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Geological Survey Branch

GEOLOGICAL FIELDWORK 1996

A Summary of Field Activities and Current Research

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J.G. McArthur

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FOREWORD

Geological Fieldwork: A Summary of Fieldwork and Current Research, 1996 is the twenty-second edition of this annual publication. It contains reports of Geological Survey Branch activities and projects during the last year. The base budget of the Branch for the 1996-97 fiscal year is $5.5 million, down slightly from the previous year. This budget has been supplemented by $1.1 million to offset the impact of the ending of the federal-provincial Mineral Development Agreement, $180 000 under the Mineral Potential Initiative and $60 000 for MINFILE and earthquake studies from the Corporate Resource Inventory Initiative. Overall funding therefore was essentially the same as in 1995-95.

As before the contents of this year's volume reflect the emphasis of Branch programs. Highlights are completion of the bedrock mapping and geochemical survey of the northern Gataga Belt, continuation of the Nechako Plateau NATMAP project, which is a collaborative effort with the Geological Survey of Canada and various universities, and regional geochemical sampling of two 1:250 000 map-sheets in north central British Columbia. The SEDEX-oriented Gataga project traced favorable lithologic units northward from Terminus Mountain to the Yukon border and conducted a lake sediment and water geochemical survey of the same area. The Branch focus within the Nechako project is the Babine porphyry belt, with its important mineral potential. The regional geochemical survey covered the congruent Toodoggone River and McConnell Creek sheets. As well, a new regional mapping project extended existing coverage of the Toodoggone volcanic belt southward to the area of the Kemess deposit. A new multidisciplinary study which keys on surficial geology, geochemistry and mineral deposits began in the Eagle Bay area; its focus is volcanogenic massive sulphide deposits.

A variety of mineral deposits are profiled in this year's Fieldwork volume, including the geological setting of Canada's first precious opal deposit. Other articles on Harper Creek (VMS), Nipple Mountain (opal), Taurus (bulk gold), Huckleberry (porphyry copper), Mount Mather Creek (sodalite), Mount Brussiloff (magnesite), Atlin (tin skarn) and other locations profile more of the province's attractive mineral resources. Three interesting articles on coal and coalbed methane provide more documentation on the single most important mineral commodity in the province. The metallogenetic study in the Tatogga Lake area completed its third and final year of mapping by defining the volcanic successions in the region and identifying the two main styles of mineralization.

The Mineral Potential project has completed coverage of all the province except the Queen Charlotte Islands. Much information from the project is posted on the Internet on the Ministry site (address: http://www.ei.gov.bc.ca/pages/geosmin.htm). The intent of the project is to have geology, geological tracts and mineral potential estimates available; at this time, the geology layer is not yet ready for posting. The geology, mineral assessment results and associated datasets are available for downloading in an Arc Export format which allows viewing and manipulation with the freeware Arcview1 program. Interactive viewing of the geology and other major datasets will be available in 1997.

Production of Geological Fieldwork to the camera-ready stage has been done in Microsoft WORD by the authors using a template prepared by Brian Grant. The Branch is now employing print-on-demand technology for its geoscience publications. Material will also be posted on the Ministry Internet site for viewing or downloading. Thanks are due to Dave Lefebure, Bill McMillan and Gib McArthur for editing and to Brian Grant for guiding the process to completion on schedule.

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EAST KOOTENAY GEOPHYSICAL SURVEY, SOUTHEASTERN BRITISH COLUMBIA (82F, G, K): SULLIVAN - NORTH STAR AREA

By D.A. Brown[1], C. Lowe[2], R.B.K., Shives[3], and M.E. Best[2]

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INTRODUCTION

This paper summaries geophysical characteristics of the Sullivan-North Star area of southeastern British Columbia, based on a preliminary examination of new multiparameter airborne data acquired as part of the East Kootenay Geophysical Survey. It complements a paper summarizing regional results of the survey (Lowe *et al.*, 1997). The new geophysical data offer improved screening of exploration targets in the region.

The contracted, helicopter-based survey was funded by the Government of British Columbia and coordinated by the Geological Survey of Canada. It provides high-quality, public-domain geoscience data to assist mineral exploration and enhance understanding of the geology and known mineral deposits of the region. Electromagnetic (EM), total field magnetic, gamma ray spectrometric, and VLF data were acquired in three areas (Figure 1). The surveying was completed by Dighem I Power, a division of CGG Canada Ltd., of Mississauga, Ontario. Data were collected in the St. Mary and Findlay Creek areas in 1995 and in the Creston area in 1996.

The survey areas lie within the Purcell anticlinorium of southeastern British Columbia and are underlain primarily by the prospective Aldridge Formation (Figure 1). The St. Mary River area covers approximately 2000 km^2 and includes the Sullivan Mine, a world class sedimentary exhalative (SEDEX) deposit. The Findlay Creek area covers about 400 km^2 south of Findlay Creek, and west of Canal Flats and includes Rusty Ridge, a promising area near the lower-middle Aldridge Formation contact with fragmental units and tourmalinite alteration. The Creston area comprises about 600 km^2 and extends east from Creston to Yahk and south to the U.S. border.

This paper discusses some of the more obvious features that are presented on B.C. Ministry of Employment and Investment Open File 1996-23 hardcopy maps released July 11, 1996. This release includes total field aeromagnetics, conductivity, potassium, thorium/potassium, and ternary radioelement maps. A comprehensive digital data set for the survey area is available from the National Geophysical Data Centre in Ottawa ((613) 995-5326). The quality and high resolution of new data collected over prospective geology warrant additional industry analysis.

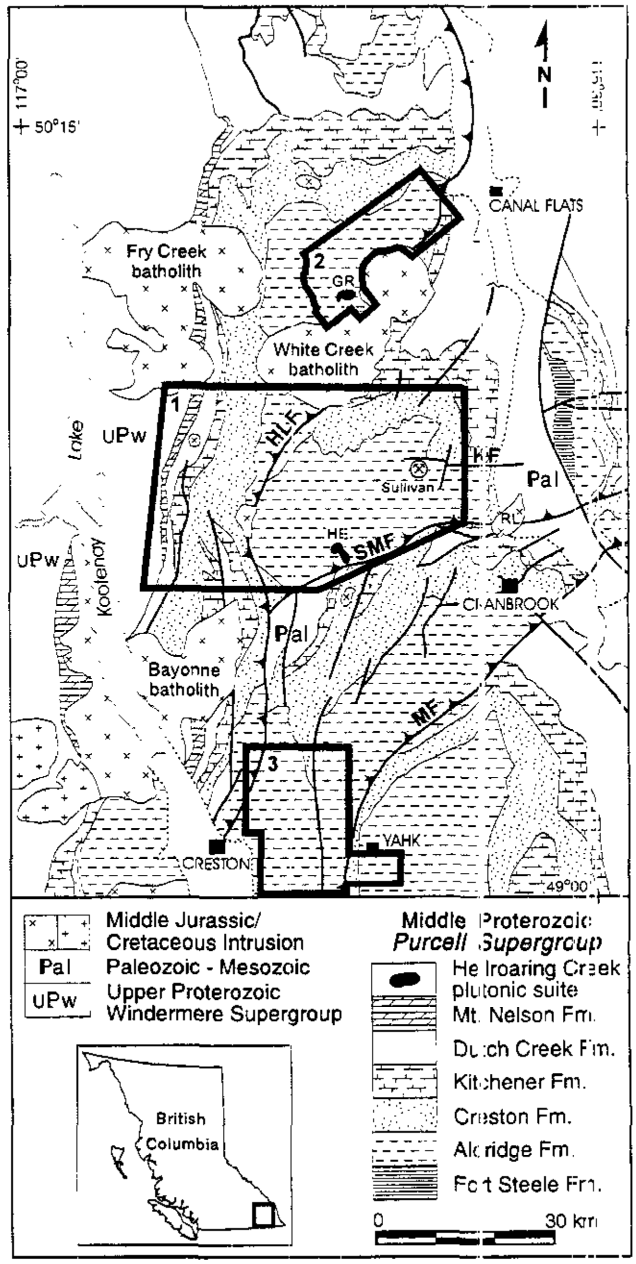

Figure 1. Regional geological setting of Purcell Supergroup showing the location of the three geophysical survey areas within the Purcell anticlinorium (modified from Höy *et al.*, 1995a). 1 = St. Mary River area; 2 = Findlay Creek area; 3 = Creston area. GR = Greenland Creek stock, HE = Hellroaring Creek stock, HLF = Hall Lake fault, KF = Kimberley fault, MF = Moyie fault, RL = Reade Lake pluton, SMF = St. Mary fault.

GEOLOGICAL SETTING

The survey areas lie within the Purcell anticlinorium, a broad north-plunging structural culmination cored by Middle Proterozoic (circa 1500 to 1350 Ma) Purcell Supergroup sedimentary rocks (Figure 1). The succession is more than 10 km thick and comprises syn-rift, deep water turbidites of the Aldridge Formation, and post-rift fill, shallow-water to locally subaerial clastic and carbonate rocks of younger units (Figure 2). Laterally extensive gabbroic sills ("Moyie sills") intrude the Aldridge sediments and provide a minimum age for the syn-rift package (1467 Ma; Anderson and Davis, 1996). Late Proterozoic conglomerate, siliciclastic and volcanic rocks of the Windermere Supergroup unconformably overlie Purcell Supergroup rocks along the margin of the anticlinorium.

Aldridge and overlying Creston Formation predominate in the survey areas. The Sullivan SEDEX deposit occurs near the transition from lower to middle Aldridge in the St. Mary River area. Faulted and structurally complex upper Purcell and Windermere Supergroup strata crop-out in the western third of the St. Mary area and Cambrian Cranbrook and Eager formations occur along the area's southern edge. Small pegmatitic plutonic rocks of middle Proterozoic age include Hellroaring Creek (4 km^2) and Greenland Creek plutons (1.6 km^2; Reesor, 1996). Large Cretaceous plutons, including parts of the White Creek and Fry Creek batholiths, and related smaller stocks plug many of the faults. More detailed maps and unit descriptions are presented in Carter and Höy (1987), Leech (1958), Höy (1984a, b; 1993), Höy and Diakow (1982), Reesor (1958, 1973, 1983, 1996), Rice (1937, 1941), and others (Figure 3).

MINERAL OCCURRENCES

There are 74 known mineral occurrences recorded in the MINFILE database for the survey areas; 63, including the Sullivan Mine, within St. Mary River area, and 11 within the Findlay Creek area. Sixty-five percent of these occurrences are hosted in the lower and middle Aldridge Formation and Sullivan-type SEDEX deposits are the most economically important. Past producers include the North Star, Stemwinder, Silver Hill, Rice, Park and Humbolt Mines. Vein and disseminated base metal sulphide deposits and occurrences are distributed throughout the stratigraphic section (Figure 2). Stratabound Cu-Ag occurrences analogous to the western Montana Copper Belt are potential targets in mud-cracked, wavy-bedded quartz arenites (shallow-water) of the Creston Formation. Locally Cretaceous stocks are related to gold mineralization and could represent the source of placer gold contained in several creeks (for example Sawmill, Lisbon and Perry creeks).

Sullivan is a world class Pb-Zn-Ag SEDEX deposit formed in an intracratonic rift setting within deep water turbidites. It occurs close to the intersection of the Kimberley fault with the Sullivan-North Star corridor (see Figure 5a). The deposit and its regional setting have been the focus of a five year multidisciplinary study, the Sullivan-Aldridge Project (results in preparation for a Geological Survey of Canada Special Paper). Fragmental units, albite and tourmaline alteration as well as discordant Moyie gabbro are features found at Sullivan deposit and many other mineral occurrences in this region.

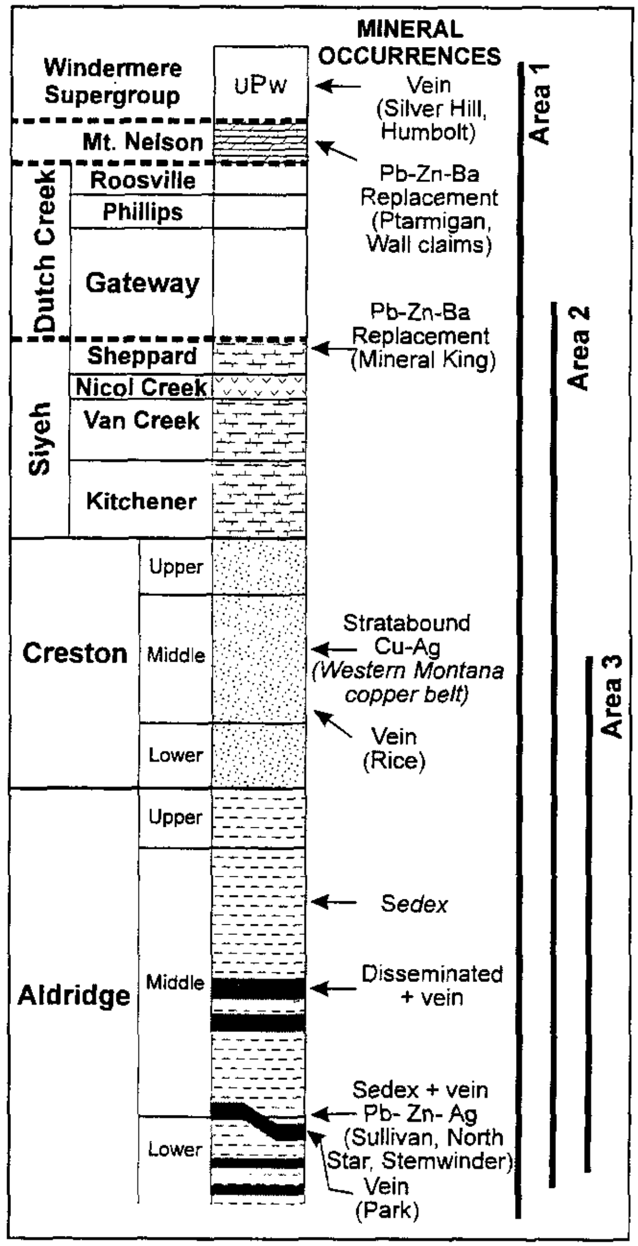

Figure 2. Stratigraphic column for the Purcell Supergroup which lies unconformably beneath the Windermere Supergroup (modified from T. Höy, written communication, 1996). Stratigraphic nomenclature along the eastern half of the Purcell anticlinorium is better defined than the west because of two important regional markers; Nicol Creek Formation lava and Phillips Formation sandstone. The stratigraphic position of several mineral occurrences are indicated. Thick vertical lines denote the range of stratigraphy exposed in each survey area.

STAKING - EXPLORATION ACTIVITY

The government's announcement of the geophysical survey and release of the new data resulted in about 200 km^2 of new staking in the St. Mary River survey area. This represents a 30% increase (about 850 km^2 of claims, Figure 4) over 1995 staking levels. New claims staked by Cominco Ltd., Eagle Plains Resources Ltd. and Miner River Resources Ltd. encompass conductive units and apparent bedrock conductors in the Dutch Creek Formation (LaFrance Creek Group of Reesor, 1996) north of Sawyer Creek, and in the Horsethief Creek Formation. Cominco also staked apparent bedrock conductors in the middle and upper Aldridge Formation in the Tower Creek area.

