between the constructors of models, who are often government and academic geologists, and the explorationists who use them, is critical to the evolution of more accurate and useable models (Hodgson, 1993). Often it is the deposits that can not be classified, or the observation that can not be explained by an existing model, which leads to an advance in our understanding of ore-forming processes or products.

Critical elements of mineral potential assessments are standard deposit-type descriptions that are used to establish groups of similar deposits. These standard descriptions can then be used as "deposit definitions" for expert analysis of the mineral potential of geological tracts, as well as providing the basis for selecting resource data for quantitative assessments, such as tabulations of grade and tonnage data (Grunsky, 1995, this volume).

Complete suites of deposit models are desirable, even though mineral assessments and exploration programs may focus on a restricted number of deposit types at any one time. For government, it is important to assess all the resource values with an eye to future exploitation of resources. There will be land tracts that will have increased mineral potential if deposit types of little significance today can be identified as possible mines of tomorrow. For industry, it is critical to be able to decide that a particular occurrence belongs to a deposit type that is not economically interesting at the present time. This helps focus exploration efforts on targets with a greater chance of economic return.

The USGS published the first comprehensive set of mineral deposit models and related grade and tonnage probability curves (Cox and Singer, 1986). They present 85 mineral deposit models and 60 associated grade and tonnage curves. Almost all the deposits described are metallic. Since then the USGS has produced a number of other publications containing summary deposit models including two significant Open File reports with a large number of industrial minerals models (Orris and Bliss, 1991, 1992). The USGS continues to work on deposit models, however, it has yet to publish models for some deposits that have been found, or could exist, in British Columbia.

B.C. MINERAL DEPOSIT PROFILES

Profiles are based on a combination of published information and the personal knowledge of the authors and, in some cases, information provided informally by industry geologists. More than 140 general deposit models are relevant to British Columbia, including 79 metal, 71 industrial mineral and four coal profiles. The Branch is completing descriptions for approximately 100 of these deposit models. It is also compiling grade and tonnage data for selected models (Grunsky, 1995, this volume).

With new data being produced every day by industry and research geologists, it is a given that some of today's models will be out-of-date tomorrow. Our profiles are intended to be part of the dynamic process described by Erickson (1982), playing their part in the continuing evolution of better deposit models to assist the exploration community and resource assessment geologists.

Deposit Profiles Format

The profiles are designed to be global models with sufficient information to describe the deposit type anywhere in the world. However, they do incorporate more information specific to British Columbia with respect to tectonic setting, age of mineralization, examples, references, resource data and economic factors.

Profiles are concise descriptions tied to a series of headings which will fit on two or three pages. A sample profile for gold skarns is presented in Table 1. This format is similar to deposit model publications by the Geological Survey of Canada and the USGS (Eckstrand, 1984; Cox and Singer, 1986). They are designed to be primarily descriptive because the ore-forming processes are sometimes poorly understood. However, a section on 'genetic models' is now part of many profiles because many of the authors and reviewers of the draft information argued strongly for its inclusion.

Classification

Another aspect of the profiles has generated considerable discussion - grouping of the different deposit types. This reflects the difficulties in any subdivision of complex natural phenomena, particularly when some deposit types are end members of a continuum. The many classification systems developed since Agricola are testimony to the elusive nature of a satisfactory classification scheme for mineral deposits. This is not surprising given the ongoing advances in our understanding of ore-forming processes. The reader is directed to summaries by Jensen and Bateman (1979) and Peters (1978) for a review of different classification systems.

With the profiles, the approach has been to regard the deposit models as the key element and any classification system as an index for placing the models in a useful context for the user. Profiles will be published with multiple indexes, such as by commodity, host lithology and deposits. An example of providing indexes to mineral deposit types is Laznicka's text (1985) which proved invaluable in researching international examples of deposits similar to those in British Columbia.

Two classification schemes for British Columbia deposit profiles are presented in this paper. The first is organized by association (Table 2) which uses a combination of characteristics to separate deposits into groupings frequently used by geologists. This is a single-entry listing with headings, such as porphyry, industrial rocks, organic and placer deposits which often relates well to areas of expertise of economic geologists. The second classification system presents the profiles grouped according to the most commonly associated host lithologies and is a multiple entry index (Table 3). This latter scheme is similar to the principle USGS classification system of Cox and Singer (1986) and is particularly useful for mineral potential assessments where the bedrock geology is the most important criteria for estimating the number of undiscovered deposits.

Within the British Columbia mineral resource assessment process more than 9900 of the occurrences in the province listed in MINFILE were classified by detailed deposit type. This assisted the analysis of the mineral potential of individual geological tracts by identifying all the deposit types that exist within the tract. It also provided a check on the effectiveness of existing deposit models to adequately describe the complete array of mineral occurrences in British Columbia. Geologists classifying occurrences quickly pointed out that there were a number of occurrences that did not fit any of the existing profiles and some that did not fit any of the USGS models either. In some cases this reflected the difficulty of classifying poorly described showings and prospects. However, it also led to identifying more deposit models that needed to be written. This exercise should be completed in any area of mineral potential assessments as it provides a very useful check on the applicability and completeness of global models being applied.

Within the two classification schemes of deposit types for British Columbia (Tables 2 and 3), the reader will notice several new deposit types that reflect the influence of new discoveries or new data. For example, there is a deposit model for Shallow Subaqueous Hot Spring Au-Ag. This is based on the Eskay Creek deposit and recent research results from the southeast Pacific (Hannington, 1993) documenting shallow, precious metal rich exhalative sulphide deposits. As more data are collected on these new deposits our increased understanding may allow them to be merged with an existing deposit model.

ACKNOWLEDGMENTS

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Table 1. EXAMPLE DEPOSIT PROFILE FOR AU SKARN

Au SKARNS K04

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic, tactite, or contact metasomatic gold deposits.

COMMODITIES (BYPRODUCTS): Au (Cu, Ag).

EXAMPLES (British Columbia - *International*): Nickel Plate (092HSE 038), French (092HSE 059), Canty (092HSE 064), Good Hope (092HSE 060); *Fortitude (USNV), McCoy (USNV), Tomboy-Minnie (USNV), Buckhorn Mountain (USWA), Butte Highlands (USMT), Thanksgiving (PLPN), Browns Creek (AUNS), Mount Biggenden (AUQL), Nambija (ECDR).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Gold-dominant mineralization genetically associated with a skarn gangue consisting of calcium-iron-magnesium silicates. It includes calcic and magnesian Au skarns.

TECTONIC SETTINGS: Most Au skarns form in orogenic belts at convergent plate margins. They tend to be associated with syn to late intra oceanic island-arc intrusions emplaced into calcareous sequences in arc or back-arc environments. However, the Butte Highlands Au skarn in Montana, U.S. (Ettlinger *et al.*, in prep) is hosted by platformal carbonates and is probably associated with melts derived from continent crust.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Most are related to plutonism associated with the development of oceanic island arcs or back arcs, such as the Late Triassic-Early Jurassic Nicola Group in British Columbia.

AGE OF MINERALIZATION: Phanerozoic (mostly Cenozoic and Mesozoic); in British Columbia they are mainly of Early to mid-Jurassic age. The unusual magnesian Au skarns of Western Australia are Archean.

HOST/ASSOCIATED ROCK TYPES: High to intermediate level stocks, sills and dikes of gabbro, quartz diorite or granodiorite intruding carbonate, calcareous clastic or volcaniclastic rocks. The island arc related, I-type intrusions are commonly porphyritic and iron rich, and have low Fe_2O_3/FeO ratios.

DEPOSIT FORM: Variable from irregular lenses and veins to tabular or stratiform orebodies with lengths and widths ranging up to many hundreds of metres.

TEXTURE/STRUCTURE: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to layered textures in exoskarn. Some hornfelsic textures. Faults and fractures can be an important loci for mineralization.

ORE MINERALOGY(Principal and *subordinate*):

Calcic Au skarns: Native gold ± chalcopyrite ± pyrrhotite ± arsenopyrite ± *tellurides* (e.g. *hedleyite, tetradymite, altaite* and *hessite*) ● *bismuthinite* ± *cobaltite* ± *native bismuth* ± *pyrite* ± *sphalerite* ± *maldonite.* Generally high sulphide content and pyrrhotite:pyrite ratios, and low Cu:Au (<2000), Cu:Ag (<1000), Zn:Au (<100) and Ag/Au (<1) ratios. Gold is commonly present as micron-sized inclusions in sulphides, or at sulphide grain boundaries associated with tellurides. Therefore, to the naked eye, Au skarn ore is often indistinguishable from waste rock.

Magnesian Au skarns: Native gold ± pyrrhotite ± chalcopyrite ± pyrite ± *magnetite* ± *galena* ± *tetrahedrite.*

EXOSKARN MINERALOGY (GANGUE):

Calcic Au skarns: extensive exoskarn, generally with high pyroxene:garnet ratios, although at the Fortitude deposit in Nevada, some higher gold values are concentrated in thin, structurally controlled garnet-rich zones. Prograde minerals include K-feldspar, Fe-rich biotite, low Mn grandite garnet (Ad_{10-100}), wollastonite, diopside-hedenbergite clinopyroxene (Hd_{20-100}) and vesuvianite. Other less common minerals include rutile, axinite and sphene. Mineral and metal zoning common in skarn envelope with proximal coarse-grained, garnet-rich skarn containing high Cu:Au ratios, and distal finer grained pyroxene-rich skarn containing low Cu:Au ratios and gold-sulphide orebodies. Late or retrograde minerals include epidote, chlorite, clinozoisite, vesuvianite, scapolite, tremolite-actinolite, sericite and prehnite.

Magnesian Au skarns: olivine, clinopyroxene (Hd_{2-50}), garnet (Ad_{7-30}) and chondrodite. Retrograde minerals include serpentine, epidote, vesuvianite, tremolite-actinolite, phlogopite, talc, K-feldspar and chlorite.

Au SKARNS K04

ENDOSKARN MINERALOGY (GANGUE):

Calcic Au skarns: moderate endoskarn with K-feldspar, biotite, Mg-pyroxene (Hd_{5-30}) and garnet.

Magnesian Au skarns: details on endoskarn are poorly documented. Argillic and propyllitic alteration with some garnet, clinopyroxene and epidote occurs in the endoskarn at the Butte Highlands Au skarn.

WEATHERING: In temperate climates, skarns often form topographic features with positive relief.

ORE CONTROLS: Stratigraphic and structural controls. Sulphide-rich ore commonly develops in distal, pyroxene-dominant portion of the skarn envelope. Some orebodies form along sill-dike intersections, sill-fault or bedding-fault intersections as well as along fold axes. In some districts, specific suites of reduced, Fe-rich intrusions are spatially related to mineralization

GENETIC MODEL: Mineral assemblages and low Fe_2O_3/FeO ratios indicate that most calcic Au skarns are highly reduced systems. However, the McCoy Au skarn in Nevada represents a more oxidized system. There is a worldwide spatial and temporal association between porphyry copper provinces and gold skarns.

ASSOCIATED DEPOSIT TYPES:

Calcic Au skarns: Au placers (C01,C02), calcic Fe and Cu skarns (K03, K01), porphyry Cu deposits (L04) and Au-bearing quartz and/or sulphide veins (I01, I02).

Magnesian Au skarns: Au placers (Co1,C02), Cu skarns (K01), porphyry Cu and Mo deposits (I04, L05), Au-bearing quartz and/or sulphide veins (I01, I02); possibly W skarns (K05).

COMMENTS: Most Au skarns throughout the world are calcic and are associated with island arc plutonism. However, unusual and distinct magnesian Au skarns are reported in the Archean greenstones of Western Australia and in Cambrian platformal dolomites at Butte Highlands in Montana, U.S.A.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Au, As, Bi, Te, Co, Cu anomalies, as well as some geochemical zoning patterns throughout the skarn envelope (notably in Cu/Au ratios). Calcic Au skarns tend to have lower Zn/Au, Cu/Au and Ag/Au ratios than any other skarn class. Their genetically related intrusions may be relatively enriched in the compatible elements Cr, Sc and V, and depleted in lithophile incompatible elements (Rb, Zr, Ce, Nb, and La), compared to intrusions associated with most other skarn classes.

GEOPHYSICAL SIGNATURE: Airborne magnetic or gravity surveys to locate plutons. Ground IP and magnetic follow-up surveys can outline some deposits (magnesian skarns tend to be magnetite bearing).

OTHER EXPLORATION GUIDES: Old placer workings.

Calcic Au skarns: Pyroxene and pyrrhotite-dominant exoskarn envelopes associated with reduced, Fe-rich intrusions in island arc environments.

Magnesian Au skarns: granodiorite intrusions in dolomitic sedimentary rocks.

ECONOMIC IMPORTANCE

TYPICAL GRADE AND TONNAGE: These deposits range from 0.4 to 10 Mt and from 2 to 15 g/t gold. Theodore *et al.* (1991) report median grades and tonnage of 8.6 g/t , 5.0 g/t Ag and 213 000 t. Nickel Plate has produced over 8 Mt grading 7.4 g/t Au. Average grade worldwide is approximately 4.5 g/t gold.

IMPORTANCE: Recently, there have been some significant Au skarn deposits discovered around the world. Nevertheless, total historic production of gold from skarn (approximately 1000 tonnes of metal) is minute compared to production from other deposit types. The Nickel Plate deposit (Hedley, British Columbia) was probably one of the earliest major gold skarns in the world to be mined. Skarns have accounted for about 16 % of British Columbia's gold production, although nearly half of this was derived as a byproduct from Cu and Fe skarns

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Table 2. B. C. Mineral Deposit Profiles Listed by Association (December 15, 1994)

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
	A - ORGANIC	
A01	Peat	
A02	Lignitic coal	"Brown coal"
A03	Sub-bituminous coal	Thermal coal, Black lignite
A04	Bituminous coal	Coking coal, Thermal coal
A05	Anthracitic coal	Stone coal
	B - RESIDUAL/SURFICIAL	
B01*	Laterite Fe	Gossan Fe
B02*	Laterite Ni	
B03*	Laterite-Saprolite Au	Eluvial placers
B04*	Bauxite Al	Lateritic bauxite
B05	Residual kaolin	Primary kaolin
B06	Fireclay	Refractory shale
B07*	Bog Fe, Mn, U, Cu, Au	
B08	Surficial U	"Calcrete U"
B09*	Karst-hosted Fe, Al, Pb-Zn	
B10	"Terra Rossa" Au-Ag	Residual Au; Precious metal gossans
B11*	Marl	
B12*	Sand and Gravel	
	C - PLACER	
C01	Surficial placers	Placer U-Au-PGE-Sn-diamond-magnetite-garnet, gems
C02	Buried-channel placers	
C03*	Marine placers	Off-shore heavy mineral sediments
C04*	Paleoplacer U-Au-PGE-Sn-diamond-Ti-mag-gar-zir	
	D- CONTINENTAL SEDIMENTS & VOLCANICS	
D01	Open-system Zeolites	
D02	Closed Basin Zeolites	
D03	Volcanic redbed copper	Basaltic Cu
D04	Basal U	Sandstone U
D05*	Sandstone U	Roll front U, Tabular U
D06	Volcanic-hosted U	"Epithermal U", Volcanogenic U
D07	Iron oxide breccias and veins Cu-U-Au	Olympic Dam type Fe (Cu-U-Au), Kiruna type
	E - SEDIMENT-HOSTED	
E01*	Almaden Hg	
E02*	Kipushi Cu-Pb-Zn	Carbonate-hosted Cu-Pb-Zn
E03	Carlin-type sediment-hosted Au-Ag	Carbonate-hosted Au-Ag
E04*	Sediment-hosted Cu	Sandstone Cu, Sediment-hosted stratiform Cu
E05	Sandstone Pb	
E06	Bentonite	Volcanic clay, Soap clay
E07*	Sedimentary kaolin	

Working Version 2.0
** no draft of PROFILE completed*

MINERAL DEPOSIT B.C. PROFILES

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
Ireland, Ontario, New Brunswick	Fraser Delta, North Coast
Estevan (Saskatchewan)	Skonun Point (Graham Island)
Highvale (Alberta), Powder River Basin (Wyoming)	Hat Creek, Princeton
Gregg River (Alberta), Sydney Coalfield (Nova Scotia)	Quintette, Bullmoose, Greenhills, Fording
Pennsylvannia Coalfields, Canmore (Alberta)	Mt Klappan

Glenravel (Ireland), Araxa (Brazil)	
Riddle (Oregon)	
Boddington, Mt. Gibson (Australia), Akaiwang (Guyana)	
Queensland, Pocos de Caldas (Brazil), Salem Hills (Oregon)	Florence (Sooke)
Germany, North Carolina, Idaho	Lang Bay, Sumas Mountain
Alabama, Georgia, Missouri	Sumas Mountain, Quinsam
Trois Riviéres (Québec)	Whipsaw Creek, Limonite Creek
Flodelle Creek (Washington)	Prairie Flats
Transvaal (Pb-Zn, South Africa), Sardinia (Pb-Zn), Jamaica (Al)	Villhalta (Fe)
Rio Tinto (Spain)	Villalta
	Cheam Lake (Chiliwack)

North Saskatchewan River (Saskatchewan), Nome (Alaska)	Fraser River, Quesnel River, Graham Island
Livingstone Creek (Yukon), Valdez Creek (Alaska)	Williams Creek, Otter Creek, Bullion mine
Australia (New South Wales, Queensland)	Middlebank (off north end of Vancouver Island)
Elliot Lake (Ontario), Wittwatersrand (South Africa)	Mulvehill

Death Valley (California), John Day Formation (Oregon)	Princeton Basin
Bowie (Arizona), Lake Magadi (Kenya)	
Keewenaw (Michigan), Coppermine (Northwest Territories)	Sustut
Sherwood (Washington)	Blizzard, Tyee
Colorado Plateau, Grants (New Mexico)	
Marysvale (Utah), Aurora (Oregon)	Rexspar, Bullion (Birch Island)
El Romero (Chile), Sue-Dianne (Northwest Territories)	Iron Range

Almaden (Spain), Santa Barbara (Peru)	
Tsumeb (Namibia), Kipushi (Zaire), Ruby Creek (Alaska)	
Carlin (Nevada), Getchell (Nevada), Cortez (Nevada)	
Kupferschiefer (Germany), White Pine (Michigan)	Sage Creek
Laisvall (Sweden), George Lake (Saskatchewan)	
Wyoming, Alberta, Rodalquilar (Spain)	Princeton, Quilchena

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
[redacted]	
Treasure Mountain (Montana), Trimaous (France), Henderson (Ontario)	Red Mountain, Silver Dollar
Eugui (Spain), Veitsch (Austria)	Mt. Brussilof, Driftwood Creek
Illinois - Kentucky, Italian Alps	Muncho Lake
Illinois - Kentucky, Italian Alps	Liard Fluorite
Viburnum Trend (Missouri), Pine Point & Polaris (Northwest Territories)	Robb Lake, Monarch
	Reeves MacDonald, H.B., Aspen, Duncan
Mount Isa (Australia), Faro, Grum (Yukon)	Sullivan, Cirque, Driftpile
Blackbird & Sheep Creek (Montana)	
Nick (Yukon), China	
Tea (Yukon), Magcobar (Ireland)	Kwadacha
[redacted]	
Molongo (Mexico), Atasu (Kazakhstan), Kalahari (South Arica)	
Paris Basin (France), Appalachian Basins (USA)	Lussier River, Windermere
Texas, Louisiana, Poland, Coronation (Alberta)	Trutch area
Lake Enon (Nova Scotia), Mexico, Germany	Kitsault Lake
Metalline Falls, Washington	
Juntura and Otis Basins (Oregon), Lake Myvatn (Iceland)	
Phosphoria Formation (Idaho), Meskala (Morocco)	Fernie synclinorium
Athabaska Basin (Saskatchewan), Florida	
Mesabi Ranges (Minnesota), Minas Gervas (Brazil)	Falcon
[redacted]	
Vermillion iron formation (Minnesota), Helen mine (Ontario)	
Olympic Mountains (Washington), Nicoya (Costa Rica)	
	Britannia, Falkland
Besshi (Japan), Greens Creek (Alaska)	Goldstream, Windy Craggy
Cyprus, Oman	Anyox, Chu Chua
Noranda (Québec), Kuroko (Japan)	Britannia, Kutcho Creek, Myra Falls
Osorezan (Japan)	Eskay Creek
[redacted]	
Sulphur Bank (California), Steamboat Springs (Nevada)	Ucluelet?
McLaughlin (California), Round Mountain (Nevada)	Cinola
El Indio (Chile), Nansatsu (Japan)	Taseko property, Expo
Comstock (Nevada), Sado (Japan)	Lawyers, Blackdome, Silbak Premier
Talamantes (Mexico), Gloryana (New Mexico)	
Black Range (New Mexico), Potosi (Bolivia), Ashio (Japan)	D Zone (Cassiar)
Emperor (Fiji), Zortman-Landusky (Montana), Cripple Creek (Colorado)	
(Cornwall (England)?)	Monteith Bay, Pemberton Hills

Table 2. B. C. Mineral Deposit Profiles Listed by Association cont.

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
E - SEDIMENT-HOSTED cont.		
E08	Carbonate-hosted talc	Dolomite-hosted talc
E09	Sparry magnesite	Veitsch-type, carbonate-hosted magnesite
E10	Mississippi Valley type barite	
E11	Mississippi Valley type fluorite	
E12	Mississippi Valley type Pb-Zn	Carbonate-hosted Pb-Zn, Appalachian Zn
E13	Kootenay Arc type Pb-Zn	
E14	Sedex Zn-Pb-Ag-S	Sullivan massive sulphide
E15	Blackbird massive sulphide Cu-Co	Sediment-hosted Cu-Co massive sulphide
E16	Sediment-hosted Ni	
E17	Sediment-hosted barite	Bedded barite
F - CHEMICAL SEDIMENT		
F01	Sedimentary Mn	
F02	Bedded gypsum/anhydrite	Marine evaporite gypsum
F03	Gypsum-hosted sulphur	Frasch sulphur
F04*	Bedded celestite	
F05*	Palygorskite	Attapulgite
F06	Lacustrine diatomite	Diatomaceous earth, Kieselguhr
F07	Phosphate, upwelling type	
F08	Phosphate, warm-current type	
F09*	Playas (hydromagnesite, sodium carbonate lake brines)	
F10*	Superior type iron formation	
G - MARINE VOLCANIC ASSOCIATION		
G01*	Algoma Fe	
G02	Volcanogenic Mn	
G03*	Volcanogenic anhydrite/gypsum	
G04	Besshi massive sulphide Zn-Cu-Pb	Kieslager
G05	Cyprus massive sulphide Cu	
G06	Noranda/Kuroko massive sulphide Cu-Pb-Zn	Noranda Cu-Pb-Zn massive sulphide
G07	Subaqueous hot spring Ag-Au	
H - EPITHERMAL		
H01*	Travertine	Tufa
H02	Hot spring Hg	
H03	Hot spring Au-Ag	
H04	Epithermal Au-Ag; high sulphidation	Acid-sulphate epithermal, Nansatsu-type
H05	Epithermal Au-Ag; low sulphidation	Adularia-sericite epithermal
H06*	Epithermal Mn	
H07	Sn-Ag veins	
H08*	Alkalic-hosted Au-Ag-Te-F veins	
H09*	Hydrothermal alteration clays-Al-Si	Kaolin, Alunite, Siliceous cap, Pyrophyllite

Table 2. B. C. Mineral Deposit Profiles Listed by Association cont.

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
	I - VEIN / BRECCIA	
I01	Gold-quartz veins	Mesothermal, Motherlode, saddle reefs
I02	Subvolcanic shear-hosted gold	
I03*	Turbidite-hosted gold veins	Meguma type
I04*	Iron formation-hosted gold	
I05	Polymetallic veins Ag-Pb-Zn	
I06*	Cu-Ag quartz veins	
I07*	Silica veins	
I08	Silica-Hg carbonate	
I09	Stibnite veins and disseminations	Simple and disseminated Sb deposits
I10	Vein barite	
I11	Barite-fluorite veins	
I12*	W veins	Quartz-wolframite veins
I13*	*Sn veins and griesens*	
I14*	U-Th-REE veins	
I15*	Felsic plutonic U	
I16*	Unconformity U-Au-Ni	Vein-like type U
I17	Magnesite veins and stockworks	Bone magnesite, Kraubath-type magnesite
	J - REPLACEMENT	
J01	Polymetallic mantos Ag-Pb-Zn	Polymetallic replacement deposits
J02	Sn mantos and stockworks	"Replacement Sn"
J03*	Mn veins and replacements	"Replacement Mn"
J04	Sulphide manto Au	Au-Ag sulphide mantos
	K - SKARN	
K01	Cu skarn	
K02	Zn-Pb skarn	
K03	Fe skarn	
K04	Au skarn	
K05	W skarn	
K06	Sn skarn	
K07	Mo skarn	
K08	Garnet skarn	
K09	Wollastonite skarn	
	L - PORPHYRY	
L01	Subvolcanic Cu-Ag-Au (As-Sb)	Enargite Au, Transitional Au-Ag
L02	Porphyry-related Au	Granitoid Au, Porphyry Au
L03	Alkalic porphyry Cu-Au	
L04	Porphyry Cu±Mo±Au	
L05	Porphyry Mo	
L06	Porphyry Sn	"Subvolcanic tin"
L07	Porphyry W	
L08	Climax-type Porphyry Mo	

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
Motherlode (California), Alaska-Juneau (Alaska), Red Lake (Ontario)	Bralorne, Erickson
	Scottie, Snip, Johnny Mountain, Iron Colt
Ballarat (Australia), Megurna (Nova Scotia)	Frasergold
Homestake (South Dakota)	
Keno Hill (Yukon)	Silver Queen, Beaverdell
Nikolai mine & Kathleen-Margaret (Alaska)	Davis-Keays?, Churchill Copper
	Gypo, Granby Point
Red Devil? (Alaska)	Pinchi, Bralorne Takla
Jerritt Canyon (Nevada), Bolivia	Minto, Congress, Snowbird
Del Rio district (Tennessee), Jebel Ighoud (Morocco)	Parson
Mongolian fluorite belt	Rock Candy, Eaglet
Pasto Bueno (Peru), Carrock Fell (England)	
Cornwall (England), Lost River (Alaska)	Duncan Lake?
Uranium City (Sakatchewan), Schwartzwalder (Colorado)	Little Gem?
Roy Creek & Bokan Mountain (Alaska), Massif Central (France)	Coryell intrusions, Surprise Lake
Key Lake (Saskatchewan), Jabiluka (Australia), Midnight (Washington)	
East Tintic (Utah), Fresnillo (Mexico), Sa Dena Hess (Yukon)	Bluebell, Midway
Renison Bell, Cleveland (Australia), Dachang district (China)	
Lake Valley (New Mexico), Phillipsburg (Montana)	
Ketza River (Yukon)	Mosquito Creek, Island Mountain
Mines Gaspé (Québec), Carr Fork (Yukon)	Craigmont, Phoenix
San Antonio (Mexico), Bari Ban (Australia)	Piedmont, Contact
Shinyama (Japan), Cornwall (Penn.)	Tasu, Jessie, Merry Widow, HPH
Fortitude (Nevada), Buckhorn Mountain (Washington)	Nickel Plate
Cantung & Mactung (Yukon), Pine Creek (California)	Emerald Tungsten, Dimac
Lost River (Alaska), JC (Yukon)	Daybreak
Little Boulder Creek (Idaho), Mt. Tennyson (Australia)	Coxey, Novelty
	Crystal Peak, Argonaut
Fox Knoll, Lewis (New York)	Sechelt
Lepanto (Philipines), Resck (Hungary), Kori Kollo (Bolivia)	Equity Silver, Thorn?
Marte/Lobo (Chile)	Snowfields?
Tai Parit (Philipines)	Afton, Copper Mountain, Galore Creek
Chuquicamata & La Escondida (Chile)	Highland Valley, Gibraltar
Quartz Hill (Alaska)	Endako, Kitsault, Glacier Gulch
Llallagua (Bolivia), Potato Hills (Yukon)	
Mount Pleasant (Nova Scotia), Logtung (Yukon)	Boya
Climax & Henderson (Colorado)	Lucky Ship?

Table 2. B. C. Mineral Deposit Profiles Listed by Association cont.

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
M - ULTRAMAFIC/MAFIC-HOSTED		
M01*	Basaltic subvolcanic Cu-Ni-PGE	
M02	Gabbroid Ni-Cu-PGE	
M03	Podiform chromite	
M04*	Anorthosite Ti-V	
M05	Zoned ultramafic Fe-Ti-V/PGE/Cr/Cu-Ni	Alaskan type Fe-Ti-V/PGE/Cr/Cu-Ni
M06	*Asbestos*	*Serpentinite-hosted asbestos*
M07	Serpentinite-hosted magnesite-talc	
M08	Vermiculite	
N - ALKALIC ASSOCIATION		
N01	Carbonatite-hosted deposits	
N02*	Kimberlite-hosted diamonds	Diamond pipes
N03*	Lamproite-hosted diamonds	
O - PEGMATITE		
O01	Rare element pegmatite - LCT family	Zoned pegmatite (Lithium-Cesium-Tantalum)
O02	*Rare element pegmatite - NYF family*	*Niobium-Ytrium-Fluorine pegmatite*
O03	Muscovite pegmatite	Mica-bearing pegmatite
O04*	Ceramic pegmatite	Barren pegmatite
P - METAMORPHIC HOSTED		
P01	Andalusite hornfels	
P02	*Kyanite family*	
P03	Microcrystalline graphite	"Amorphous" graphite
P04	Crystalline flake graphite	
P05	Vein graphite	"Lump and chip graphite"
P06	Corundum in aluminous metasediments	
Q - GEMS AND SEMI-PRECIOUS STONES		
Q01	Jade	
Q02	Rhodonite	
Q03*	Agate	
Q04*	Amethyst	
Q05*	Jasper	
Q06	Columbia-type emerald	
Q07	Schist-hosted emerald	
Q08	Sediment-hosted opal	
Q09	Gem corundum in contact zones	
Q10	Gem corundum hosted by alkalic rocks	
Q11	Volcanic-hosted opal	

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES

[redacted]

Noril'sk, Duluth	
Lynn Lake (Manitoba), Kluane (Yukon), Noril'sk-Talnakh (Russia)	Giant Mascot, Nickel Mountain
Josephine ophiolite (Oregon)	
Roseland (Virginia), Piuma Hidalgo (Mexico)	
Duke Island (Alaska)	Tulameen
Thetford (Québec)	Cassiar
Thetford & Magog (Québec), Deloro (Ontario)	Nahatlatch River, Atlin area
Enoree (USA), Palabora (South Africa)	

[redacted]

Palabora (South Africa), Oka (Québec), Mountain Pass (California)	Aley, Mount Grace tuff
Kimberley & Premier (South Africa)	Cross
Argyle (Australia)	

[redacted]

Bikita Field (Zimbabwe), Blackhills (South Dakota)	
South Platte district (Colorado), Bancroft (Ontario)	
Rajahstan (India), Appalachian Province (USA)	

[redacted]

Transval (South Africa), Brittany (France)	Leech River
Willis Mountain (Virginia), NARCO (Québec)	
Raton (New Mexico), Sonora (Mexico)	
Lac Knife (Québec)	AA
Calumet & Clot (Québec), Bogala (Sri Lanka)	
Gallatin & Madison Counties (Montana)	

[redacted]

	Cry Lake, Ogden Mountain
	Hill 60, Arthur Point, Cassiar
Thunder Bay (Ontario)	
Chivor and Muzo districts (Columbia)	
Habachtal (Austria), Leysdsdorp (South Africa)	
Coober Pedy (Australia)	
Yogo Gulch (Montana)	
Querétaro State (Mexico)	

Table 2. B. C. Mineral Deposit Profiles Listed by Association cont.