In the Findlay Creek area, about 105 km^2 of new claims were staked representing a 440% increase over 1995 staking levels. Staking occurred predominantly around Rusty Ridge and west of Doctor Creek. Grass-roots exploration is underway. In addition, coincident magnetic and EM anomalies were drilled jointly by Eagle Plains Resources Ltd. and Miner River Resources Ltd.

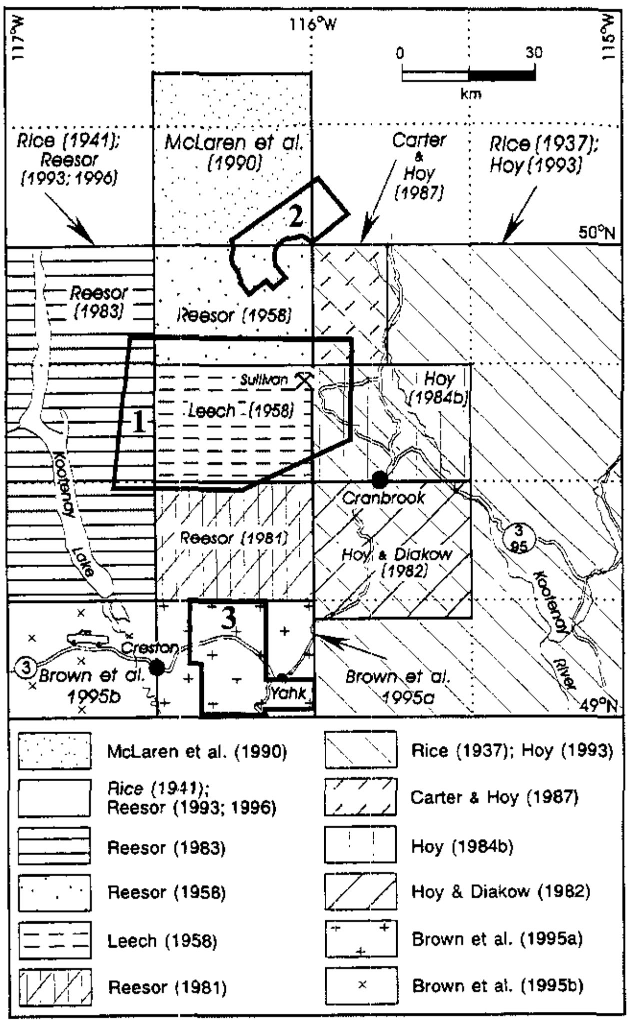

Figure 3. Regional geological mapping coverage adjacent to the geophysical survey areas: 1 = St. Mary River area, 2 = Findlay Creek area, and 3 = Creston area.

Data acquisition for the Creston area was completed in September, 1996 but results were not available to include in this report. Since announcement of the survey in this area there has been a 65% increase in staking and more is expected upon release of the data. Some of the new claims are related to Iron Range mineralization (Figure 4) and a newly recognized pluton south of Highway 3. Claims east of Yahk are part of a larger group acquired by Abitibi Mining Corp. and Sedex Mining Corp; extending beyond the surveyed area to the northeast.

GEOPHYSICAL DATA ACQUISITION

Electromagnetic, magnetic, gamma ray spectrometric, and VLF-EM data were acquired using a helicopter flown at a mean terrain clearance of 60 m. Flight lines were 400 m apart with control lines approximately 5 km apart. The system configuration for the survey is illustrated in Plate 1. Instrumentation and coil configurations are detailed in British Columbia Ministry of Employment and Investment Open File 1996-23 and Lowe et. al (1997).

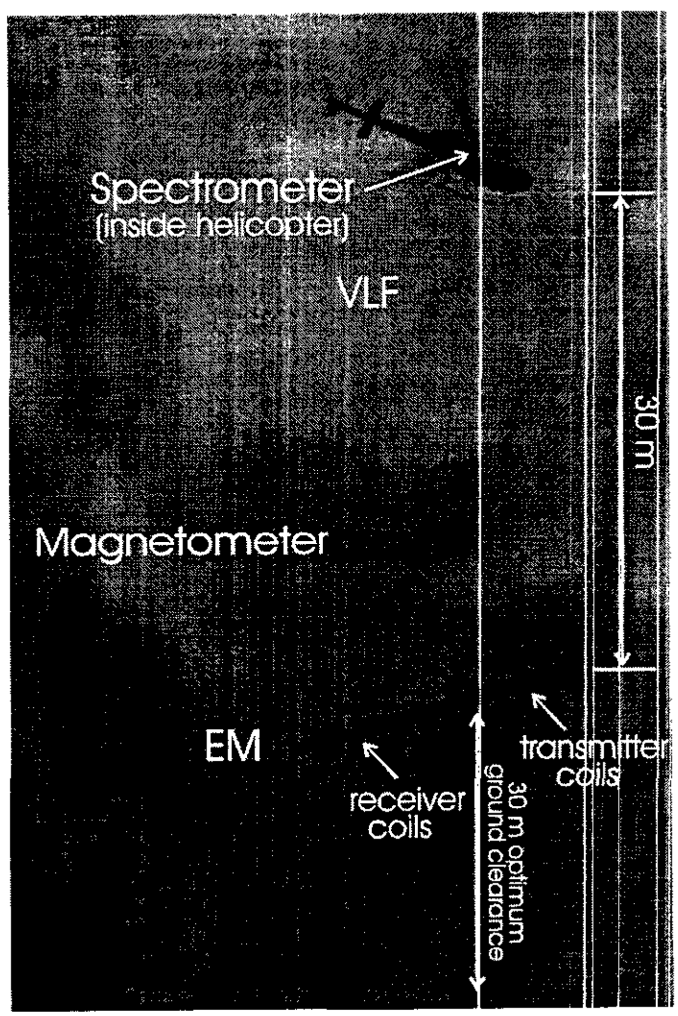

Plate 1. Bird configuration for the East Kootenay Geophysical Survey. The EM bird contains three transmitter and receiver coils. The spectrometer is housed inside the helicopter.

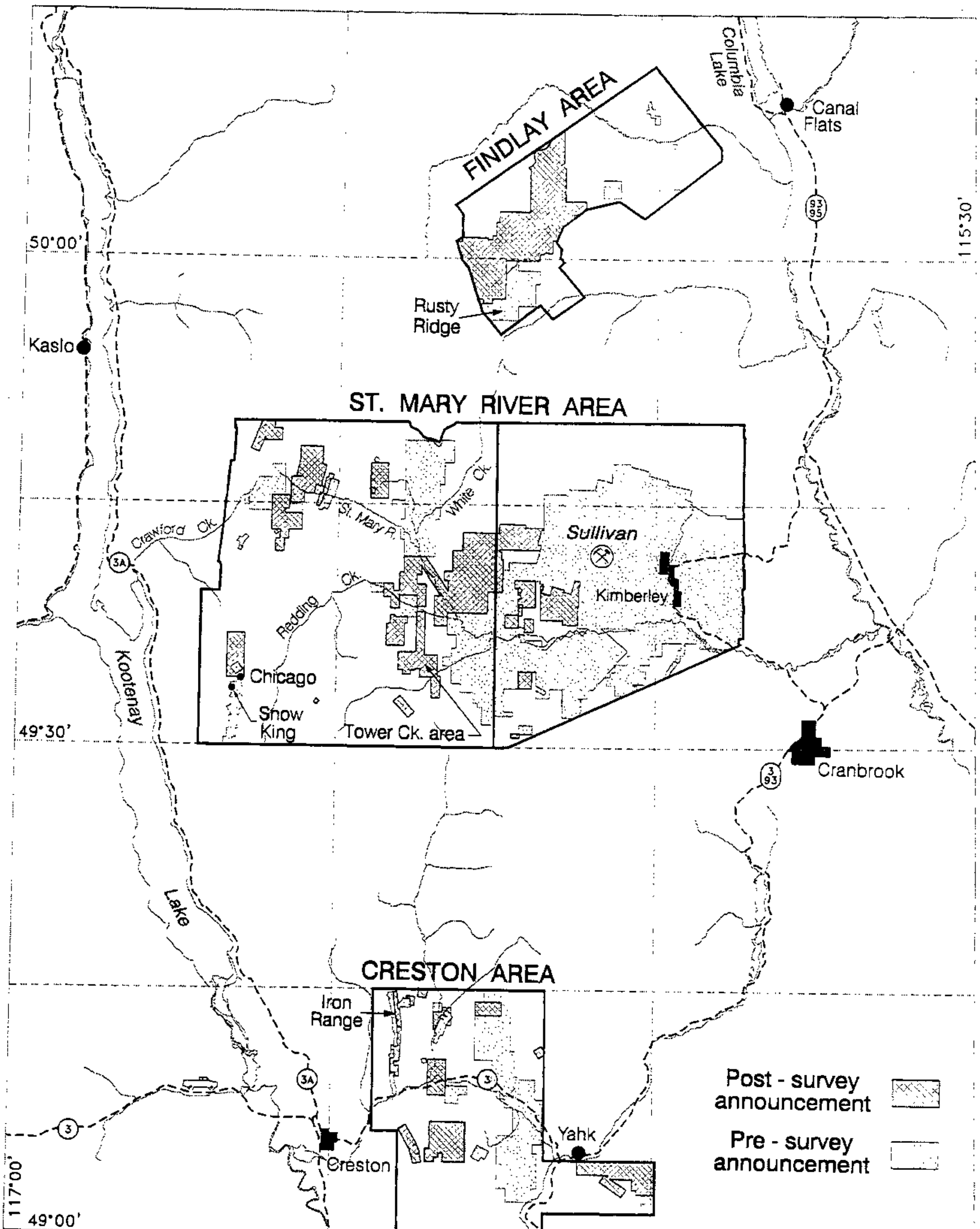

Figure 4. Simplified representation of claim staking pre- and post-announcement of the geophysical survey. Increases were 30%, 440% and 65% for the St. Mary River, Findlay Creek and Creston areas, respectively.

SULLIVAN-NORTH STAR CORRIDOR

The Sullivan-North Star corridor is a 6 km by 1.5 km, north-trending zone of fragmental and disrupted sedimentary rocks that are intensely altered and locally mineralized (Hagen, 1983; Höy, 1984a). The corridor hosts Sullivan, North Star and Stemwinder deposits (Figure 5). It is truncated by the Kimberley fault to the north and pinches-out to the south due to deeper stratigraphic levels and thicker Quaternary cover. The North Star and Stemwinder stratiform and vein deposits were mined up to 1929 and contained about 100,000 tonnes of ore. The corridor is interpreted to be a rift-related hydrothermal field (Turner *et al.*, 1995).

The Sullivan deposit has been in continuous production since 1900 and is one of the world's largest stratiform, sediment-hosted massive sulphide deposits. It has produced over 140 MT of ore containing 9 million kg silver, 8 billion kg lead and 7.4 billion kg zinc. The total resource was estimated to be more than 160 Mt grading 6.5% Pb, 5.6% Zn, 25.9% Fe and 67 g/t Ag (Ransom *et al.*, 1985). The mine is projected to close in 2001. It has been extensively documented by geological studies including Hamilton *et al.* (1983), Hamilton (1984), Ransom *et al.* (1985), Höy *et al.* (1995b) and Turner *et al.* (1993, 1995). The deposit comprises a discordant western vent zone (Leitch and Turner, 1992) and an eastern stratiform zone of bedded ores close to the lower-middle Aldridge contact. Deposit characteristics include footwall chaotic breccia, intraformational conglomerate, tourmalinite alteration pipe, muscovite and albite-biotite-chlorite-alteration, manganiferous garnet-rich beds, a gabbro arch, and gently east-dipping stratiform massive and laminated sulphides. The orebody comprises massive pyrrhotite and banded pyrrhotite-galena and sphalerite. Its maximum thickness is about 100 m and it thins rapidly to the east. The dimensions of the vertical projection of the deposit to surface are about 2.0 km by 1.6 km (Figure 5a).

The following is a description of the geophysical responses around the Sullivan Mine and Sullivan - North Star corridor near Kimberley. Despite extraction of over 140 MT of ore from the Sullivan Mine, the remaining portions still produce significant but subdued magnetic and conductivity responses. In addition, accumulations of altered, barren to weakly mineralized waste rock on the surface around the deposit correspond with pronounced magnetic and EM anomalies as well as with distinctive radioelement concentrations.

Electromagnetics

At the Sullivan Mine, non-cultural EM conductors are coincident with the surface projection of the sulphide-rich Sullivan horizon, especially where it is cut by the Sullivan fault along the west side of the deposit, and along the south side of the open pit (Figure 5). The Sullivan fault zone contains pyrrhotite at depth (R.J.W. Turner, personal communication, 1996) and this is most likely the source of the conductors on the west side of the deposit. The undisturbed pyrrhotite replacement body as well as other unmined massive sulphide ore may also contribute to the high conductivity values observed here. The finite conductors are quite broad, less than 15 m deep, with in-phase and quadrature values generally larger than 15 ppm. They also have large conductance (conductivity times thickness) values, as calculated from the 900 Hz coaxial data assuming a two-dimensional vertical conductor in free space. Curiously, the collapse zone of the deposit, where mining has been closest to surface, does not correspond to a conductivity anomaly.

There are also a number of EM conductors related to cultural features including mine buildings, heavy equipment, and powerlines lines immediately east and south of the Sullivan open pit (Plate 2). In general, the deeper a given conductor is buried the lower the absolute values of both the in-phase and quadrature components. However, the ratio of the in-phase and quadrature components is only slightly affected by burial depth. This ratio is an important indicator of conductivity; the larger the ratio the better the conductor (see Figures 5 and 6).

The most prominent and concentrated cluster of EM anomalies for the entire survey area occurs in the vicinity of the North Star-Stemwinder Mines, over an area 1.0 km by 1.2 km. The cluster is comprised of shallow conductors with larger conductance values than those at Sullivan. These conductors result from north-trending sulphide deposits including those in the abandoned mine areas and sulphide filled fractures. The associated conductivity anomaly dies-out where the Stemwinder vein pinches-out north of Mark Creek, in an area of thick Quaternary cover and deep weathering. This deep weathering zone comprises oxidized and friable bedrock up to 146 m below surface and probably represents a preserved zone of Tertiary weathering (P. Ransom, personal communication, 1996).

A broad, east-trending zone of moderate to high conductivity (900Hz coaxial) with numerous apparent conductors east of Kimberley along highway 95A corresponds to powerlines and transformers, homes and possibly wet, clay-rich surficial material.

Magnetics

Within the Sullivan-North Star corridor there is an irregularly-shaped (4.5 km by 3.2 km), moderately positive magnetic anomaly with localized zones of high anomaly values over the Sullivan and North Star deposits (Figure 5b). The anomaly is truncated to the north by the east-trending Kimberley fault. The western and southern boundaries are less well defined. To the east the anomaly abruptly terminates at a narrow (< 500 m wide), south-trending magnetic linear that extends from the St. Mary River valley to the Kimberley fault.

The localized zones of maximum magnetic anomaly values at Sullivan and North Star (peak amplitudes are approximately 90 and 60 nT, respectively), correspond to the shallowest portions of the mineralized zones and at Sullivan occur along the trace of the Sullivan fault (Figure 5b). The Sullivan "high" is due in part to the massive pyrrhotite replacement body (up to 50 m thick and 500 m long, P. Ransom, personal communication, 1996) and to the network of pyrrhotite-quartz-carbonate veins beneath the western portion of the orebody. Most of this pyrrhotite must be weakly magnetic otherwise a stronger anomaly would be produced. Although the eastern portion of the orebody includes stratiform beds of magnetite (cumulative thickness of less than 1 metre), this material is volumetrically minor and much of it has been mined, accounting for the lower magnetic amplitudes observed in this region.

The North Star "high" is situated between the North Star and Stemwinder Mines, where abundant disseminated and fracture-filled pyrrhotite occurs. As within the Sullivan Mine the magnitude of the anomalies suggests that a considerable proportion of the pyrrhotite must be in the ideally antiferromagnetic form (i.e. troilite). North of the Stemwinder Mine lower magnetic amplitudes correspond to the zone of thick Quaternary cover and deep bedrock weathering discussed above.

Gamma Ray Spectrometry

In the Sullivan Mine area, elevated radioelement concentrations (K- potassium, eU - equivalent uranium, and eTh - equivalent thorium) are associated with the open pit, collapse zone and waste dumps (Figure 5b and Plate 2). Although these anomalies are enhanced by the increased exposure and better drained material resulting from mining, ground spectrometry confirms that elevated concentrations are present. Subtle eTh/K ratio lows are apparent over the eastern and southern waste dumps, but are not associated with the open pit or collapse area. This suggests that the transported waste rock contains relatively more potassium than that exposed near or at surface in bedrock and surficial materials. Elevated K, eU and eTh patterns extend northward from the pit area, across the Kimberley fault, over argillaceous units of the upper Aldridge Formation on Sullivan Hill. This trend is lithologic, but unrelated to the mineralization and sericite alteration that characterize the Sullivan-North Star corridor.

Patterns over the North Star deposit show similar increases in all three radioelements, and the airborne eTh/K lows in this area and in situ spectrometry on bedrock and talus indicates that relative enrichment of potassium does occur. The enrichment corresponds closely to exposed sericite alteration within the sub-

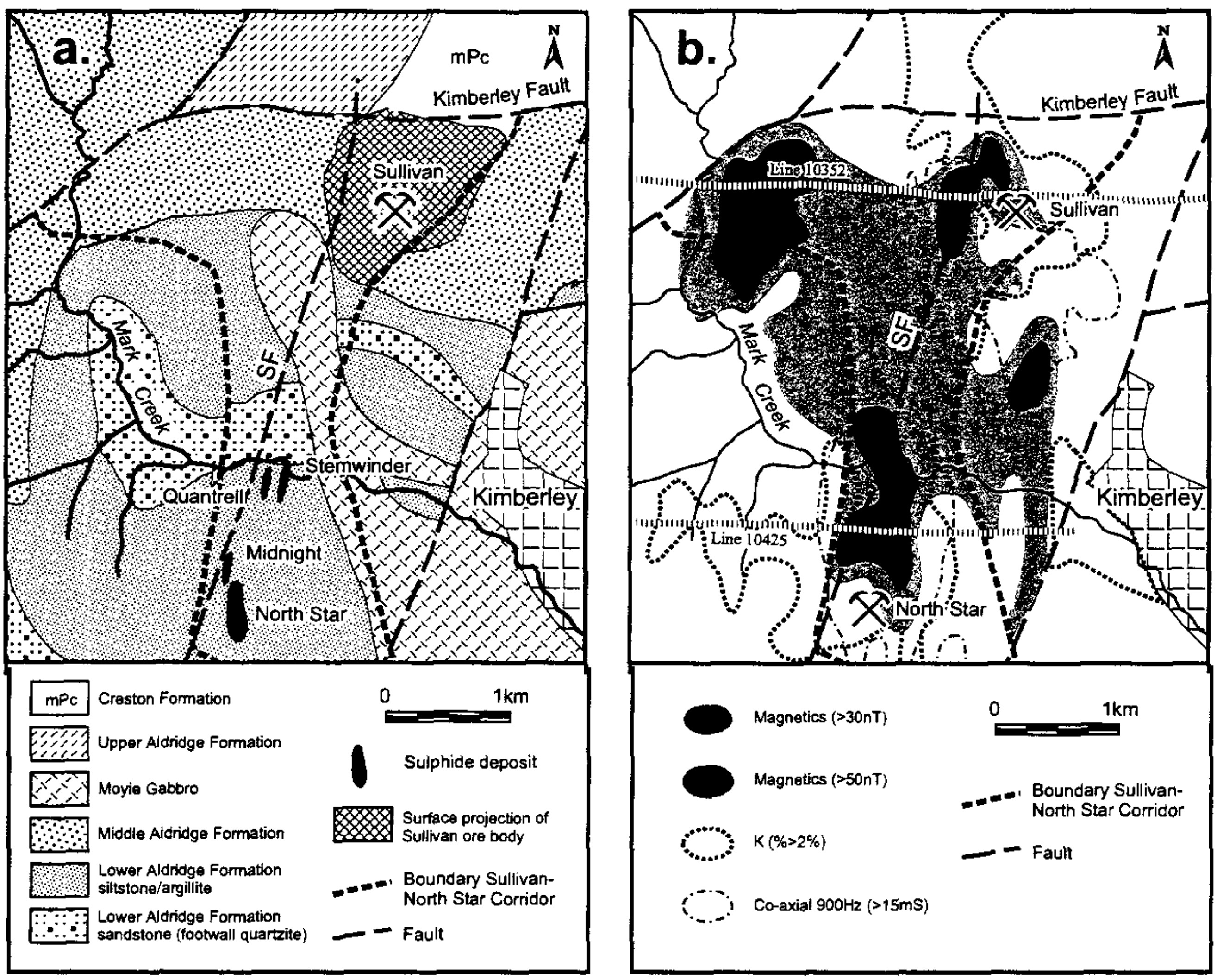

Figure 5. a) Geological map of the Sullivan-North Star corridor (modified from Hagen, 1985; Höy, 1993); b) Simplified magnetic, EM (900Hz coaxial) and K anomalies for the region shown in (a). SF = Sullivan fault.

vertical root zone of the Sullivan-North Star corridor. This includes the narrow, north-trending high K, low eTh/K ratio pattern which extends 2.0 km to the south. These patterns are enhanced by increased bedrock exposure related to old mine workings (ex. North Star Mine area), trenches, cleared ski runs or talus, however, they still reflect the primary north-trending alteration system.

Lower amplitude K highs with coincident eTh/K lows occur west and northwest of North Star Hill, in steeply sloping or bowl shaped areas covered with a very thick clay-rich till. While these anomalies accurately reflect the relatively K rich chemistry of the till, the corresponding low magnetic total field response suggests that the radioelement anomalies do not represent exploration targets as characterized by those known within the Sullivan-North Star corridor. The combination of radiometric and magnetic/electromagnetic patterns may provide useful exploration vectors for these SEDEX deposits. This combination has been clearly demonstrated over many other deposit types, such as alkalic and calc-alkalic porphyry-Cu-Au+/-Mo deposits and volcanic-hosted massive sulphide deposits elsewhere (Shives *et al.*, 1995).

Borehole geophysical logs and tables for Sullivan Mine stratigraphy drilled east of Kimberley are presented in Killeen *et al.* (1995) distal (about 5 km southeast) from the altered core zone that constitutes the Sullivan-North Star corridor. These logs show that massive sulphide encountered in the hole produces intensely positive conductivity and magnetic susceptibility anomalies but no significant radiometric signature. From this point of view the massive sulphide in this hole must be unusual as nowhere else in the region do such strong responses occur. However, most subunits of the Aldridge are weakly magnetic and resistive. This illustrates the challenge faced by explorationists in SEDEX camps because alteration zonation can be restricted or absent on the fringe of a deposit.

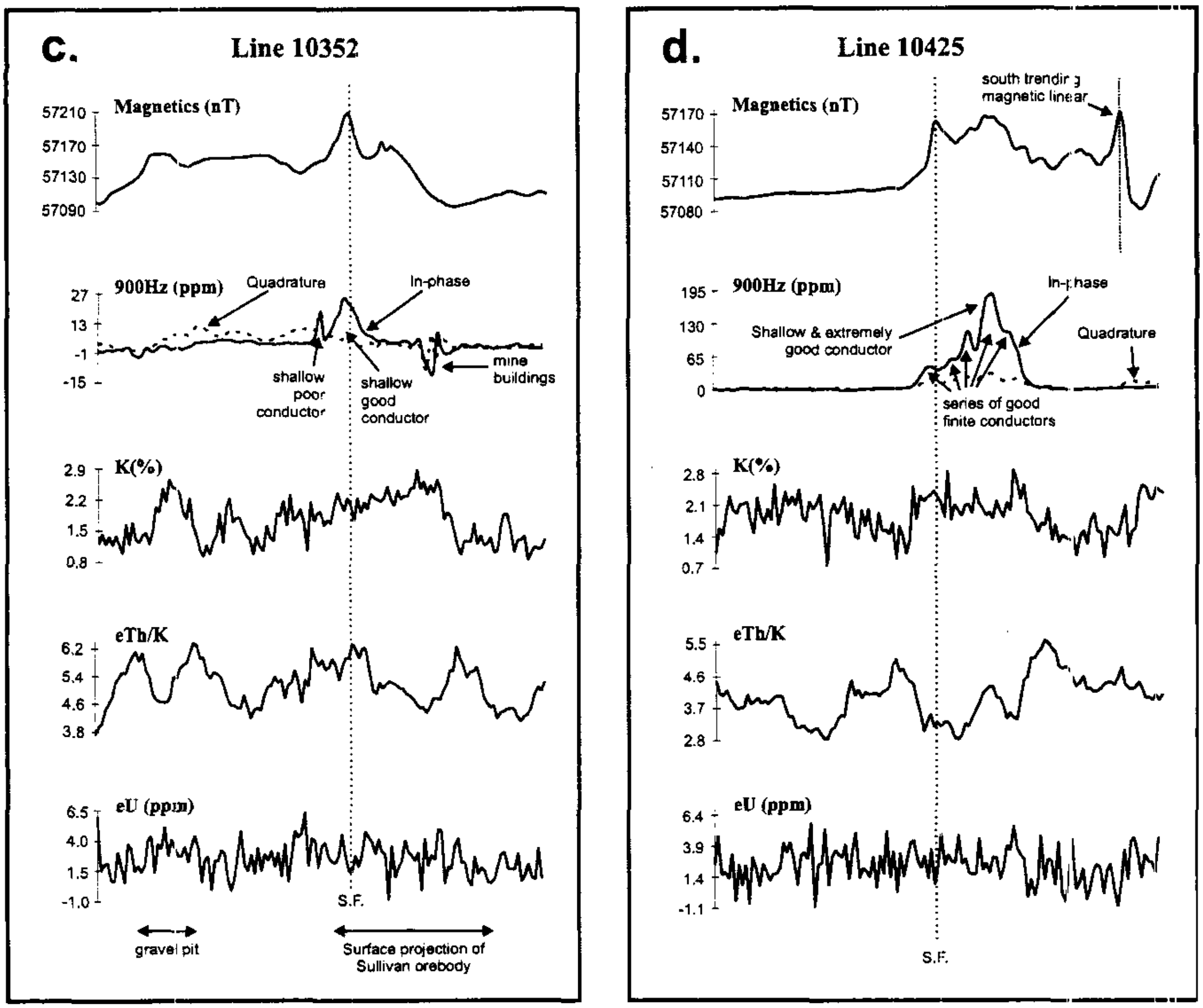

Figure 5. c and d) stacked profiles of magnetic, conductivity, K, eTh, and eU along the east-trending flight lines 10352 and 10425 over the Sullivan and Stemwinder deposits, respectively. SF = Sullivan fault.

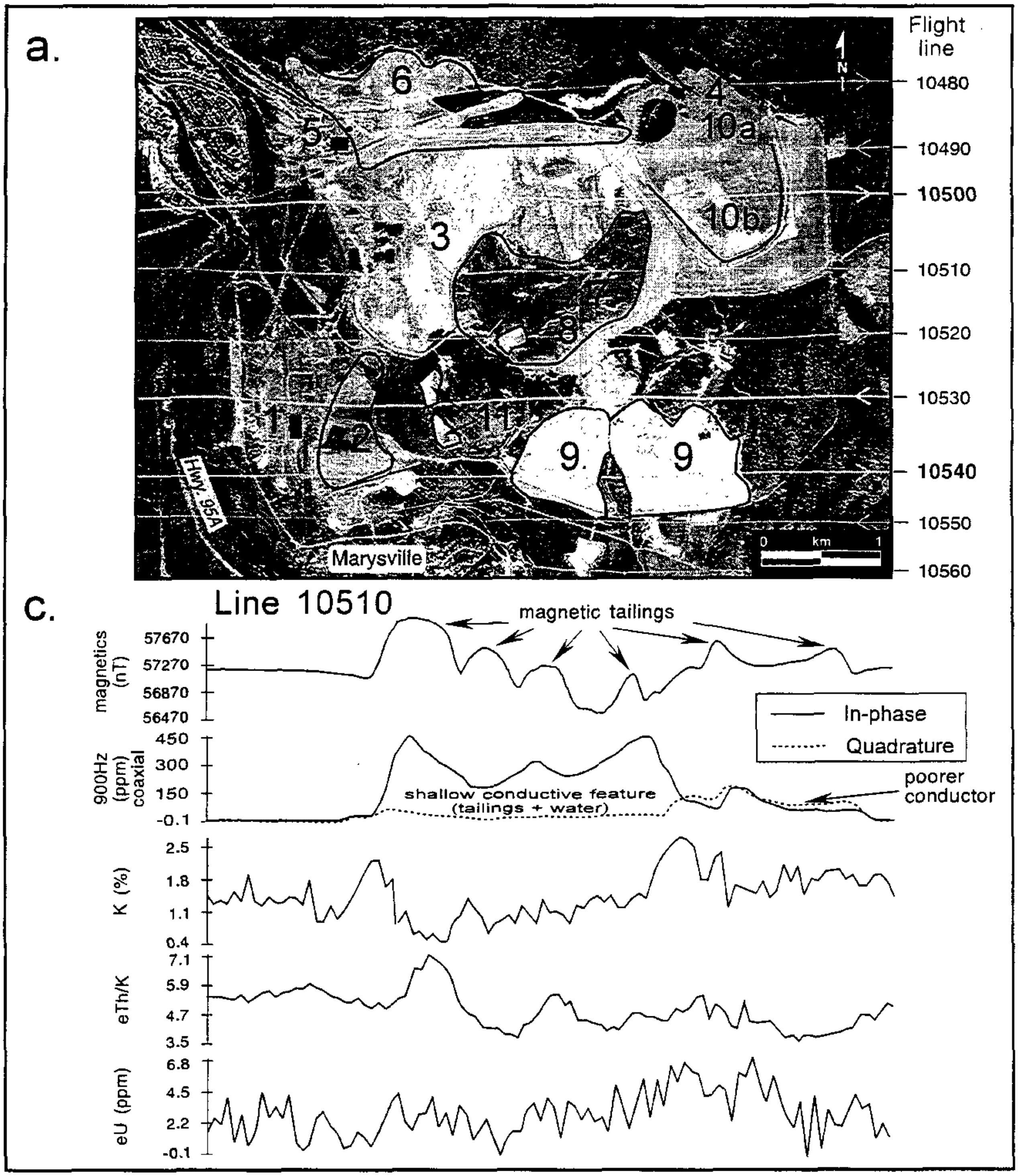

Figure 6. a) Surface features of the Sullivan tailings area, airphotograph supplied by Cominco Ltd. (photo FFC94016-29, August 10, 1994). 1 = fertilizer plant buildings (demolished); 2 = calcine tailings; 3 and 4 = old iron tailings (pyrrhotite concentrate; 40 years); 5 = mill buildings; 6 = float/waste rock; 7 = active tailings (post 1987) deposited over old iron tailings; 8 = water; 9 = gypsum tailings; 10a = siliceous tailings covered by float rock and glacial till and revegetated; 10b = siliceous tailings partially covered by float rock; 11 = thin layer of gypsum with minor water (old cooling ponds for gypsum plant. Arrows on flight lines indicate direction of helicopter during data acquisition; and c) stacked profile of magnetic, conductivity, K, eTh, and eU along flight line 10510.