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
R - INDUSTRIAL ROCKS		
R01	Cement shale	
R02	Expanding shale	
R03	*Dimension stone - granite*	
R04	Dimension stone - marble	
R05	Dimension stone - andesite	
R06*	Dimension stone - sandstone	
R07	Silica sandstone	High-silica quartzite
R08*	Flagstone	
R09	Limestone	
R10*	Dolomite	
R11*	Volcanic ash - pumice	
R12*	Volcanic glass - perlite	
R13*	Nepheline syenite	
R14*	Alaskite	
R15*	Crushed rock	Road metal, Rip rap

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
	Dunsmuir shale, Sumas Mountain
Wabamun shales (Alberta)	Nanaimo shale, Saturna Island
Riviére a Pierre (Québec), Black Hills (South Dakota)	Nelson Island
Vermont, Alabama, Georgia	Marblehead, Texada Island, Anderson Bay
	Haddington Island
	Moberley
Southowram (England)	
	Texada Island, Saanich Inlet
	Meagher Mountain, Buse Lake
	Blackdome
Blue Mountain (Ontario)	Trident Mountain, Tuktakamin
Spruce Pine alaskite (North Carolina)	

Table 3. B. C. Mineral Deposit Profiles Listed by Lithological Affinities (December 15, 1994)

DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
SURFICIAL DEPOSITS			
Peat		A01	- -
Bog Fe, Mn, U, Cu, Au		B07*	- -
Surficial U	"Calcrete U"	B08	- -
RESIDUAL			
Laterite Fe	Gossan Fe	B01*	- -
Laterite Ni		B02*	38a
Laterite-Saprolite Au	Eluvial placers	B03*	38g
Bauxite Al	Lateritic bauxite	B04*	38b
Residual kaolin	Primary kaolin	B05	38h*
Fireclay	Refractory shale	B06	38i*
Karst-hosted Fe, Al, Pb-Zn		B09*	- -
"Terra Rossa" Au-Ag	Residual Au; Precious metal gossans	B10	- -
ALLUVIUM			
Sand and Gravel		B12*	- -
Surficial placers	Placer U-Au-PGE-Sn-diamond-magnetite-garnet, gems	C01	39a
Buried-channel placers		C02	39a
SEDIMENTS			
Marl		B11*	- -
Marine placers	Off-shore heavy mineral sediments	C03*	39f*?
SEDIMENTARY ROCKS			
CHEMICAL SEDIMENTARY ROCKS			
Playa Evaporites			
(Closed basin zeolites)		D02	25ob
Playas (hydromagnesite, sodium carbonate lake brines)		F09*	35ba,bm(T)
Marine Evaporites			
Bedded gypsum/anhydrite	Marine evaporite gypsum	F02	35ae
Gypsum-hosted sulphur	Frasch sulphur	F03	- -
Bedded celestite		F04*	35aa*
Restricted Basin			
(Sedex Zn-Pb-Ag-S)	Sullivan massive sulphide	E14	31a
(Sediment-hosted Ni)		E16	- -
(Sediment-hosted barite)	Bedded barite	E17	31b
(Sedimentary Mn)		F01	34b
Shelf			
Sedimentary Mn		F01	34b
Palygorskite	Attapulgite	F05*	34e*
Phosphate, upwelling type		F07	34c
Phosphate, warm-current type		F08	34d
(Superior Type Iron formation)		F10*	34a
Oceanic			
Superior Type Iron Formation		F10*	34a
(Cyprus massive sulphide Cu)		G05	24a

DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
SEDIMENTARY ROCKS cont.			
CARBONATE ROCKS			
No Associated Igneous Rocks			
Kipushi Cu-Pb-Zn	Carbonate-hosted Cu-Pb-Zn	E02*	32c
(Carlin-type sediment-hosted Au-Ag)	Carbonate-hosted Au-Ag	E03	26a,19c
Sparry magnesite	Veitsch-type, carbonate-hosted magnesite	E09	18?l*
Mississippi Valley type barite		E10	- -
Mississippi Valley type fluorite		E11	32d*
Mississippi Valley type Pb-Zn	Carbonate-hosted Pb-Zn, Appalachian Zn	E12	32a/32b
Kootenay Arc type Pb-Zn		E13	- -
(Sedex Zn-Pb-Ag-S)	Sullivan massive sulphide	E14	31a
Mn veins and replacements	"Replacement Mn"	J03*	19b
Sulphide manto Au	Au-Ag sulphide mantos	J04	- -
Limestone		R09	- -
Dolomite		R10*	- -
Vein barite		I10	M27e
(Barite-fluorite veins)		I11	26c*
Associated Igneous Rocks			
Carlin-type sediment-hosted Au-Ag	Carbonate-hosted Au-Ag	E03	26a,19c
(Polymetallic mantos Ag-Pb-Zn)	Polymetallic replacement deposits	J01	19a
(Sn mantos and stockworks)	"Replacement Sn"	J02	14c
(Mn veins and replacements)	"Replacement Mn"	J03*	19b
(Sulphide manto Au)	Au-Ag sulphide mantos	J04	- -
(Cu skarn)		K01	18a,b
(Zn-Pb skarn)		K02	18c
(Fe skarn)		K03	18d
(Au skarn)		K04	- -
(W skarn)		K05	14a
(Sn skarn)		K06	14b
(Garnet skarn)		K08	- -
(Wollastonite skarn)		K09	18g
CLASTIC SEDIMENTARY ROCKS			
Biogenic			
Lacustrine diatomite	Diatomaceous earth, Kieselguhr	F06	31s
(Phosphate, upwelling type)		F07	34c
(Phosphate, warm-current type)		F08	34d
Clays			
(Bentonite)	Volcanic clay, Soap clay	E06	28e?*
Sedimentary kaolin		E07*	31k*
Shale-Siltstone			
(Lignitic coal)	"Brown coal"	A02	- -
(Sub-bituminous coal)	Thermal coal, Black lignite	A03	- -
(Bituminous coal)	Coking coal, Thermal coal	A04	- -
(Anthracitic coal)	Stone coal	A05	- -
(Volcanic redbed copper)	Basaltic Cu	D03	23
(Carlin-type sediment-hosted Au-Ag)	Carbonate-hosted Au-Ag	E03	26a,19c
(Sediment-hosted Cu)	Sandstone Cu, Sediment-hosted stratiform Cu	E04*	30b
Sedex Zn-Pb-Ag-S	Sullivan massive sulphide	E14	31a
(Blackbird massive sulphide Cu-Co)	Sediment-hosted Cu-Co massive sulphide	E15	24d
Sediment-hosted Ni	-	E16	- -

Table 3. B. C. Mineral Deposit Profiles Listed by Lithological Affinities cont.

DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
SEDIMENTARY ROCKS cont.			
Shale-Siltstone cont.			
Sediment-hosted barite	Bedded barite	E17	31b
(Besshi massive sulphide Zn-Cu-Pb)+D260	Kieslager	G04	24b
Columbia-type emerald deposits		Q06	31c
Cement shale		R01	--
Expanding shale		R02	--
Sandstone			
Lignitic coal	"Brown coal"	A02	--
Sub-bituminous coal	Thermal coal, Black lignite	A03	--
Bituminous coal	Coking coal, Thermal coal	A04	--
Anthracitic coal	Stone coal	A05	--
Basal U	Sandstone U	D04	--
Sandstone U	Roll front U, Tabular U	D05*	30c
(Iron oxide Cu-Au-U breccias and veins)	Olympic Dam type Fe (Cu-U-Au), Kiruna type	D07	29b,25i
(Kipushi Cu-Pb-Zn)	Carbonate-hosted Cu-Pb-Zn	E02*	32c
Sediment-hosted Cu	Sandstone Cu, Sediment-hosted stratiform Cu	E04*	30b
Sandstone Pb		E05	30a
Blackbird massive sulphide Cu-Co	Sediment-hosted Cu-Co massive sulphide	E15	24d
(Polymetallic veins Ag-Pb-Zn)		I05	22c, 25b
Sediment-hosted opal		Q08	--
Agate		Q03*	--
Dimension stone - sandstone		R06*	30d*
Silica sandstone	High-silica quartzite	R07	30e*
Flagstone		R08*	--
Conglomerate and Sedimentary Breccia			
Paleoplacer U-Au-PGE-Sn-diamond-Ti-mag-gar-zir		C04*	39c,d,e
(Volcanic redbed copper)	Basaltic Cu	D03	23
(Sandstone U)	Roll front U, Tabular U	D05*	30c
Jasper		Q05*	--
VOLCANIC ROCKS - Felsic-Mafic			
SUBAERIAL VOLCANIC ROCKS			
Mainly Volcanic Host			
Open-system zeolites		D01	25oa
Closed basin zeolites		D02	25ob
(Volcanic redbed copper)	Basaltic Cu	D03	23
Volcanic-hosted U	"Epithermal U", Volcanogenic U	D06	25f
Iron oxide Cu-Au-U breccias and veins	Olympic Dam type Fe (Cu-U-Au), Kiruna type	D07	29b,25i
Travertine	Tufa	H01*	35d*
Hot spring Au-Ag		H03	25a
Epithermal Au-Ag; high sulphidation	Acid-sulphate epithermal, Nansatsu-type	H04	25d
Epithermal Au-Ag; low sulphidation	Adularia-sericite epithermal	H05	25c
Epithermal Mn		H06*	25g
Sn-Ag veins		H07	25h, 20b
Hydrothermal alteration clays-Al-Si	Kaolin, Alunite, Siliceous cap, Pyrophyllite	H09*	25lb*
(Subvolcanic shear-hosted gold)		I02	--
Cu-Ag quartz veins		I06*	?

Table 3. B. C. Mineral Deposit Profiles Listed by Lithological Affinities cont.

DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
VOLCANIC ROCKS - Felsic-Mafic cont.			
Mainly Volcanic Host cont.			
Silica veins		I07*	--
Volcanic-hosted opal		Q11	--
Dimension stone - andesite		R05	--
Volcanic ash - pumice		R11*	--
Perlite		R12*	--
Interbedded or Underlying Calcareous Rocks			
(Carlin-type sediment-hosted Au-Ag)	Carbonate-hosted Au-Ag	E03	26a,19c
Barite-fluorite veins		I11	26c*
Interbedded or Underlying Clastic Rocks			
Almaden Hg		E01*	27b
Hot spring Hg		H02	27a
Silica-Hg carbonate		I08	27c
Stibnite veins and disseminations	Simple and disseminated Sb deposits	I09	27d,27e
(Vein barite)		I10	IM27e
(Subvolcanic shear-hosted gold)		I02	--
SUBAQUEOUS VOLCANIC ROCKS			
Mainly Volcanic Host			
Bentonite	Volcanic clay, Soap clay	E06	28e?*
(Volcanic-hosted U)	"Epithermal U", Volcanogenic U	D06	25f
Algoma Fe		G01*	28b
(Volcanogenic Mn)		G02	24c
Volcanogenic anhydrite/gypsum		G03*	--
Besshi massive sulphide Zn-Cu-Pb	Kieslager	G04	24b
Cyprus massive sulphide Cu		G05	24a
Noranda/Kuroko massive sulphide Cu-Pb-Zn	Noranda Cu-Pb-Zn massive sulphide	G06	28a
Subaqueous hot spring Ag-Au		G07	--
Subvolcanic shear-hosted gold		I02	--
Rhodonite		Q02	--
(Jasper)		Q05*	--
(Lacustrine diatomite)	Diatomaceous earth, Kieselguhr	F06	31s
VOLCANIC ROCKS - Mafic			
SUBAERIAL VOLCANIC ROCKS			
Volcanic redbed copper	Basaltic Cu	D03	23
MARINE (including ophiolites)			
(Blackbird massive sulphide Cu-Co)	Sediment-hosted Cu-Co massive sulphide	E15	24d
(Besshi massive sulphide Zn-Cu-Pb)	*Kieslager*	G04	24b
Cyprus massive sulphide Cu		G05	24a
(Volcanogenic Mn)		G02	24c
VOLCANIC ROCKS - Alkalic			
(Carbonatite-hosted deposits)		N01	10
(Gem corundum hosted by alkalic rocks)		Q10	--
GRANITIC INTRUSIONS			
Felsic plutonic U		I15*	--
Rare element pegmatite - LCT family	Zoned pegmatite (Lithium-Cesium-Tantalum)	O01	13a*,b*
Rare element pegmatite - NYF family	Niobium-Yttrium-Fluorine pegmatite	O02	--
Muscovite pegmatite	Mica-bearing pegmatite	O03	13f*

Table 3. B. C. Mineral Deposit Profiles Listed by Lithological Affinities cont.			
DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
GRANITIC INTRUSIONS cont.			
Ceramic pegmatite	Barren pegmatite	O04*	- -
Amethyst		Q04*	- -
Dimension stone - granite		R03	- -
Alaskite		R14*	- -
Calcareous Wallrocks			
Polymetallic mantos Ag-Pb-Zn	Polymetallic replacement deposits	J01	19a
Sn mantos and stockworks	"Replacement Sn"	J02	14c
(Mn veins and replacements)	"Replacement Mn"	J03*	19b
W skarn		K05	14a
Sn skarn		K06	14b
Calcareous Wallrocks cont.			
(Garnet skarn)		K08	- -
(Wollastonite skarn)		K09	18g
(Gem corundum in contact zones)		Q09	S4
Other Wallrocks			
(Iron oxide Cu-Au-U breccias and veins)	Olympic Dam type Fe (Cu-U-Au), Kiruna type	D07	29b,25i
(Gold-quartz veins)	Mesothermal, Motherlode, saddle reefs	I01	36a
W veins	Quartz-wolframite veins	I12*	15a
Sn veins and greisens		I13*	15b, 15c
(Andalusite hornfels)		P01	- -
(Kyanite family)		P02	- -
Gem corundum in contact zones		Q09	S4
ANORTHOSITE INTRUSIONS			
Anorthosite Ti-V		M04*	7b
Calcareous Wallrocks			
(Wollastonite skarn)		K09	18g
PORPHYRITIC INTRUSIONS PRESENT			
INTRUSIVE HOST			
Alkalic porphyry Cu-Au		L03	- -
Porphyry Cu±Mo±Au		L04	17,20,21a1
Porphyry Mo		L05	21b
Porphyry W		L07	21c*
Climax-type Porphyry Mo		L08	16
CALCAREOUS WALLROCKS			
(Carbonate-hosted talc)	Dolomite-hosted talc	E08	18?I*
(Vein barite)		I10	IM27e
(Barite-fluorite veins)		I11	26c*
(Polymetallic mantos Ag-Pb-Zn)	Polymetallic replacement deposits	J01	19a
(Mn veins and replacements)	"Replacement Mn"	J03*	19b
Cu skarn		K01	18a,b
Zn-Pb skarn		K02	18c
Fe skarn		K03	18d
Au skarn		K04	- -
(W skarn)		K05	14a
(Sn skarn)		K06	14b
Mo skarn		K07	- -
Garnet skarn		K08	- -
Wollastonite skarn		K09	18g
(Microcrystalline graphite)		P03	- -

Table 3. B. C. Mineral Deposit Profiles Listed by Lithological Affinities cont.

DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
PORPHYRITIC INTRUSIONS PRESENT cont.			
COEVAL VOLCANIC WALLROCKS			
(Epithermal Mn)		H06*	25g
(Sn-Ag veins)		H07	25h, 20b
(Alkalic porphyry Cu-Au)		L03	--
Porphyry Cu±Mo±Au		L04	17,20,21a1
Porphyry Sn	"Subvolcanic tin"	L06	20a
OTHER WALLROCKS			
Sn-Ag veins		H07	25h, 20b
Polymetallic veins Ag-Pb-Zn		I05	22c, 25b
(Gold-quartz veins)	Mesothermal, Motherlode, saddle reefs	I01	36a
(Subvolcanic shear-hosted gold)		I02	--
Subvolcanic Cu-Ag-Au (As-Sb)	Enargite Au, Transitional Au-Ag	L01	22a/25e
Porphyry-related Au	Granitoid Au, Porphyry Au	L02	20d
(Microcrystalline graphite)	"Amorphous" graphite	P03	--
MAFIC AND ULTRAMAFIC INTRUSIONS			
(Laterite Ni)		B02*	38a
(Surficial placers)	Placer U-Au-PGE-Sn-diamond-magnetite-garnet, gems	C01	39a
(Buried-channel placers)		C02	39a
(Gold-quartz veins)	Mesothermal, Motherlode, saddle reefs	I01	36a
(Silica-Hg carbonate)		I08	27c
Magnesite veins and stockworks	Bone magnesite, Kraubath-type magnesite	I17	--
Podiform chromite		M03	8a/8b
Zoned ultramafic Fe-Ti-V/PGE/Cr/Cu-Ni	Alaskan type Fe-Ti-V/PGE/Cr/Cu-Ni	M05	9
Asbestos	Serpentinite-hosted asbestos	M06	8d
Serpentinite-hosted magnesite-talc		M07	8f*
(Andalusite hornfels)		P01	--
(Jade)		Q01	--
COEVAL VOLCANIC ROCKS			
Basaltic subvolcanic Cu-Ni-PGE		M01*	5a/5b
Gabbroid Ni-Cu-PGE		M02	7a
ALKALINE INTRUSIONS			
Alkalic-hosted Au-Ag-Te-F veins		H08*	22b
Kimberlite-hosted diamonds	Diamond pipes	N02*	12
Lamproite-hosted diamonds		N03*	12
(Gem corundum hosted by alkalic rocks)		Q10	--
Nepheline syenite		R13*	--
Carbonatites			
Carbonatite-hosted deposits		N01	10
Vermiculite		M08	--

Table 3. B. C. Mineral Deposit Profiles Listed by Lithological Affinities cont.

DEPOSIT TYPE	SYNONYMS	BC PROFILE #	U.S.G.S. MODEL #
REGIONALLY METAMORPHOSED ROCKS			
Carbonate-hosted talc	Dolomite-hosted talc	E08	18?l*
Gold-quartz veins	Mesothermal, Motherlode, saddle reefs	I01	36a
Turbidite-hosted gold veins	Meguma type	I03*	36a
Iron formation-hosted gold		*I04**	*36b*
Unconformity U-Au-Ni	Vein-like type U	I16*	37a
U veins		I14*	- -
(Wollastonite skarn)		K09	18g
(Asbestos)	*Serpentinite-hosted asbestos*	*M06*	*8d*
(Rare element pegmatite - LCT family)	Zoned pegmatite (Lithium-Cesium-Tantalum)	O01	13a*,b*
(Rare element pegmatite - NYF family)	Niobium-Ytrium-Fluorine pegmatite	O02	- -
(Muscovite pegmatite)	*Mica-bearing pegmatite*	O03	13f*
(Ceramic pegmatite)	Barren pegmatite	O04*	- -
Kyanite family		P02	- -
Microcrystalline graphite	"Amorphous" graphite	P03	- -
Crystalline flake graphite		P04	- -
Vein graphite	*"Lump and chip graphite"*	P05	- -
Corundum in aluminous metasediments		P06	- -
Jade		Q01	- -
Schist-hosted emerald deposits		Q07	- -
Dimension stone - marble		R04	- -

TWO INTRIGUING MINERAL DEPOSIT PROFILES FOR BRITISH COLUMBIA

By David V. Lefebure

KEYWORDS: economic geology, mineral deposits, models, British Columbia, metallic, iron oxide, Kiruna type, Olympic Dam type, shale-hosted sulphides.

INTRODUCTION

As part of its mineral resource potential assessment process, the British Columbia Geological Survey Branch is utilizing deposit models to define and characterize mineral and coal deposits which exist, or could exist, in the province. A fundamental part of this process is compilation of information about mineral deposits including descriptions, classification and resource data (Lefebure *et al.*, 1995, this volume). The resulting deposit models (called 'PROFILES') are being used to classify known deposits and occurrences, to guide experts in their identification of possible undiscovered mineral deposits, and to group deposits to allow compilation of representative grade and tonnage data.

The profiles may draw attention to deposit types with the potential to occur in British Columbia that may warrant exploration consideration. Two models with no known orebodies in the province, but intriguing exploration potential, are discussed in this article: iron oxide breccias and veins carrying copper, gold, uranium and rare earth elements; and shale-hosted nickel, zinc, molybdenum and platinum group deposits. Iron oxide breccias are now known to occur in southeast British Columbia (Stinson and Brown, 1995, this volume). The current interest in this deposit type stems from the possibility that a major polymetallic orebody similar to the Olympic Dam deposit in South Australia may exist in British Columbia. In the second deposit type, high-grade nickel, zinc, molybdenum and platinum group mineralization is hosted by black shale sequences. Although currently regarded as little more than a geological curiosity because the known deposits are thin (commonly less than 15 cm), there is the possibility that thicker deposits will be found or a new technology developed to mine these deposits.

IRON OXIDE BRECCIAS AND VEINS

Deposits characterized by high iron oxide contents (generally greater than 20%) that crosscut their hostrocks have been described by Einaudi and Oreskes (1990), Hauck (1990), Hitzman *et al.* (1992) and Gandhi and Bell (1993) and grouped as Olympic Dam type, Kiruna type, iron oxide rich deposits or Proterozoic iron oxide deposits. The iron oxides may be magnetite, magnetite and hematite, or hematite in breccia zones or veins which form pipes and tabular bodies. The deposits are hosted by continental volcanics and sediments and intrusive rocks and vary from monometallic to polymetallic with significant copper, gold, rare earth element and uranium values.

The profile for iron oxide breccias and veins lists many features of these deposits, including key exploration guides (Table 1). They can be subdivided into Kiruna-type deposits with a magnetite-apatite mineralogy (USGS model 25i, Cox and Singer, 1986) which grade to polymetallic Olympic Dam type hematitic orebodies (USGS 29b). Although magnetite-apatite deposits occur widely through time (post-Archean), the Olympic Dam type deposits may be restricted to the Middle Proterozoic as noted by Hauck (1992) and Hitzman *et al.* (1992).

Iron oxide breccia and vein deposits can be large; average tonnage for the magnetite-apatite iron ore deposits is 40 million tonnes (Cox and Singer, 1986). The Kirunavaara orebody in Sweden contains 2.6 billion tonnes grading 60% iron with significant phosphorus (Hitzman *et al.*, 1992).

Current interest in iron oxide deposits stems from discovery in 1975 of the Olympic Dam hematite-rich orebody within rocks of the Stuart Shelf in Australia. It contains 2 billion tonnes grading 1.6% Cu, 0.6 g/t Au, 0.35 g/t Ag and 0.6 kg/t U_3O_8 with a total gross value in place of more than US$110 billion (Sidder and Day, 1993). In recent years there have been a number of other iron oxide deposits with significant copper and gold values found in Australia, including the Ernest Henry and Osborne in northwest Queensland.

The most well known geological environment for iron oxide deposits in Canada is in the southern part of the Great Bear magmatic zone in the Northwest Territories (Hildebrand, 1986). There are occurrences of magnetite, apatite and actinolite veins and fracture fillings and magnetite, hematite and epidote breccias with uranium, copper, gold, cobalt and nickel minerals (Gandhi, 1994). The latter occurrences are similar to Olympic Dam type deposits and include two deposits, the Sue-Dianne and Mar.

In British Columbia, only the Iron Range deposit located northeast of Creston has been identified as an iron oxide breccia deposit (Alldrick, 199?; Stinson and Brown, 1995, this volume) which is possibly analogous

TABLE 1. DEPOSIT PROFILE FOR IRON OXIDE BRECCIAS AND VEINS

Iron Oxide Cu-Au-Ag-U-P Breccias and Veins D07

IDENTIFICATION

SYNONYMS: Olympic Dam type, Kiruna type, Apatite iron ore, Porphyrite iron (Yangtze Valley), Iron oxide rich deposits, Proterozoic iron oxide (Cu-U-Au-REE), Volcanic-hosted magnetite.

COMMODITIES (BYPRODUCTS): Fe, P, Cu, Au, Ag, U (potential for REE, Ba, F).

EXAMPLES (British Columbian - *Canadian/International*): Iron Range (082FSE014 - 028) - *Sue-Dianne, Northwest Territories; Wernecke Breccias, Yukon, Kiruna District, Sweden; Olympic Dam, Australia; Pea Ridge and Boss-Bixby, Missouri; El Romeral, Chile.*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Magnetite and/or hematite breccia zones and veins which form pipes and tabular bodies hosted by continental volcanics and sediments and intrusive rocks. The deposits exhibit a wide range in their nonferrous metal contents. They vary from Kiruna type monometallic (Fe ± P) to Olympic Dam type polymetallic (Fe ± Cu ± U ± Au ± REE).

TECTONIC SETTING: Associated with stable cratons, typically associated with grabens related to rifting. Intracratonic extensional tectonics coeval with hostrock deposition. Upper crustal igneous or sedimentary rocks.

DEPOSITIONAL ENVIRONMENT/ GEOLOGICAL SETTING: Found crosscutting a wide variety of sedimentary and igneous rocks; magnetite-apatite deposits show an affinity for volcanics and associated hypabyssal rocks.

AGE OF MINERALIZATION: Proterozoic to Tertiary and believed to be virtually contemporaneous with associated suite of intrusive and/or volcanic rocks. Polymetallic iron oxide deposits are commonly mid-Proterozoic age varying from 1.2 to 1.9 Ga.

HOST/ASSOCIATED ROCK TYPES: Veins and breccias crosscut, or are conformable with, a wide variety of continental sedimentary and volcanic rocks and intrusive stocks, including felsic volcanic breccia, tuff, clastic sedimentary rocks and granites. There may be a special association with a felsic alkalic rock suite ranging from "red" granite, and rapakivi granite to mangerite and charnockite and various volcanic equivalents. Iron oxides have been reported as common accessories in the associated igneous rocks. In some deposits the iron oxide forms the matrix to heterolithic breccias which are composed of lithic and iron oxide clasts (usually hematite fragments), hematite-quartz microbreccia and fine-grained massive breccia. Some deposits have associated hematite-rich breccias, bedded iron oxides and iron oxide bearing volcanic rocks which are conformable with associated volcanic rocks. Magnetite lavas and feeder dikes exist on the El Laco volcano in Chile.

DEPOSIT FORM: Discordant pod-like zones, veins (dike-like), tabular bodies and stockworks; in some deposits dikes are overlain by iron oxide tuffs and flows. The veins and tabular zones extend horizontally and vertically for kilometres with widths of metres to hundreds of metres.

Iron Oxide Cu-Au-Ag-U-P Breccias and Veins D07

TEXTURE/STRUCTURE: Cu-U-Au mineralization is typically hosted in the iron oxide matrix as disseminations with associated microveinlets and sometimes rare mineralized clasts. Textures indicating replacement and microcavity filling are common. Intergrowths between minerals are common. Hematite and magnetite may display well developed crystal forms, such as interlocking mosaic, tabular or bladed textures. Some of the deposits (typically hematite rich) are characterized by breccias at all scales with iron oxide and hostrock fragments which grade from weakly fractured hostrock on the outside to matrix-supported breccia (sometimes heterolithic) with zones of 100% iron oxide in the core. Breccias may be subtle in hand sample as the same iron oxide phase may comprise both the fragments and matrix. Breccia fragments are generally angular and have been reported to range up to more than 10 m in size, although they are frequently measured in centimetres. Contacts with hostrocks are frequently gradational over scale of centimetres to metres. Hematite breccias may display a diffuse wavy to streaky layered texture of red and black hematite.

ORE MINERALOGY [Principal and *subordinate*]: The deposits vary between magnetite-apatite deposits with actinolite or pyroxene (Kiruna type)and hematite-magnetite deposits with varying amounts of copper sulphides, Au, Ag, uranium minerals and REE (Olympic Dam type). Hematite (variety of forms), specularite, magnetite, bornite, chalcopyrite, chalcocite, pyrite; *digenite, covellite, native copper, carrolite, cobaltite, Cu-Ni-Co arsenates, pitchblende, coffinite, brannerite, bastnaesite, monazite, xenotime, florencite, native silver and gold and silver tellurides.* At Olympic Dam, copper is zoned from a predominantly hematite core (minor chalcocite-bornite) to chalcocite-bornite zone then bornite-chalcopyrite to chalcopyrite-pyrite in the outermost breccia. Uraninite and coffinite occur as fine-grained disseminations with sulphides; native gold forms fine grains disseminated in matrix and inclusions in sulphides. Bastnaesite and florencite are very fine grained and occur in matrix as grains, crystals and crystal aggregates.

GANGUE MINERALOGY [Principal and *subordinate*]: Gangue occurs intergrown with ore minerals as veins or as clasts in breccias. Sericite, carbonate, chlorite, quartz, fluorite, barite, and sometimes minor *rutile and epidote.* Apatite and actinolite or pyroxene with magnetite ores (Kiruna type). Hematite breccias are frequently cut by 1 to 10 cm veins with fluorite, barite, siderite, hematite and sulphides.

ALTERATION MINERALOGY [Principal and *subordinate]*: A variety of alteration assemblages with differing levels of intensity are associated with these deposits, often with broad lateral extent. Olympic Dam type: Intense sericite and hematite alteration with increasing hematite towards the centre of the breccia bodies at higher levels. Close to the deposit the sericitized feldspars are rimmed by hematite and cut by hematite veinlets. Adjacent to hematite breccias the feldspar, rock flour and sericite are totally replaced by hematite. Chlorite or potassium feldspar alteration predominates at depth. Kiruna type: Scapolite and albite?; there may also be actinolite-epidote alteration in mafic wallrocks. With both types of deposits quartz, fluorite, barite, carbonate, rutile, orthoclase ± epidote and garnet alteration are also reported.

WEATHERING: Supergene enrichment of Cu and U, for example, the pitchblende veins in the Great Bear magmatic zone.

ORE CONTROLS : Strong structural control with emplacement along faults or contacts, particularly narrow grabens. Mid-Proterozoic rocks particularly favourable hosts. Hydrothermal activity on faults with extensive brecciation. May be associated with felsic volcanic and alkalic igneous rocks. In some deposits calderas and maars have been identified or postulated. Deposits may form linear arrays more than 100 km long and 40 km wide with known deposits spaced 10-30 km along trend.

Iron Oxide Cu-Au-Ag-U-P Breccias and Veins D07

ASSOCIATED DEPOSIT TYPES: Volcanic-hosted U (D06)?; alkaline porphyry Cu-Au deposits (L03); supergene uranium veins.

COMMENTS: Hitzman *et al.* (1992) emphasize that these are low-titanium iron deposits, generally less than 0.5% TiO_2 and rarely above 2% TiO_2 which allows distinction from iron oxides associated with anorthosites, gabbros and layered mafic intrusions. Iron and copper sulphides may be more common with hematite iron oxides.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalously high values for Cu, U, Au, Ag, Ce, La, Co, ± P, ± F, and ± Ba in associated rocks and in stream sediments.

GEOPHYSICAL SIGNATURE: Large positive gravity anomalies because of iron oxides. Regional aeromagnetic anomalies related to magnetite and/or coeval igneous rocks. Radiometric anomaly (such as airborne gamma-ray spectrometer survey) expected with polymetallic deposits containing uranium.

OTHER EXPLORATION GUIDES: Proterozoic faulting with associated iron oxides (particularly breccias), possibly related to intracratonic rifting. Widespread hematite, sericite or chlorite alteration related to faults. Possibly form linear arrays 100 or more kilometres long and up to tens of kilometres wide.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : Deposits may exceed 1 billion tonnes grading greater than 20 % Fe and frequently are in 100 to 500 Mt range. Olympic Dam deposit has estimated reserves of 2.0 billion tonnes grading 1.6% Cu, 0.06% U_3O_8, 3.5 g/t Ag and 0.6 g/t Au with a measured and indicated resource in a large number of different ore zones of 450 million tonnes grading 2.5% Cu, 0.08 % U_3O_8, 6 g/t Ag and 0.6 g/t Au with ~5,000 ppm REE. The Eastern Henry deposit in Australia contains 100 Mt at 1.6% Cu and 0.8 g/t Au. Sue-Dianne deposit in the the Northwest Territories contains 8 million tonnes averaging 0.8% Cu and 1000 ppm U and locally significant gold. The Kiruna district contains 3.4 billion tons of iron oxide apatite ore grading 50-60% iron and 0.5 -5 % phosphorus. The largest orebody at Bayan Obo deposit in Inner Mongolia, China contains 20 Mt of 35 % Fe and 6.19% REE.

ECONOMIC LIMITATIONS: Larger iron oxide deposits may be mined for iron only; however, polymetallic deposits are more attractive.

IMPORTANCE: These deposits continue to be important producers of iron and represent an important deposit type for producing Cu, U and possibly REE.

REFERENCES

Einaudi and Oreskes (1990); Gandhi and Bell (1993); Hauck (1990); Hitzman *et al.* (1992); Oreskes and Einaudi (1990); Parak (1975); Reeve *et al.* (1990); Research Group of Porphyrite Iron Ore (1977); Roberts and Hudson (1983); Sidder and Day (1993).

to the Olympic Dam type deposits. However, there are other iron oxide breccias in rocks of equivalent age in the Wernecke Supergroup in the Yukon (Laznicka and Gaboury, 1988) with copper and uranium mineralization (Thorkelson and Wallace, 1992). The Igor deposit in the Wernecke Mountains contains 0.5 million tonnes grading 1 % Cu (Hitzman *et al.*, 1992).

Recent work on the age and provenance of zircons from Belt Supergroup rocks in the northwest United States by Ross *et al.* (1992) supports a continental reconstruction that places the Stuart Shelf of south Australia offshore of the west coast of ancient North America in the Middle to Late Proterozoic. This idea was proposed initially by Bell and Jefferson (1987). Ross has found zircons in Belt sediments, derived from an unknown western source, that yield 1590 Ma dates. These dates are consistent with Bell and Jefferson's hypothesis, as the Gawler volcanics on the Stuart Shelf are virtually the same age. This has led Ross to suggest that there is potential for Olympic Dam type deposits in the Belt-Purcell Supergroup (G.M. Ross, personal communication, 1994).

Therefore, the best possibility for finding a polymetallic iron oxide deposit in British Columbia would appear to be in the Proterozoic Purcell Supergroup or the equivalent Muskwa assemblage in the northeastern part of the province (Figure 1).

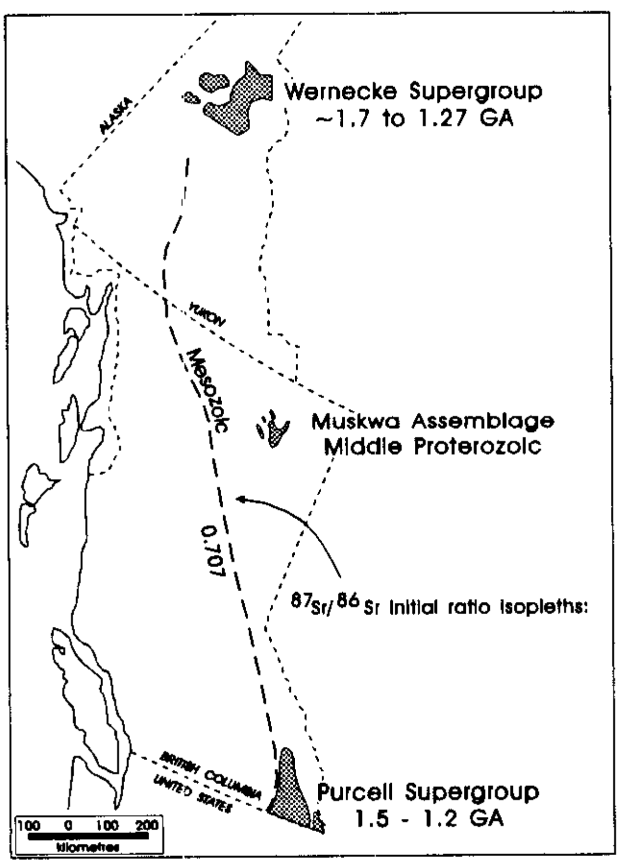

Figure 1. Mid-Proterozoic Sequences in British Columbia with Potential for Polymetallic Iron Oxide Breccias and Veins.

SHALE-HOSTED Ni-Zn-Mo-PGE DEPOSITS

The discovery of the Nick deposit in the Selwyn Basin in 1981 (Hulbert *et al.*, 1992) has drawn attention to the potential of Cordilleran black shales to host nickel, zinc and platinum group element mineralization. Subsequent reports on similar deposits in China (Nansheng and Coveney, 1989; Coveney and Nansheng, 1991) provided more information about these deposits, including the potential for high molybdenum contents.

These shale-hosted sulphide deposits consist of thin layers of pyrite, vaesite (NiS_2), amorphous molybdenite and sphalerite in black shale with associated phosphatic chert and carbonate rocks. The horizons have formed in anoxic basins within clastic sedimentary sequences containing black shales. As these deposits occur in the same settings as sedex lead-zinc-silver-barite deposits, there is an opportunity to discover them as well. The profile for these unusual deposits lists many of their features, including key exploration guides (Table 2).

The only production from these deposits has been from small tonnage mines in southeast China relying on labour-intensive methods. Currently only the Zunyi mine in southeast China is in operation. It is producing approximately 2000 tonnes of molybdenum ore annually with a cutoff of 4.1% Mo and grades between 4.1 and 7.1% Mo with up to 7.1% Ni, 2% Zn, 2.5% As, 0.57 g/t Pt, 0.66 g/t Pd and 0.55 g/t Au in ore samples (Coveney *et al.*, 1992, 1993). Currently the Chinese are only recovering molybdenum by roasting followed by caustic leaching to produce ammonium molybdate (Coveney *et al.*, 1992). The Nick mineralized layer in the Yukon contains, on average, 5.7% Ni, 1.2% Zn, 0.24% Mo, 0.39 g/t Pt, 0.24 g/t Pd and 0.15 g/t Au (Hulbert *et al.*, 1992).

The known deposits of this type are too thin to be economic at current metal prices, except where labour costs are very low. However, these deposits contain enormous tonnages of nickel, zinc and molybdenum because of their remarkable lateral extent and high grades. For example, the Nick horizon is believed to contain 0.9 million tonnes of nickel assuming a 3-centimetre horizon (Hulbert *et al.*, 1992). Such material will be exploited if thicker deposits can be found or a relevant new technology is developed.

Regional geochemistry is the most effective exploration tool for these deposits because the mineralized horizons are so laterally extensive and the contained metals contrast strongly with background values in the sedimentary succession. For example, the Nick occurrence was found as the result of anomalous stream sediment samples collected by the Geological Survey of Canada during a regional survey. Shale-hosted nickel-zinc-molybdenum--platinum group mineralization is characterized by elevated abundances of Ni, Mo, Au, PGE, C, P, Ba, Zn, Re, Se, As, U and S. Increased organic content appears to correlate with higher Ni, Mo and Zn values (Maughan, 1976). There is a strong spatial correlation with phosphatic horizons; mineralized layers are typically enriched in phosphate.

TABLE 2. PROFILE FOR SHALE-HOSTED Ni-Zn-Mo-PGE DEPOSITS

SHALE-HOSTED Ni-Zn-Mo-PGE E16

IDENTIFICATION

SYNONYMS: Sediment-hosted Ni-Mo-PGE, Stratiform Ni-Zn-PGE.

COMMODITIES (POSSIBLE BYPRODUCTS): Ni, Mo (stone coal, P, Zn, Pt, Pd, Au).

EXAMPLES (British Columbia - *Canada/International*): *Nick, Yukon*; *large number of deposits in southeastern China including mining camps of Tianeshan, Xintuguo, Tuansabao and Jinzhuwoin, north central Guizhou Province and Zunyi Mo deposits, Dayong-Cili District.*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Thin layers of pyrite, vaesite (NiS_2), jordisite (amorphous MoS_2) and sphalerite in black shale sub-basins with associated phosphatic chert and carbonate rocks.

TECTONIC SETTING(S): Continental platform sedimentary sequences and possibly successor basins. All known deposits associated with orogenic belts, however, strongly anomalous shales overlying the North American craton may point to as yet undiscovered deposits over the stable craton.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Anoxic basins within clastic sedimentary (flysch) sequences containing black shales.

AGE OF MINERALIZATION: Post-Archean. Known deposits are Early Cambrian and Devonian, however, there is potential for deposits of other ages.

HOST/ASSOCIATED ROCK TYPES: Black shale is the host; associated limestones, dolomitic limestones, calcareous shale, cherts, siliceous shale, siliceous dolomite, muddy siltstone and tuffs. Commonly associated with phosphate horizons. In the Yukon at base of a 10 to 20 m thick phosphatic shale bed and in China the Ni-Mo beds are in black shales associated with phosphorite.

DEPOSIT FORM: Thin beds (0 to 15 cm thick, locally up to 30 cm) covering areas up to at least 100 hectares and found as clusters and zones extending for tens of kilometres.

TEXTURE/STRUCTURE: Semimassive to massive sulphides, phosphorite, quartz and organic matter as nodules, spheroids, framboids and streaks or segregations in a fine-grained matrix of sulphides, organic matter and nodular phosphorite or phosphatic carbonaceous chert. Mineralized bed may be rhythmically laminated; often has thin discontinuous laminae. Brecciated clasts and spheroids of pyrite, organic matter and phosphorite. In China nodular textures (~ 1 mm diameter) grade to coatings of sulphides on tiny 1-10 μm spherules of organic matter. Fragments and local folding reflect soft-sediment deformation. Abundant plant fossils at Nick occurrence and numerous fossils of microorganisms (cyanobacteria, algal mats) in the Chinese ores.

ORE MINERALOGY [Principal and *subordinate*]: Pyrite, vaesite (NiS_2), amorphous molybdeum minerals (jordisite MoS_2), bravoite ($[Fe,Ni]S_2$), *sphalerite, wurtzite, polydimite (Ni_3S_4), gersdorffite (NiAsS), violarite(Ni_2FeS_4), millerite, sulvanite, pentlandite, tennanite and, as traces, native gold, uraninite, tiemannite (HgSe), arsenopyrite, chalcopyrite and covellite.* Discrete platinum group minerals may be unusual. Some ore samples are surprisingly light because of abundant organic matter and large amount of pores.

GANGUE MINERALOGY: Chert, amorphous silica, phosphatic sediments, barite and bitumen. May be interbedded with pellets of solid organic matter (called stone coal in China). Barite laths are reported in two of the Chinese deposits.

ALTERATION MINERALOGY: Siliceous stockworks and bitumen veins with silicified wallrock occur in the footwall units. Carbonate concretions up to 1.5 m in diameter occur immediately below the Nick mineralized horizon in the Yukon.

WEATHERING: Mineralized horizons readily oxidize to a black colour and are recessive. Phosphatic horizons may be resistant to weathering.

SHALE-HOSTED Ni-Zn-Mo-PGE E16

ORE CONTROLS : The deposits developed in restricted basins with anoxic conditions. Known deposits are found near the basal contact of major formations. Underlying regional unconformities and major basin faults are possible controls on mineralization. Chinese deposits occur discontinuously in an arcuate belt 1600 km long, possibly controlled by basement fractures.

GENETIC MODEL: Several genetic models have been suggested, reflecting the limited data available and the unusual presence of PGEs without ultramafic rocks. Syngenetic deposition from submarine springs with deposition of metals on or just beneath the seafloor is the most favoured model. Siliceous venting tubes and chert beds in the underlying beds in the Yukon suggest a hydrothermal source for metals.

ASSOCIATED DEPOSIT TYPES: Phosphorite layers (F07?), stone coal, Sedex Pb-Zn (E14), Sediment-hosted barite (E17), sediment-hosted Ag-V, uranium deposits.

COMMENTS: Ag-V and V deposits hosted by black shales have been described from the same region in China, hosted by underlying late Precambrian rocks.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Ni, Mo, Au, PGE, C, P, Ba, Zn, Re, Se, As, U, V and S in rocks throughout large parts of basin and derived stream sediments. In China average regional values for host shales of 350 ppm Mo, 150 ppm Ni, several wt % P_2O_5 and 5 to 22% organic matter. Organic content correlates with metal contents for Ni, Mo and Zn.

GEOPHYSICAL SIGNATURE: EM for pyrite horizon. Scintillometer to detect anomalous U.

OTHER EXPLORATION GUIDES: Anoxic black shales deposited in sub-basins within marginal basins. Chert or phosphate-rich *sediments associated with a pyritiferous horizon. Barren pyrite layers from 5 mm to 1.5 cm thick, located up to tens of metres* above mineralized horizon.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : These thin sedimentary horizons (not economic) may represent hundreds of thousands of tonnes grading in percent values for Ni, Mo or Zn with significant PGEs. In China the Zunyi Mo mines yield ~ 2000 tonnes *per year averaging ~4% Mo and containing up to 4% Ni, 2% Zn, 0.7 g/t Au, 50 g/t Ag, 0.3 g/t Pt, 0.4 g/t Pd and 30 g/t Ir.* The ore is recovered from a number of small adits using labour-intensive mining methods.

ECONOMIC LIMITATIONS: In China the Mo-bearing phase is recovered by roasting followed by caustic leaching to produce ammonium molybdate. Molybdenum-bearing phases are fine grained and all ore (cutoff grade 4.1% Mo) is shipped directly to the smelter after crushing.

IMPORTANCE: Current world production from shale-hosted Ni-Zn-Mo-PGE deposits is approximately 1000 tonnes of ore with grades of approximately 4% Mo. Deposits of this type are too thin to be economic at current metal prices, except in special conditions. However, these deposits contain enormous tonnages of relatively high grade Ni, Mo, Zn and PGE which may be exploited if thicker deposits can be found.

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There is potential to find these deposits in a number of sedimentary sequences in British Columbia. The most obvious is the southeasterly extension of the Devonian black shales of the Selwyn Basin that host the Nick deposit, into the Kechika Trough of northeastern British Columbia (Figure 2). Although no shale-hosted nickel sulphide occurrences have been reported from this area, there is geochemical evidence that they could exist. In 1978 Texasgulf Inc. found a tufa deposit with up to 8.4%. Zn immediately northeast of the confluence of the Kechika and Gataga rivers (Carne, 1991). Subsequently Noranda Exploration Company, Limited and Archer, Cathro and Associates Limited outlined widespread areas with high Zn-Cu-Mo-Ag values. Archer, Cathro and Associates Limited have since found values in excess of 10000 ppm Zn and 4000 ppm Ni near Red Bluff Creek, in the area, now covered by the Netson claims (Figure 2). As there are no igneous rocks in the area, shale-hosted nickel sulphide occurrences are currently the presumed source of the nickel and molybdenum. The anomaly lies near the transition between dominantly calcareous or dolomitic shale and mudstone of the Ordovician to Lower Devonian Road River Group and siliciclastic turbidite and debris-flow deposits interlayered with carbonaceous cherty argillites of the Middle Devonian to Mississippian Earn Group (Ferri *et al.*, 1995, this volume).

Other potentially prospective black shale sequences are the Bowser Lake Group of central British Columbia and the Exshaw and Fernie Formations in the southeastern corner of the province.

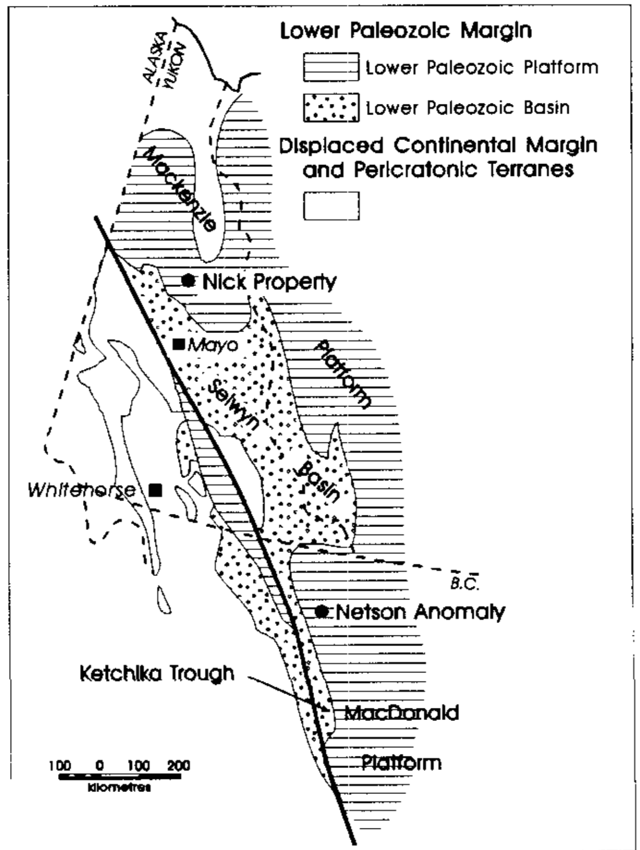

Figure 2. The extension of the Mackenzie Platform into northeastern British Columbia is a prospective area for finding shale-hosted Ni-Zn-Mo-PGE deposits. Both the Nick occurrence and Netson property are hosted by shale outliers similar to Road River Group and Earn Group rocks found within the Selwyn Basin and Kechika Trough. Figure modified from Hulbert *et al.* (1992).

SUMMARY

There is potential to find a wide variety of orebodies in British Columbia. The mineral deposit profiles being developed by the British Columbia Geological Survey Branch may provide explorationists with information on deposit types with no known orebodies in the province.

ACKNOWLEDGEMENTS

These two deposit profiles represent the results of a literature review by the author. The only "ground truthing" is thanks to reviews and instructive conversations with Sunil Gandhi and Larry Hulbert of the Geological Survey of Canada and Ray Coveney of the University of Missouri -Kansas City. Comments by Tom Setterfield of Westminer Canada Ltd. and Rob Carne of Archer, Cathro and Associates Limited were also appreciated.

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NOTES

VOLCANIC STRATIGRAPHY AND LITHOGEOCHEMISTRY OF THE SENECA PROSPECT, SOUTHWESTERN BRITISH COLUMBIA (92H/5W)

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(MDRU Contribution 060)

KEYWORDS: Economic geology, Harrison Lake Formation, Seneca deposit, Kuroko, synvolcanic, stratigraphy, dacite, andesite, rhyolite, massive sulphide, alteration.

INTRODUCTION

The Seneca property in southwestern British Columbia is located approximately 120 kilometres east of Vancouver (Figure 1). The property is accessible from the Lougheed Highway at Harrison Mills by the Morris Valley Road and the Chehalis-Fleetwood logging road.

The property has been described as a zinc-copper-lead-barite volcanogenic massive sulphide environment similar in many aspects to the Kuroko-type deposits (Urabe et al., 1983; McKinley et al., 1994). There are three major zones of sulphide mineralization on the property; the Pit area, the Vent zone and the Fleetwood zone, within a 4.5 by 3 kilometre area east of the Chehalis River (Figure 1). Current geological reserves are estimated at 1.5 million tonnes grading 3.57% Zn, 0.60% Cu and 0.14% Pb. Mineralization occurs as replacement sulphides associated with volcaniclastic sediments and as stockwork-style stringer sulphides hosted in a sequence of felsic to intermediate volcanic rocks of the Harrison Lake Formation.

The objective of this study is to better constrain the spatial, temporal, and geochemical relationships of the various rock units and the accompanying alteration and mineralization. Fieldwork in the 1994 season involved the logging of diamond-drill cores to complete a longitudinal geological cross-section through the property, as well as some outcrop examination.

EXPLORATION HISTORY

The Seneca prospect, formerly known as the Lucky Jim property, was discovered in 1951 as an indirect result of logging operations and was optioned by Noranda Exploration Company at that time (Thompson, 1972). The sulphide mineralization was believed to be part of a steeply dipping vein or shear system. In 1961 stripping, trenching and some underground work were carried out, but the results were not encouraging. The property was held by Noland Mines, Ltd. from 1964 to 1965 and was bought by Zenith Mining Corporation, Ltd. in 1969. Cominco Ltd. optioned the property in 197 and carried out further exploration based on the concept that the zone represented Kuroko-style conformable mineralization. The property was acquired by Chevron Standard Ltd. in 1977 and further diamond drilling was completed over the next ten years in joint ventures with International Curator Resources Ltd. and B.P. Canada Inc. Further logging in the area led to the discovery in 1986 of the Vent zone stockwork mineralization 1.75 kilometres to the west of the original discovery. In 199 drilling by Minnova, Inc., 1 kilometre to the west of the Vent zone, led to the discovery of the Fleetwood zone. The property is currently held by International Curator Resources Ltd. and is under option to Metall Mining Corporation.

REGIONAL GEOLOGY

The Harrison Terrane on the west side of Harrison Lake comprises a sequence of Triassic to Cretaceous volcanic and sedimentary rocks. The stratigraphically lower part of the sequence is intruded by Upper Jurassic quartz diorite batholiths west and north of the property (Monger, 1970; Mahoney, 1994). The Harrison Lake Formation, within the Harrison Terrane, is a Lower to Middle Jurassic succession up to 2500 metres thick that strikes north-northwest with gentle to moderate easterly dips (Mahoney, 1994). From oldest to youngest, the Harrison Lake Formation is composed of the Celia Cove Member, the Francis Lake Member, the Weaver Lake Member and the Echo Island Member (Arthur, 1986; Mahoney, 1994). The Celia Cove Member comprises mostly deep water sedimentary rocks unconformably overlying Triassic rocks. The Francis Lake Member represents the onset of volcanism that characterizes the Harrison Lake Formation. Regionally the Weaver Lake Member is dominated by intermediate to felsic volcanic rocks and related intrusions and is overlain by the Echo Island Member which comprises mostly volcaniclastic sediments (Mahoney, 1994). Although not fully constrained, the Seneca property is interpreted to lie within the upper part Weaver Lake Member.

GEOLOGY OF THE SENECA PROPERTY

In general the strata on the property strike approximately northwest and are essentially flat lying or moder-

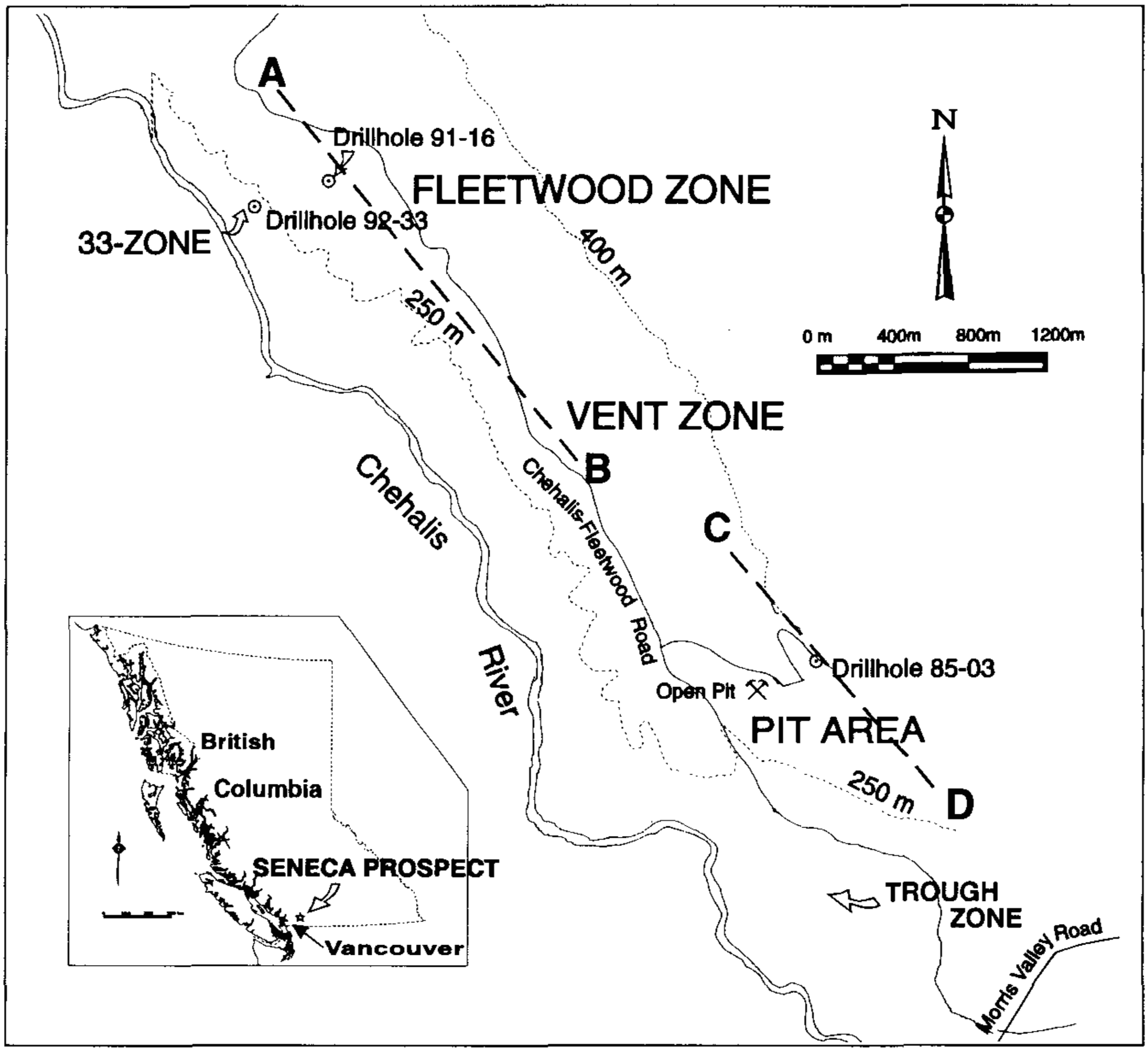

Figure 1: Location map of the Seneca prospect and the mineralized zones on the property.(A-B and C-D are longitudinal geological sections shown in Figure 2)

ately dipping in an easterly direction. The Seneca stratigraphy has undergone very little deformation or metamorphism and, in general, the rocks retain pristine volcanic textures. Metamorphic grade in the Seneca area is zeolite facies. The major lithologic units are subdivided into three principal volcanic facies as follows (see Figure 2):

- Facies 1 - Lavas (vent- proximal facies) consist of basaltic to rhyolitic composition flows, domes and associated *in situ* hyaloclastites and autoclastic breccias.
- Facies 2 - Volcaniclastic rocks (vent-proximal to distal facies) consist of juvenile to reworked coarse volcanic breccias and tuffs to fine grained siltstones and ashes.
- Facies 3 - Synvolcanic intrusions consist of basaltic to rhyolitic sills and dikes that have intruded lavas and wet volcaniclastic sediments.

A fourth facies consists of an argillite that often contains flattened quartz-feldspar-phyric pumice clasts (fiamme) and is often in close proximity to mineralization. However, this facies is spatially restricted to the Pit area and does not correlate across the property. The three principal facies are generally seen in all drillholes, but their relative abundances vary greatly from hole to hole.

FACIES 1: LAVAS

Lava flows are defined by their contact relationships and the occurrence of flow textures and autobrecciation. The felsic lavas contain 5 to 15 % subhedral to euhedral plagioclase phenocrysts that are typically 1 to 2 millimetres long. Quartz phenocrysts are less common, but may comprise up to 7 % of the rock. They are generally

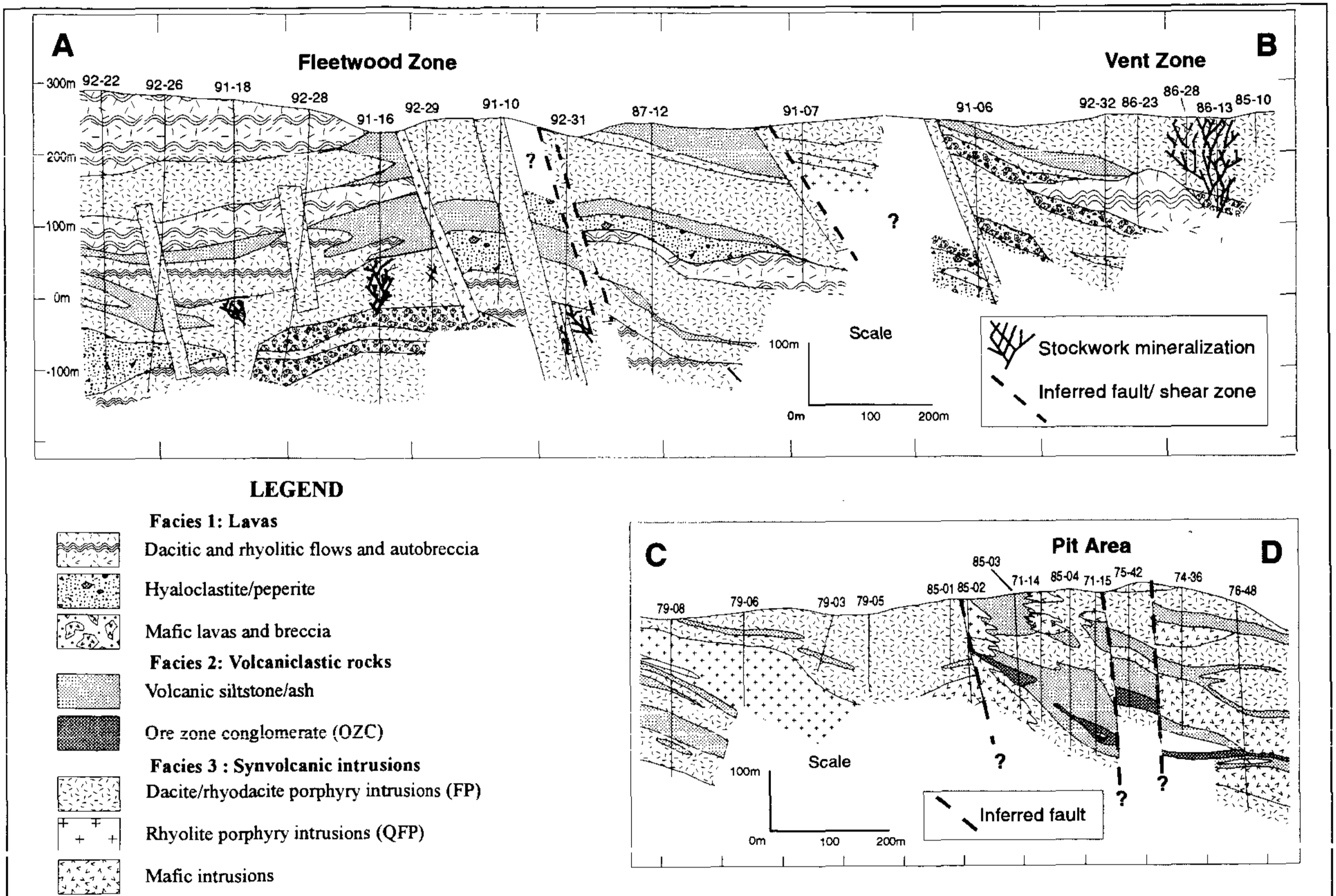

Figure 2. Simplified longitudinal geological sections of the Fleetwood and Vent zones (upper section) and the Pit area (lower section) at the Seneca prospect.

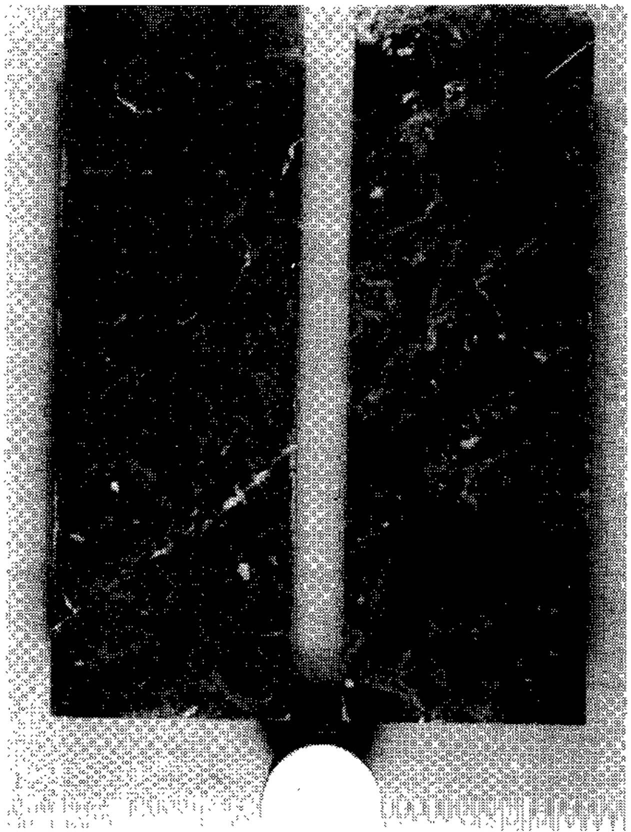

Photo 1. Basaltic lavas (facies1) from the Fleetwood zone. Amoeboid-shaped lava clasts (fire fountain debris) are in a matrix of chloritized glass.

subrounded and less than 5 millimetres in diameter. Chloritized hornblende laths are also usually present (up to 5 %) and average 1 to 2 millimetres in size. Individual felsic flows range from one to several tens of metres thick, and have flow brecciated upper contacts and chilled and/or slightly brecciated lower contacts. The flow breccias have generally been weakly to moderately silicified, probably by syndepositional seawater interaction. In some instances several coherent flow-flow breccia sequences occur in vertical succession up to 100 metres thick, but less than 200 metres in lateral extent, forming a dome-like morphology. The cores of the thicker flows are typically massive and greyish green in colour, and are often accompanied by a lateral transition from autobreccia to reworked hyaloclastite and volcaniclastics at the margins. These relationships suggest that the felsic flows have both tabular and dome-like morphologies similar to those described by McPhie and Allen (1992) for the Mount Read volcanics in western Tasmania. The domes and flows are intruded into and extruded through other lavas, fine-grained volcaniclastics and coarse lava clast breccias (Figure 2).

Unbrecciated andesites at Seneca tend to be featureless and without pillow forms. However, massive coherent mafic flows are inferred by the presence of stretched amygdules and their association with autoclastic breccia. A unit that consists of subrounded to amoeboid fragments of vesicular basaltic andesite surrounded by angular andesite clasts and hyaloclastite occurs in the western part of the property (Photo 1). The fragments are typically 1 to 10 centimetres in size, are light green or purplish grey in colour and consist of a core of massive andesite with chilled or brecciated rims. The textures of the fragments, together with their amoeboid shape and tail-like ends, suggests that they were ejected as molten material either subaqueously or subaerially and landed in water while still semi-molten (R. Allen, pers-onal communication, 1993). This unit is interpreted to be a vent-proximal facies as the surrounding angular hyalo-clastite has not been reworked. This facies is referred to as 'fire fountain debris' and is only seen in lower parts of the drillholes.