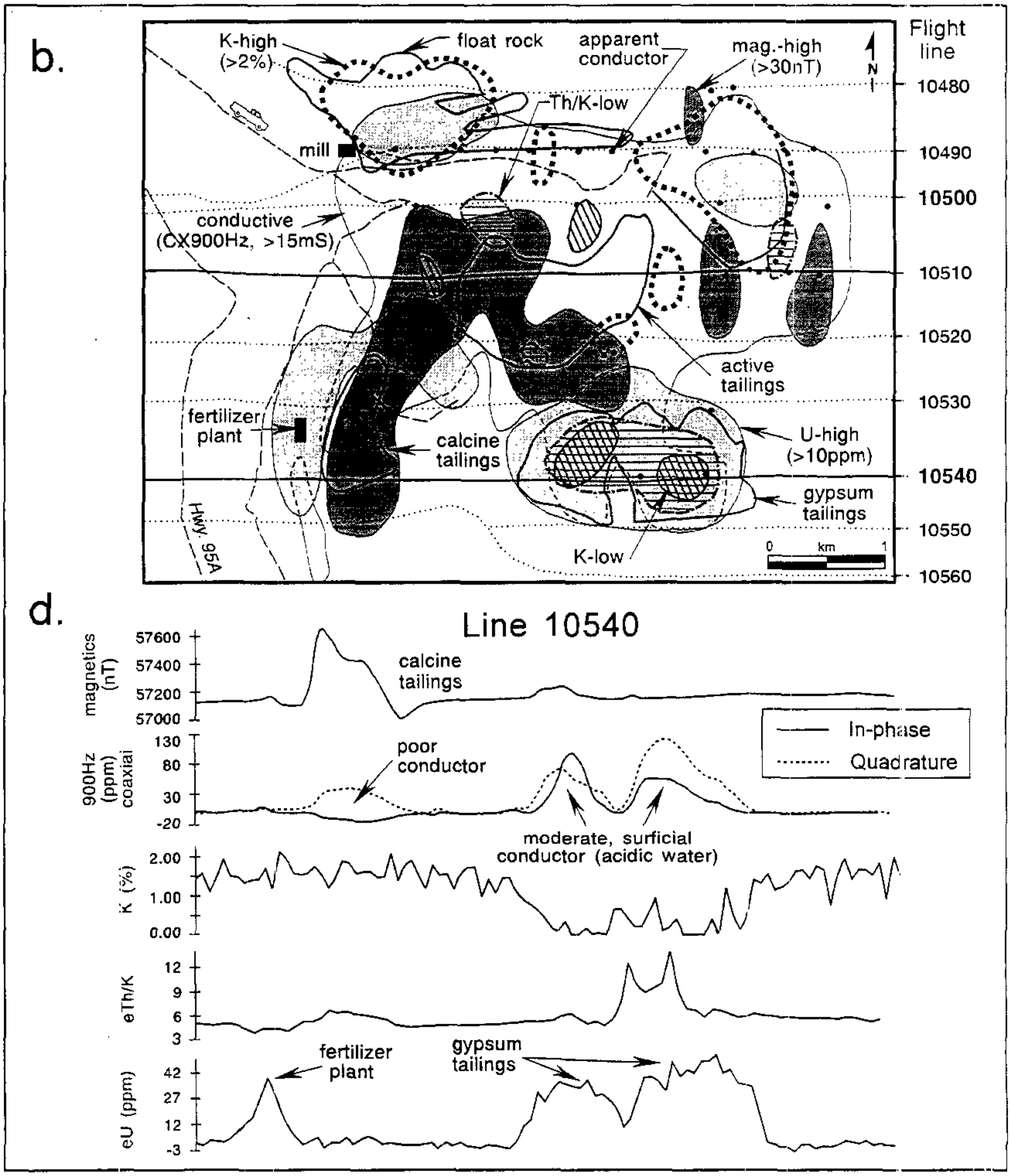

Figure 6. b) Corresponding simplified magnetic, EM (900Hz coaxial), K, eTh/K and eU anomalies for the region shown in (a); and d) stacked profile of magnetic, conductivity, K, eTh, and eU along flight line 10540.

SULLIVAN TAILINGS AREA

There are prominent geophysical anomalies in a 12 km^2 area over the Sullivan tailings (Figure 6). These anomalies result from base-metal extraction and fertilizer production. The northern tailings areas are dominated by waste material acquired from different parts of the Sullivan Mine and deposited over a 90 year interval.

The southern part of the tailings area includes the demolished fertilizer plant that operated from 1953 to 1987 and its associated two gypsum ponds. The phosphate rock was mined in Montana and processed into fertilizer: sulphate mixed with sulphuric acid formed gypsum and phosphoric acid (ammonia phosphate fertilizer). The gypsum by-product is now contained in two tailings ponds that have a unique gamma ray response which is described below.

Electromagnetics

The entire tailings area, including the gypsum tailings, form a broad zone of high conductivity, probably

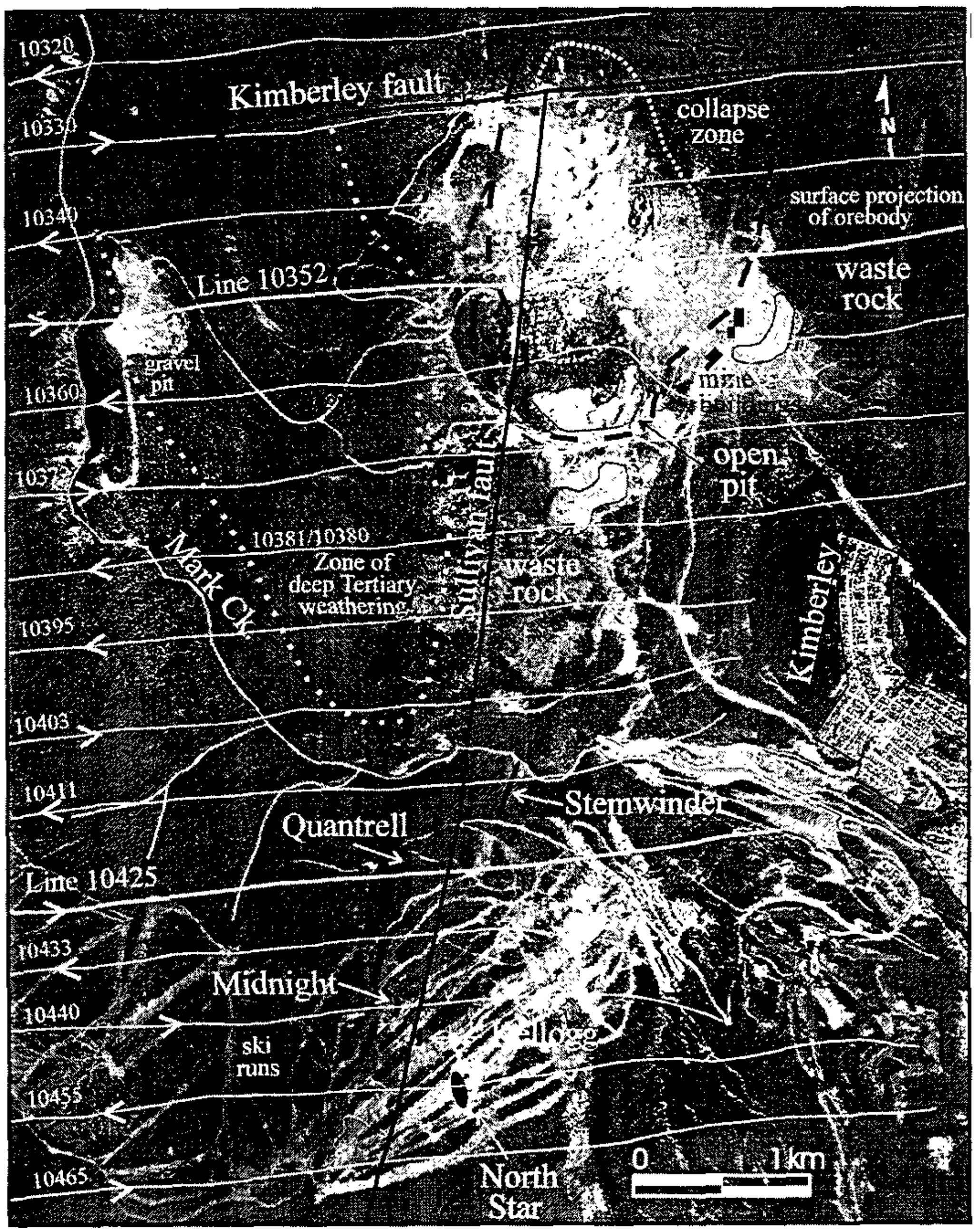

Plate 2. Surface features around the Sullivan-North Star corridor. Airphotograph supplied by Cominco Ltd. (photo FFC94016-19, August 10, 1994). Arrows on flight lines indicate direction of helicopter during data acquisition. The extent of the deep Tertiary weathering zone is courtesy of P. Ransom (written communication, 1996).

resulting from metal-rich acidic pore water. The pH and sulphate content of the tailings is variable, in part due to mixing of alkaline groundwater that seeps into the area from the north. In the gypsum tailings, residual sulphuric and phosphoric acid, and dissolved sulphate produce the low pH water (<2) that also has a high content of dissolved iron. Such a solution would be conductive. This high conductivity zone is equal in extent to the combined Sullivan and North Star conductivity anomalies, but is related to acidic pore water rather than bedrock.

Weak apparent conductors are observed within the tailings area also. Those in the south and west are mainly cultural (power lines, metal buildings, etc.) in origin. The remainder lie within the tailings area proper (Figure 6b) and are of variable strength. Several broad, moderate strength conductors have unknown origin. Conductors imaged along flight line 10490 may be related to the tailings slurry carried in a PVC pipe.

Magnetics

The magnetic patterns do not follow present day surface features as more recent, less magnetic waste covers the sulphide-rich tailings. However, three strongly positive magnetic anomalies correspond to areas where pyrrhotite- and magnetite-rich tailings have been deposited (Figure 6). The magnitude of the anomalies reflects differing concentrations of magnetic minerals present in the tailings, as well as their depth of burial. Prior to 1987 tailings were separated into "siliceous" and "iron" varieties with 10% and 25-30% sulphur, respectively. Since then, one type of tailings has been deposited with about 18% sulphur (Bob Gardiner, personal communication, 1996). Field checking also suggests that the top layer of the sulphide-rich tailings (one metre or so depending on the level of the water table) is highly oxidized (limonitic) and less magnetic (magnetic susceptibility (MS) = 1.5×10^{-3} SI) than deeper, less oxidized tailings below this cap (MS = 6.0×10^{-3} SI).

The southwestern prong of the prominent, inverted V-shaped magnetic anomaly includes the iron-oxide pond (calcine; Figure 6b). Calcine is a by-product derived from roasting pyrrhotite concentrate to produce sulphuric acid (used in fertilizer production). The roasting process drove off sulphur and replaced it with oxygen, thus converting pyrrhotite to hematite. However, as much of the calcine is exceptionally magnetic (MS ≈ 250×10^{-3} SI), it is inferred that much of the pyrrhotite was converted into ferromagnetic hematite (maghemite, gamma-Fe_2O_3).

The three smaller positive anomalies in the northeastern part of the tailings area occur where iron-rich material (pyrrhotite) is buried beneath siliceous waste rock.

Gamma Ray Spectrometry

As expected, radioelement patterns in the tailings area correlate closely with surficial material. The exposed float rock is characterized by elevated K, eU and eTh values, and depressed magnetic amplitudes. As observed in the Sullivan Mine area, this barren but altered material yields strong eTh/K lows which reflect the increased hydrothermal sericite content. Therefore, the two largest zones of elevated K correspond closely to areas of "float" rock and "siliceous" tailings (Figure 6). Three small K-lows reflect wetter or water covered portions of the tailings. The strongest eU concentrations correspond to the gypsum tailings and float/waste rock. Elevated eU in the Sullivan deposit could be related to allanite (C.H.B. Leitch, personal communication, 1996), an epidote mineral commonly with minor Th and U.

The two anhydrite tailings have unique, high eU and very low eTh and K signatures (Figure 6). The eU anomaly can be traced along the haulage way to the fertilizer plant. These tailings have recently (post airborne survey) been covered by silicic waste rock from the Sullivan Mine.

DISCUSSION

The analysis of the geophysical responses observed in the Sullivan-North Star corridor area provides baseline data that can be applied to mineral exploration elsewhere in the Purcell Basin.

High magnetic anomaly values, high electrical conductance, and low eTh/K ratios are characteristic of mineralization and sericitic bedrock alteration in the Sullivan-North Star corridor. This combination of geophysical responses is clear even in the vicinity of the Sullivan deposit, where up to 90% of the mineralization has been removed. On average, the depth of penetration of airborne EM system is about 100 metres and the radiometric system essentially samples only the top 20 to 30 centimetres; these limitations must be borne in mind when studying the new data.

The broad, moderate magnetic anomaly over the Sullivan-North Star corridor is distinct from local intense anomalies related to altered Moyie sills (cf. Lowe *et al.*, 1997). Another similar low amplitude, broad magnetic anomaly lies 8 km west of Sullivan in the lower Aldridge Formation near Matthew Creek. Although this anomaly lacks associated EM anomalies it warrants further analysis and follow-up investigation. Much of the Aldridge surveyed is characterized by low magnetic anomaly values implying that if present, undiscovered magnetic, massive sulphide deposits must be more deeply buried than the near surface portions of the Sullivan and North Star Mines.