FACIES 2: VOLCANICLASTIC SEDIMENTS

There is a variety of volcanic-derived sediments and breccias on the Seneca property with clasts ranging from silt size to block size (<15 cm). These units represent the deposition and reworking of volcanic debris derived from lava flows, domes and eruptions, with the probable addition of fine sediments of more distal origin. They are subdivided into four facies:

- Facies 2.1. Monolithic to heterolithic, massive to well bedded or laminated and normal density graded, moderately to poorly sorted lava clast breccias, pebble conglomerates, vitric-crystal tuffs and volcanic sandstones, interpreted to have been deposited as debris flow deposits and turbidites.
- Facies 2.2. Massive to well laminated volcanic siltstone and fine ash deposited subaqueously by gravity settling.
- Facies 2.3. Dacitic to rhyolitic pumice beds (often flattened).
- Facies 2.4. Reworked dacitic debris flow deposits and conglomerate interpreted to have been deposited in a fluvial or deltaic environment.

The 'ore zone conglomerate', located in the Pit area, hosts disseminated to massive sulphide mineralization, and varies from 1 to 15 metres in thickness. The unit consists of moderately silicified, mostly subrounded dacite lava clasts ranging from sand size up to 3 centi-metres in diameter in a sandy or silty matrix. The unit can be matrix or clast supported, and also contains clasts and matrix that have been replaced and/or infilled by sulphides. It should be noted that the term ore zone conglomerate refers to the entire unit which hosts sulphide mineralization and that much of the unit contains only sulphides, but is texturally distinct from other volcaniclastic units.

A dacite lava clast breccia (facies 2.1) occurs stratigraphically below the ore zone conglomerate in the Pit area, and generally above the major mafic units in the Fleetwood and Vent zones (Photo 2). Typically the unit is clast supported (up to 90% clasts up to 10 cm in diameter) and consists dominantly of subangular dense fragments of feldspar-phyric dacite lava and lesser amounts of dark green vitric or pumiceous clasts, andesitic fragments and occasional silty rip-up clasts.

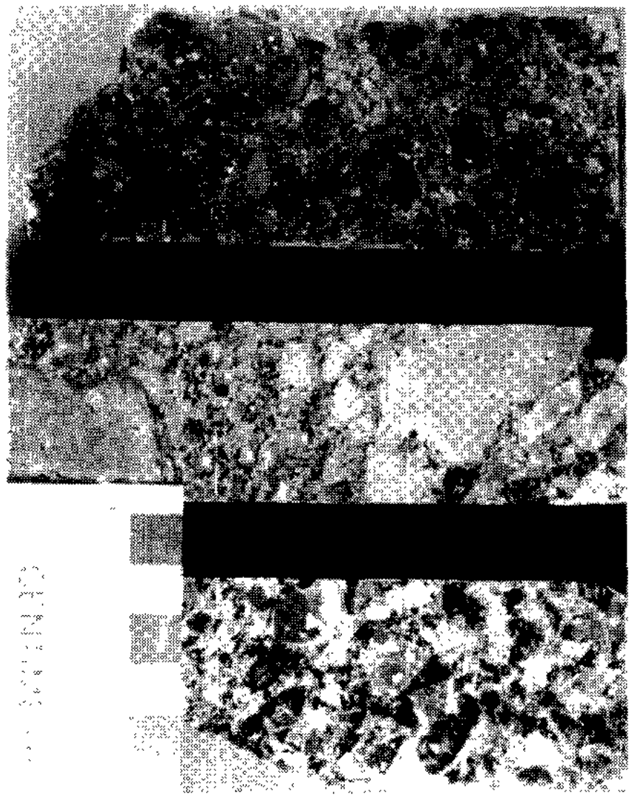

Photo 2. Coarse volcaniclastic breccias (facies 2). These consist dominantly of dacite lava clasts deposited by debris flows

The dacite clasts vary in colour from light grey to reddish tan, possibly repre-senting subaerial deposition and later reworking. The unit is moderately to poorly sorted, suggesting deposition by debris flows.

Compared to the Pit area, the Fleetwood and Vent zones contain a greater abundance of reworked andesitic lava clast breccias, comprising centimetre-size, subangular, amygdaloidal andesite fragments and hyaloclastite, and up to 30% dacite lava clasts. The true thickness of the unit is difficult to determine due to dilation by synvolcanic intrusions, but individual intersections are some 5 to 10 metres thick. Andesite lava clast breccias are less common at higher stratigraphic levels, and where they do occur, contain smaller clasts that are more rounded.

Fine-grained volcaniclastic sediments (facies 2.1 and 2.2) are common throughout the property, particularly in the upper part of the stratigraphy (Photo 3). The sediments form light to dark grey beds of silt to coarse sand-sized material. Individual beds range from 2 centimetres to 5 metres thick, and vary from massive to well laminated and normal graded. The basal contacts of normal graded beds are often sharp and are characterized by coarse sand to gravel-sized material, often with a component of dacite pumice fragments, glassy shards and feldspar crystals. These beds grade upward through massive or weakly laminated sands to well-laminated and occasionally cross bedded fine sand, silt and mud and may represent individual turbidite layers. Graded beds become more common higher in the stratigraphy.

In the Trough zone, in the southeastern part of the property (Figure 1), drillhole 91-03 intersected an uninterrupted sequence of facies 2.1 and 2.2 volcani-clastic sandstone and siltstone. This interval lacks the felsic intrusions and flows that are ubiquitous elsewhere on the property. There is a gradual fining upwards in the sequence and the upper parts are well bedded and laminated. The upper part contains a component of quartz-feldspar-phyric rhyolite pumice clasts 2 to 10 centimetres in size, suspended in fine-grained ash. The pumice and the ash/siltstone are possibly derived from a subaerial felsic eruption. The Trough zone is interpreted as a more distal facies of the Pit area stratigraphy.

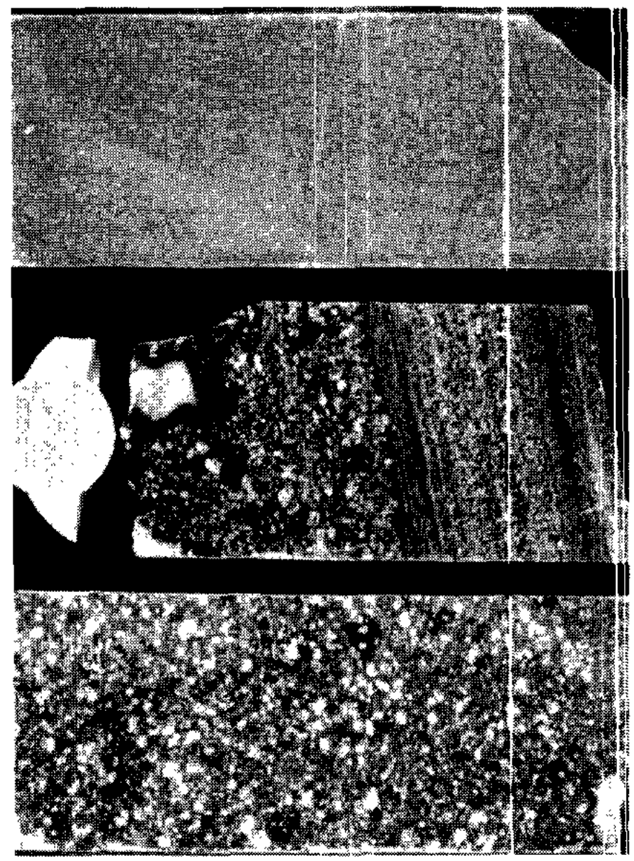

Photo 3. Volcaniclastic rocks. Top: massive volcanic siltstone (facies 2.2); Centre: bedded volcanic sandstone (facies 2.1); Bottom: crystal-rich dacitic tuff.

FACIES 3: SYNVOLCANIC INTRUSIONS

Synvolcanic intrusions are distinguished from flows by their contact relationships and textural features. Commonly, the contacts are bedding parallel, and the units lack flow banding and autobreccia (Photo 4). Chilled margins and contacts at high angles to stratigraphy provide simple criteria for the recognition of dikes.

The most common intrusions are feldspar-phyric dacite to rhyodacite porphyry sills. They range from one to several tens of metres thick, and are often columnar jointed in outcrop. Mineralogically, and often texturally, these rocks are identical to the dacite flows described earlier and are only distinguishable by their contact relationships. Dacite sills, where they cut other intrusions

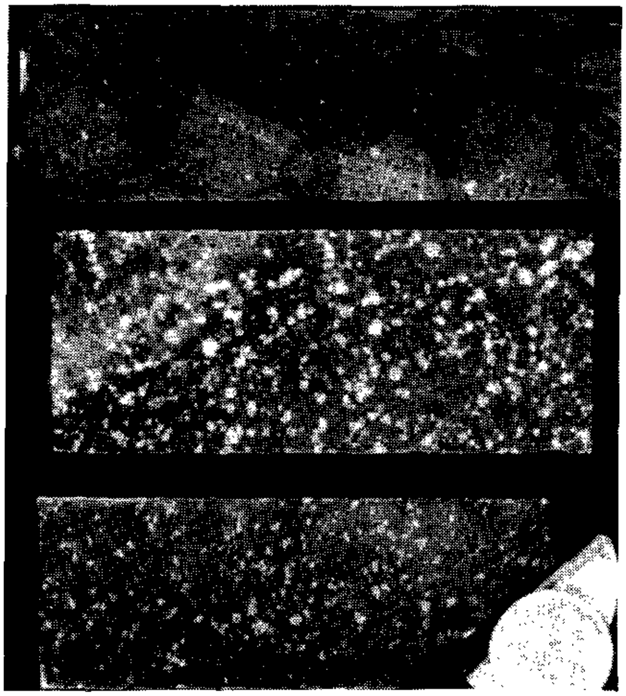

Photo 4. Synvolcanic intrusions. Bottom: feldspar-phyric dacite porphyry (FP); Centre: quartz-feldspar-phyric rhyolite porphyry (QFP); Top: Andesite sill showing peperitic textures.

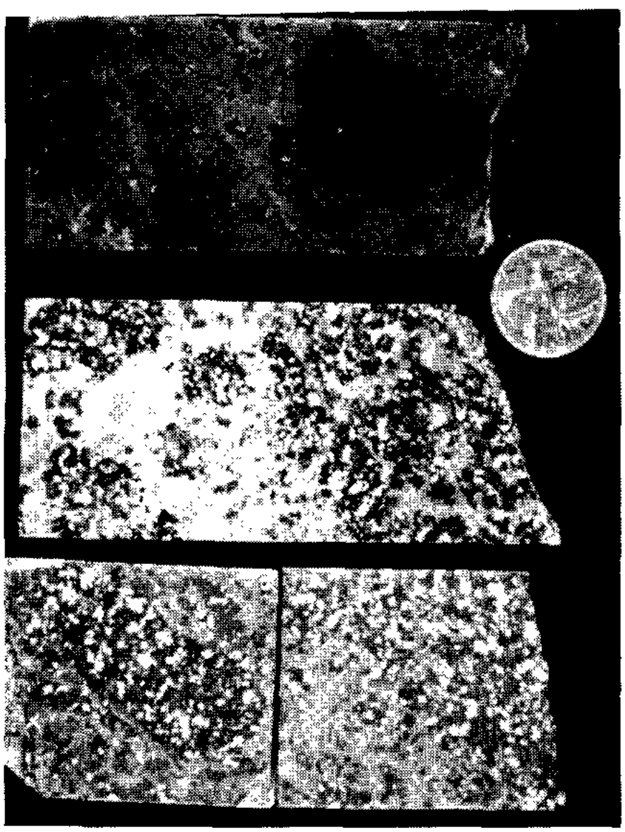

Photo 5. Peperitic textures from a sediment-sill contact zone. Drillcore samples show a downward progression from a mixed zone of siltstone and hyaloclastite at the contact (top) to the main body of the sill below the contact showing decreasing intensities of quenching, fracturing and alteration downwards (centre and at bottom).

or flows, commonly have chilled contacts over widths of 10 centimetres to more than 1 metre, and are only slightly brecciated. Where the sills intrude the volcaniclastic sediments and breccias, the contacts commonly have peperitic textures (Photo 5). In peperitic zones the contacts tend to be quenched and brecciated with angular to cus-pate hyaloclastic fragments less than 1 centimetre to 20 centimetres in size in a matrix of the finer volcaniclastic sediment. These interaction zones reach thicknesses of several metres and usually occur at the top of the sills. The textures indicate that the sills have intruded into wet, unconsolidated sediments (*cf.* McPhie and Allen, 1992).

Mafic intrusions are less common than felsic bodies and tend to occur in the lower part of the stratigraphy. Similar to the dacite porphyries, they have both cross-cutting and bedding-parallel contacts with chilled margins. The andesites are generally massive and dark green with chlorite-filled amygdules 0.5 to 1 millimetre in diameter. Where the andesites intrude sediments, they exhibit quenching, brecciation, and mixing similar to the felsic intrusions, except that brecciated zones tend to be more extensive (in the range of several metres). In many of the drillholes in the Pit area, these mafic sills intrude the ore zone conglomerate and units immediately above and below it.

The third type of intrusion is quartz-feldspar-phyric rhyolite porphyry. These rocks are less common than the other two types and their mode of emplacement is uncertain. They occur at higher levels in the stratigraphy and as a result their upper contacts are not always seen. Their size and massive nature suggest that they may be synvolcanic sills, but they may also represent emergent domes. The rhyolite porphyries are easily distinguishable from the dacite porphyries by their greyish brown groundmass and by the presence of up to 10% sub-rounded quartz phenocrysts 2 to 7 millimetres in diameter. There are also 5 to 15% plagioclase phenocrysts 1 to 2 millimetres in size, as well as minor hornblende. The rhyolite porphyry bodies range from a few to more than 30 metres thick.

MINERALIZED ZONES

Three types of mineralized zones are present at Seneca (Figure 2):

- Conformable massive sulphide lenses.
- Semi-massive and disseminated sulphides associated with volcaniclastic rocks.
- Stockwork and stringer mineralized zones.

Conformable, stratabound lenses of semi-massive sphalerite, pyrite, and chalcopyrite with lesser galena are exposed in the Pit area, and to a lesser degree in an intersection (drillhole 92-33) in the 33-zone in the Fleetwood area. The sulphides in both locations are hosted by fragmental rocks and occur as discontinuous pods that do not correlate between adjacent drillholes. In the 33-zone, a 2-metre intersection of massive sulphides is underlain by a quartz-carbonate-chlorite zone and a dacite porphyry intrusion, and is sharply overlain by a cherty sulphide

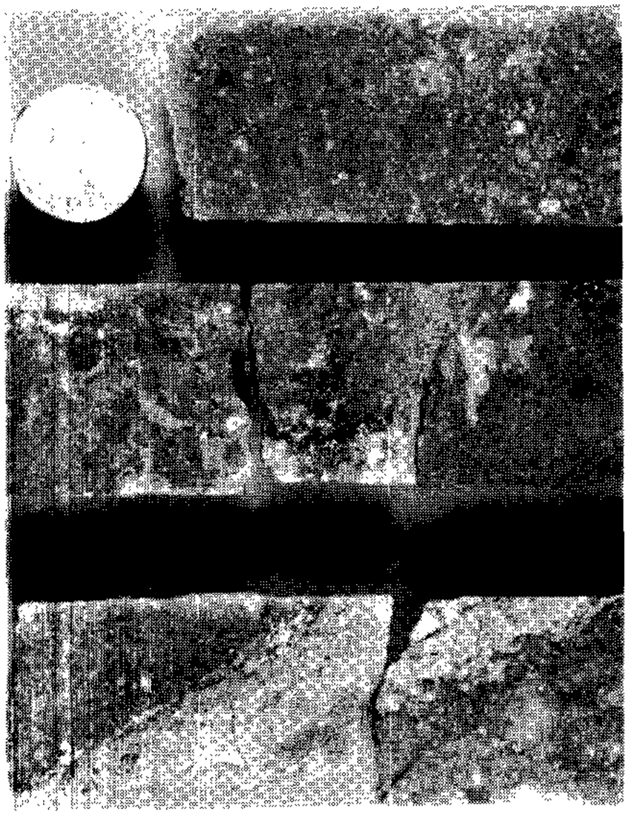

Photo 6. Ore zone conglomerate (OZC). Drillcore samples show variations within this mineralized unit. The samples contain disseminated, semi-massive and stringer pyrite-sphalerite-chalcopyrite mineralization hosted by strongly altered volcaniclastic rocks.

layer and a zone of strongly chloritized fragmental material. Unlike the 33-zone, the massive sulphides in the Pit area are underlain by siliceous stringer and disseminated mineralization. Blades of barite are intergrown with the sulphides in both locations.

Massive to disseminated sulphides are associated with the volcaniclastic ore zone conglomerate (Photo 6) and tend to be restricted to the upper portions of the unit. The best such intersection is 0.5 metres of massive pyrite, sphal-erite and barite with lesser chalcopyrite, underlain by 3.5 metres of mostly semi-massive pyrite (drillhole 85-03). More commonly the mineralization hosted by the ore zone conglomerate consists of clasts that are partially replaced, or matrix that is partly infilled by pyrite and occasionally sphalerite. Some of the clasts are rimmed by later pyrite. There is no evidence of bedded clastic sulphides.

Stockwork and stringer sulphides are the dominant style of mineralization in the Fleetwood and Vent zones (Photo 7). The Vent zone stockwork consists of veinlets up to 1 centimetre wide of sphalerite, pyrite and quartz (± chalcopyrite) in strongly altered dacitic flows, breccias, intrusions, and mixed lava clast breccia. In the Fleetwood zone (drillhole 91-16) 1.1 metres of massive sphalerite, pyrite and chalcopyrite occur immediately above about 30 metres of stockwork sphalerite-pyrite-chalcopyrite-quartz -anhydrite veinlets in altered dacite and fine volcaniclastics similar to the Vent zone. Shorter intersections of

Plate 7. Vent zone stockwork. The sample from outcrop consists of pyrite-sphalerite-quartz veins in st ongly altered dacite porphyry.

similar stockwork mineralization occur in drillholes between the Fleetwood and Vent zones.

All of the mineralized zones in the Fleetwood Area occur at about the same stratigraphic level and have similar lithologic associations (Figure 2a). The stockwork zones are most commonly hosted by felsic lavas and autobreccias which immediately overlie mafic lavas and reworked mafic-dominated volcaniclastic rocks (facies 2.1), and which occur below the fine-grained volcaniclastics (facies 2.2). These overlying fine volcaniclastics are essentially unmineralized and unaltered except for occasional fine sulphide laminations. The mineralized zones are often associated with narrow fault zones and moderate to strong, fine anhydrite veining. Similar lithologic relationships are also seen in the Vent zone.

ALTERATION

Typically most of the rocks at the Seneca property are relatively unaltered, with pristine preservation of volcanic textures. Macroscopically recognizable alteration is restricted to the Vent and Fleetwood zones where it is characterized by intense silicification and sericitization associated with massive to flow-banded and flow-brecciated dacite porphyry. The stockwork veining is restricted to the dacites, but alteration extends 10 to 20 metres into the surrounding fragmental rocks, obliterating the original textures. The dacites are identified on the basis of the relict feldspar "ghosts" left by the alteration. Alteration in the Pit area is mostly restricted to the ore zone conglomerate which is commonly strongly silicified and/or clay altered. There appears to be little footwall alteration below this horizon except for occasional clay alteration of some of the coarse felsic volcaniclastics. This suggests that the alteration and

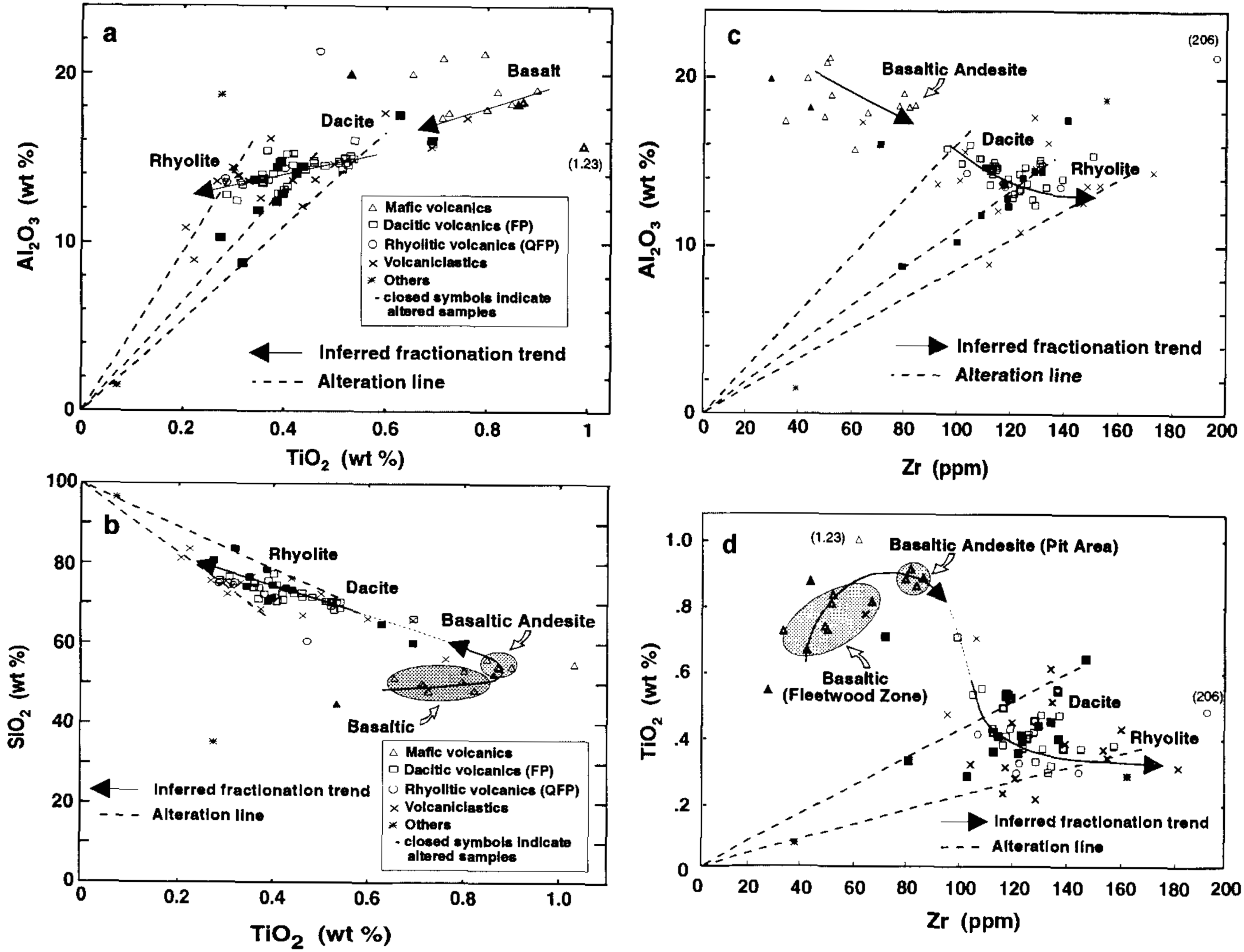

Figure 3. Plots of major and trace element lithogeochemical data for volcanic rocks at the Seneca prospect.

mineralization may have been controlled by the porosity and permeability in the coarse-grained host.

LITHOGEOCHEMISTRY

A suite of 82 samples was analysed for major and trace elements using x-ray fluorescence at McGill University in Montreal. The samples were selected to be representative of the major lithologies on the Seneca property.

Plots of major and trace element geochemical data are used in this study to illustrate fractionation and alteration trends in the volcanic rocks (Figure 3). Inferred fractionation trends were established using vari-ous pairs of compatible, incompatible, mobile and imm-obile elements, with the igneous incompatible element being used as the monitor of fractionation. Zirconium is used most often as a monitor of fraction-ation as it is immobile, relatively abundant and can be measured accurately using XRF techniques (MacLean, 1990). Figures 3a and 3b both show near continuous linear to curvilinear trends from rocks of basaltic andesite composition to dacite and rhyolite compositions. However, there is a 'gap' in the data set corresponding to compositions of about 55 to 63% SiO_2, This suggests that the data set is bimodal. However, the data of Mahoney (1994) do not support a bimodal nature for the entire Weaver Lake Member. As the majority of the samples are relatively unaltered, we believe that the near linear or curvilinear trends in the felsic samples are related to fractionation. Further geochemical work is required to determine if the felsic and mafic rocks are directly related by fractionation.

Within the mafic rocks, there appear to be two groupings of samples (Figure 3); one of these has a basaltic andesite composition and the other has a less evolved basaltic composition with lower titanium and zirconium contents. The mafic samples are inferred to lie along a curving trend in Figures 3b and 3d, in which the initial increase in TiO_2 reflects the enrichment of titanium in the residual magma during the early stages of crystallization, with the subsequent decrease corresponding to the onset of crystallization of titanium-bearing phases (Winchester and Floyd, 1977). The basaltic samples also have lower Zr/Y ratios consistent with a tholeiitic to transitional magmatic affinity. The andesitic samples are synvolcanic sills taken entirely from the Pit area, whereas the basaltic samples are extrusive lavas and intrusions from the Fleetwood and Vent zones. The relative stratigraphic positions of these samples suggests that the more evolved basaltic andesites intruded at a slightly higher stratigraphic level.

In immobile-incompatible element and immobile-immobile plots, altered samples lie along lines that extend from the unaltered precursor composition to the origin. Such trends involving the altered felsic samples are best shown in Figures 3a and 3c. The effect of silicification, which is the dominant alteration in many rocks, is shown in Figure 3b where the altered samples lie along alteration lines which trend towards 100% SiO_2. These altered samples are from mineralized stock-works in the Fleetwood and Vent zones.

The volcaniclastic samples consist of fine-grained facies 2.1 and 2.2 volcanic siltstones and fine sandstones. All of them, except for one of mafic composition, lie within the same field as the dacitic to rhyolitic lavas and intrusions and were probably derived from flows or pyroclastic eruptions of these compositions, with little or no addition of mafic material. Mafic volcaniclastic rocks on the Seneca property are less prevalent than those of felsic composition.

DISCUSSION

The volcanic sequence at the Seneca Prospect consists of felsic and mafic lava flows and massive to normal-graded volcaniclastic sediments that were intruded prior to lithification by synvolcanic sills and dikes. The volcaniclastic rocks were deposited by mass flows, turbidites and gravity settling. These units become progressively finer grained and better graded upwards in the succession. Felsic porphyries intrude all levels of stratigraphy, including the earlier mafic intrusives. Mineralization consists of conformable lenses of massive, semi-massive and disseminated sulphides in the Pit area and the 33 zone, and stockwork-style sphalerite-pyrite-chalcopyrite-quartz veinlets and stringers in the Vent and Fleetwood zones. Major zones of silicification and sericitization are associated with the stockwork zones.

The lower most parts of the Seneca stratigraphy are dominated by vent-proximal, mafic lavas and breccias, and slightly reworked coarse-grained mafic volcaniclastic rocks. Mafic volcanism was followed by the onset of extrusive felsic volcanism. Felsic flows, domes and autoclastic and hydroclastic breccias often directly overlie the mafic extrusive rocks and are accompanied by felsic synvolcanic intrusions. The felsic flows are interlayered with and overlain by fine-grained and reworked felsic volcaniclastic rocks (facies 2.2). The greater proportion of fine-grained volcaniclastic rocks compared with flows and breccias in the upper parts of the Seneca stratigraphy, and the fining upward nature of the entire sequence, may reflect an overall deepening of the depositional basin and/or a transition towards a more quiescent setting dominated by sedimentary processes.

The mineralized stockworks are interpreted to have formed at about the same time and stratigraphic level. Their association with flow-top breccias and their proximity to enclosing volcaniclastic units suggests that they formed at or near the paleoseafloor. This mineraliz-ing event also roughly corresponds to the onset of extrusive felsic volcanism. The deposition of the finer volcaniclastics was probably contemporaneous with, or post-dated, the mineralizing event. The zones of alteration and mineralization occur along a roughly linear trend that approximately parallels the inferred strike of the units; these zones taper out rapidly at their upper and lower contacts. Thus, it is possible that the mineralizing fluids were channelled by a single or several related, steeply dipping sructure(s). Such structures may also have been the feeders for the extrusive felsic domes and flows which host the mineralization.

ACKNOWLEDGMENTS

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GEOLOGICAL INVESTIGATIONS OF THE HIDDEN CREEK DEPOSIT, ANYOX, WEST-CENTRAL BRITISH COLUMBIA (103/P5)

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(MDRU contribution 061)

KEYWORDS: Economic geology, Anyox, massive sulphide, pyrite, pyrrhotite, chalcopyrite, metavolcanic, chert, turbidites, hydrothermal alteration, lithogeochemistry

INTRODUCTION

The Hidden Creek deposit constitutes the largest accumulation of known sulphide mineralization in the Anyox pendant, a volcanic-sedimentary succession preserved as a roof pendant along the eastern margin of the Coast Plutonic Complex, approximately 160 kilometres north of Prince Rupert, British Columbia (Figure 1). The deposit was discovered in 1901 and was operated between 1914 and 1935 by Granby Consolidated Mining and Smelting Company. During this period over 21 million tonnes of ore grading 1.5 % Cu, 9.25 g/t Ag and 0.17 g/t Au was mined. The mine was closed on August 1, 1935 and purchased by The Consolidated Mining and Smelting Company of Canada, Limited, now Cominco Ltd., on October 25, 1935 (Davis *et al.*, 1992). From 1936 to 1989 a number of exploration programs were carried out by Cominco and various joint venture partners. The property is now held by TVI Pacific; a 1990 economic assessment of the property indicated a geological reserve of 10.8 to 13.6 million tonnes grading 0.7% to 0.75% Cu (Davis *et al.* 1992).

This study is in the final year of a two-year program designed to examine the geological and geochemical relationships associated with sulphide mineralization in the Anyox pendant. Over the past two years, 24 drillholes totalling over 5300 metres were sampled for lithogeochemistry, petrography and fluid inclusion studies. Detailed mapping on 1:1200 and 1:2400 scales was carried out with special attention given to the ore zones and volcanic-sedimentary contact. Fieldwork this year focused on mineralization styles in the ore zones and associated stockwork zones, and on the extent, spatial distribution and paragenesis of the main alteration facies associated with the ore.

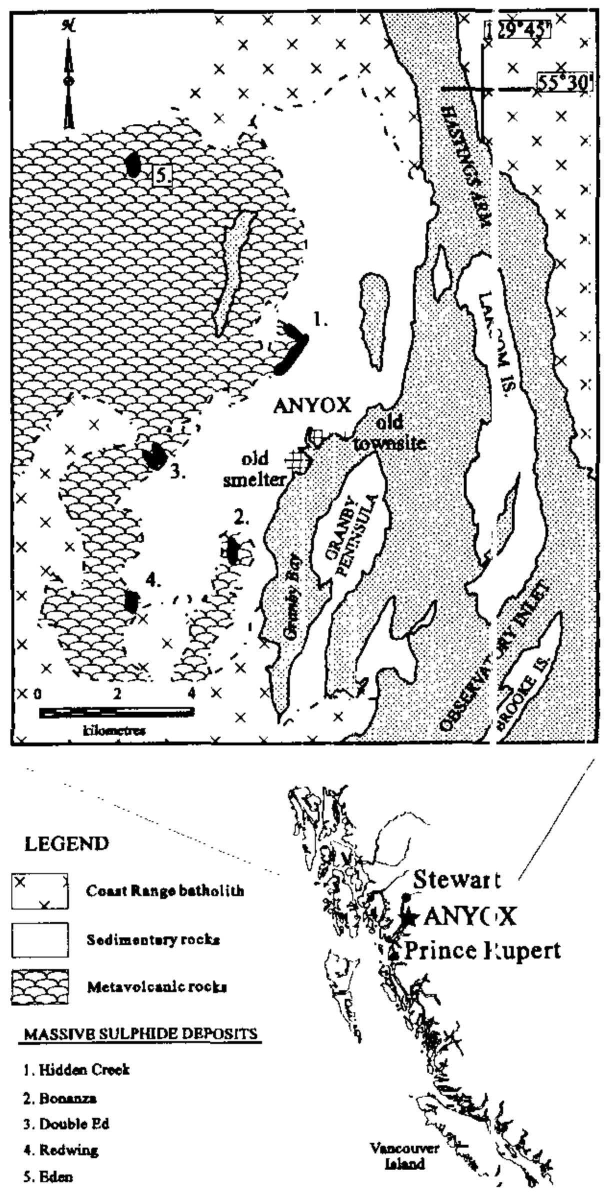

Figure 1. Location and general geology of the east Anyox pendent (after Aldrick, 1986).

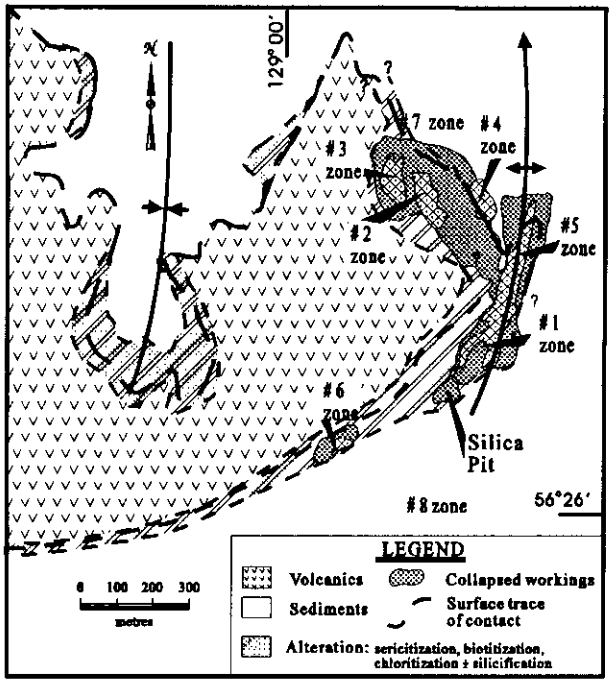

Figure 2. Generalized geology of the Hidden Creek mine area showing the distribution of ore zones and major structures. The Nos. 7 and 8 ore zones are small subsurface deposits indicated by drilling (after Davis, 1993).

REGIONAL GEOLOGY

Recent regional geological mapping in the Anyox pendant by Sharp (1980), Grove (1986), Alldrick (1986) and Macdonald *et al.* (1994) indicates that a thick volcanic sequence of tholeiitic basalt to basaltic andesite with subordinate volcaniclastic layers is overlain by a sequence of siltstone, greywacke and sandstone with minor calcareous and conglomeratic beds. Chert outcrops discontinuously along the volcanic-sedimentary contact. Mafic plutonic rocks occur in several localities in the pendant and may represent the basement to the volcanic sequence. Most recently the geochemistry of volcanic rocks in the pendant has been described by Smith (1993).

GEOLOGY OF THE HIDDEN CREEK AREA

The stratigraphy at the mine site consists of a basal metavolcanic unit overlain by exhalative chert and carbonate lenses of variable thickness, which in turn are capped by a thick turbiditic sedimentary sequence. Rocks in the volcanic-sedimentary sucession are variably altered with mineralogies dominated by chlorite, biotite, sericite and actinolite. Alteration is most intense adjacent to the contact between the volcanic and sedimentary rocks, ext-

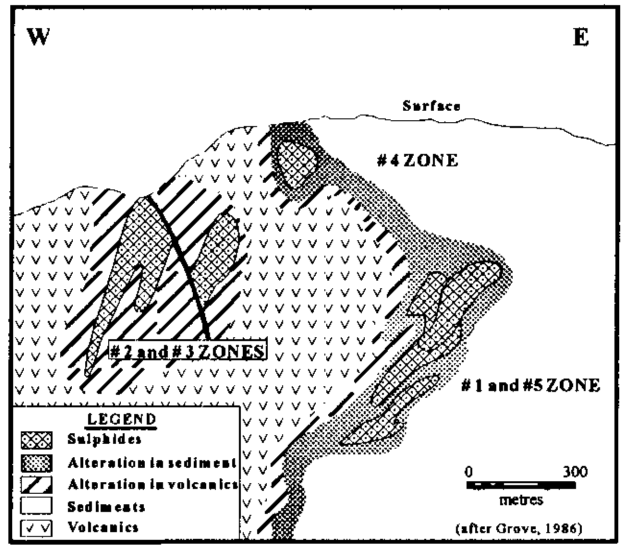

Figure 3. Schematic cross-section from west to east through the Hidden Creek mine showing the distribution of the major ore lenses in the folded volcanic-sedimentary sequence.

ending from the footwall volcanic rocks through the exhalative zone and for tens of metres into the hangingwall sedimentary sequence

The Hidden Creek deposit consists of eight distinct sulphide lenses all occurring at or within tens of metres of the sedimentary-volcanic contact (Figure 2). Sharp (1980) reports that the No. 2 and 3 orebodies are located within the footwall metavolcanic rocks; the Nos. 1, 4 and 5 orebodies are located at the volcanic-sedimentary contact and are intimately associated with cherty and carbonate chemical sediments; and the Nos. 6, 7 and 8 orebodies occur stratigraphically above the contact in hangingwall turbiditic sedimentary rocks. Lithogeochemical results presented in this paper show that the Nos. 1, 4 and probably the No. 5 deposits are actually sediment hosted and that further investigation is required to confirm the stratigraphic position of the Nos. 2 and 3 orebodies.

The orebodies are within the hinge zone and the overturned limb of the Hidden Creek anticline (Figure 3), a northerly trending, south and easterly verging structure. The arcuate shape of the contact at surface appears to be the result superposition of at least two phases of deformation and the rotation of the axis of the anticline to a moderate northerly plunge. Deformation in the sedimentary sequence is expressed as open to tight, upright to recumbent folds with wavelengths on a scale of metres to tens of metres. Strong planar and crenulated fabrics in the alteration assemblages, and shear fabrics in the metavolcanic rocks, are the dominant expressions of deformation in these lithologies. The orientation of these structures varies from mainly northtrending throughout most of the map area to westtrending along the southern

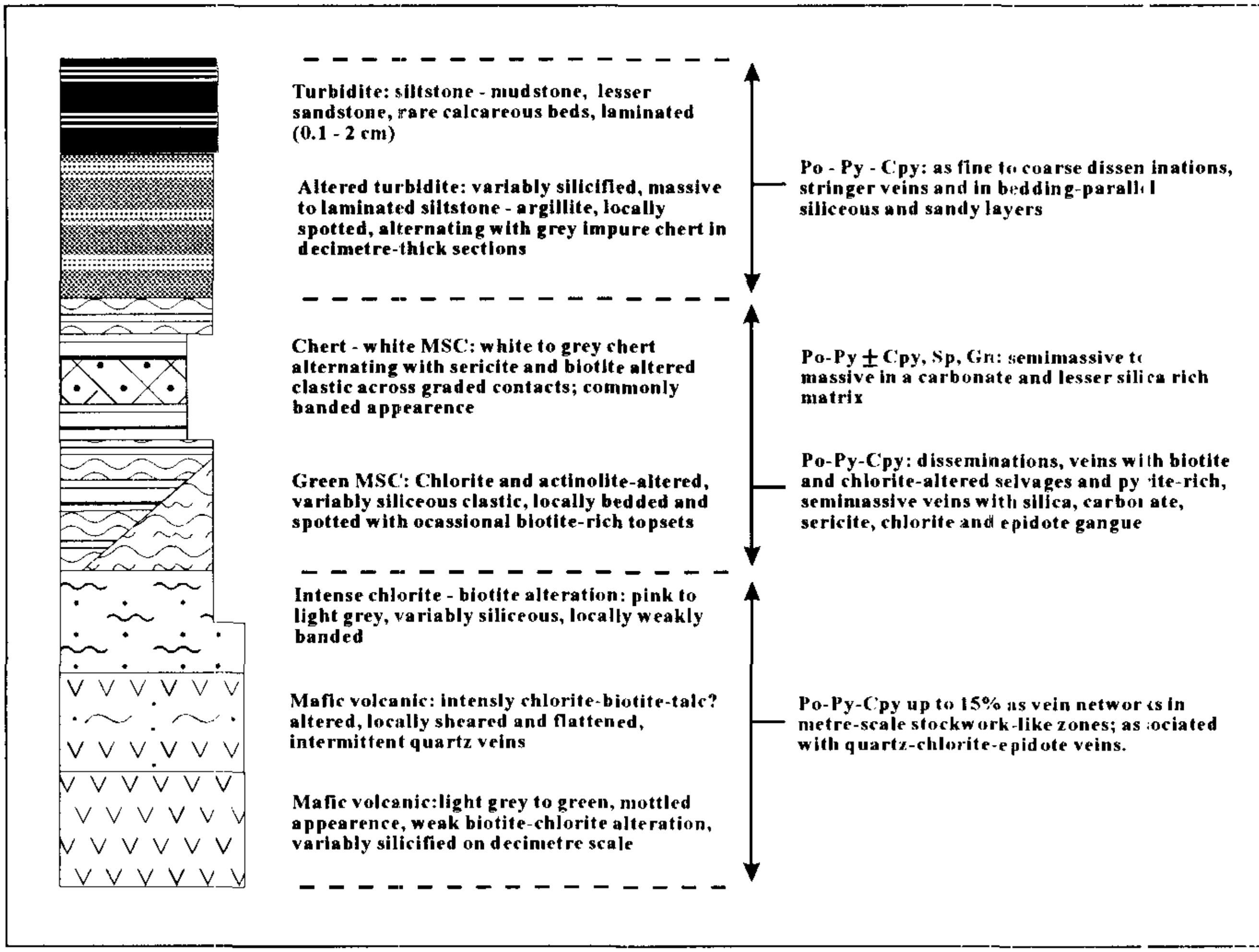

Figure 4. A composite stratigraphic section of the Hidden Creek mine. The section is schematic and represents the gross spacial distribution of the dominant lithological units and alteration assembleges from the basal volcanic sequence through the contact zone and into the overlying, unaltered sedimentary cap of the ore zones

edge of the map where structures are subparallel to the contact.

STRATIGRAPHY

Massive to pillowed flows and fragmental metavolcanic rocks form part of the footwall to the Hidden Creek sulphide lenses. These rocks are fine grained to porphyritic and have been altered to assemblages of chlorite, actinolite, biotite, sericite, clinozoisite and zoisite. Pillows, where observed, range from 10 centimetres to 1 metre in longest dimension and typically have length to width ratios of 2:1. Pillow selvages are 1 to 2 centimetres thick, aphanitic and darker than the pillow cores. The interpillow fill consists of aphanitic to fine-grained, black to dark green to reddish coloured rock of predominately chlorite and biotite. In mineralized zones, the pillow selvages and interpillow fill are locally silicified and suphide bearing.

Fragmental rocks crop out in several localities throughout the map area and are commonly recognizedin drill core. The rocks consist of subangular to tear-shaped, actinolite-rich mafic clasts, 5 to 30 centimetres long, separated by an anastomosing network of 0.2 to 1- centimetre, aphanitic and fine-grained quartz veins and granular volcanic rock. Individual clasts are flattened and vein networks have consistent trends over tens of metres, imparting a banded appearance to these outcrops. The origin of these rocks is enigmatic as they have a similar appearance, on a small scale, to the silicified pillowed sequences that locally grade into fragmental rocks across zones of more intense deformation.

Thin to thickly bedded saccharoidal chert and carbonate occur along the volcanic-sedimentary contact at the Hidden Creek mine. The chert varies in colour from bone-white to grey, reddish or pale green. Individual beds vary from less than a centimetre to several centimetres in thickness and are separated by sericitic laminae. In drill core, chert intervals vary in thickness from less than a metre to a maximum of about 30 metres. White, coarsely crystalline carbonate occurs as the matrix to the massive pyrrhotite and pyrite, and as discontinuous bands up to 1 centimetre thick where it forms up to 50% of the sulphide intervals. It is closely associated with chert and locally alternates with silica as the matrix to the massive sulphide lenses. Microfossils have not been identified in either the chert or carbonate horizons. The variable thickness of the units and close association with the sulphide lenses suggest that the chert, carbonate and sulphide may have a hydrothermal origin.

An unaltered siltstone-mudstone turbidite sequence forms the hangingwall of the deposit. These rocks consist of laminated to interbedded siltstone, argillite and fine sandstone. Individual beds range from less than a centimetre to tens of centimetres thick; they are commonly massive with thinly laminated tops and rarely display good grading. Flame and load structures mark the boundaries of beds, with crosslaminations preserved in finer layers. Small, discontinuous limestone lenses are common near the base of the sequence immediately overlying the metavolcanics. The lenses are less than a metre thick and occur as boudins within disrupted sedimentary layers.

ALTERATION FACIES

Hydrothermal alteration in the volcanic and sedimentary sequences is most intense and extensive in the vicinity of the Nos. 1 and 5 orebodies where it affects a zone up to 150 metres wide; it decreases in width and intensity laterally along the contact away from the ore zones. Alteration is divisible into three main types: chlorite-biotite-altered volcanic and sedimentary rocks; chlorite and actinolite-altered sedimentary rocks and sericite-biotite-altered sedimentary rocks (Figure 4). Petrography indicates that biotite and actinolite formed later in the paragenetic sequence than the sericite and chlorite assemblages and are probably a metamorphic overprint of hydrothermally altered rocks.

Alteration in the volcanic rocks is dominated by an assemblege of biotite, chlorite and epidote found as discrete veins, in altered selvages to siliceous veins, and as penetrative alteration of the entire hostrock. Alteration increases in intensity toward sulphide and quartz-vein stockwork zones, and stratigraphically up-section toward the sedimentary contact.

Hydrothermally altered and metamorphosed, variably siliceous clastic sedimentary rocks (MSC) overlie the volcanic sequence and form the footwall to the Nos. 1, 4 and 6 ore zones. The basal sedimentary package consists of intensely altered chlorite and biotite-rich rocks. These rocks are commonly associated with an increase in silica and locally grade into pink chert. Rocks at the volcanic-sedimentary contact are commonly so intensely chloritized and biotitized that lithologies can only be identified using lithogeochemical data.

The chlorite-biotite-altered volcanic and sedimentary rocks grade into overlying white to red, sericite biotite-rich clastic sediment (white MSC) and olive-green, chlorite-actinolite-rich clastic sediment (green MSC). These rocks are variably siliceous and range from silica-poor phyllosilicate schists to silica-rich inpure cherts. Transitions between silica-rich and silica-poor zones have a banded or fragmented appearance. Normal-graded bedding and porphyroblasts that are recognized in the green and the white MSC facies may be equivalent to structures in the hangingwall turbidite.

Green MSC stratigraphically overlies biotite-chlorite-altered volcanic rocks in several drillholes that intersect the footwall of the No. 1 ore zone. To the south and north of the No. 1 orebody, the chlorite-biotite sediments grade stratigraphically upward into white MSC which alternates in decimetre to decametre intervals with exhalative carbonate, chert and sulphides, and intervals of unaltered turbidites. Transitions between these intervals are gradational. Where observed, green MSC grades stratigraphically upward into white MSC and then to unaltered turbidite. The presence of chert, white MSC and green MSC in a drillhole along the southern margin of the No. 1 ore zone appears to reflect the lateral zoning from an exhalitive and sericite-dominated hydrothermal system in the vicinity of the silica pit to a chlorite-dominated system underlying the No. 1 ore zone.

LITHOGEOCHEMISTRY

Major and trace element data clearly distinguish between the volcanic, sedimentary and intrusive rocks underlying the Hidden Creek area and provide a chemical basis for characterizing the nature of hydrothermal alteration. Chemically, the least altered mafic volcanic footwall rocks are tholeiitic basalts to basaltic andesites in composition. Sedimentary rocks, including both clastic and exhalative components, are distinguished from the volcanic rocks by higher SiO_2 and lower TiO_2 contents.

Binary immobile element plots can be used to show primary fractionation trends within the volcanic rocks, as well as the effects of alteration on all the rocks. In the TiO_2 *versus* Zr plot (Figure 5a), least altered mafic volcanic rocks plot in two clusters that may be related through fractionation. Similarly, altered mafic volcanic rocks also appear to form two clusters, although the clusters are less distinct, presumably as a result of alteration. The immobile element plot clearly indicates that the sedimentary rocks are not derived from the mafic volcanic rocks, and the mafic dikes are not related to the mafic volcanic rocks. Sedimentary rocks including chert, green MSC, white MSC and turbidites lie along alteration lines emanating from the origin. Displacement of altered samples from their precursor trends reflects a combination of mass loss or gain, dilution by mixing with exhalative silica and carbonate, or high quartz contents in the precursor sediment.

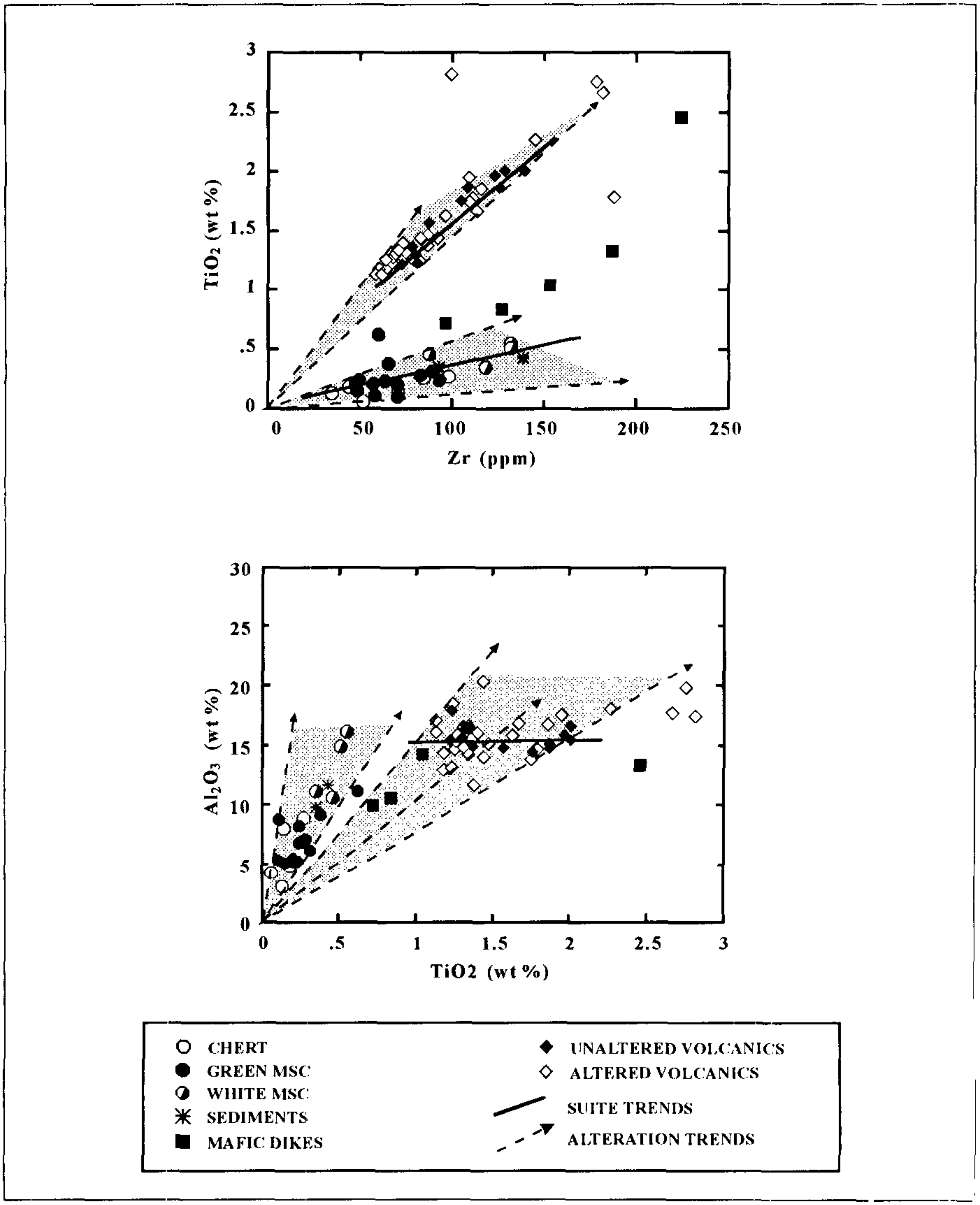

Figure 5. Plots of a) TiO_2 *verus* Al_2O_3 and b) Al_2O_3 *verus* TiO_2 for volcanic rocks, sedimentary rocks anc mafic dikes from the Hidden Creek area.

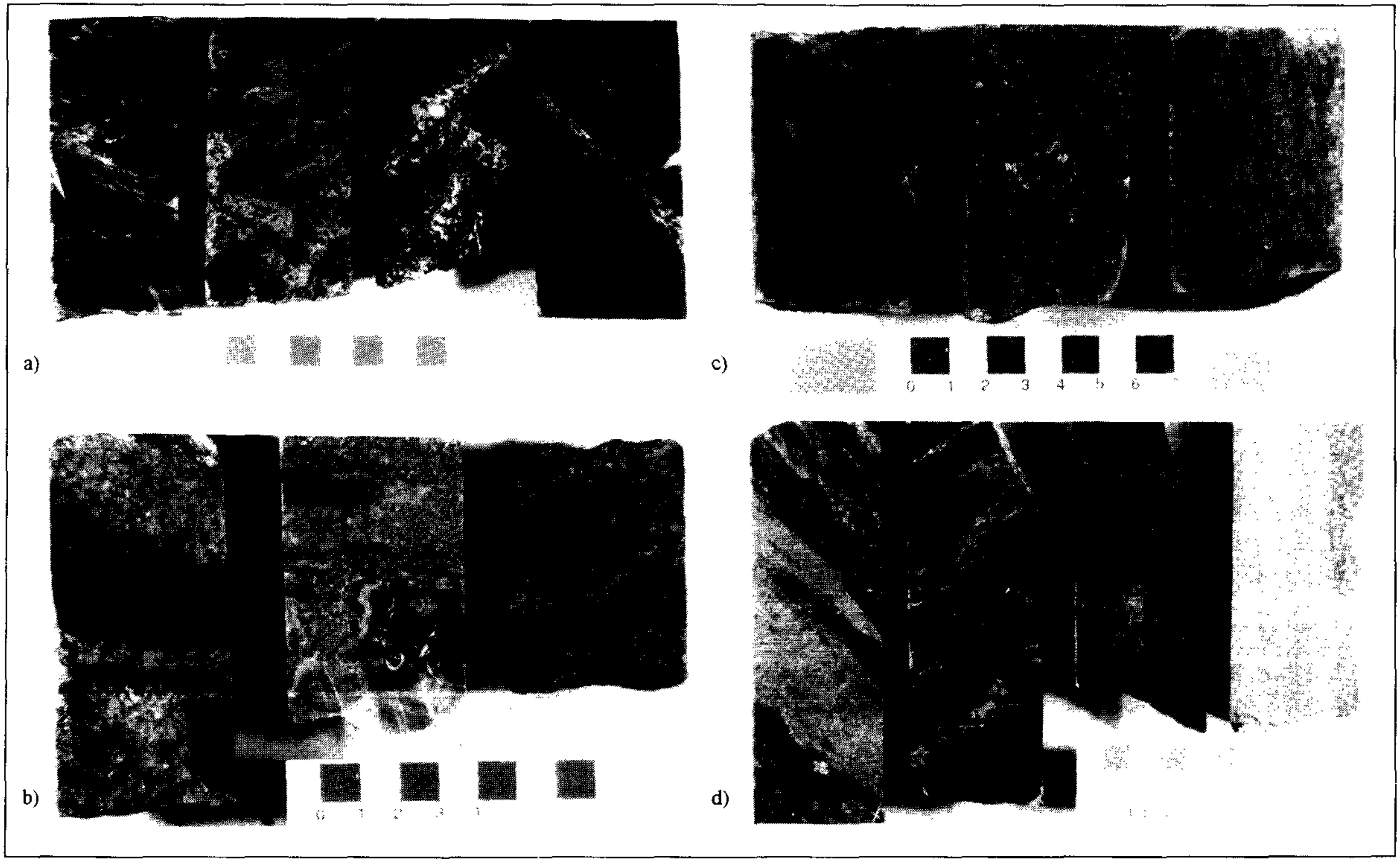

Photo 1. a) Quartz-sulphide veins with darkened chloritized selvages in volcanic rocks b) Carbonate-chlorite-silica-sulphide veins in the metaclastics; c) Pyrrhotite, pyrite and calcopyrite-rich massive sulphides in carbonate matrix; d) Mineralized layers in turbidites

A plot of Al_2O_3 *versus* TiO_2 (Figure 5b) makes a clearer distinction between fractionation processes and alteration processes than the TiO_2 *versus* Zr plot. In Figure 5b, fractionation trends in the volcanic rocks run obliquely to potential alteration trends. As in the previous graph, unaltered volcanic samples plot in two clusters and lie along a potential fractionation trend. Altered volcanic rocks are dispersed around the trend, along alteration lines emanating from the origin for reasons outlined above. The dispersed pattern in the sedimentary rocks appears to represent some combination of primary clastic source variations, and alteration-related mass gains or losses.

Previous authors have never clearly identified the origin or extent of the green MSC unit but have tended to simply associate it with silicified volcanic or volcaniclastic rocks within the contact alteration zone. The green MSC unit has a clastic sedimentary affinity and major and trace element ratios comparable to those in unaltered turbiditic sediments. The green MSC may therefore represent a chlorite-actinolite-altered equivalent to the turbidites, with little or no silicification involved in the alteration. Green MSC rocks are found in drillholes intersecting the footwall of the No. 1 orebody, which indicates that this orebody, the largest in the Hidden Creek mine, is entirely sediment hosted and does not occur at the contact between the volcanic and sedimentary rocks.

MINERALIZATION AND SULPHIDE MORPHOLOGY

Quartz-pyrite-pyrrhotite-chalcopyrite veins occurring in chert, MSC and metavolcanic units stratigraphically below the sulphide lenses probably represent footwall stockwork mineralization. These veins range from less than 0.2 to several centimetres wide and commonly contain quartz. Within intensely chloritzed volcanic rocks, sulphides form feathery textured, braided networks, whereas in siliceous clastic rocks and cherts, sulphides occur as discrete veins with well defined chlorite and biotite-altered selvages (Photos 1 a and b).

Thick intervals of chemical sediments and sulphides occur in several diamond-drill holes and are also exposed in the No. 1, Nos. 2/3 and No. 6 pits. These appear to be lateral equivalents of the mined-out ore zones which Grove (1986) has described as tabular to sheet-like and consisting mainly of pyrite, pyrrhotite and chalcopyrite, with minor sphalerite, galena and magnetite (Photo 1 c). There is a strong association between chalcopyrite and pyrrhotite in the sulphide lenses and underlying vein networks. Pyrite-dominated lenses are copper poor. Semimassive to massive pyrite with minor sphalerite and galena in a matrix of silica and carbonate dominates the stratigraphically lower intervals, in the ore zones. Pyrrhotite, chalcopyrite and pyrite with minor sphalerite occur in stratigraphically higher intervals and form more discrete and massive layers in a carbonate-dominated matrix. In diamond-drill hole 93 D-9, the transition between the two types of massive sulphide interval is characterized by large euhedral pyrite crystals within a finer grained pyrrhotite-chalcopyrite matrix. In the No. 6 pit, the two sulphide intervals are seperated by 1.5 metres of argillite. In the No. 1 pit, a thick pyrite lens occurs within altered turbidite and chemical sediments. It may stratigraphically underlie a pyrrhotite-chalcopyrite-pyrite interval that was intersected in diamond-drill hole 93 D-2, although the transition between the two is not observed.

The clastic and exhalative sequences contain ubiquitous fine to medium-grained disseminated pyrite, pyrrhotite and lesser chalcopyrite. Sulphides also occur in coarse sandstone layers as discrete, bedding-parallel siliceous layers, typically less than 2 centimetres thick, and in more diffuse layers that coalesce into thick semimassive bands (Photo 1 d). Gangue minerals associated with the sulphide bands most commonly include silica, carbonate and sericite, except in the sedimentary footwall of the No. 1 ore zone where carbonate, chlorite and epidote comprise the most common assemblage.

Chloritized turbidites underlie the largest orebodies. Sericitized clastic sediments with associated exhalites flank and cap the chlorite zone and host much of the mineralization (Figure 4). Soft-sediment deformation is observed in association with coarse disseminated sulphides. Together with the lithogeochemical data, this suggests that mineral deposition was at least partly contemporaneous with early turbidite-mudstone deposition; some of the sulphide lenses were formed after mafic volcanism had ceased, but at the same time as the associated chert and carbonate exhalites.

SUMMARY

A preliminary interpretation of the geological history of the Hidden Creek mine area is: 1) Accumulation of a thick mafic volcanic sequence composed of basaltic to basaltic andesite flows, pillowed flows and lesser fragmental components.

2) Deposition of a basal turbidite siltstone-mudstone sequence (the turbidites are not related to the mafic volcanics).
3) Precipitation of exhalative chert, carbonate and sulphides contemporaneous with sediment deposition.
4) Contemporaneous hydrothermal fluid circulation resulting in the development of stockwork mineralization and intense sericite and chlorite alteration in the volcanic, clastic and exhalative sedimentary rocks underlying the ore zones.
5) Continued accumulation of a thick turbiditic siltstone-mudstone sequence on the cessation of hydrothermal activity;
6) Deformation and regional metamorphism resulting in biotite-actinolite alteration assemblages.
7) Intrusion of calcalkaline mafic dikes.

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U-Pb GEOCHRONOLOGY OF THE MOUNT STAPLER QUARTZ MONZONITE: EVIDENCE FOR EARLY JURASSIC MAGMATISM IN THE TULSEQUAH GLACIER AREA, NORTHWEST BRITISH COLUMBIA (104K/13)

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(M.D.R.U. Contribution P-058; Contribution to the Canada - British Columbia Mineral Development Agreement 1991-1995)

KEYWORDS: geochronology, Early Jurassic, Tulsequah Glacier, Mount Stapler suite, monzonite, age, Stikine assemblage

INTRODUCTION

The Tulsequah Glacier area is within the rugged Coast Mountains of northwestern British Columbia (Figure 1) at the westernmost edge of northern Stikine Terrane. Fieldwork in 1993 consisted of property-scale sampling and relogging of core from the Tulsequah Chief and Big Bull volcanogenic massive sulphide deposits by F.C. (Sherlock *et al.*, 1994) and 1:50 000-scale mapping of NTS map sheets 104K/12 and 13 by M.M. (Mihalynuk *et al.*, 1994a, b). Mapping on Mount Stapler revealed a tabular quartz monzonite stock with associated dissected dikes and (?)apophyses. The intrusive body dated in this study is truncated by splays of the Llewellyn fault, a long-lived crustal-scale north-northwest-trending fault with both sinistral and dextral motion.

GEOLOGICAL SETTING

Four tectonic elements constitute the gross geology between the Tulsequah Glacier area and the Yukon border. Two basement elements have been recognized: a regionally metamorphosed suite (here included with the Yukon-Tanana Terrane, *sensu* Mortensen, 1992) to the west, and late Paleozoic arc strata of the Stikine assemblage (Monger, 1977) to the east. They are overlapped by a succession of Jurassic and perhaps Upper Triassic rocks of mainly arc-derived marine sediment. All are cut by the Llewellyn fault. In northwestern British Columbia, these geologic elements have been mapped for 180 kilometres within the eastern Coast Ranges (Mihalynuk and Rouse, 1988b; Doherty and Hart, 1988; Mihalynuk *et al.*, 1989, 1990, 1994b, 1995, this volume; Currie, 1990). To the north, in southern Yukon Territory, the Llewellyn fault has been interpreted to converge with the Tally-Ho shear zone (Doherty and Hart, 1988).

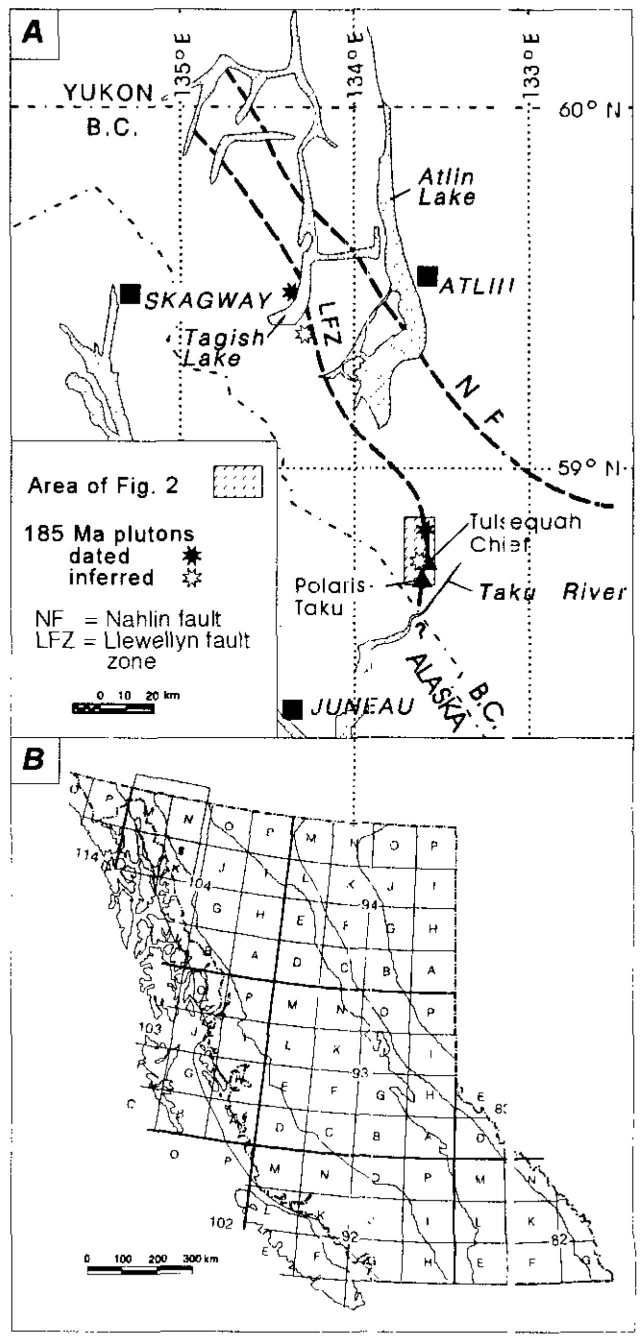

Figure 1. General location of the study area with respect to (a) geographic and cultural features and (b) the National Topographic System.