The new data are a useful tool for other types of exploration. The spatial association of Cretaceous stocks to lode gold mineralization and placer deposits (for example Sawmill, Lisbon and Perry creeks) suggests a genetic link between the intrusions and gold. Preliminary analyses show that many of these plutons and/or magnetite-hematite breccias and stringer zones in nearby associated fault zones produce positive magnetic anomalies and distinct radioelement signatures. Therefore, a more thorough assessment of the new data may provide valuable information. Indeed, Lowe *et al.* (1997) demonstrate the utility of the data for refining the spatial distribution of the Reade Lake stock and for mapping distinctive phases within several of the other Cretaceous granitoids, including the White Creek batholith.

Another example where the new data provide complementary information for mineral exploration is illustrated in the southwest corner of the St. Mary River area. Here, deformed stratabound and vein mineralization includes disseminated galena, sphalerite, pyrite and tetrahedrite hosted within carbonate of the Dutch Creek or Mount Nelson formation. This rift-cover succession with alternating carbonate, argillite and quartzite hosts a number of stratabound Pb-Zn-Ba occurrences. These units are exposed in trenches and adits at the Chicago and Snow King, past producers near the headwaters of Redding Creek (Wall-Dave claims; Slingsby, 1980, 1981; Callan, 1990). A schistose mafic sill crops out on the east side of a sulphide vein at one of the Chicago trenches. The sill produces a strong magnetic high on the aeromagnetic map. Ground measurements across 2 metres of the sill indicate that the magnetic susceptibility increases from 0.68 to 30 x 10^{-3} SI units toward the mineralization, although there are no visible signs of alteration. Therefore, the identification of other magnetic sills and the direction of increasing magnetization may vector toward new zones of sulphide-rich veins.

Outside the survey area similar stratabound mineralization hosted by the same stratigraphic units include the past producing Mineral King Mine and Leg prospect (cf. Pope, 1989; Brown and Klewchuk, 1995).

Numerous other geophysical features within the survey areas require follow-up. A surprisingly large number of geophysical anomalies occur in the northwest part of the St. Mary River survey block. The upper Purcell Supergroup geology, including the Dutch Creek and Mount Nelson formations here is less well known but a recent map by Reesor (1996) provides a better base than that provided on the geophysical maps in British Columbia Employment and Investment Open File 1996-23. Analysis of these geophysical anomalies will undoubtedly provide a new perspective for explorationists working here.

CONCLUSIONS

In summary, the new and detailed geophysical data can be used to characterize and target several types of mineralization. In the case of sediment-hosted massive sulphides at Sullivan, analysis shows coincident high magnetic values, moderate to strong bedrock conductors, elevated K, low eTh/K are characteristic. This signature, with even stronger conductors, is also apparent around the North Star and Stemwinder Mines. Stratabound replacement occurrences are locally associated with magnetic sills and therefore careful follow-up of high magnetic values in the Dutch Creek and Mount Nelson part of the stratigraphy could lead to future mineral discoveries. Magnetic and radioelement patterns detail lithologic variations of Cretaceous plutons. Some of these bodies have potential to host or be related to gold mineralization. In addition, with the aid of the geophysical patterns current geological maps could be refined and sub-units distinguished. This could lead to new models and mineral targets.

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Doug Anderson, Craig Kennedy, Peter Klewchuk, Craig Leitch, Paul Ransom, Tim Termuende, and Bob Woodfill provided helpful ideas and valuable information. Bob Gardiner and Gray Gibson's knowledge of the Sullivan tailings area was very useful. Doug Barraclough safely guided us around the collapse zone at Sullivan Mine. Jim Turner provided information on claim staking. Verna Vilkos and Richard Franklin's drafting expertise is appreciated. Ralph Currie and Dave Lefebure are thanked for their comments that improved the manuscript.

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Geological Fieldwork 1996

U-PB AGES FROM THE SELKIRK ALLOCHTHON, SEYMOUR ARM MAP AREA, SOUTHEAST BRITISH COLUMBIA (82M/8 AND 9)

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KEYWORDS: Goldstream pluton, Downie Creek orthogneiss, Clachnacudainn complex, Lardeau Group, Badshot Formation, geochronology, radiogenic isotopes, U-Pb.

INTRODUCTION

During the course of 1:50 000 scale regional mapping in the Northern Selkirk Mountains (NTS 082M) various granitic rocks were sampled for U-Pb geochronology. This report presents new U-Pb data, interpreted ages, and the implications of these results for two such samples from the Selkirk Allochthon: the Downie Creek orthogneiss, and the Goldstream Pluton.

The Downie Creek orthogneiss consists of a series of foliated granite and granodiorite sheets which intrude a quartz-rich sequence of garnet-muscovite-biotite and chlorite bearing paragneiss and schist within the Selkirk Allochthon. These orthogneisses were affected by regional ductile polyphase contractional deformation and related metamorphism and later overprinted by brittle deformation associated with the Columbia River fault. They are lithologically and structurally similar to, and likely correlative with, Devono-Mississippian gneisses of the Clachnacudainn suite exposed near Revelstoke (Parrish, 1992). U-Pb geochronology of the Downie Creek orthogneiss was undertaken to strengthen or refute this correlation.

The Goldstream Pluton is an elongate, east-trending plutonic complex consisting of granitic to monzodioritic sills intimately mixed with metasedimentary pendants, septa and xenoliths. These granitoids commonly have foliated margins and massive interior zones. The Goldstream Pluton was previously thought to have been emplaced prior to, or during regional deformation, based largely on its regional structural concordance with surrounding foliated country rocks, (Höy, 1979). However, the presence of a chiefly retrograded contact metamorphic aureole, which overprints penetrative foliations in the country rocks, indicates that this body post-dates most of the ductile deformation in the area. This conclusion is further supported by the presence of foliations in xenoliths and pendants, which are interpreted to be correlative with regional deformation fabrics, and are cut by the Goldstream pluton. Hornblende and biotite $^{40}Ar/^{39}Ar$ plateau ages of 114±4.5 Ma and 100±1 Ma, respectively, have been previously reported for the Goldstream pluton, indicating a relatively slow cooling rate for this body (Logan and Colpron, 1995). U-Pb geochronology of this body was carried out to determine its crystallization age, and to complement these $^{40}Ar/^{39}Ar$ cooling data.

REGIONAL GEOLOGY

The Downie Creek area, within the northern Selkirk Mountains, straddles the boundary between rocks assigned to the North American miogeocline and the pericratonic Kootenay Terrane (Wheeler *et al.*, 1991; Wheeler and McFeely, 1991). The area lies in southeastern British Columbia, in the Omineca Morphogeologic Belt, an uplifted region extending the length of the Canadian Cordillera that is underlain extensively by metamorphic and granitic rocks (Gabrielse *et al.*, 1991).

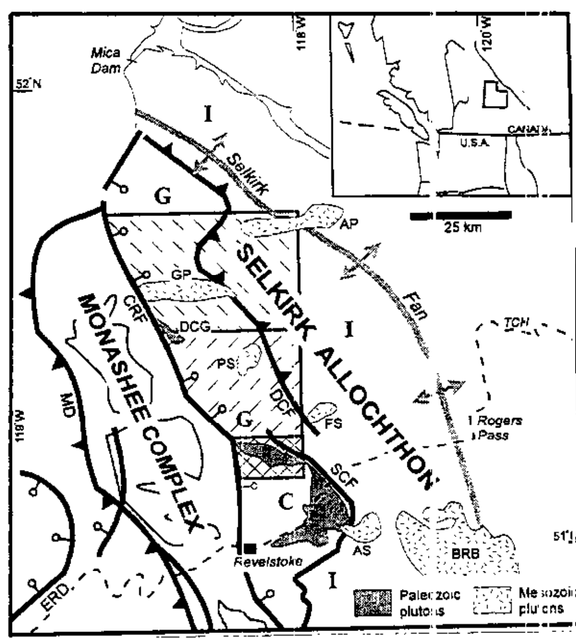

Figure 1: Geological setting and location of the Goldstream River (southeasterly dashed), Downie Creek (southwesterly dashed) and La Forme Creek (hatched) map-areas along the western flank of the Selkirk fan structure, within the Selkirk allochthon; modified after Brown and Lane (1988). I = Illecillewaet 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 pluton, GP = Goldstream pluton, AP = Adamant pluton, DCG = Downie Creek gneiss, TCH = Trans-Canada Highway

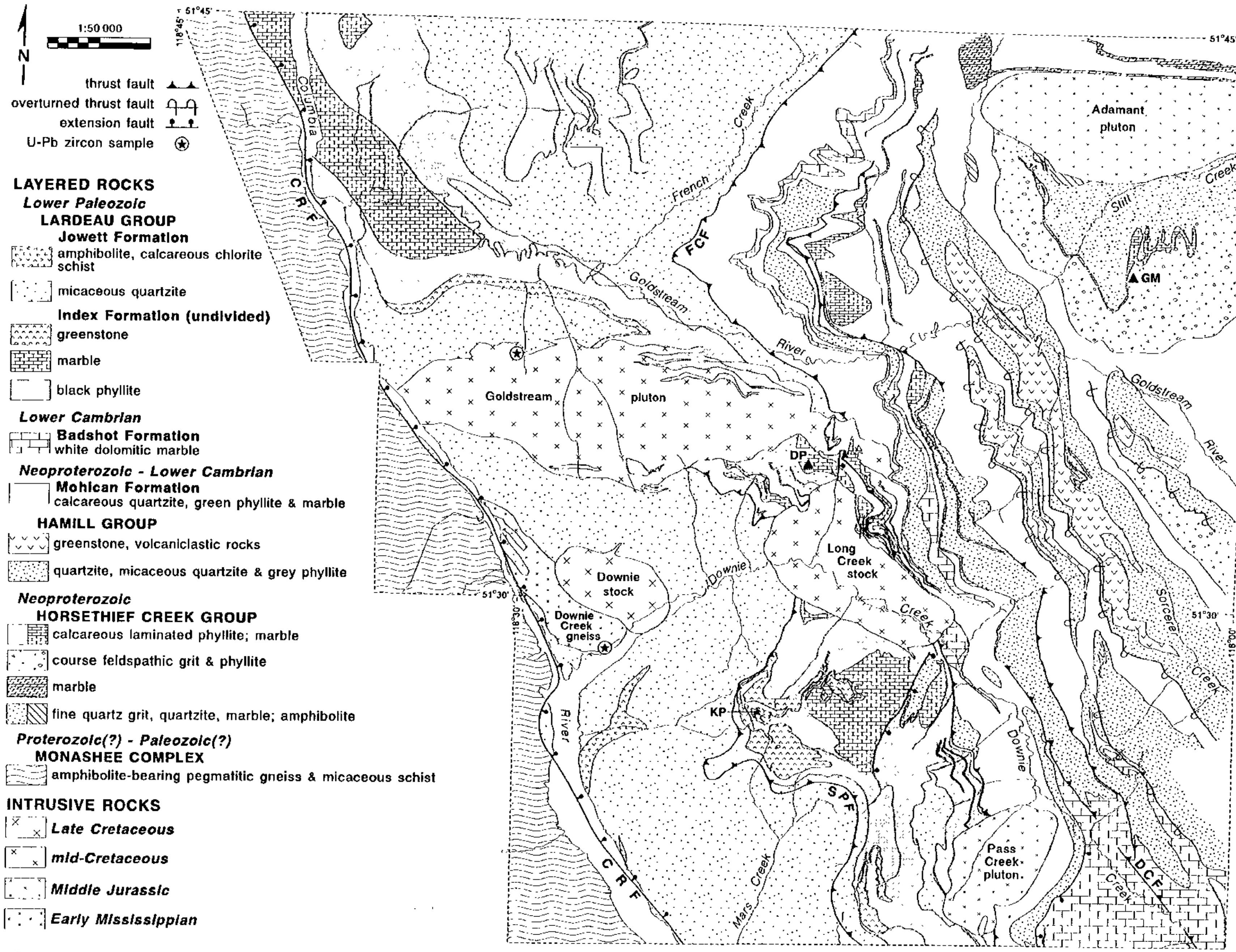

Figure 2. Geological map of the Goldstream River and Downie Creek areas compiled from mapping completed in 1996, from Colpron *et al.* (1995) and from Logan *et al.* (1996). U-Pb zircon sample sites are shown by stars. Topographic features: GM = Goldstream Mountain, DP = Downie Peak, KP = Keystone Peak. Faults: CRF = Columbia River Fault, FCF = French Creek Fault, DCF = Downie Creek Fault, SPF = Standard Peak Fault.

The study area lies within the Selkirk Allochthon, a regional nappe structure related to thick-skinned thrusting that formed largely during Middle Jurassic to Paleocene contractional deformation and telescoping associated with the accretion of arc and oceanic terranes from the west (Price, 1981; Brown *et al.*, 1986, 1992a). This contractional deformation resulted in a complex pattern of superposed folding and faulting, dominated by the northwest-trending Selkirk fan structure. The eastern flank of this structure is characterized by a northeast-verging imbricate thrust system; the western flank is dominated by southwest-verging fold-nappes and thrust faults (Wheeler, 1963, 1966; Raeside and Simony, 1983). Eocene brittle extensional structures, such as the Columbia River fault which defines the western margin of the Selkirk Allochthon, overprint earlier contractional features (Figure 1).

Stratigraphic units recognized and subdivided within dominantly metasedimentary sequences of the northern Selkirk Mountains (Figure 2) include the Neoproterozoic Horsethief Creek Group (Windermere Supergroup), the Eocambrian Hamill Group, the Lower Cambrian, *Archaeocyathid*-bearing Badshot Formation, and the lower Paleozoic Lardeau Group (Wheeler, 1963, 1965). These rocks have been intruded by granitoids belonging to several plutonic suites (Gabrielse and Reesor, 1974; Armstrong, 1988; Woodsworth *et al.*, 1991): Devono-Mississippian orthogneisses of the Clachnacudainn suite; syn- to late-deformational, Middle Jurassic (*ca.* 180-165 Ma) alkaline and calc-alkaline granitoids of the Kuskanax and Nelson plutonic suites, respectively; Mid-Cretaceous (*ca.* 110-90 Ma), two-mica and biotite-hornblende granites and granodiorites of the largely post-deformational Bayonne plutonic suite; and, a less voluminous Late Cretaceous (*ca.* 70 Ma) suite of leucogranites (Parrish, 1992).

LOCAL GEOLOGY

DOWNIE CREEK ORTHOGNEISS

Biotite-hornblende granite, quartz monzonite and granodiorite gneiss crop out at Downie Creek (Figure 2), and extend north into the Goldstream River map area, where they have been included in a mixed package of orthogneiss and paragneiss (Logan and Colpron, 1995). Late Cretaceous two-mica granite of the Downie stock intrudes the eastern edge of the gneiss and the Columbia River fault separates it from rocks of the Monashee Complex to the west.

The Downie Creek orthogneiss includes sills and sheets of foliated granitic orthogneiss up to 1,000 metres thick. It varies in modal composition from biotite-hornblende granodiorite to granite and is I-type in character. Typically, the gneiss is strongly foliated, with biotite and rarely hornblende-rich mafic layers and flattened quartz and plagioclase-rich felsic layers (Photo 1). Oval aggregates of biotite crystals give the gneiss a distinctive spotted texture and locally define a good lineation. Local low strain zones within the gneiss are characterized by rounded inclusions of fine-grained mafic diorite within a more felsic granite to quartz monzonite matrix.