Original mapping in the Tulsequah area by Souther (1971) correlated most of the unmetamorphosed volcanic arc rocks with the Upper Triassic Stuhini Group. Recent biochronology (Nelson and Payne, 1984; Mihalynuk *et al.*, 1994b, 1995) and U-Pb geochronology (Sherlock *et al.*, 1994) have shown these rocks to be at least Early Permian to early Mississippian in age.

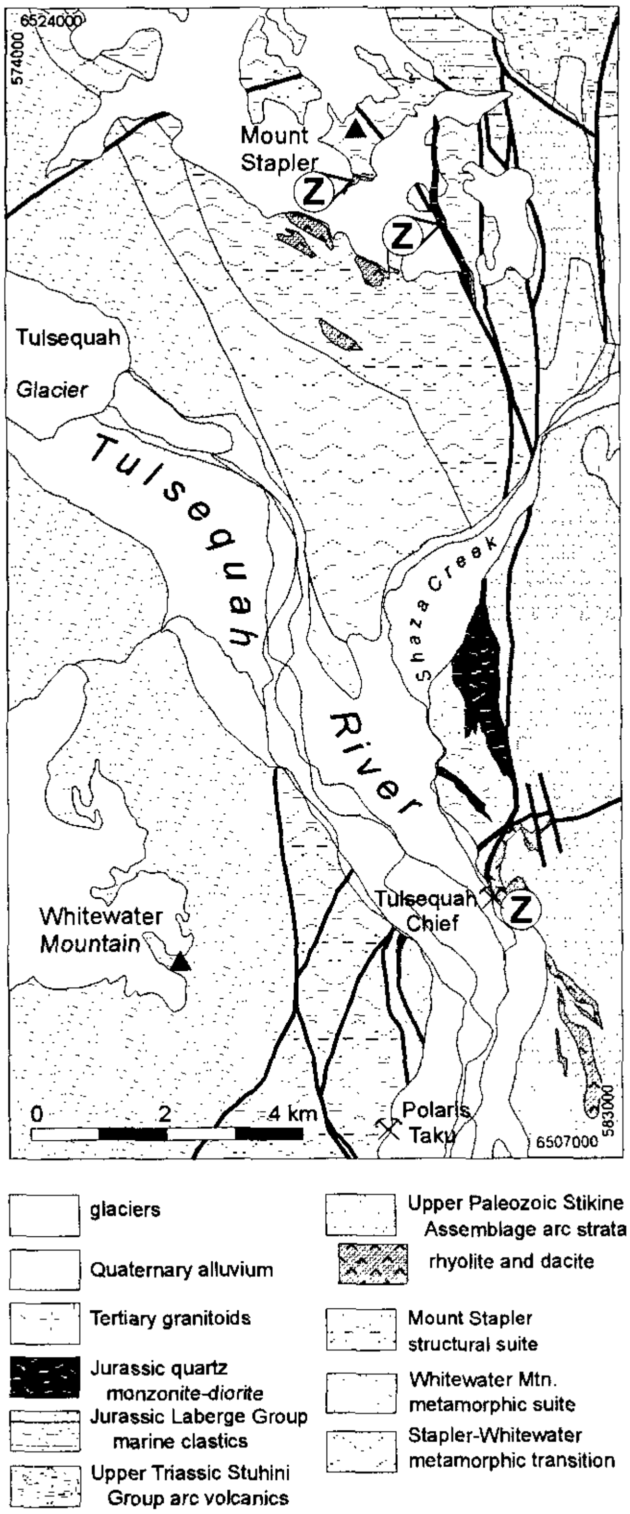

Figure 2. Distribution of metamorphic and structural suites, and Early Jurassic intrusive rocks near Tulsequah (simplified from Mihalynuk *et al.*, 1994b). 'Z' indicates sites of U-Pb zircon age date samples discussed.

Regionally metamorphosed rocks form a narrow (5 to 50 km), southward-broadening belt. For most of its northern length the metamorphic belt is composed of deformed volcanic rocks of arc derivation. These have been metamorphosed to transitional greenschist-amphibolite grade and are known as the Boundary Ranges Metamorphic Suite (Mihalynuk and Rouse, 1988a). Currie (1992) suggested that the Boundary Ranges suite is partially coeval with the Stikine assemblage; a contention which is supported by the data presented here.

Metamorphic grade in the belt culminates near the south end of Atlin Lake where sillimanite overprints kyanite. Protoliths there are thick carbonates, semipelites and quartzites of probable continental margin derivation. This package is known as the Florence Ranges Metamorphic Suite (Currie, 1990). Between Atlin Lake and the Tulsequah River area, several abrupt changes in structural style and/or protolith are recognized as separate metamorphic or structural suites. These include the Whitewater Metamorphic Suite that consists of quartz-rich graphitic schist, lesser metabasite and quartzite, and sparse carbonate and ultramafic rocks, and the Mount Stapler structural suite that consists of volcanic arc derived strata with relict protolith textures (Mihalynuk *et al.*, 1994a, b). The Mount Stapler suite is divided into upper and lower divisions, dominated by volcanic and sedimentary rocks, respectively. Rocks of the volcanic-dominated succession include pyroxene-phyric basaltic breccia and tuff (Photo 1), rhyolite tuff (Photo 2), tuffaceous sediment, and carbonate (Photo 3). Rocks of the lower division are primarily clastic sediments that change, structurally down-section, with decreasing tuffaceous component and increasing quartz content. At lowest structural levels, isoclinally refolded graphitic quartz siltstone gives way to graphitic schist of the Whitewater suite. The contact is interpreted to have originally been stratigraphic.

MOUNT STAPLER QUARTZ MONZONITE

The Mount Stapler suite is cut by one or more irregular, dissected intrusions of pink quartz monzonite cut by the Llewellyn fault (Figure 2). Quartz monzonitic rocks are most common near the contact between basaltic breccia dominated strata and siltstone-limestone dominated strata, and clearly intrude both.

The intrusion ranges in composition from leucogabbro to quartz monzonite. Foliation is variably developed; moderately strong foliation is typical but original igneous fabrics are locally preserved. The original texture is sparsely potassium feldspar porphyritic (<5%, up to 2 cm, pink) in a hypidomorphic matrix of plagioclase, quartz, altered hornblende and biotite. The monzonite is cut by aplite and pegmatitic dikelets that, in turn, are cut by minor brittle faults with apparent dextral

Photo 1a. Deformed basaltic tuff of the Mount Stapler suite. Note preservation of original breccia fragments, now flattened in the foliation. (1b) More intensely deformed, finer grained and less competent mafic ash tuff.

Photo 2. Deformed early Mississippian rhyolite of the Mount Stapler suite. Wavy white streaks are flattened and deformed lapilli.

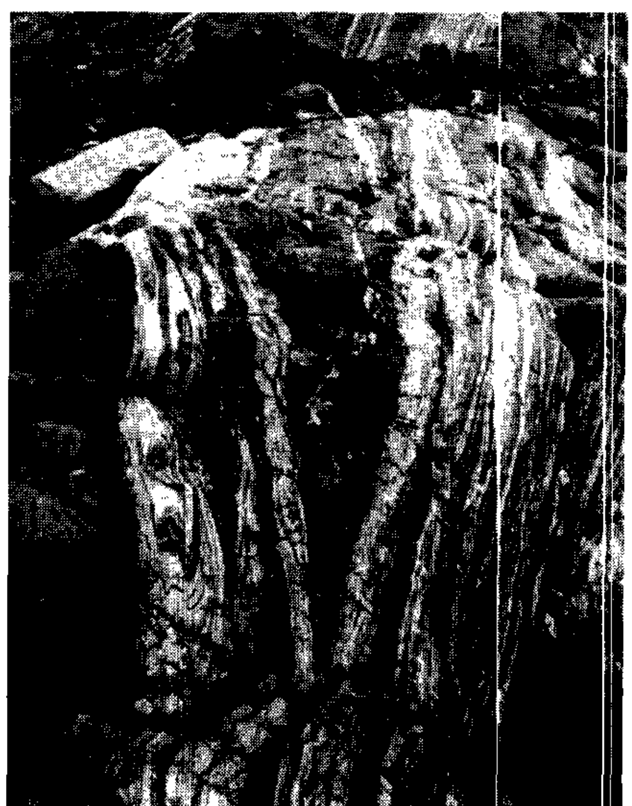

Photo 3. Intensely folded, foliated, rusty carbonate of the Mount Stapler suite.

offset (Photo 4). No clear indication of shear sense is apparent within the ductile fabric; however, rotation of monzonite blocks is consistent with an overall sinistral shear sense (Photo 5). In places, brittle shears offset and isolate segments of monzonite dike (Photo 6).

GEOCHRONOLOGY

A sample was collected for U-Pb geochronology from the largest pink quartz monzonite body, a tabular stock 1.75 kilometres southeast of Mount Stapler (Figure 2). An effort was made to select the freshest, coarsest and most quartz-rich portion of the body. Approximately 40 kilograms, devoid of crosscutting dikelets, was collected. The results are presented below.

ANALYTICAL TECHNIQUES

The sample was processed and zircon was separated using conventional crushing, grinding, Wilfley table and heavy liquid techniques. All fractions were air abraded prior to analysis, to reduce the effects of surface-correlated lead loss (Krogh, 1982).

Photo 5. An apophysis of light-weathering pink quartz monzonite intrudes coarse basaltic tuff. It has been subjected to cataclasis, but the original eastern (left) contact is preserved (striking 170°, view to the north). Discrete shears offset the eastern contact in a consistently dextral sense, but do not offset the western contact, which is a ductile shear zone within chlorite schist. Counterclockwise rotation of the blocks is consistent with an overall sinistral shear sense.

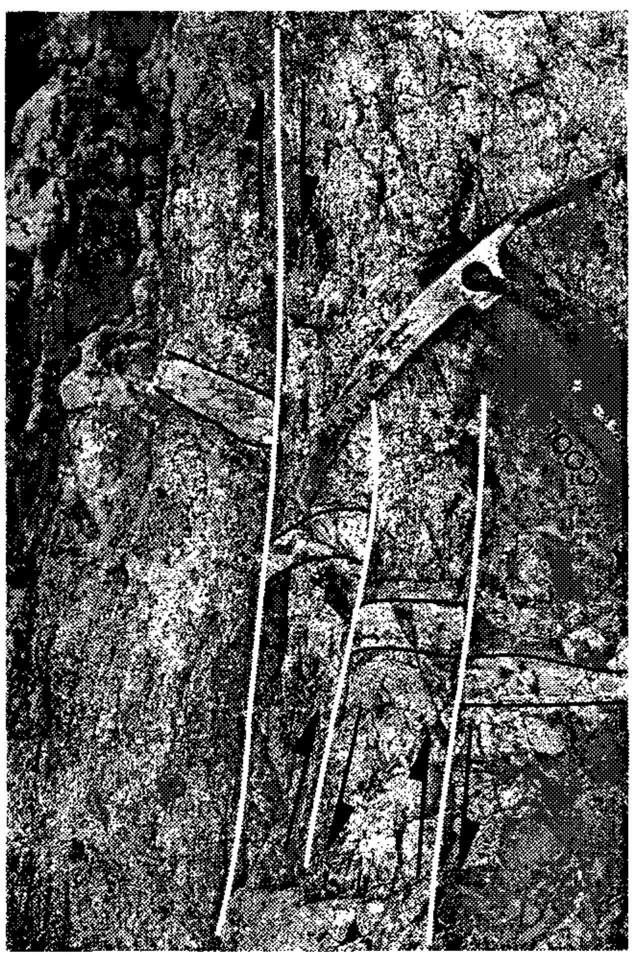

Photo 4. Pink quartz monzonite displays a weak to moderately developed foliation that is cut by late-phase(?) aplite and pegmatitic dikes. Dikes are cut by brittle faults with apparent dextral offset.

Photo 6. A light-weathering quartz monzonite dike near the Llewellyn fault zone is dissected by late brittle shears. In this photo, structurally isolated blocks float in matrix of chlorite schist with relict basaltic breccia fragments.

Sample preparation and U-Pb analyses were carried out at the Geochronology Laboratory of the University of British Columbia. Zircon grains were selected based on criteria such as magnetic susceptibility, clarity, morphology and size. Procedures for dissolution of zircon and extraction and purification of uranium and lead follow those of Parrish *et al.* (1987). Uranium and lead were loaded onto single, degassed refined rhenium filaments using the silica gel and phosphoric acid emitter technique. Procedural blanks were 9 and 6 picograms for lead and uranium, respectively. Errors assigned to individual analyses were calculated using the numerical error propagation method of Roddick (1987) and all errors are quoted at the 2σ level. Ages were calculated using the decay constants recommended by Steiger and Jäger (1977). Common lead corrections were made using the two-stage growth model of Stacey and Kramers (1975). Discordia lines were regressed using a modified York-II model (York, 1969; Parrish *et al.*, 1987). Uranium-lead analytical results are presented in Table 1.

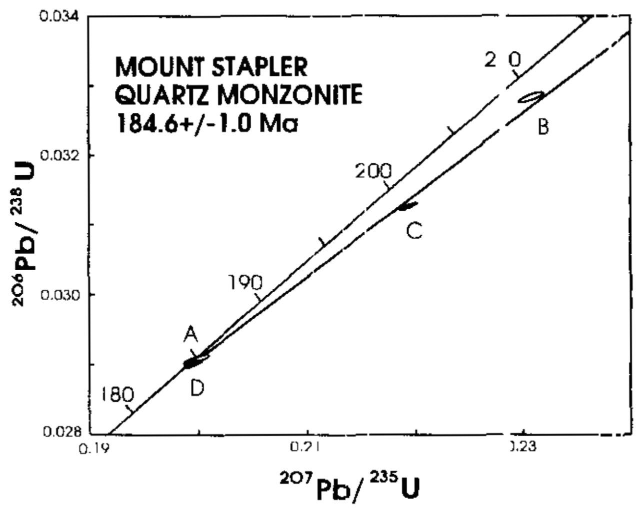

Figure 3. $^{206}Pb/^{238}U$ versus $^{207}Pb/^{238}U$ concordia diagram for the Mount Stapler quartz monzonite.

ANALYTICAL RESULTS

Zircons from this rock were high-quality prisms, with a length:width ratio of ~3:1. The grains had good clarity and contained minor colourless rod and bubble-shaped inclusions. Minimal material was found in the nonmagnetic separate therefore all fractions were picked from the 2°M separate. Initially three multi-grain fractions (A to C) of euhedral prisms, none with visible cores, were picked and separated on the basis of size. These three fractions yield $^{207}Pb/^{206}Pb$ ages which range from 185.2±10.4 to 240.2±7.8 Ma, for one concordant and two discordant analyses (Figure 3; Table 1). These results indicate an Early Jurassic crystallization age and the presence of an older, inherited zircon component, either as "cryptic" cores or xenocrysts. To confirm the age of the concordant fraction A, a fourth fraction was analyzed. Fraction D consisted of a single grain, broken in half and abraded to physically remove material which may have been present as an inherited component in the core of the grain. Fraction D is also concordant and is in good agreement with fraction A. Regression of the four fractions yields a loosely constrained lower Paleozoic upper intercept of 482 $^{+161}/_{-145}$ Ma. This is consistent with the region being underlain by the Paleozoic Stikine assemblage. The best estimate of the age of crystallization of the quartz monzonite is given by the overlapping $^{206}Pb/^{238}U$ ages of fractions A and D, at 184.6 ±1.0 Ma.

CORRELATION AND IMPLICATIONS

Pink quartz monzonite within the Mount Stapler suite shares many lithological characteristics with coeval pink quartz monzonite of the Long Lakes Plutonic Suite in the Yukon (*sensu* Hart, 1994; Mortensen e al., 1994). In southwest Yukon, these upper crustal level plutons intrude strongly foliated mid-crustal level quartz diorite bodies of the Aishihik Plutonic Suite (Hart, 1994; Johnston and Erdmer, in press), but both yield

TABLE 1. U-Pb ZIRCON ANALYTICAL DATA MOUNT STAPLER QUARTZ MONZONITE

Fraction[1]	Wt.	U	Pb[2]	$^{206}Pb^{3}$	Pb[4]	$^{208}Pb^{5}$	Isotopic ratios(±1σ,%)[6]			Isotopic dates(Ma, 2σ)[6]		
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
A,m,M2,p(13)	0.072	241	7.2	1005	31	8.1	0.02909±0.11	0.1997±0.31	0.04979±0.23	184.8±0.4	184.8±1.0	185.2±10.4
B,f,M2,p(20)	0.072	263	8.7	1881	20	8.9	0.03284±0.12	0.2309±0.25	0.05099±0.17	208.3±0.5	210.9±0.9	240.2±7.8
C,f,M2,p(100)	0.144	508	15.8	4145	34	8.4	0.03126±0.10	0.2193±0.20	0.05088±0.11	198.5±0.4	201.3±0.7	235.3±5.1
D,c,M2,p(1)	0.012	2685	71.4	3562	16	8.6	0.02902±0.11	0.1993±0.23	0.04981±0.14	184.4±0.4	184.5±0.8	186.1±6.6

[1]All fractions are air abraded. Grain size, smallest dimension: c = +134μm, m = -134 μm + 74 μm, f = -74 μm;
Magnetic codes: Franz magnetic separator sideslope at which grains are magnetic; e.g., M2=magnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: p=prismatic; number in brackets refers to number of grains in analysis.
[2]Radiogenic Pb
[3]Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ±20% (Daly collector)
[4]Total common Pb in analysis based on blank isotopic composition
[5]Radiogenic Pb
[6]Corrected for blank Pb, U and common Pb (Stacey-Kramers model Pb composition at the $^{207}Pb/^{206}Pb$ date of fraction, or age of sample)

crystallization ages that are the same within error. Near the south end of Tagish Lake, hornblende granodiorite orthogneiss is interleaved with metamorphosed volcanic arc rocks of the Boundary Ranges suite (Mihalynuk *et al.*, 1990; Currie, 1990). This unit yielded a U-Pb age of 185±1 Ma (Currie, 1992), similar to the lithologically identical Aishihik batholith (187 $^{+9.7}/_{-1.0}$ Ma; Johnston, 1993).

Plutons of identical age and similar composition are also present within the Stikine Terrane to the south, in the Iskut River area. These include 186±1 Ma plagioclase porphyry in the Brucejack Lake area (Davies *et al.*, 1994) and the 185±5 Ma Eskay porphyry (Macdonald *et al.*, 1992).

The Mount Stapler suite is interpreted to be metamorphosed Stikine assemblage. This correlation is supported by similarities between the Stikine assemblage and Mount Stapler lithologies (where relict protolith textures are preserved) and the proportion of similar lithologies within Stikine assemblage in the Tulsequah area. The correlation is further supported by a preliminary early Mississippian U-Pb age from a metarhyolite from Mount Stapler (F. Childe, preliminary data, not presented in this paper). Zircons from this unit have similar morphology and degree of inheritance to zircon from the early Mississippian Stikine assemblage rhyolite that hosts massive sulphide mineralization at the Tulsequah Chief mine (Sherlock *et al.*, 1994).

DISCUSSION

The Early Jurassic U-Pb age of 184.6±1.0 Ma from pink quartz monzonite intruding the Mount Stapler suite is significant as it strengthens correlations between upper units of the northern Stikine Terrane with those in the Yukon-Tanana Terrane to the north. If correlations between the Mount Stapler structural suite and the Stikine assemblage are correct, then many of the metavolcanic rocks to the north may be prospective for volcanogenic massive sulphide accumulations, similar to those at the Tulsequah Chief deposit.

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NOTES

GEOLOGY OF THE TULSEQUAH CHIEF VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT, NORTHWESTERN BRITISH COLUMBIA (104K/12)

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(MDRU contribution 062)

KEYWORDS: Economic geology, Tulsequah Chief, stratigraphy, alteration, massive sulphides.

INTRODUCTION

The Tulsequah Chief massive sulphide deposit is located along the east bank of the Tulsequah River, 100 kilometres south of Atlin, British Columbia and 70 kilometres northeast of Juneau, Alaska (Figure 1, inset). The Tulsequah Chief mine produced 622 136 tonnes of ore between 1954 and 1957. Exploration was resumed in the Tulsequah area in 1987 by Cominco Ltd. and Redfern Resources Ltd. In 1992 Redfern Resources purchased Cominco's interest in the mine. At the end of 1994 reserves for all ore intervals and classes were 8 500 000 tonnes at 1.41% copper, 1.23% lead, 6.65% zinc, 2.52 g/t gold and 105.66 g/t silver.

Fieldwork in the summer of 1994 consisted of detailed logging of drill core and underground mapping of the 5400 level main haulage. The main objective of this work was to further define the mine stratigraphy and the distribution of mineralization and alteration facies. Particular attention was given to the depositional style and character of the sulphides, the felsic volcanic host rocks and the mafic footwall of the deposit.

REGIONAL GEOLOGY

A brief overview of regional geology follows, summarized from Mihalynuk *et al.* (1994).

The Tulsequah Chief deposit is hosted within an arc-related bimodal mafic-felsic volcanic suite of latest Devonian to earliest Mississippian age (Sherlock *et al.*, 1994) in the Stikine Terrane. The host volcanics comprise the Mount Eaton structural block which has been divided into lower, middle and upper divisions (Mihalynuk *et al.*, 1994).

The lower division is dominated by felsic tuffs and includes lesser volumes of felsic feldspar and quartz-phyric flows, brecciated flows and volcaniclastics. The latter two lithologies are the main ore host at Tulsequah Chief (Figure 1). The felsic flows and volcaniclastics overlie chlorite-quartz-amygdaloidal basaltic andesite breccias in the mine area. A U-Pb date of 353.4+15.8-0.9 Ma (Late Devonian to early Mississippian) was obtained from zircons contained in the felsic rocks in the mine area (Sherlock *et al.*, 1994).

Middle division rocks are represented by green pyroxene and locally feldspar-phyric breccias and agglomerates. Lesser amounts of basalt flows, mafic ash tuff, pyroxene-feldspar crystal tuff, tuffite and turbidites are also present.

The upper division rocks are sediment dominated and consist of polymictic volcanic conglomerate at the base succeeded by coarse-grained limestone and volcanic-rich debris flows, lapilli ash tuffs, volcanogenic turbidites, basalt breccias, and notably, an upper sequence of bioclastic rudites, micrites and calcareous turbidites. A middle Pennsylvanian age has been assigned to the fossil debris in this upper unit (Nelson and Payne, 1984).

MINE SEQUENCE STRATIGRAPHY

The mine stratigraphy at the Tulsequah Chief deposit comprises a northward-younging, folded succession of mafic and felsic volcanic rocks (Figure 2). The stratigraphically lowest unit (unit 1) is composed of mafic volcanics of basaltic andesite composition (Sherlock *et al.*, 1994). This unit is directly overlain by a

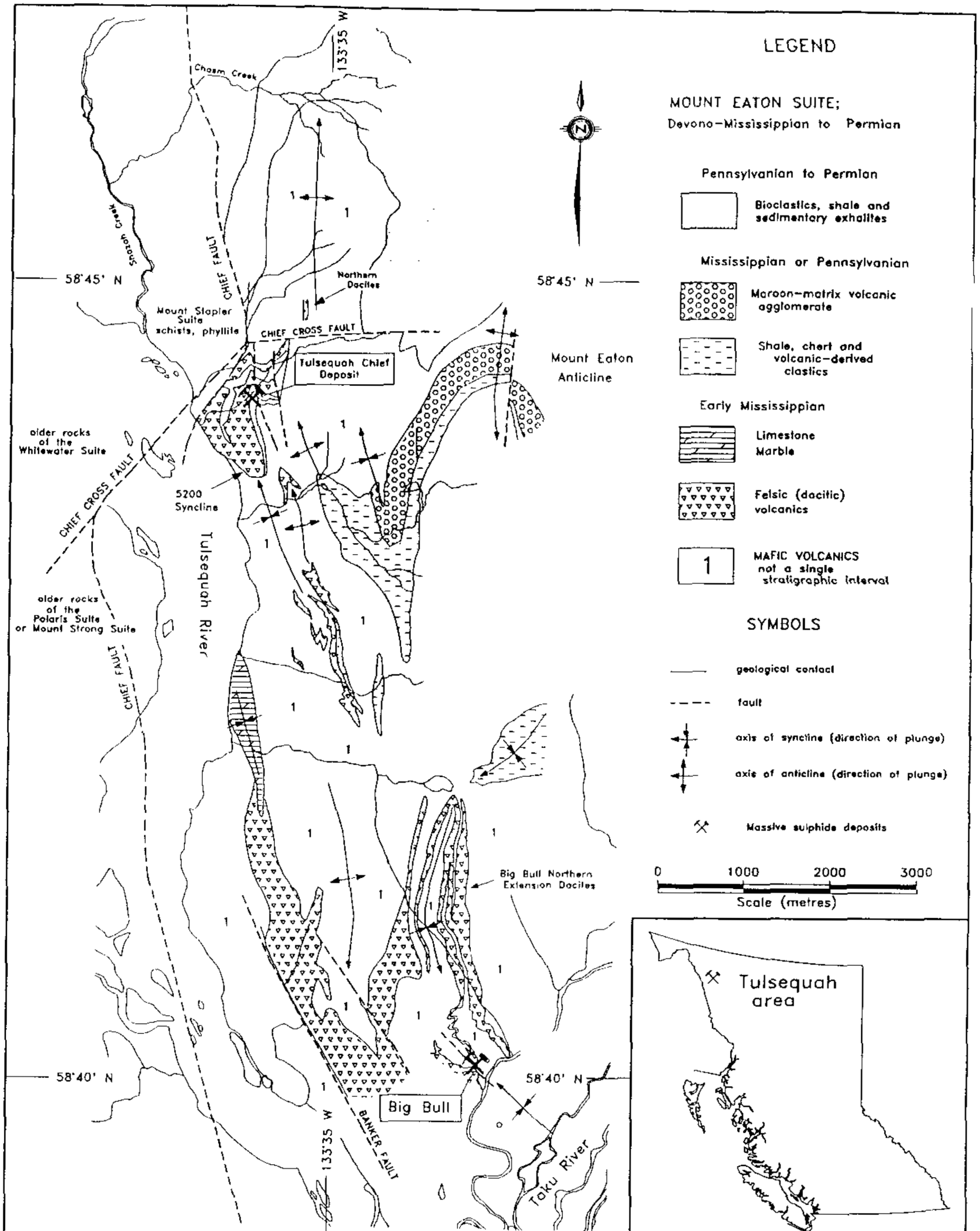

Figure 1. Simplified geology of the Tulsequah area, modified from Mihalynuk *et al.* (1994) and Nelson and Payne (1984).

series of felsic volcanics and reworked felsic-rich volcaniclastic debris (unit 2). The felsic sequence is intruded by a large gabbro sill (unit 4). A sequence of basaltic flows, sills and mafic-rich volcaniclastic sediments (unit 3) caps the felsic volcanics (Sherlock *et al.*, 1994). This second mafic sequence may represent the lowermost part of the middle division of the Mount Eaton block. All of these units are cut by felsic Sloko dikes of Tertiary age which tend to parallel or occupy major fault zones running north or northeast. Holes TCU92-36 and TCU92-37 (Figure 3 and 4) provide representative examples of the mine stratigraphy.

Unit 1

Unit 1 forms the stratigraphic footwall to the massive sulphide deposits and comprises mainly massive to vesicular brecciated mafic volcanics of basaltic andesite composition. Minor intervals of fine-grained mafic sandstones are also present. The flows at the top of this unit are commonly strongly amygdaloidal and the amygdules are typically filled by quartz and pyrite. Locally the unit is composed of angular to subrounded, strongly vesicular, scoria-like fragments hosted in an angular clast-rich (possibly hyaloclastic) matrix with plagioclase feldspar. The vesicular fragments range from 0.5 to 30 centimetres across and locally contain zoned quartz-filled vesicles. The sandstones display normal grading in some laminations which fine upwards from feldspar crystal rich bases.

Unit 2

Unit 2 comprises the felsic package. Lithogeochemical results indicate that these rocks vary from dacitic to rhyolitic composition (Carmichael *et al.*, 1995, this volume). The upper portion, between the 4400E and 5300E faults, is composed of a sequence of flow breccias and massive to banded flows ranging from 3 to 15 metres thick. Individual units may be separated by unhealed quench brecciated to autoclastic fragmentals. The top of the felsic sequence is locally capped by a layer of granular to blocky, partially reworked quench brecciated debris up to 15 metres thick. The lower part of the sequence in the main mine block tends to have thinner layers of flows and flow breccias 1 to 6 metres thick, and a slightly higher proportion of unhealed autoclastics to partially reworked felsic-rich volcaniclastic debris.

Porphyritic textures are common in the flows and flow breccias, which typically host a combined volume of about 5 to 8% subhedral to euhedral feldspar and subordinate quartz crystals, 1 to 3 millimetres in diameter. Two groups of porphyritic felsic units are recognized by the presence or absence of visible quartz phenocrysts. Quartz grains are most prevalent in the upper part of the pile. This contrasts with flows and flow breccias at the base of the sequence, beneath the main sulphide lenses, that are purely feldspar porphyritic.

The feldspar quartz porphyries in the upper part of the felsic sequence are typically massive with local fracturing. Only rare examples of well developed flow banding were observed. Some of these units may be shallow sills that have intruded into a brecciated pile (Sherlock *et al.*, 1994).

The healed flow breccias are typically weakly banded and feature porphyritic to bleached-aphanitic, rounded to subangular blocks in a relatively darker, chlorite-altered, feldspar-quartz-porphyritic matrix. Banded sheared autoclastites, jigsaw-textured quench breccias and other flow-derived fragmentals also occur as intercalations throughout the sequence

The volcaniclastic debris contains rounded to angular dacite blocks (up to 30 cm across) with pumice, lithic, chert and barite fragments. It varies from chaotic unstratified mass-flow units to well sorted, graded volcaniclastic sandstones. The preservation of angular pumice fragments in some portions suggests that the volcaniclastic material has not been highly reworked. The debris also locally includes rounded vesicular fragments of altered mafic footwall (unit 1), up to 5 centimetres in diameter.

The upper part of the felsic package, east of the 5300E fault, contains a greater proportion of volcaniclastic material, mainly dacite-rich mass flows with pumice, lithic, chert and barite fragments. These felsic rocks are host to the I zone sulphide lens, which was the main focus of early mining activity. Similar dacite-rich mass flows are dominant to the west of the 4400 E fault in the western limb of the F anticline. Hole TC93-09 (Figure 5) intersected a part of the stratigraphy in this area.

Unit 3

The upper mafic sequence consists primarily of massive basalt flows and equivalent sills, with intercalated sediments including: variably muddy basaltic siltstones (possibly reworked ash tuffs), basaltic lapillistones, and feldspar and mafic crystal-rich tuffaceous sandstones. A few chlorite and quartz-filled vesicles occur in the flows and sills. Normally graded beds with feldspar crystal rich bottoms and flame structures were noted in some of the siltstones. This unit is typically unaltered and lies above all known mineralization. A series of mudstones, vitric (pumiceous) lapilli tuffs, and felsic ash layers occurs at the base of the sequence and marks the transition to the felsic volcanics (unit 2) below.