Gneiss bodies intrude a thick, predominantly quartzose package of medium-bedded micaceous quartzite with thin-interlayered metapelitic horizons, muscovite-biotite schist and coarse garnet amphibolite. Regionally, the micaceous quartzite package occupies a stratigraphic position between the Index and Jowett formations of the Lower Paleozoic Lardeau Group. Schists and quartzites adjacent to the gneisses contain synkinematic garnet pophyroblasts, which are commonly mantled by retrograde chlorite rims. Regional relationships indicate a Middle Jurassic age for the southwesterly-verging deformation and the peak of regional metamorphism (Archibald *et al.*, 1983; Brown *et al.*, 1992b).

Photo 1. Foliated biotite monzodiorite of the Downie Creek orthogneiss, 1 kilometre east of zircon sample location on Highway 23.

Photo 2. Biotite quartz monzonite; felsic phase of the Goldstream pluton. Penetratively foliated inclusions in the intrusion indicate it postdated the dominant Mesozoic phase of deformation.

GOLDSTREAM PLUTON

The Goldstream pluton is an elongate, east-trending intrusive complex consisting of monzodiorite and granite sills intimately mixed with pendants, septa and xenoliths of foliated, dominantly metasedimentary country rock. The pluton is a composite body consisting predominantly of an older hornblende biotite monzodiorite phase (dated in this study) and a younger, more felsic, biotite quartz monzonite to granite phase.

The apparent structural concordance of locally foliated granitic sheets with regionally foliated country rock led previous workers to the conclusion that the Goldstream pluton pre-dated, or was synchronous with contractional deformation in the area (Höy, 1979). Subsequent workers have re-evaluated the contact relationships of the Goldstream pluton and now believe that its emplacement post-dates most of the ductile contractional structures and fabrics in the area. Critical features observed which led to this re-interpretation are: randomly oriented porphyroblasts within contact metamorphosed penetratively foliated metapelitic country rocks; foliations in xenoliths and pendants, interpreted to be correlative with regional deformation fabrics, are cut by the Goldstream pluton; and, reinterpretation of the biotite foliation, locally present within the granitic phase of the pluton, as either a magmatic foliation or a ghost foliation inherited from assimiliated xenoliths (Photo 2).

U-PB GEOCHRONOLOGY

In this section we report new U-Pb data and interpreted ages for the Downie Creek orthogneiss and Goldstream pluton. A brief description of each rock sample is followed by a discussion of the U-Pb geochronology, including zircon descriptions and data interpretation. U-Pb data are tabulated in Table 1 and plotted on concordia diagrams in Figure 3 and 4. Sample preparation and U-Pb analyses were carried out at the Geochronology Laboratory of the University of British Columbia. Complete U-Pb analytical procedures employed at the UBC Geochronology Laboratory are reported in Mortensen *et al.* (1995).

Zircons were selected for analysis on the basis of their magnetic susceptibility, clarity, colour, grain size and morphology. In general only high quality, crack- and inclusion-free grains were chosen. All fractions were then air abraded (Krogh, 1982), removing about 10-20 volume per cent of each grain.

DOWNIE CREEK ORTHOGNEISS

An approximately 20 kg sample of penetratively foliated, light grey to white, biotite quartz monzonite was collected from a road cut located north of Downie Creek on B.C. Highway 23. The outcrop has been cut by younger (post-ductile deformation) leucocratic veins and dikes, and has been chlorite-altered along steep brittle fractures related to the Columbia River fault zone. Sampling was restricted to the least altered, granitic phase of the gneiss. The sample yielded abundant high quality, clear, colourless to rarely pale yellow, euhedral, stubby to elongate prismatic zircons.

Four analysed zircon fractions are disposed along a linear trend that indicates the presence of inherited zircon (Figure 3). A chord passed through these data gives an early Mississippian lower intercept of 354.4+/-1.0 Ma (MSWD=2.87), which is considered as the best estimate for the igneous age of this rock. An upper intercept of 2.3±0.07 Ga gives an indication of the average age of inherited zircon in the analysed fractions. The coarsest stubby grains contain significant inherited zircon (fraction A), while finer and elongate grains (fractions B and D) and tips manually broken from elongate grains (fraction C) contain a greater late Paleozoic magmatic component.

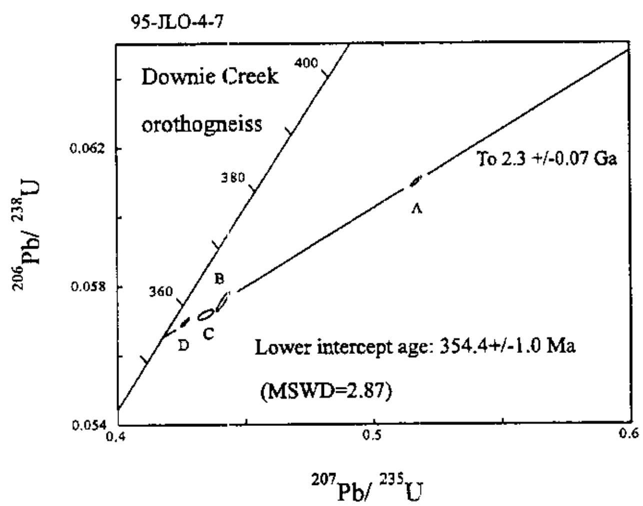

Figure 3: Concordia plot for the Downie Creek orthogneiss. Error ellipses are plotted at the 2σ level of precision. See text for details.

GOLDSTREAM PLUTON

An approximately 25 kg sample of hornblende biotite monzodiorite, the older phase of the pluton, was collected from a roadcut along the northern margin of the pluton, approximately 7 kilometres southwest of the Goldstream Mine. It comes from the same site as the sample 93JLO15-100, from which biotite and hornblende $^{40}Ar/^{39}Ar$ cooling ages were previously determined (Logan and Colpron, 1995: sample). The rock is massive and homogeneous, with no penetrative foliations developed and primary igneous textures are well preserved. It is apparently unaltered, with the exception of minor chlorite coated fractures.

This rock yielded abundant high quality, clear, colourless equant, stubby prismatic to elongate prismatic, and acicular zircon.

Five zircon fractions are concordant and overlapping at about 104 Ma (Figure 4). The best estimate for the age of the rock, which is 104.3+1.4/-1.8 Ma, is based on the average $^{206}Pb/^{238}U$ age of all fractions. The quoted error envelope is derived from the total overlap of all error ellipses with the concordia curve.

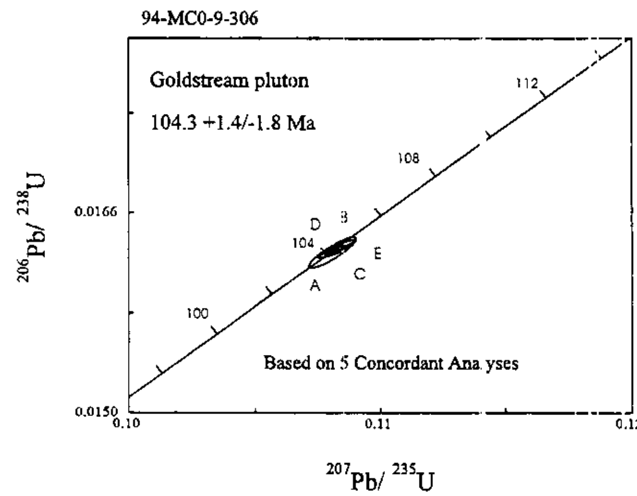

Figure 4: Concordia plot for the Goldstream pluton. Error ellipses are plotted at the 2σ level of precision. See text for details.

DISCUSSION

DOWNIE CREEK ORTHOGNEISS

The Downie Creek orthogneiss has yielded a U-Pb zircon, lower intercept crystallization age of 354.4 ±1.0 Ma, which overlaps, within precision, with a U-Pb age of 358±6 Ma for the Clachnacudainn gneiss (Parrish, 1992). The similar ages, composition and structural setting of the Downie Creek and Clachnacudainn gneisses provide strong evidence that they belong to a single Devono-Mississippian plutonic suite. They are likely part of a more extensive suite of Late Paleozoic rocks which also includes the Seymour Range gneiss (359±3 Ma; Parrish, 1992), and the Mount Fowler gneiss, (372±6 Ma; Okulitch *et al.*, 1975), located west of the Monashee Décollement.

GOLDSTREAM PLUTON

U-Pb data presented herein establish a mid-Cretaceous age of 104.3 +1.4/-1.8 Ma for igneous crystallization of the early phase of the Goldstream pluton, which can be considered as a maximum age for

TABLE 1. U-Pb ANALYTICAL DATA FOR INTRUSIVE ROCKS FROM THE DOWNIE CREEK AREA

Fraction[1]	Wt	U[2]	Pb*[3]	^{206}Pb[4]	Pb[5]	^{208}Pb[6]	Isotopic ratios (1σ,%)[7]			Apparent ages (2σ,Ma)[7]	
	mg	ppm	ppm	^{204}Pb	pg	%	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	^{206}Pb/^{238}U	^{207}Pb/^{206}Pb
Downie Creek orthogneiss: 95-JLO-4-7											
A m,N5,p,s	0.120	5584	37	12597	21	11.1	0.06101 (0.12)	0.5169 (0.19)	0.06145 (0.09)	381.8 (0.9)	655.0 (4.1)
B m,N5,p,s	0.117	663	39	5868	47	11.2	0.05755 (0.24)	0.4411 (0.29)	0.05559 (0.11)	360.7 (1.7)	436.0 (4.8)
C m,N5,p,ti	0.071	733	43	1086	172	11.6	0.05717 (0.12)	0.4345 (0.35)	0.05511 (0.27)	358.4 (0.9)	417 (12)
D f,N5,p,e	0.088	703	42	16132	13	12.8	0.05695 (0.12)	0.4264 (0.19)	0.05430 (0.09)	357.1 (0.8)	383.4 (4.2)
Goldstream pluton: 94-MCO-9-106											
A c,N1,p,e	0.269	406	7	2452	45	20.4	0.01629 (0.38)	0.1081 (0.44)	0.04814 (0.20)	104.1 (1.6)	106.1 (9.6)
B m, N1,p,e	0.255	411	8	4038	27	21.0	0.01635 (0.10)	0.1086 (0.22)	0.04815 (0.13)	104.6 (0.2)	106.5 (6.3)
C f, N1,p,e	0.163	378	7	2855	22	22.1	0.01627 (0.09)	0.1080 (0.23)	0.04811 (0.16)	104.1 (0.2)	104.8 (7.5)
D c, N1,eq	0.175	444	8	1635	49	20.1	0.01631 (0.10)	0.1082 (0.25)	0.04812 (0.17)	104.3 (0.2)	105.3 (8.1)
E m, N1,p,e	0.100	401	8	2637	16	22.2	0.01631 (0.10)	0.1082 (0.22)	0.04811 (0.14)	104.3 (0.2)	104.7 (6.8)

Notes: Analytical techniques are listed in Mortensen *et al.* (1995).

[1] Upper case letter = fraction identifier; All zircon fractions air abraded; Grain size, intermediate dimension: c= >180 μm and >134μm, m= <134μm and >104μm, f= <104μm; Magnetic codes:Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1=nonmagnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: b= broken fragments, e=elongate, eq=equant, p=prismatic, s=stubby, t=tabular, ti=tips.

[2] U blank correction of 1-3pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3] Radiogenic Pb

[4] Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 10pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

[5] Total common Pb in analysis based on blank isotopic composition

[6] Radiogenic Pb

[7] Corrected for blank Pb, U and common Pb. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the ^{207}Pb/^{206}Pb age of the fraction.

the plutonic complex. These data corroborate field relationships indicative of late-to post-deformational emplacement, with respect to contractional structural elements of the Selkirk Allochthon.

The U-Pb igneous crystallization age of 104.3 +1.4/-1.8 Ma for the Goldstream Pluton is consistent with a previously determined biotite ^{40}Ar/^{39}Ar plateau cooling age of 100±1 Ma, but conflicts with a hornblende ^{40}Ar/^{39}Ar cooling age of 114±4.5 Ma. Data from this latter age did not yield a good plateau, and we interpret these results as anomalously old, possibly due to the presence of excess radiogenic Ar.

The age and stuctural style of the pluton are consistent with it belonging to the mid-Cretaceous Bayonne Plutonic suite of southeastern British Columbia.

CONCLUSIONS

The Downie Creek area is underlain by variably metamorphosed Lower Paleozoic rocks of the Hamill and Lardeau groups, and the intervening Badshot Formation. The area is intruded by several composite granitic bodies. Data from this study and others (R.L. Armstrong; U.B.C. data file) indicate the presence of at least four intrusive suites: Early Mississippian (Downie Creek orthogneiss, circa 354 Ma), mid-Cretaceous (Goldstream Pluton, circa 104 Ma), Late Cretaceous (Downie stock, circa 66 Ma) and post-Late Cretaceous leucogranite and pegmatites. Contact relations and structural/textural features suggest that peak metamorphism and ductile deformation in the Downie Creek area occurred prior to intrusion of the Goldstream Pluton, probably during Middle Jurassic time.

Another long-lived intrusive centre occurs north of Revelstoke in the Clachnacudainn Range. The Clachnacudainn igneous complex (Crowley, 1992) is composed of mainly 5 granitoid suites, similar in age and composition to those at Downie Creek. It intrudes Lower Paleozoic (?) rocks in the northern part of the Clachnacudainn salient of Wheeler (1963, 1965).

The similar stratigraphic, magmatic and deformational history preserved at Downie Creek and in the Clachnacudainn complex suggest continuity along the east side of the Monashee complex between these two areas (Figure 1). This supports Crowley's (1992) contention that the Standfast Creek fault is a tectonically insignificant fault and the Clachnacudainn igneous complex is, like the Downie Creek area, an integral part of the Selkirk allochthon.

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NORTHERN SELKIRK PROJECT, GEOLOGY OF THE LAFORME CREEK AREA (NTS 082M/01)

By J. M. Logan and C. Rees

KEYWORDS: LaForme Creek, Carnes Creek, Clachnacudainn complex, Lardeau Group, Index Formation, Badshot Formation, Hamill Group, Mastodon Mine, stratabound massive sulphides.

INTRODUCTION

Lower Paleozoic rocks of the northern Selkirk Mountains host numerous volcanogenic massive sulphide occurrences. These include the Goldstream copper-zinc mine, which has produced 70 000 tonnes of copper and 49 000 tonnes of zinc from 1 738 500 tonnes milled between April, 1991 and October, 1995 (S. Robertson, personal communication, 1995), and the arsenical, gold-rich J&L deposit which has probable and possible reserves in excess of 5 million tonnes averaging 2.71 % Pb, 4.33 % Zn, 7.23 g/t Au and 72 g/t Ag. The stratiform nature of these deposits makes understanding the regional stratigraphic and structural setting fundamental to exploration for new deposits. The main objectives of the Northern Selkirk project are to establish the stratigraphic and structural framework of known volcanogenic massive sulphide deposits in the northern Selkirk Mountains, and to assess the potential for similiar deposits in correlative successions elsewhere.

This report presents the results of regional bedrock mapping in the LaForme Creek area (NTS 82M/1) during the summer of 1996. The 1996 field season marks the completion of fieldwork in the Selkirk Mountains. Reconnaissance mapping and deposit studies were initiated in 1993. Mapping in 1994 and 1995 covered the areas east of the Columbia River on 82M/8, 9 and part of 10. The short 1996 program was designed to complete mapping coverage of the Downie Creek map area and trace prospective stratigraphy southward to the northern boundary of Mount Revelstoke Park. This area hosts carbonate replacement Pb-Zn deposits and is on strike with several new massive sulphide occurrences discovered during the 1995 mapping season. Mapping was focused on prospective stratigraphy in the areas north and east of LaForme Creek. The geology farther west, and along the slopes overlooking the Columbia River was compiled from mapping carried out last year with Maurice Colpron and Bradford Johnson, and from published sources.

GEOLOGY

The Selkirk Mountains straddle 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, 1965; 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

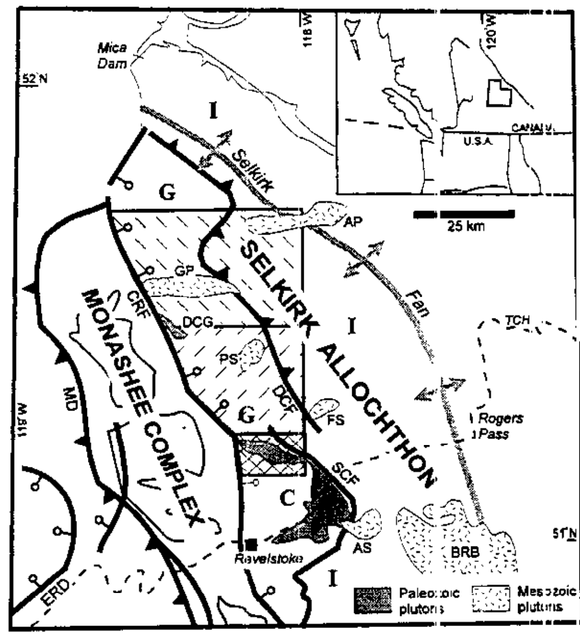

Figure 1. Geological setting and location of the Goldstream River (southeasterly dashed), Downie Creek (southwesterly dashed) and La Forme Creek (hatched) map-areas along the western flank of the Selkirk fan structure, within the Selkirk allochthon; modified after Brown and Lane (1988). I = Illecillewaet 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 pluton, GP = Goldstream pluton, AP = Adamant pluton, DCG = Downie Creek gneiss, TCH = Trans-Canada Highway

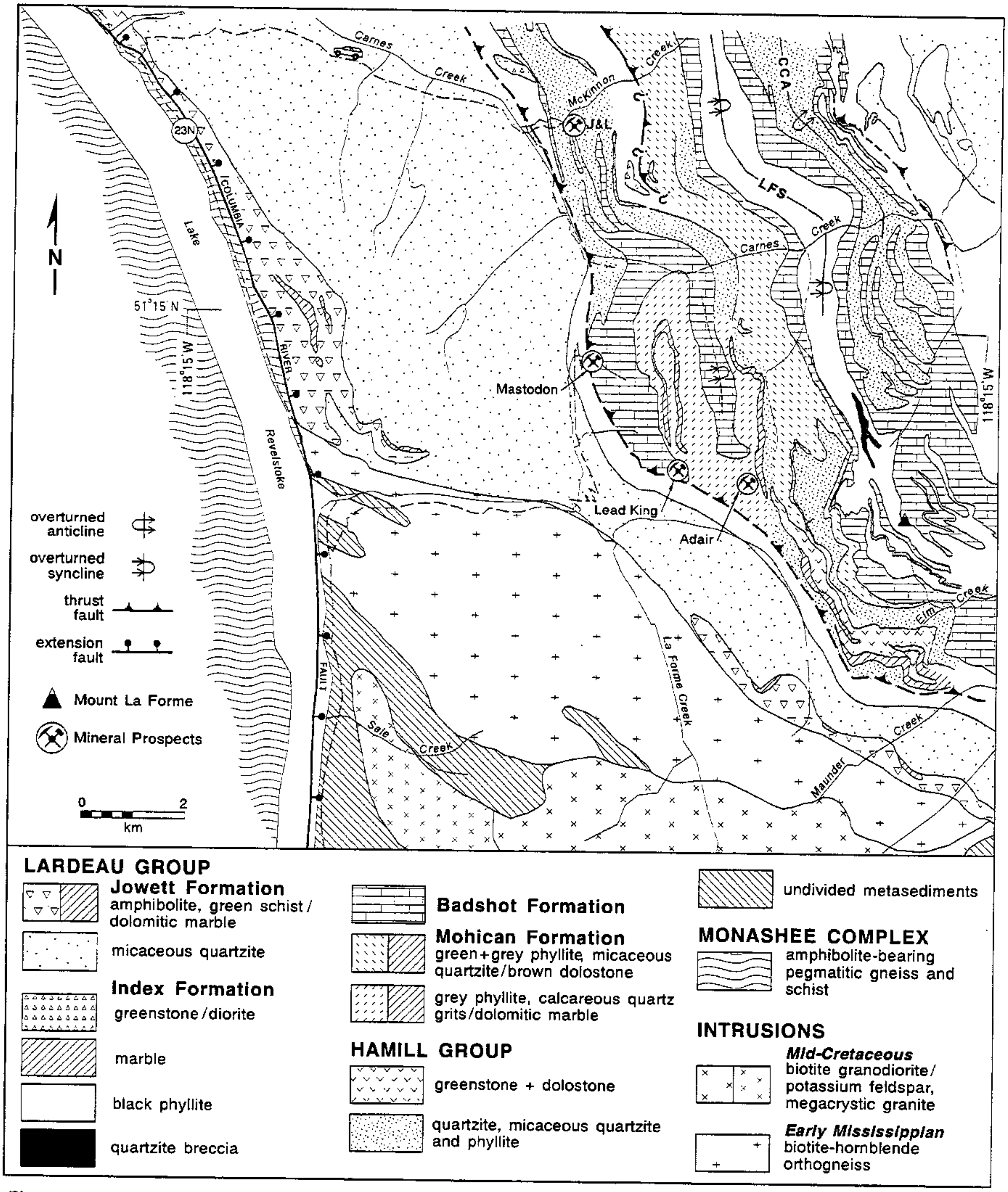

Figure 2. Geological map of the La Forme Creek area compiled from mapping completed in 1995, this year and from Crowley (1992). Fold axis: CCA = Carnes Creek anticline, LFS = La Forme syncline

the Intermontane Superterrane (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).

The northern Selkirk Mountains are underlain by 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 to the south, by Walker (1926), Walker and Bancroft (1929), and Fyles and Eastwood (1962) in the Purcell anticlinorium and the Kootenay Arc, northwestward 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, archaeocyathid-bearing Badshot Formation, and the lower Paleozoic 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). Okulitch *et al.* (1975) and Parrish (1992) have shown that orthogneisses of the Clachnacudainn Complex are, in part, Devonian to Mississippian in age.

The northern Selkirk Mountains form part of a large allochthon that was displaced eastward some 200 to 300 kilometres between Late Jurassic and Paleocene time (Price, 1981; Brown *et al.*, 1986, 1992a). The Selkirk allochthon 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 this structure is characterized by a northeast-verging imbricate thrust system which is part of the Rocky Mountain fold and thrust belt. It 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, extending 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 time. 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 been recognized within the Clachnacudainn Complex (Parrish, 1992)

STRATIGRAPHY OF THE LAFORME CREEK AREA

Rocks of the Hamill and Lardeau groups, and the intervening Mohican and Badshot formations, comprise the majority of exposures in the LaForme Creek area (Wheeler, 1965; Figure 2). The western half of the map-area, between Carnes and LaForme creeks, is underlain by a comparatively simple overturned succession consisting of micaceous quartzite and metavolcanic rocks of the Lardeau Group. East of this quartzite assemblage is a structurally complex series of interlayered Hamill Group siliciclastic rocks, Mohican Formation calcareous siliciclastic rocks, Badshot Formation marble and Index Formation pelites.

South of LaForme Creek are various intrusions of Early Mississippian, Jurassic to Cretaceous, mid-Cretaceous and Late Cretaceous ages (Hakkinen, 1977; Crowley and Brown, 1994) which characterize the northern-half of the Clachnacudainn igneous complex (Crowley, 1992).

HAMILL GROUP

The Hamill Group, in the northern Selkirk Mountains consists of three stratigraphic divisions: a lower sandstone unit; a greenstone-graded sandstone unit; and an upper sandstone unit (Devlin, 1989). The lower and middle units have been mapped in the Goldstream River and Downie Creek areas (Logan and Colpron, 1995; Logan *et al.*, 1996). Interbedded micaceous quartzite and dark phyllite make up most of the Hamill Group exposures in the Downie Creek area. These rocks extend south into the LaForme area and crop out in three main areas: north of Mount LaForme, west and south of Mount LaForme, and in the area of the J&L deposit (Figure 2).

North of Mount LaForme pale greenish-grey massive and trough cross-bedded micaceous quartzites with interbedded phyllite and thin orange-weathering dolostone layers form the eastern exposures of Hamill Group rocks. The interbedded micaceous quartzite and dark phyllite are tightly folded with marbles of the Badshot Formation in the core of the Carnes Creek anticline, a large southwest-verging, south-plunging antiformal structure. The upper contact with the Badshot Formation marbles is gradational through approximately 35 metres of limonitic-weathering grey and green calcareous phyllite and orange-weathering phyllitic dolostone of the Mohican Formation.

West of Mount LaForme are thick-bedded, mature orthoquartzite and interbedded dark grey siliceous phyllite. Orange-weathering, light pink and white orthoquartzite and interbedded greenish-grey, thin laminated micaceous quartzite cap the east-trending ridge 2 kilometres west of Mount LaForme. Tabular cross laminations indicate that bedding tops face to the west; tight symmetrical folds in the rocks indicate that the quartzite occupies an anticlinal fold closure.

South of Mount LaForme, structurally below, but presumably stratigraphically above the Hamill quartzites are mafic metavolcanic rocks. Discontinuous, 5 to 20 metre thick, thinly foliated grey marble interlayered with pink quartzite and calcareous phyllite separate the predominantly volcanic succession from siliceous and calcareous rocks of the Hamill Group and Mohican Formation. The metavolcanic rocks are medium grey to dark green, thinly foliated to massive, homogeneous greenstones composed of actinolite, feldspar, patchy chlorite and calcite and euhedral disseminated magnetite crystals. Massive greenstones are interlayered with thinly foliated, calcareous tuffaceous wacke, orange-weathering phyllitic dolostone, volcanic sandstone and lesser quartzite and phyllite beds. The greenstones are predominantly volcaniclastic rocks. Below this sequence, in fault contact, is black graphitic and calcareous phyllite of the Index Formation.

Preliminary trace element geochemistry from two samples from north of Maunder Creek indicate the volcaniclastic rocks are alkaline basalts of within plate affinity, similiar to Hamill Group and Mohican Formation volcanic rocks from the Goldstream River and Downie Creek areas (Logan *et al.,* 1996). The Hamill greenstone-volcanic assemblage present in the Goldstream and Downie areas do not have a large component of carbonate or calcareous phyllite, but regional continuity northward into the Downie Peak area supports correlation with the Hamill Group and/or Mohican Formation greenstone.

South of the J&L deposit, the Hamill Group is characterized by medium to thickly-bedded white and pink orthoquartzite interbedded with dark grey phyllite and micaceous quartzite. These are gradational into calcareous quartz grits, phyllite and marble of the Mohican Formation. The orthoquartzites occupy the cores of tight folds in this area.

MOHICAN FORMATION

The Mohican Formation (Fyles and Eastwood, 1962) represents the transition between quartz-rich sediments of the Hamill Group and the carbonate-rich rocks of the Badshot Formation. In the Downie Creek map area to the north (Brown, 1991; Logan *et al.,* 1996) the Mohican Formation forms a prominent north-trending belt of rusty-weathering rocks west of Carnes Peak. This belt extends south into the LaForme Creek area east of the J&L deposit, where it is composed of rusty-weathering, green and grey calcareous phyllite, dolostone and micaceous quartzites. This mainly calcareous phyllite sequence includes beds of light grey marble, up to 2 metres thick, interlayered with orange-weathering phyllitic dolostone and metre-thick beds of white, light green and pink micaceous quartzite with thin phyllite partings. Farther west, a second belt of rocks correlated with the Mohican Formation occupies the core of an antiformal structure located 2 kilometres east of the Mastodon mine. The rocks in this area consist of light grey and green phyllite, intercalated with orange-weathering sandy dolostone, calcareous quartz-granule conglomerate and calcareous and siliceous grit. Upper and lower contacts are gradational into Badshot Formation marble and Hamill Group quartzite, respectively. Near its contact with the overlying Badshot Formation the Mohican is characterized by calcareous green phyllite and pale yellow sericite schist.

On the ridge separating McKinnon and Carnes creeks, and east of the Mastodon mine on the ridge overlooking LaForme Creek, the typical calcareous-phyllite-quartzite dominated Mohican Formation contains beds of dark green calcareous phyllite, chlorite schist and rare fragmental volcaniclastic horizons. The greenstone is thinly foliated, consists of white carbonate, chlorite and feldspar, and several percent euhedral magnetite crystals. The volcanic rocks comprise a minor constituent, but potentially important metallogenic component of the Mohican Formation at these locations.

BADSHOT FORMATION

White and light grey archaeocyathid-bearing marble of the Badshot Formation crops out at Roseberry Mountain and Bridgeland Pass (Read and Brown, 1979). The Badshot marbles are traceable southward from Bridgeland Pass to Mount LaForme and beyond the map area. The marble outlines a pair of southwest-verging, south-plunging folds, the Carnes Creek anticline and LaForme syncline (Figure 2). White to buff massive, dolomitic marble crops out in the area of the Mastodon mine on the ridge south of Carnes Creek. A second prominent belt of white to buff marble crops out 1 kilometre to the east. It can be traced north into Carnes Creek, but like the Mastodon marble it pinches out to the south in the steep cliffs above the north tributary of LaForme Creek. These two marble exposures are correlated with the Badshot Formation marble on Roseberry Mountain.

Light grey to brillant white-weathering coarsely crystalline marble characterizes the Badshot Formation in the LaForme area. North of Mount LaForme, the Badshot Formation consists of interlayered coarse crystalline white marble and dark grey fine-grained marble, with rare pisolitic horizons and buff-weathering sandy dolomitic layers. Northeast of Mount LaForme, the upper(?) Badshot is characterized by a siliceous interval. The 50-metre section contains several silicified dolostone conglomerate horizons, 2 to 5 metres thick, massive silicified, white marble, and an interbedded sequence of buff orthoquartzite and dolostone. This section is overlain by interlayered black and green graphitic and calcareous phyllite, limestone conglomerate and quartzite breccia units of the basal Index Formation.