Unit 4

A massive mafic sill, up to about 100 metres thick, intrudes and dilates the felsic package. The margins of the sill are chilled and locally host intercalations of dacitic material at both the upper and lower contacts. The primary mineralogy of the sill comprises augite, plagioclase and sparse, altered olivine phenocrysts in a

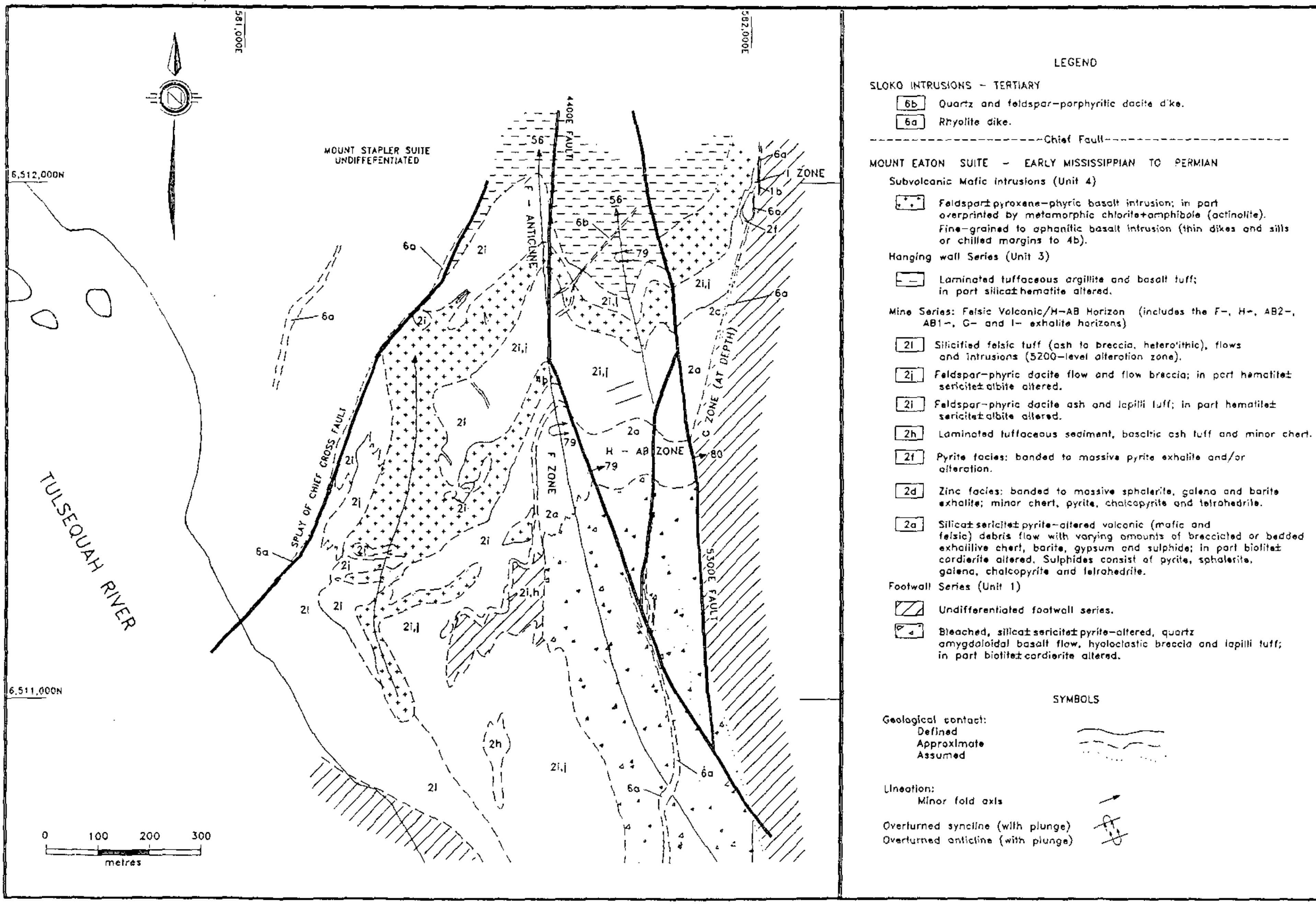

Figure 2: Tulsequah Chief surface geology.

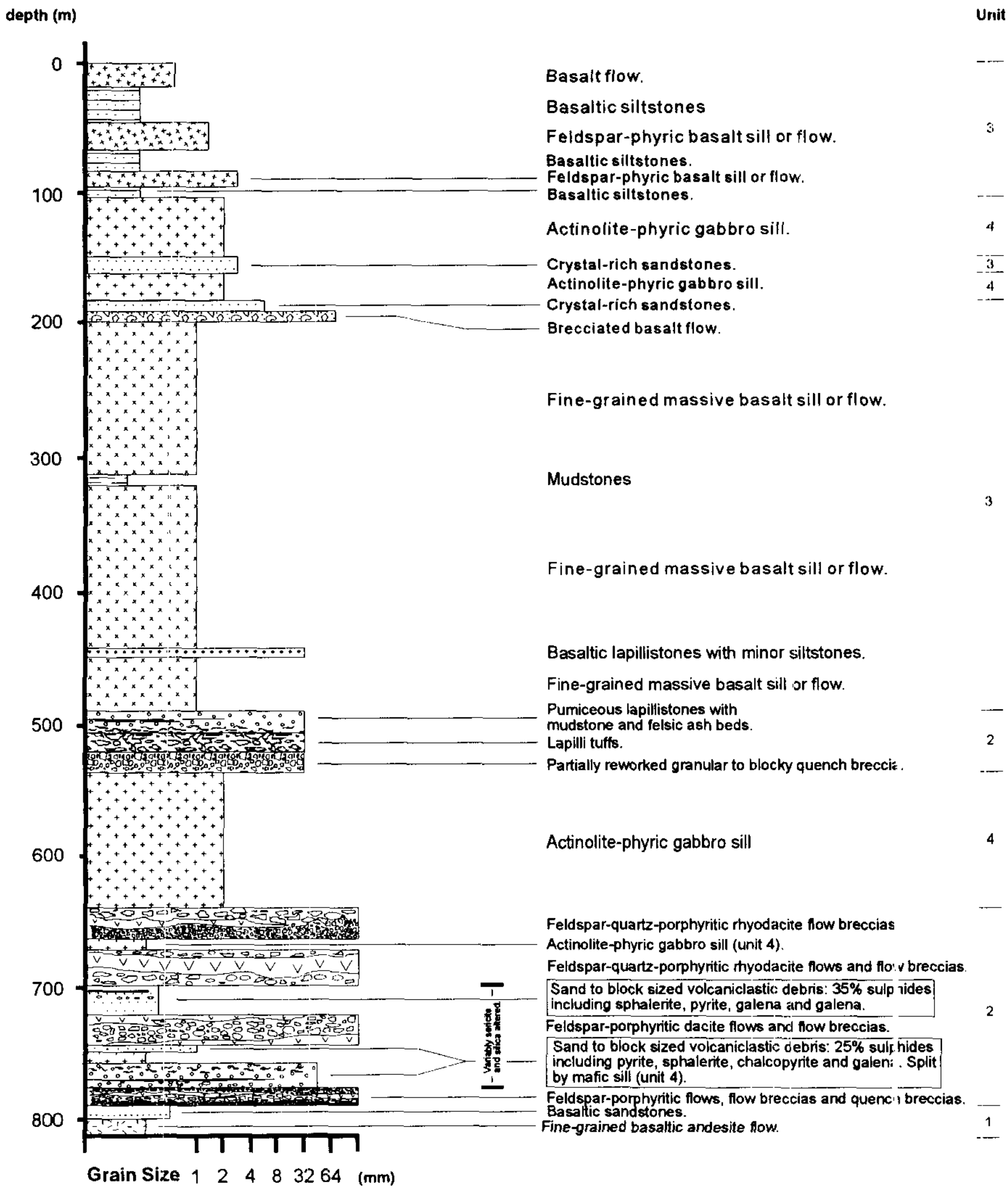

Figure 3: Simplified stratigraphy for diamond-drill hole TCU92-36.

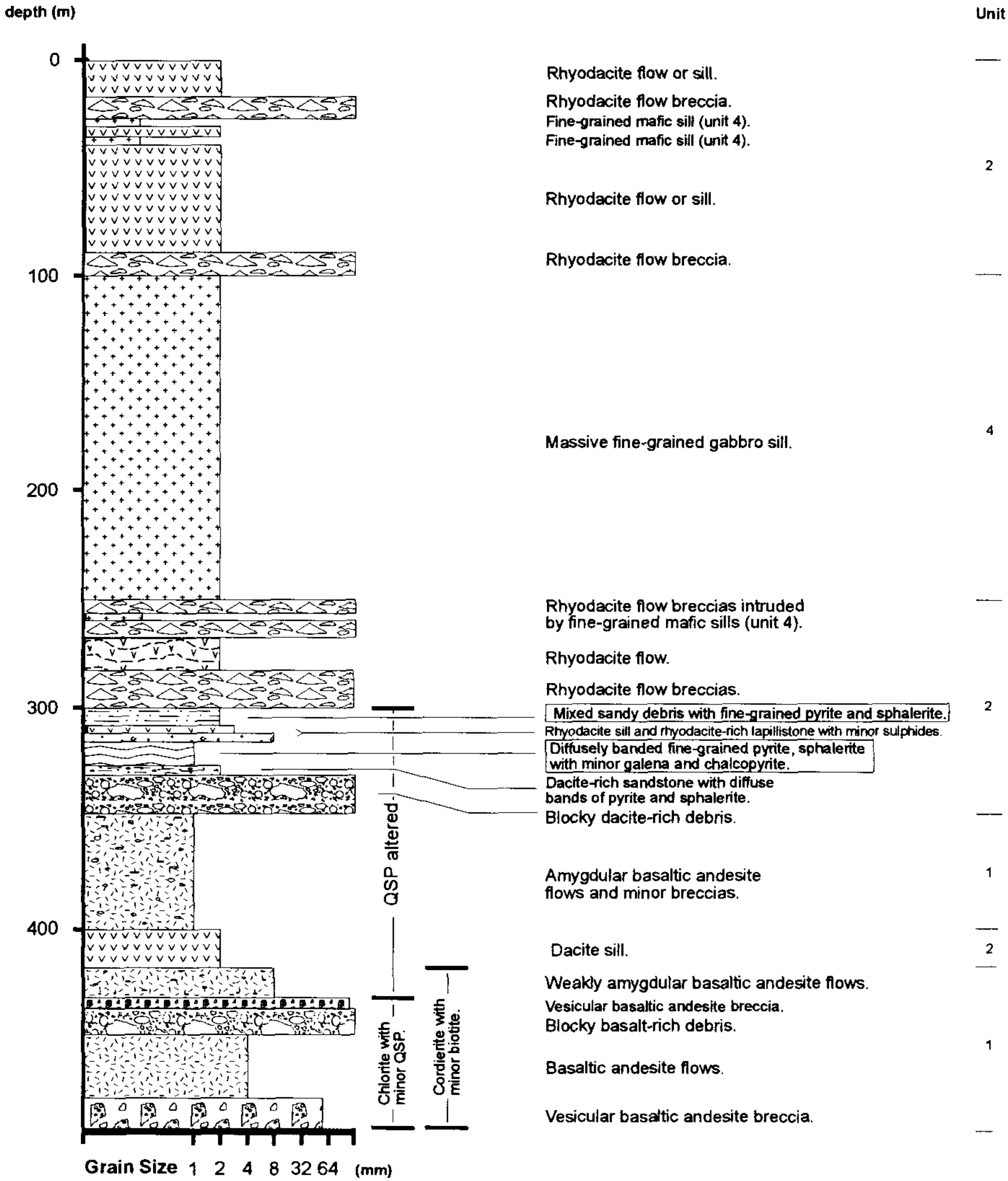

Figure 4: Simplified stratigraphy for diamond-drill hole TCU92-37.

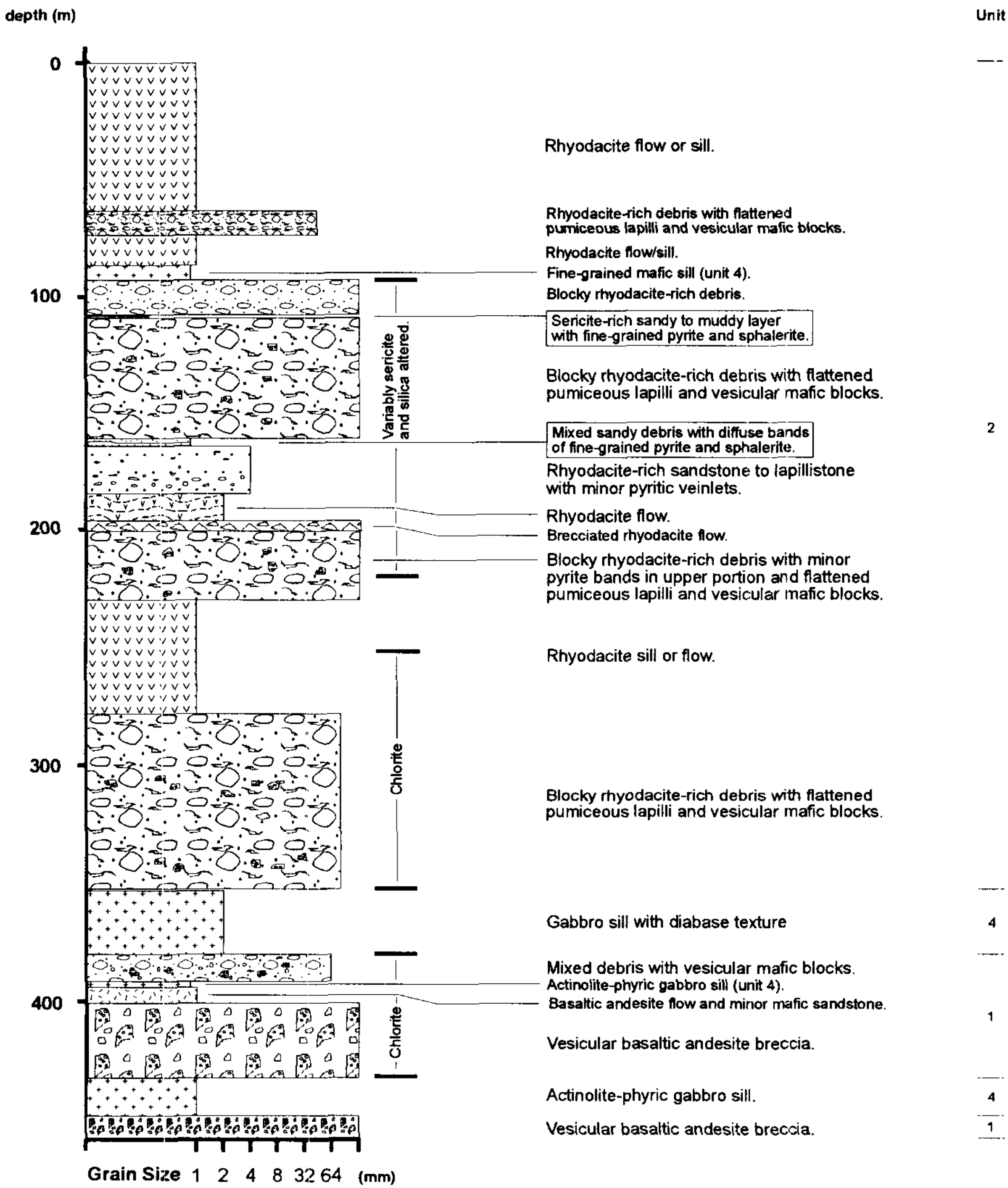

Figure 5: Simplified stratigraphy for diamond-drill hole TC93-09.

fine-grained, matted plagioclase dominated groundmass. Diabasic texture is common. In some areas, an overprint of coarse-grained chlorite and actinolite, probably of metamorphic origin, imparts a pseudocumulate texture to the rock.

This unit appears to be relatively unaltered when compared to units 1 and 2, which suggests that it was emplaced after the hydrothermal activity. The sill appears to be slightly discordant to stratigraphy on the basis of its contact relationships. It intrudes the felsic volcanic package in holes TCU92-36 and TCU92-37 but occurs much lower in the stratigraphy in hole TC93-09 where it intrudes mixed volcaniclastic debris immediately above the mafic footwall. Similar discontinuous actinolite-phyric sills have been noted in the hangingwall mafics; comparisons of adjacent drill hole intersections indicate that they may grade into flows along strike. Dark fine-grained mafic dikes and sills on the order of several metres thickness frequently cut footwall mafic rocks and the felsic pile (Figures 4 and 5). These mafic intrusives are also relatively unaltered and may be smaller apophyses of the gabbroic intrusive.

LOCAL STRUCTURE

Stratigraphic units at Tulsequah Chief outline a series of east-verging, moderately north to northwest-plunging folds (the F-anticline, the A-syncline and the H-syncline, Figure 2). These folds are interpreted to be parasitic structures on the western limb of the Mount Eaton anticline. This folded succession is subdivided into three discrete structural blocks by the north trending 5300E and 4400E faults (Figure 2).

The 5300E fault is the most significant and probably has the largest displacement. Kinematic indicators record an early period of dextral motion with a gently northward-plunging slip vector, followed by movement along a southerly plunging slip vector of unknown sense. The dextral motion is probably the most important in terms of displacement, but determination of absolute displacements requires a detailed analysis of stratigraphy in the central and eastern mine blocks. The 4400E and minor unnamed faults of variable orientation cause no large-scale displacement of stratigraphic contacts (Sherlock *et al.*, 1994).

The Chief cross fault dextrally offsets the mine stratigraphy and the Mount Eaton block immediately north of the mine workings. The displacement on this structure may be on the order of 2 kilometres (Mihalynuk *et al.*, 1994).

MINERALIZATION

Several massive sulphide lenses, termed the F, AB_1, AB_2, H, I and G zones, are hosted in unit 2 felsic autoclastics, coarse-grained felsic-rich mass flows and other finer grained mixed volcaniclastics. The ore lenses are composed of variable proportions of banded to disseminated, semimassive sulphides intercalated or intermixed with barite fragments, cherty clasts, variably altered fine to coarse-grained felsic-dominated lithic and vitric detritus.

Sulphide deposition occurred during the felsic volcanic cycle and was interrupted by a resurgence of felsic volcanism consisting of the extrusion of flows and the intrusion of shallow sills. The presence of felsic-rich mass-flow layers and of occasional sulphide rip-up clasts in some brecciated flow units indicates an active environment that locally reshaped and reworked the sulphide deposits.

Several sulphide facies have been defined by Cambria Geological Limited (McGuigan *et al.*, 1993). The pyrite facies consists mainly of fine-grained banded to massive pyrite with little base metal content. The zinc facies is composed primarily of semimassive, pale yellow, fine-grained sphalerite, pyrite and galena with subordinate chalcopyrite and tetrahedrite. The copper facies is mainly massive pyrite with up to 10% intergrown chalcopyrite. Stringer mineralization is common in the immediate footwall and is composed of thin, anastomosing quartz veins with dark red sphalerite and minor chalcopyrite. Chalcopyrite and tetrahedrite also frequently occur in crosscutting veinlets within the sulphide lenses.Barite and chert tend to be clastic and are generally minor constituents in sulphide-rich volcaniclastic debris; together they constitute less than 10% of the ore, volumetrically.

The sulphide-rich lenses in the felsic volcaniclastics may have been partially formed as infillings from hydrothermal fluids that precipitated metals within the highly permeable felsic mass-flows, close to the seafloor (Sherlock *et al.*, 1994). However, some sections of the zinc facies display finely laminated to diffusely banded textures and may be of exhalative origin. The presence of detrital massive sulphide fragments, altered to unaltered lithic and minor vitric fragments, the clastic habit of chert and barite, and the composite bedded succession of mixed sulphide and volcaniclastic layers indicates that reworking has occurred.

A detailed example of the mineralization in hole TCU92-36 is given in Figure 6. The sulphides occur in two distinct lenses separated by feldspar-porphyritic flows and flow breccias. They are mainly fine-grained banded to disseminated sphalerite, pyrite and minor galena, accompanied by clastic chert and barite, hosted in sericitized and silicified volcaniclastic debris. Total sulphide content is between 25% and 40% (by volume). The banding is often contorted or discontinuous. The lower sulphide-rich interval contains clastic sections with some pyritic lapilli. Occasional beds and laminations of massive pyrite and massive, mixed fine-grained sphalerite and pyrite also occur. The associated debris consists of rounded to subangular felsic blocks and lapilli, some strongly sericitized, and pervasively sericitized to chloritized flattened lapilli which have been interpreted as pumice. The same type of lapilli is also a common constituent in the blocky felsic-rich debris in hole TC93-09 (Figure 5).

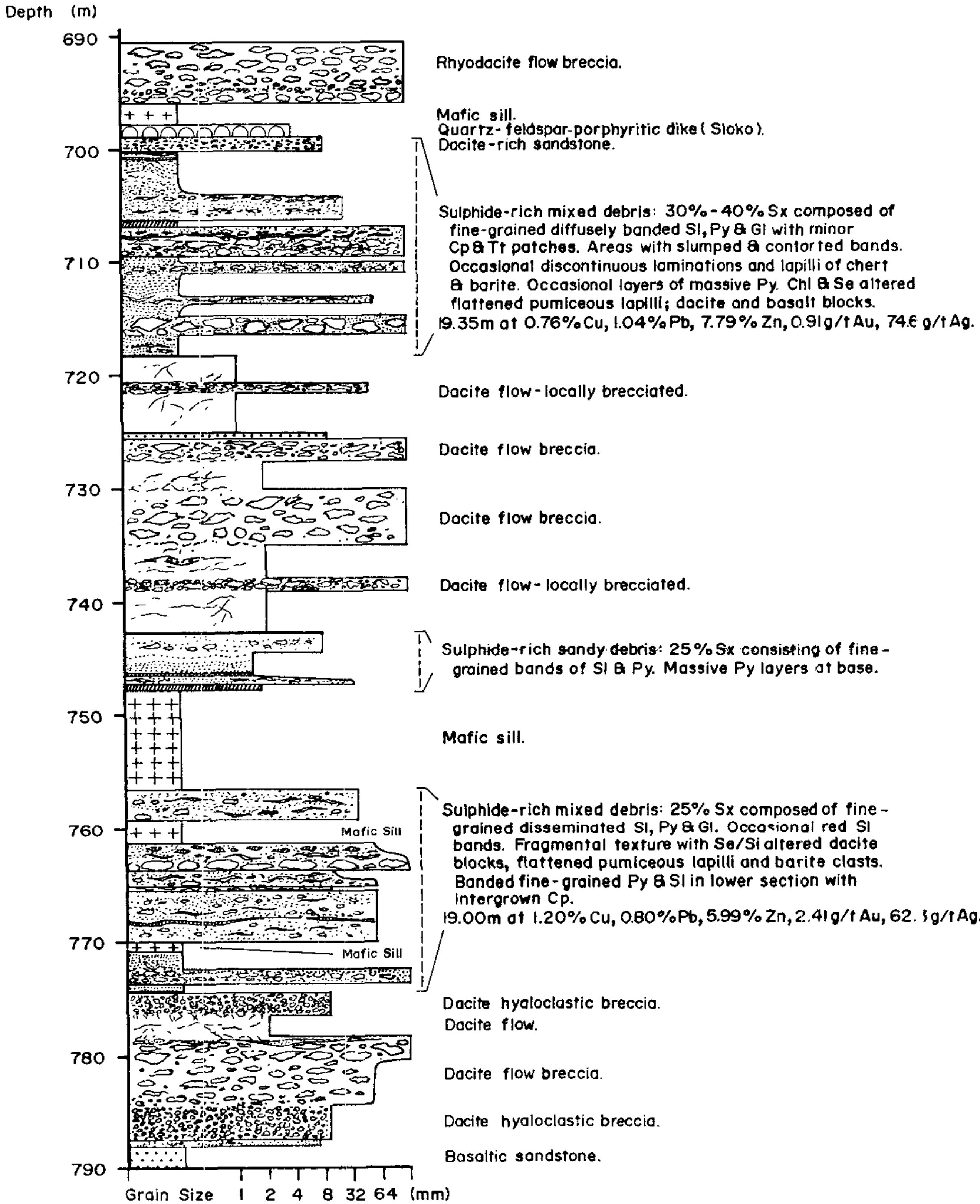

Figure 6: Detail of mineralization in diamond-drill hole TCU92-36.

ALTERATION

Alteration attributed to hydrothermal activity has affected parts of the footwall mafic suite, the heterolithic mass-flow debris found beneath the massive sulphides lenses, and in some cases the felsic volcanics and equivalent fragmentals between sulphide lenses. Two significant mineral assemblages are noted: quartz-sericite-pyrite (QSP), and chlorite with or without quartz and pyrite.

Most of the QSP alteration is confined to the footwall immediately beneath the sulphides in the main mine block between the 4400E and 5300E faults, where it is often so intense that it obscures primary textures. Both alteration types are often observed as repetitive, alternating zones subparallel to bedding. This was seen in the lower part of hole TCU92-37 where QSP alteration occurs with chlorite in the footwall mafics and in the mixed debris and dacite flows below the sulphide intersections. Variable amounts (up to 10% by volume) of disseminated fine to coarse-grained pyrite and crosscutting quartz-pyrite patches and veinlets are associated with both the QSP and chlorite assemblages and may constitute stockwork mineralization. The QSP alteration of the mafic footwall is notably less intense in the western limb of the F anticline (hole TC93-09) where it has mainly affected the upper section of blocky volcaniclastic debris.

Cordierite porphyroblasts and fine-grained biotite are variably developed, generally in areas immediately underlying the sulphide mineralization, often with chlorite. Cordierite also occasionally occurs with sericite and pyrite, and has been noted in the sericitized and silicified altered volcaniclastic debris surrounding the sulphide mineralization. These occurrences of cordierite may be the result of a metamorphic overprint of an original clay-rich hydrothermal alteration. A similar origin is possible for the biotite. Both biotite and cordierite occur in the mudstone beds capping the felsic volcanics.

A strongly bleached, sericitic alteration zone, up to 1 metre, wide locally penetrates into the felsic flows and fragmentals capping the sulphide lenses. Quartz-sericite alteration, not necessarily with pyrite, is also common in the felsic-rich to mixed volcaniclastic gangue within sulphide-bearing beds. The degree of alteration in these units is variable, however. Some of the coarser debris units contain both bleached quartz-sericite altered and unaltered dacite blocks. Both chloritized and sericitized pumiceous lapilli occur in the same-sulphide rich lenses. This variation in the degree of alteration of fragments may be a reflection of reworking.

Significant chlorite occurs in some of the dacite-rich clastic rocks and fragmental flows above and below the sulphide-rich lenses. It is succeeded by sericite-rich assemblages close to the lenses.

Silicification is highly variable in intensity and is not necessarily associated with sericite. This is notable in large portions of the chlorite-altered mafic footwall, where the silicification is usually accompanied by pyrite in patches and veinlets. Silicification is also found as local alteration in fractured mafic and dacite flow units with chlorite, epidote and, in places, hematite.

Crosscutting chlorite veinlets hosting various combinations of magnetite, quartz, epidote and locally pink garnet are found throughout the mine stratigraphy. These veinlets frequently display selvages of white to pearly quartz and possibly albite. They may represent a later hydrothermal event, possibly related to the gabbro intrusion.

DISCUSSION AND SUMMARY

Detailed logging of the drill core indicates that the sulphide mineralization at Tulsequah Chief is hosted in a felsic-dominated sequence. This felsic package was emplaced on a pre-existing basement of basaltic andesite breccias, flows and minor fine-grained mafic-derived sediments. The style and chemistry of felsic volcanism varies from a preponderance of quenched to autobreccia-rich feldspar-porphyritic intervals and dacite-rich debris flows in the lower part, to an upper section dominated by massive feldspar-quartz-porphyritic flows or sills. The proportion of blocky felsic-rich debris *versus* brecciated dacite flows varies from hole to hole and increases significantly to the west and to the east of the main mine block. The lower part hosts the sulphide lenses, which are sometimes accompanied by finer grained, reworked volcanic sandstones or lapillistones.

Sulphide deposition took place in a volcanically active and gravitationally unstable environment. The frequent clastic to discontinuous to disturbed textures observed in the sulphide lenses, together with their composite nature and significant content of volcanic debris, suggest that reworking possibly by mass flows and slumpage, was an important process. The presence of finely banded layers of sphalerite and pyrite with rare intact barite laminations implies that exhalation was also an important depositional mechanism. Some of the stratiform sulphides may be of replacement-infilling origin but further evidence is required to substantiate this hypothesis. Some of the copper mineralization consists of crosscutting veinlets and patchy intergrowths with banded sphalerite and pyrite-rich sulphides, and therefore is a late-stage mineralizing event.

The most intense sericite-silica alteration occurs immediately beneath the sulphide lenses in the main mine block (in the hinge of the A syncline). It alternates with chloritic alteration and extends outward laterally, subparallel to stratigraphy. Crosscutting siliceous and pyritic veinlets may represent stockwork mineralization.

Banded to laminated mudstone beds and chert laminations occur at the contact between the felsic volcanics (unit 2) and the overlying basaltic flows and sediments (unit 3). The gabbro sill (unit 4) is relatively unaffected by alteration and similar sills are present within the upper basaltic package. These observations suggest that unit 3 and unit 4 are coeval.

ACKNOWLEDGMENTS

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NOTES

The Geology of the Big Bull Polymetallic Volcanogenic Massive Sulphide Deposit, Northwestern British Columbia (104K/12)

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KEYWORDS: economic geology, Big Bull, Tulsequah Chief, volcanogenic, massive sulphide, copper, lead, zinc, gold, silver, Stikine, Mount Eaton Group

INTRODUCTION

The Big Bull mine is one of two historic base and precious metal producers on Redfern Resources Ltd.'s Tulsequah Chief property, located in northwestern British Columbia, 110 kilometres southwest of Atlin (Figure 1). The Big Bull deposit is situated on the northeast bank of the Taku River, about 8.5 kilometres south of the Tulsequah Chief deposit.

The Big Bull deposit is a polymetallic volcanogenic massive sulphide body hosted by a variably altered sequence of mafic and felsic volcanic flows, sills and volcaniclastic rocks, which together form part of the upper Paleozoic Stikine assemblage (Milhalynuk *et al.*, 1994). Quartz-sericite-pyrite alteration of the felsic rocks is intimately associated with, but laterally more extensive than the mineralization. The geometry of the deposit and associated alteration package is complicated by two generations of folds and several faults.

EXPLORATION AND MINING HISTORY

The Big Bull deposit was staked by V. Manville of Juneau in 1929. Massive sulphide ore outcropped in a small creek bed over a width of 2 to 8 metres, and a strike length of about 140 metres. Sporadic drilling and underground work were carried out by various parties until 1946, when Cominco Ltd. acquired the property. Big Bull went into production in August, 1951, and continued until December, 1955, with a total production of 326 658 tonnes grading 1.2% Cu, 1.9% Pb, 7.3% Zn, 5.14 g/t Au and 154 g/t Ag. The ore was milled at the nearby Polaris-Taku minesite.

The Big Bull mine was developed on three underground levels, with access to the two lower levels provided by a 90-metre shaft. Approximately 100 000 tonnes of ore was mined from the glory hole, using both surface and underground methods. In December, 1955, low metal prices combined with more favourable economics at the Tulsequah Chief mine forced the closure of the Big Bull mine. Reserves remaining at closure totalled 57 540 tonnes grading 1.1% Cu, 1.5% Pb, 5.6% Zn, 3.43 g/t Au and 154 g/t Ag.

Interest in the Tulsequah Chief property was rekindled in the early 1970s with the recognition that the deposits are volcanogenic rather than structurally controlled sulphide replacements. Cominco resumed exploration in 1987, mainly at Tulsequah Chief with only limited work at the Big Bull deposit. In 1992, Cambria Geological Limited. undertook a detailed surface mapping program at Big Bull and, in 1993, Redfern Resources Limited initiated a detailed compilation and exploration program. During 1993 to 1994, Redfern drilled 9 084 metres in 27 holes, successfully demonstrating that massive sulphide mineralization continued below the old workings with several holes intersecting ore grade material over widths up to 6 metres.

REGIONAL GEOLOGY

The regional geology of the Big Bull area is only summarized here; readers are referred to Mihalynuk *et al.* (1994) for a more complete discussion. The Tulsequah area is underlain by a geologically complex sequence of Mesozoic to Paleozoic rocks that are crosscut by Cretaceous to Tertiary intrusions (Figure 1). Hostrocks for massive sulphide mineralization have been assigned to the middle to upper Paleozoic Stikine assemblage. Mihalynuk *et al.* (1994) divided the Stikine assemblage in the Tulsequah area into three structural-stratigraphic blocks: the Mount Eaton block, the Sittakanay block and the Mount Strong block. The Big Bull and Tulsequah Chief deposits occur within the Mount Eaton block, an arc-related bimodal mafic-felsic volcanic package which is divided into lower, middle and upper stratigraphic divisions.

The lower division rocks are dominated by augite-phyric, chlorite-quartz amygdaloidal mafic flows and breccias with minor interbedded limestone. The mafic

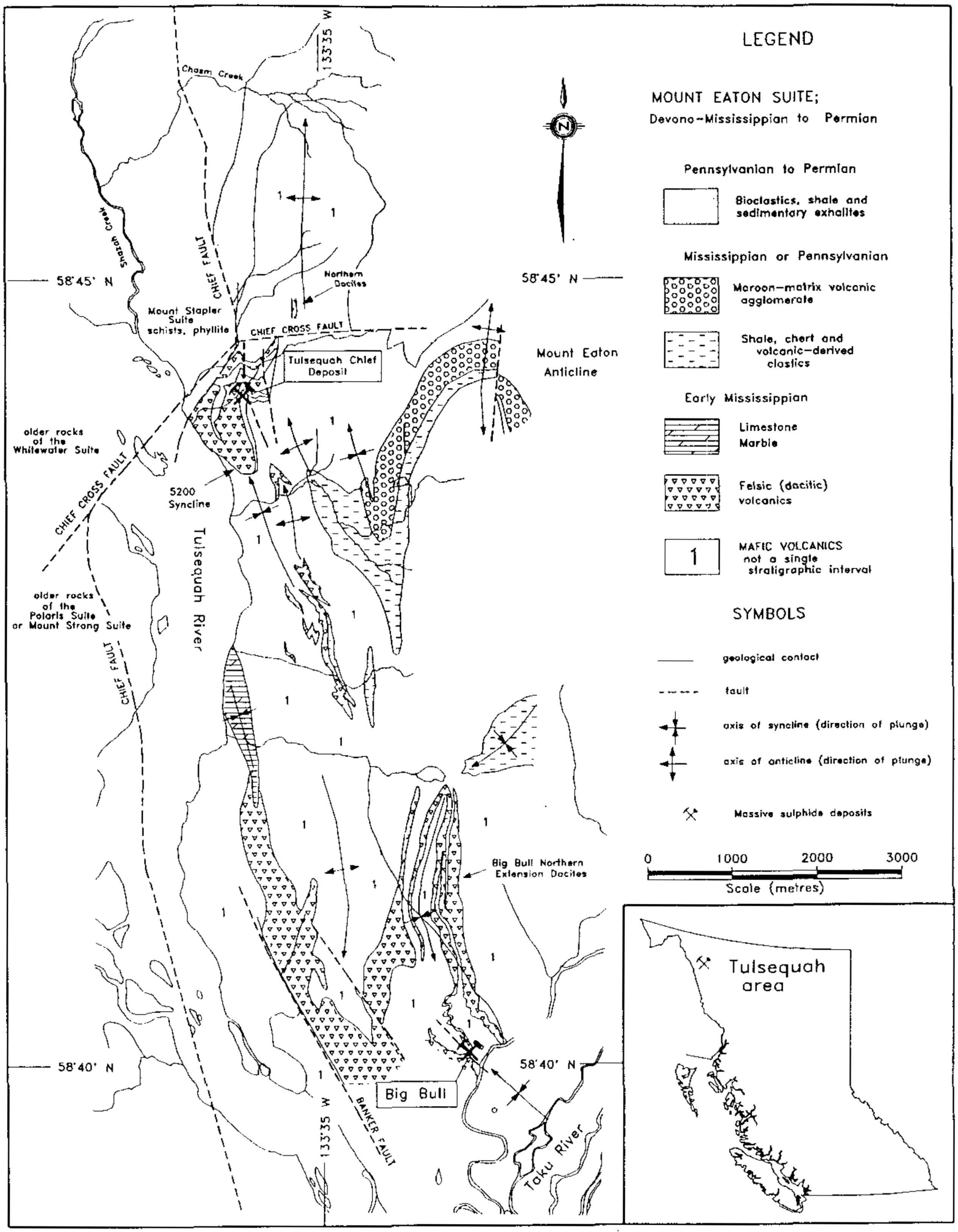

Figure 1. Simplified geology of the Tulsequah area, modified from Mihalynuk *et al.* (1994) and Nelson and Payne (1984).

rocks are typically massive and homogeneous, although pillows are preserved locally. Overlying this mafic package is a sequence of felsic tuffs and feldspar and quartz-phyric felsic flows, brecciated flows and volcaniclastic rocks. The Big Bull and Tulsequah Chief deposits are associated mainly with felsic tuffaceous rocks of this division (Figure 1). A U-Pb date of 353.4 + 15.8 - 0.9 Ma (Sherlock *et al.* 1994) was obtained from zircons in the dacitic volcaniclastic and flow rocks at the Tulsequah Chief mine.

Middle division rocks are dominated by green pyroxene and occasionally feldspar-phyric mafic breccias and agglomerates. Lesser amounts of basalt flows, mafic ash tuff, pyroxene-feldspar crystal tuff, tuffite and turbidites are also present. The upper division rocks are sediment dominated and consist of polymictic volcanic conglomerate at the base, succeeded by coarse-grained limestone and volcanic-rich debris flows, lapilli ash tuffs, volcanogenic turbidites and basalt breccias. A middle Pennsylvanian age has been assigned to fossil debris in a sequence of bioclastic rudites, micrites and calcareous turbidites at the top of this section (Nelson and Payne 1984).

The Mount Eaton block is characterized by at least two phases of folding: a prominent post-Early Jurassic phase which trends north-northwest, and a later east-trending phase of gentle warping. Metamorphism is sub-greenschist to middle greenschist facies. The regionally significant Llewellyn fault is the largest of a series of north to northwest-trending faults in the area, and can be traced as far north as the southern Yukon. In the Tulsequah area, the Llewellyn fault has been traced to the Tulsequah Chief mine, where it is offset to the west by the Chief cross fault, and then continues south, under gravels of the Tulsequah River valley.

The Sittakanay block is separated from the Mount Eaton block by the Taku River. It is lithologically similar to the Mount Eaton block, although more deformed, and has been correlated with Mount Eaton stratigraphy by Mihalynuk *et al.* (1994). The Mount Strong block is a sediment-dominated package that is separated from the Mount Eaton block by the Tulsequah River. Correlations between the Mount Strong and other blocks are uncertain. The Mount Strong block hosts the mesothermal gold mineralization at the Polaris-Taku deposit.

DEPOSIT STRATIGRAPHY

The Big Bull stratigraphy has been divided into five main lithologic units: unit 1 mafic volcanic rocks, unit 2 dacite tuffs and minor flows, unit 3 maroon andesite tuffs, unit 4 basalt tuffs, and unit 5 mafic intrusives (Figure 2). These subdivisions represent a modification of previous work by Dawson and Harrison (1993) and Carmichael and Curtis (1994). Feldspar-phyric mafic dikes and a distinctive quartz feldspar porphyry dike postdate all other lithologies, and are thought to be related to the Eocene Sloko Group.

UNIT 1: MAFIC VOLCANIC ROCKS

The oldest unit in the Big Bull mine stratigraphy is only exposed to the east of the deposit, and has not been intersected in drill core. It is characterized by mixed mafic lapilli and ash tuffs, with occasional fine-grained, massive, homogeneous, feldspar-phyric sections which are interpreted as flows. Lapilli tuffs typically contain quartz-amygdaloidal basalt fragments, and tend to be massive. Ash tuffs are thinly (1-2 cm) bedded to massive.

UNIT 2: FELSIC TUFFS AND FLOWS

Felsic crystal, crystal lithic, and lapilli tuffs host the ore at the Big Bull deposit (Photo 1). This unit is primarily a grey to greenish grey, laminated to chaotically banded dacite, which Payne (1993) has petrographically identified as metamorphosed and deformed dacite tuff and crystal tuff. The tuffs are commonly weakly porphyritic, with plagioclase phenocrysts in a compositionally layered plagioclase-sericite-rich groundmass. Magnetite and/or hematite occur as disseminations and disrupted bands forming up to 15% of the unit locally. Unit 2 typically shows chaotic banding on a 2 to 5-millimetre scale, although fragmental textures are rare. Locally well preserved bed forms show grain-size grading which helps to establish local structural relationships. Occasional massive, feldspar-phyric flows have been identified within this unit.

UNIT 2a: QUARTZ-SERICITE-PYRITE

Unit 2a represents parts of unit 2 that were hydrothermally altered during the formation of the Big Bull deposit. The rock comprises a strongly foliated sericite-quartz-pyrite assemblage, containing 5 to 20% disseminated and stringer pyrite, with local base metal sulphides and tetrahedrite. The quartz-sericite-pyrite alteration appears to form a stratiform layer near the top of the felsic tuffs, but may in places be discordant to stratigraphy.

UNIT 2b: MASSIVE SULPHIDE

Unit 2b includes mineralization that ranges from massive, banded sulphides, to 30 to 40% disseminated and stringer sulphides in a matrix of barite, sericite

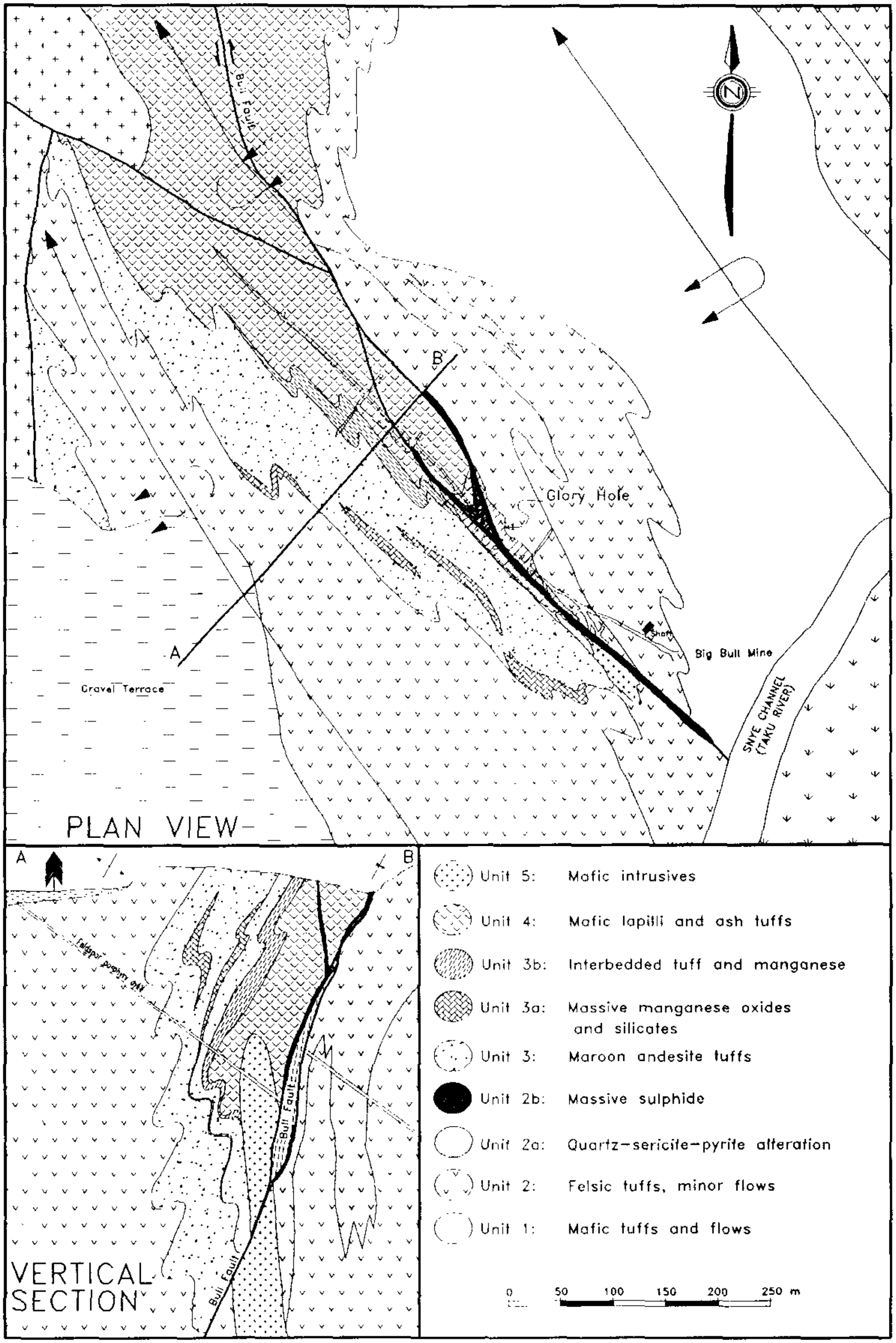

Figure 2. Big Bull Deposit, plan view and vertical section showing simplified geology.

Photo 1. Well bedded dacite tuff (unit 2), host to the massive sulphide mineralization.

and silica. The mineralogy comprises pyrite, galena, sphalerite, chalcopyrite and tetrahedrite, in a matrix of barite and sericitized lithic fragments. The sulphides are recrystallized, with well developed annealed textures that have obliterated any primary features. The sericitic fragments within the mineralized lenses may represent altered lithic fragments that were incorporated in the mineralized interval. Base metal grades can be visually estimated within this unit, but gold and silver values are difficult to predict.

UNIT 3: ANDESITE TUFF

Grey to maroon, fine to coarse-grained, locally phyllitic andesitic fragmental rocks conformably overlie unit 2 felsic tuffs. The maroon colour is typically due to fine-grained disseminated red hematite, and hematite-discoloured fragments that range in size from 0.5 to 50 millimetres. This unit is variably calcareous, with some sections containing up to 30% disseminated white calcite. The tuffs range from massive to very well bedded, with graded bedding and scour marks commonly, but not exclusively, indicating an overturned section. Fine-grained hematite gives the rock a distinctive maroon colour in places.

UNIT 3a: MANGANESE CHEMICAL SEDIMENT

Massive, black, fine-grained manganese oxides and silicates typically occur near the stratigraphic base of unit 3. They reach a maximum known thickness of 31 metres in drillhole BB94020. Interbeds of red mudstone occur locally within the manganese unit, as do breccia and replacement textures. Geochemistry and x-ray diffraction suggests that the manganese minerals present are braunite and piemontite.

UNIT 3b: INTERBEDDED TUFF AND MANGANESE

This distinctive unit often occurs at the stratigraphic top of unit 3. Its bedded nature and unique appearance make it useful as a marker interval. Maroon to pink crystal and ash tuff are interbedded with black, massive manganese silicates on a 1 to 10-centimetre scale. Manganese beds are contorted and disrupted, and appear to represent thinly bedded equivalents of unit 3a.

UNIT 4: BASALT TUFF

Unit 4 comprises dark green, chlorite-epidote-rich, mafic lapilli, ash and crystal tuffs. Patches and streaks of black hematite (1 to 20 mm) characterize this unit. Sausseritized feldspar crystals and crystal fragments are common, locally forming up to 30% of the rock. This unit is in conformable, and often gradational contact with unit 3.

UNIT 5: MAFIC INTRUSIVES

Mafic intrusives occur as both dark green, fine-grained diabase sills, and as larger diorite bodies. They are included as one unit here, although the relationship between the intrusives is unknown. Sills are typically massive to moderately well foliated, contain abundant chlorite and biotite, and are devoid of primary textures. Their interpretation as intrusive is based largely on contact relations and stratigraphic position. However, they can be difficult to differentiate from massive intervals of unit 4, particularly when they are intrusive into that unit. A large body of blocky weathering diorite outcrops northwest of the glory hole area; the diorite is massive, equigranular to weakly feldspar phyric, and medium to fine grained.

LITHOGEOCHEMISTRY

Lithogeochemical data suggest that the volcanic rocks at the Big Bull deposit are chemically similar to those at Tulsequah Chief. As the rocks from both deposits are variably altered, wholerock geochemistry is best compared in terms of immobile element ratios, as described by Barrett and MacLean (1994). In a plot of Al_2O_3 *versus* TiO_2, felsic rocks at Big Bull outline a narrow fan of alteration lines (Figure 3). This indicates that they were derived from a narrow range of felsic precursor compositions through mass loss and mass gain effects during hydrothermal alteration. Some of the largest net mass loss effects occur in proximity to the mined-out massive orebodies.

Mafic rocks at Big Bull show a range in TiO_2/Al_2O_3 ratios that are interpreted as resulting

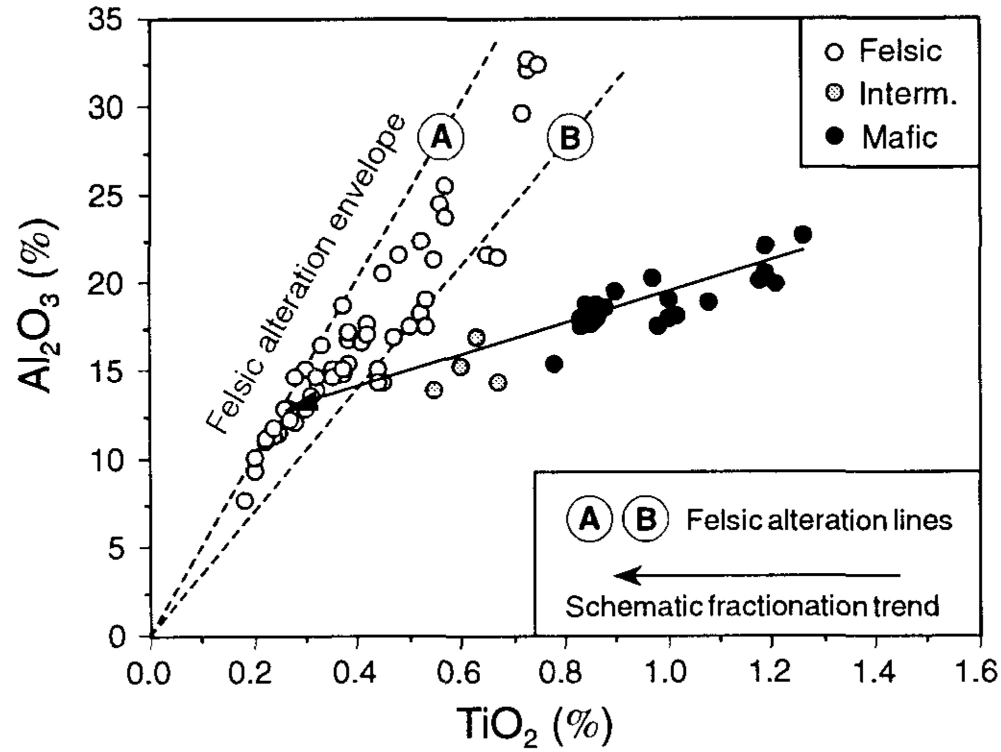

Figure 3. Lithogeochemical Al_2O_3 *versus* TiO_2 plot for host volcanic rocks at the Big Bull deposit. Samples are from both drillholes and outcrop within several hundred metres of the old mine workings. The dashed lines represent bounding compositions for the altered felsic rocks. A schematic fractionation trend is shown linking least altered rock types, although confirmation of this relationship requires further work.

largely from fractionation effects. Although not plotted here, the mafic rocks can be effectively subdivided using trace element plots such as nickel *versus* chromium. Mafic intrusives are typically characterized by higher nickel, chromium and magnesium abundances relative to the mafic volcanics, indicating that the former were derived from a more primitive mafic magma. The mafic intrusives are relatively unaltered, and probably represent a second phase of mafic magmatism that occurred after the main phase of sulphide-forming hydrothermal activity.

STRUCTURE

Rocks in the Big Bull area have been affected by two phases of folding and several episodes of faulting, creating an area of structural complexity (Figure 2; Barclay, 1993; Dawson and Harrison, 1993; Lewis, 1993; Carmichael and Curtis, 1993). The lithologic contacts (S_0) trend north-northwest, with steep dips to the southwest.

The first and most important phase of folding (S_1) consists of tight, approximately cylindrical, moderately overturned, folds with axial planar cleavage oriented at about 140/84° southwest, and fold axes trending 321° and plunging at 30 to 50° (Photo 2). A stereonet plot of measured bedding orientations (Figure 4) defines a great circle, the pole of which has an orientation of 321/54°, approximately parallel to the measured fold axis, suggesting that only one major phase of deformation has occurred. Parasitic folds on the east side of the glory hole are consistent with a synclinal closure to the west. The first phase of folding is represented by the Big Bull syncline, which repeats unit 2 dacites west of the glory hole (Figure 2).

A second, very weak phase of folding is indicated by a spaced, planar crenulation fabric which does not appear to have significantly reoriented either S_0 or S_1 fabrics. Axial planes are oriented roughly east-west, and dip steeply to the north.

Brittle faulting is an important element in the structural history of the Big Bull deposit. The Bull fault is a northwest-striking, steeply west-dipping structure which is approximately axial planar to the Big Bull syncline. In many instances the Bull fault has disrupted the massive sulphide lenses, with brecciated and rotated mineralized blocks present in the fault gouge. The fault has had a complex history involving several periods and directions of movement, the latest of which offsets a quartz feldspar porphyry dike of probable Eocene age. Although the amount and direction of displacement across the fault is unknown, apparent offsets of lithologic units suggest sinistral strike-slip movement. Detailed structural mapping in the collapsed stope area indicates that faults occurring

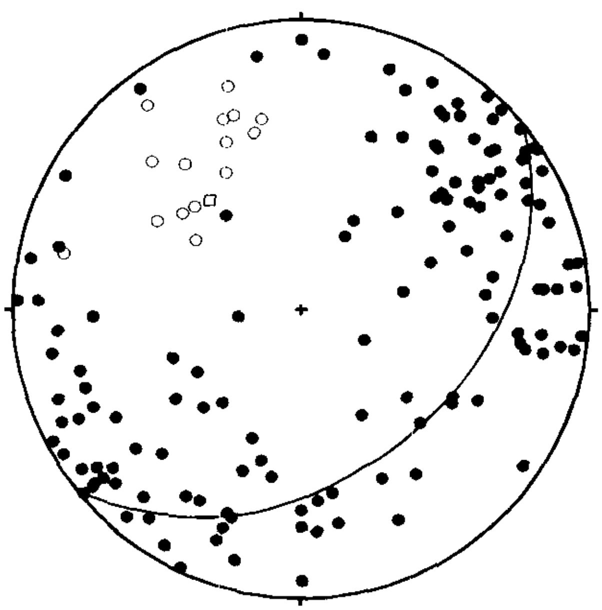

Figure 4. Stereonet plot of poles to bedding surfaces, and measured fold axes. Also shown is the pole to the great circle defined by the poles to the bedding. ● Bedding orientations; □ pole to the great circle; ○ fold axes.

within unit 2a, subparallel to S_0 and S_1, generally show a dextral offset along southeast-plunging axes or sinistral offset along shallow northwest-plunging axes (Barclay, 1993).

DISCUSSION

The Big Bull deposit is associated with the same suite of felsic-mafic volcanic rocks that hosts the Tulsequah Chief massive sulphide deposit (Figure 1). The stratigraphy at Big Bull includes a mafic footwall (unit 1) that is overlain by an altered felsic package (unit 2) which is in turn overlain by a second package of mafic rocks (units 3, 4). The altered felsic package is the host to the massive sulphide mineralization. This sequence of rocks has been intruded by a diabase-textured mafic sill (unit 5), that has dilated the altered felsic interval, but is relatively unaltered itself, suggesting it was intruded after hydrothermal activity but prior to structural deformation. This overall sequence of lithologies is similar to the stratigraphy at the Tulsequah Chief deposit (Sherlock *et al.* 1994; Sebert *et al.* 1995).

Lithogeochemistry suggests that the volcanic rocks (and mafic intrusives) at Big Bull are closely comparable to those at Tulsequah Chief (Figure 5). At both deposits, the felsic rocks form alteration trends that largely overlap, suggesting that they were derived from similar precursor compositions. Mafic rocks in the stratigraphic footwall at Tulsequah Chief have lower values of nickel, chromium and commonly MgO than mafic rocks that are interpreted as synvolcanic intrusives within the felsic hangingwall stratigraphy.

Photo 2. Outcrop-scale folding.

The mafic intrusive rocks at Tulsequah Chief are weakly altered relative to footwall mafic volcanics and are also closer to basalt in composition. At Big Bull, a group of mafic rocks with high Ni-Cr values is similarly interpreted as representing more primitive intrusives into felsic stratigraphy.

The main difference between the hostrocks at Big Bull and Tulsequah Chief is the nature of the volcaniclastic rocks. Felsic volcanic rocks at Tulsequah Chief are primarily coarse grained, poorly bedded, unsorted debris-flow units which are interbedded with felsic flows and intruded by felsic sills. The felsic rocks are altered, variably mineralized, and are interpreted to have been emplaced contemporaneously with the hydrothermal activity that formed the ores. At Tulsequah Chief, the coarse-grained and poorly sorted nature of the felsic volcaniclastic rocks, and the prevalence of flows and sills suggests that they were deposited close to a felsic volcanic centre.

The volcaniclastic rocks at the Big Bull deposit contrast sharply with those at Tulsequah Chief in that they are finely laminated and very fine grained, with well preserved bed forms, although these have been contorted and locally disrupted by subsequent deformation. At Big Bull, massive felsic lavas, either as flows or sills, are rare. These features support a distal setting for the volcaniclastic rocks at the Big Bull deposit.

In addition to the massive sulphide mineralization at Big Bull, there is a second phase of hydrothermal activity represented by massive manganese oxide and silicates (unit 3a). This unit appears to occur stratigraphically above the massive sulphides, in the andesite tuffs (unit 3). The manganese mineralization may represent a low temperature hydrothermal system that existed after the higher temperature system that formed the sulphides, or it may be a lateral facies equivalent of the massive sulphides. The structural

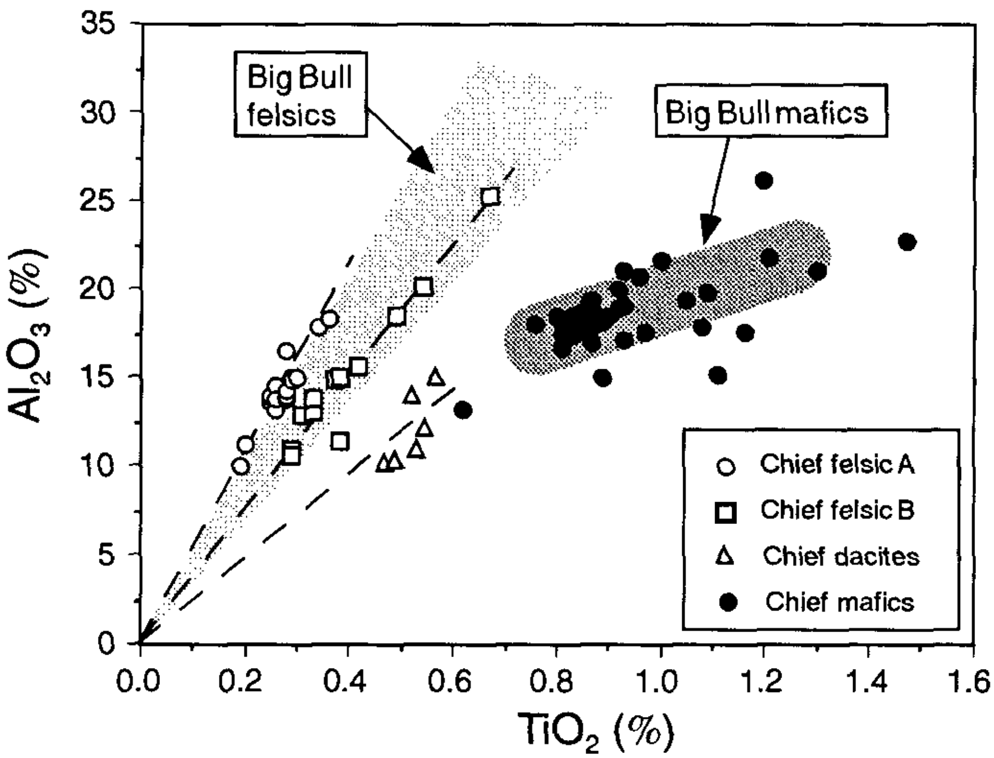

Figure 5. Al_2O_3 *versus* TiO_2 plot comparing host volcanic rocks at the Big Bull and Tulsequah Chief deposits. Samples from Tulsequah Chief are mainly from drillholes within several hundred metres of the old mine workings. At Tulsequah Chief, two fairly distinct felsic alteration trends (A and B) are evident, and also a smaller group of dacitic samples that may represent mixtures of felsic and mafic debris. The mafic rocks at Tulsequah Chief can be divided into two groups based on Ni-Cr data; the mafic intrusives lie within the TiO_2 = 0.8-1.0% interval.

complexity at the Big Bull deposit presently precludes the establishment of the sulphide-manganese relationships.

SUMMARY

The Big Bull deposit is a polymetallic volcanogenic massive sulphide deposit which occurs in a bimodal, largely tuffaceous sequence within the Paleozoic Stikine assemblage. The hostrocks are chemically similar and roughly stratigraphically equivalent to those at the nearby Tulsequah Chief deposit. The sequence of events that formed the Big Bull deposit is outlined below, and shown schematically in Figure 6.

1. Deposition of widespread mafic footwall rocks.
2. Deposition of finely bedded felsic tuffs, with contemporaneous hydrothermal activity, alteration of the felsic package, and deposition of massive sulphides.
3. Deposition of finely bedded mafic tuffs, with coeval low-temperature hydrothermal discharge and the formation of massive manganiferous chemical sediments. These chemical sediments may represent cooling of the first, sulphide-depositing hydrothermal system or, alternatively, the lateral margin of a second hydrothermal system.
4. Intrusion of mafic sills ± flows after the main phase of hydrothermal activity had ended.
5. Folding of the stratigraphy into a syncline in the Big Bull area.
6. Offset of the stratigraphy along the Bull fault, forming the present deposit configuration.

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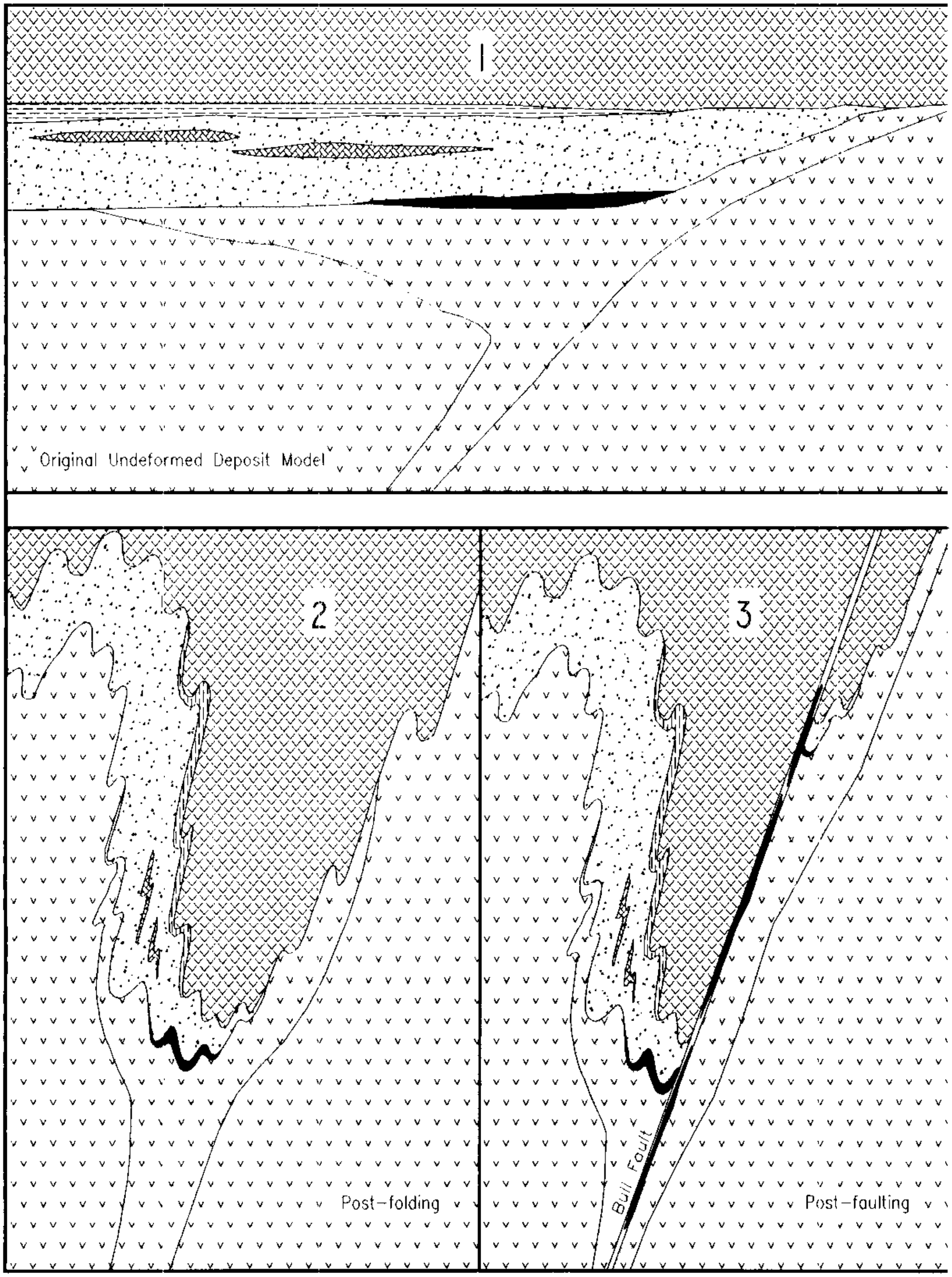

Figure 6. Schematic diagrams through the Big Bull deposit, showing its structural evolution. 1: deposition of the volcanic strata; 2: folding of the strata into a syncline; and 3: offset of the strata along the Bull fault (see Figure 2 for legend).

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Melluish, J.M.: Examination of the Mineralogical Effects of Biologically-Assisted Leaching of a Mixed Copper Sulphide Ore from the Ivan Mine, Chile. (M.Sc.)

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Johannessen, D.J.: Slope stability assessment of the Loss Creek area, River Jordan, British Columbia. (B.A.Sc.)

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Robinson, M.: Geology, Mineralization and Alteration of the Battle Zone, Buttle Lake Camp, Central Vancouver Island, Southwestern British Columbia. (M.A.Sc.)

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