Marble in the lower limb of the Mount LaForme syncline is also highly silicified and brecciated, where it crops out 2 kilometres northwest of Mount LaForme. The upper section of marble is interbedded with orthoquartzites similiar to those in the section northeast of Mount LaForme. The marble layers are variably replaced by silica-flooding along some bedding planes, or cut by quartz stockworks and sigmoidal quartz-filled tension gashes. The buff-coloured quartzite beds are finely crackle-brecciated. Here, the Badshot Formation is less than 25 metres thick.

Upper contacts with the Index Formation and lower contacts with the Mohican Formation are gradational and conformable. The occurrence of archaeocyathid indicates a late Early Cambrian age for marbles of the Badshot Formation.

LARDEAU GROUP

The Lardeau Group (Walker and Bancroft, 1929) conformably overlies the Badshot Formation and is unconformably overlain by the Milford Group (Read and Wheeler, 1976). As defined by Fyles and Eastwood (1962) in the Ferguson area, it includes six formations. In ascending stratigraphic order these are: 1) dark grey and green phyllites, thin limestone and volcanic rocks of the Index Formation; 2) black siliceous argillite of the Triune Formation; 3) grey quartzite of the Ajax Formation; 4) grey siliceous argillite of the Sharon Creek Formation; 5) volcanic rocks of the Jowett Formation; and 6) grey and green quartz-feldspar grit and phyllite of the Broadview Formation. As the Lardeau stratigraphy is traced northward into the Akolkolex River area, the Ajax quartzite pinches out and an intervening unit of grit is exposed between the black phyllites of the Index Formation and the overlying Sharon Creek and Jowett formations (Read and Wheeler, 1976; Sears, 1979). 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 (Colpron and Price, 1993). Colpron and Price (1993; 1995a) assigned all three units to the Index Formation. A similar three-fold subdivision of the Lardeau Group has been recognized in the Goldstream River map area (Gibson and Höy, 1994; Logan and Drobe, 1994) and was also assigned to the Index Formation (Logan and Colpron, 1995).

In the LaForme Creek area, the Lardeau Group consists of the same five lithostratigraphic units recognized in the Downie Creek area (Figure 4, Logan *et al.,* 1996). They include, in approximate stratigraphic order: 1) black graphitic, calcareous and/or siliceous phyllite, discontinuous quartzite breccia and limestone; 2) light grey marble; 3) greenstone and metavolcaniclastic rocks; 4) micaceous quartzite, quartzite, quartz grit and grey phyllite; and 5) metavolcaniclastic rocks, greenstone and marble. Units 1 to 3 are correlated with the Index Formation, unit 5 is correlated with the Jowett Formation.

INDEX FORMATION

Black Phyllite

The lower part of the Index Formation consists of a 250 to 500-metre succession of dark grey to black calcareous phyllite, brown-weathering phyllitic dolostone and black graphitic phyllite which contains minor dark grey calcitic marble layers. Locally, dark grey micaceous and dolomitic quartzite beds, light grey marble up to 20 metres thick, quartz grit and chlorite phyllite occur within the black phyllite unit (Logan *et al.,* 1996).

In the eastern half of the LaForme map area black phyllite and brown-weathering calcareous phyllite of the Index Formation comprise the majority of the Lardeau Group exposures. Black phyllite defines four north-trending belts of Index Formation. Interbedded with the typically thinly-foliated commonly crenulated orange- and black-weathering calcareous and graphitic phyllite are quartzite breccias, limestone conglomerates, green phyllite and micaceous quartzites.

North of Mount LaForme, near Bridgeland Pass (Logan *et al.*, 1996), the contact between the Badshot Formation marble and black phyllite of the Index Formation is marked by a distinctive white orthoquartzite breccia unit. The unit has minor black phyllite layers and directly overlies buff-weathering dolomitic limestone conglomerate, phyllitic marble and massive grey marble of the Badshot Formation.

East of Mount LaForme, approximately 20 metres of white and pale pink crackle-brecciated quartzite is in sharp contact with a limestone cobble conglomerate unit of the Badshot Formation. The quartzite unit is typically fine to medium-grained, with a sucrosic texture. It is always brecciated. The breccias are tectonic in origin and clasts vary from angular and interlocking with minimal amounts of rotation to well-rounded and flattened with mantles of a darker matrix of insoluble residues formed during silica and/or calcite(?) dissolution.

Northwest of Mount LaForme, in the core of the LaForme syncline are several fold-duplicated quartzite breccia layers, within the black phyllite of the Index Formation. These quartzite units are buff-weathering, and locally have a calcareous matrix.

Marble

Light grey and white crystalline marble, thinly foliated buff-weathering phyllitic carbonate, and sandy dolostone beds are interbedded with dark phyllite and calcareous-micaceous quartzites of the black phyllite unit southwest of Mount LaForme. The marble, in general appearance is similiar to marble of the Badshot

Formation. Typical Index marble is phyllitic and a darker grey.

Greenstone

The greenstone unit is exposed north of Maunder Creek and in the Mastodon area. It consists predominately of dark green volcaniclastic units and massive sills which occur within black and green phyllites. The volcaniclastic rocks consist of pale grey-weathering, green tuffaceous phyllites, greenstone and calcareous, feldspathic volcanic wacke. In both these areas individual volcanic layers are less than 15 metres thick and are gradational into black phyllite. The greenstone is characterized by abundant small, white albite porphyroblasts. Sills of foliated metadiorite and metagabbro intrude black graphitic phyllite north of Maunder Creek. A second body of diorite crops out on the slopes north of the confluence of Carnes and McKinnon creeks (R. Pegg, personal communication, 1996). The sills have foliated margins and coarse-grained, equigranular cores, are concordant with the dominant foliation, and are composed of chlorite and plagioclase. The sill at Maunder Creek, which is approximately 20 metres thick; has a core of interlocking, 1 to 3 centimetre crystals of hornblende and plagioclase.

Index Formation volcanic rocks in the Standard and Keystone Peak areas are tholeiitic basalts of mid-ocean ridge basalt (MORB) affinity (Logan *et al.*, 1996).

MICACEOUS QUARTZITE

A thick(?) succession of well-bedded quartzite, micaceous quartzite and quartz-muscovite schist underlies the western-half of the map-area north of LaForme Creek. South and east of the creek, this belt of quartz-rich metasediments narrows and swings eastward following the northern contact of the Clachnacudainn orthogneiss. North, in the Downie Creek map-area, this quartzite and schist unit overlies the black phyllite and greenstone units of the Index Formation. Brown (1991) correlated it with the Broadview Formation; Logan *et al.* (1996) suggested it is older than the Jowett Formation and distinct from the Broadview Formation.

North of Maunder Creek, adjacent to the phyllite unit, the lower sections of the quartzite succession consist of thick-bedded white and pink orthoquartzite and interbedded micaceous quartzite. Up section the quartzites are interbedded with siliceous phyllite and rusty-weathering muscovite schist. Amphibolite, marble and metavolcaniclastic rocks of the overlying Jowett Formation are interlayered and in gradational contact with the top of the micaceous quartzite unit.

In the extreme northeast corner of the map is an upright-facing succession of interbedded rusty phyllite and calcareous quartz-feldspar grit and micaceous quartzite that overlies thinly bedded black graphitic, calcareous and locally pyritic phyllite of the lower Index Formation. Graded bedding and flame structures are present in the grit and provide way-up control north of Tumbledown glacier (Logan *et al.*, 1996).

JOWETT FORMATION

Green metavolcanic rocks and interlayered dolomitic marble are exposed along the slopes of the Columbia River (Brown, 1991; Logan *et al.*, 1996). Brown *et al.* (1983) correlated these rocks with the Jowett Formation, as did Crowley (1992) for the amphibolite, metatuff and interlayered marble exposed south of Mount LaForme (Figure 2). In both areas the rocks occupy an inverted stratigraphic panel; those north of LaForme Creek form the hangingwall of the Columbia River fault. Crowley (1992) shows the latter to occupy the hangingwall of the Lower Standfast Creek fault.

The rock units consist of layered mafic fragmental and epiclastic rocks and massive amphibolite. The amphibolite is characterized by massive sections consisting predominantly of fine acicular crystals of hornblende with rare plagioclase and minor epidote, calcite and pyrite.

INTRUSIVE ROCKS

Intrusive rocks are confined to the northern part of the Clachnacudainn salient of Wheeler (1963, 1965). The large variety of ages, compositions and deformation of the intrusions in the Clachnacudainn igneous complex make it a unique feature of the Selkirk allochthon (Crowley, 1992). Recent age dating in the Goldstream River and Downie Creek areas indicates an equally diverse plutonic history with similar ranges in composition and ages (Logan and Friedman, 1997, this volume). Two of the five major igneous suites present in the Clachnacudainn complex are represented in the LaForme area: the Early Mississippian Clachnacudainn orthogneiss, and the large, east-trending mid-Cretaceous composite granitic body that crops out at the headwaters of LaForme Creek.

EARLY MISSISSIPPIAN CLACHNACUDAINN GNEISS

Biotite hornblende granodiorite orthogneiss crops out south and east of LaForme Creek (Figure 2), and extends southward in an arcuate outcrop pattern to Albert Canyon and just east of Revelstoke (Crowley, 1992) (Figure 1). The orthogneiss at Albert Canyon was dated by Parrish (1992) at 358±6 Ma (U-Pb, zircon). South of LaForme Creek, on the old Mastodon mine road the gneiss is characteristically a well-foliated granitoid composed of alternating quartz and feldspar-rich leucocratic layers and biotite and/or hornblende-rich mafic layers. Quartz and plagioclase grains are flattened and recrystallized. Leucocratic, pegmatites and aplitic dikes are transposed into the main regional northwest-trending foliation. Ovoid crystal aggregates of biotite locally define a well-developed stretching lineation in the gneiss. The main foliation is deformed into north-trending folds and crenulated by steep north-trending kink bands.

The contact zone with the overlying micaceous quartzite and muscovite-garnet-biotite schists of the Lardeau Group is concordant with the dominant regional foliation. The contact is well exposed between the headwaters of LaForme and Maunder creeks. At three separate locations the gneiss is in sharp contact with amphibolite of the Jowett Formation. At the westernmost locale, pendants of rusty weathering micaceous quartzite and calcsilicate schists in orthogneiss define a concordant 5 metre wide contact zone. The contact with the micaceous quartzite succession is interpreted to be intrusive.

MID-CRETACEOUS GRANITOIDS

A composite intrusive body composed of biotite granodiorite, biotite granite and hornblende diorite intrudes the Devono-Mississippian orthogneiss at the southern end of the study area (Crowley, 1992). Pendants and screens of undivided metasediments occur within and along the margins of these two intrusions. The metasedimentary rocks consist of sillimanite, kyanite and amphibole-bearing quartzite, amphibolite and calcareous schist.

Near its western end, at Sale Creek, the granite is a greyish-pink biotite monzogranite with 1 to 4-centimetre long potassium feldspar megacrysts. It contains screens of hornblende biotite quartz monzodiorite and segregations of fine-grained leucogranite. Along its western side, the granite intrudes amphibolite-grade mylonitic metasedimentary rocks correlative with cover gneisses of the Monashee Complex (Brown *et al.,* 1993). It is mainly coarse grained with well-preserved igneous textures, although locally the potassium feldspar megacrysts and xenoliths define a weak to moderate foliation. The granite is mylonitized within a 400 to 500-metre thick north-trending shear zone at Sale Creek (Murphy, 1980). In outcrop the zone is composed of purple and light green mylonites with rounded potassium feldspar porphyroclasts. The contacts are sharp to gradational over a few centimetres between the mylonites and the biotite potassic feldspar megacrystic granite. Locally, the mylonites constitute up to 20 per cent of the granite. The granite is dated as mid-Cretaceous (U-Pb zircon, R.L. Armstrong, unpublished data).

The granitoids are compositionally similiar to, and coeval with the Battle Range batholith, Albert stock and Goldstream pluton; all are part of the mid-Cretaceous Bayonne Plutonic Suite of southeastern British Columbia.

DIKES AND SILLS

Steep-dipping, northeast-trending dikes of dark orange-brown weathering, vesicular porphyritic trachyte, 1 to 2 metres wide, intrude rocks of the Hamill and Lardeau groups west of Mount LaForme. The trachyte is composed of coarse, irregular clots of resorbed hornblende, potassic feldspar and quartz phenocrysts in a fine-grained trachytic groundmass of plagioclase and pyroxene. The dikes intrude the strata at a high angle to the dominant schistosity and consist of two, and in one locale three parallel dikes

STRUCTURE

At the regional scale, the structure of the LaForme area is dominated by northwest-trending, southwest-verging folds and faults that are characteristic of the west flank of the Selkirk fan structure. These are second generation structures as they are superposed upon older isoclinal nappes which locally inverted the stratigraphic sequence, such as in the Downie Creek area to the north (Read and Brown, 1979). Evidence for this early deformation in the Clachnacudainn Terrane is the preservation of an older schistosity in the hinges of the dominant folds, and as inclusion trails in garnets (Crowley, 1994). Both sets of structures are deformed by still younger east-southeast trending open folds.

The dominant structures that define the map pattern in the area around Mount LaForme are second generation, tight to isoclinal, overturned to recumbent or reclined folds and thrust faults (Figures 2 and 3). These have all apparently developed in upright-facing lower Paleozoic stratigraphy. Foliations and the axial planes of folds dip moderately to the northeast. Minor fold axes commonly plunge down-dip to the northeast, such that they and the larger-scale folds have the geometry of reclined folds. The effect of this geometry on the map pattern is that, at least locally, the stratigraphic succession youngs along rather than across the northwest-southeast regional strike This makes tracing out map units particularly difficult in this area.

Stereograms of planar and linear data from the LaForme area show no large variation across the map, and affirm that bedding-cleavage intersections and hinge lines of minor folds plunge moderately to the northeast (Figure 4). This unusual orientation is not directly compatible with the regional southwest-verging folding of the western Selkirk allochthon, which elsewhere is represented at the outcrop scale by northwest or southeast-plunging minor structures No evidence was found for major refolding, such as interference patterns or crenulation foliations, which could account for these structures. The most likely explanation is that local zones of high shear strain produced a progressive rotation of fold elements toward the southwest, the direction of structural vergence.

In the upper reaches of Carnes Creek are two major, moderately dipping, isoclinal folds, the Carnes Creek anticline and the LaForme syncline (Figure 2).

Figure 3. Northwest-trending recumbent isoclinal fold, cored by marble and interlayered schist of the Badshot Formation, located on the north flank of Mount LaForme. Viewed towards the northwest.

The Carnes Creek structure is a southwest-verging, southeast-plunging overturned anticline which is cored by Hamill Group micaceous quartzite. Badshot Formation marble occupies the limbs and forms the closure around the Hamill Group in the headwaters of Carnes Creek. The southwest-verging LaForme syncline is structurally beneath the Carnes Creek anticline. Black phyllite, quartzite breccia, calcareous quartzite and marble of the Index Formation core the syncline. Badshot Formation marble forms the closure north of McKinnon Creek (Logan *et al.*, 1996). The southern extension is not well exposed, but may be enclosed by Badshot Formation marble, in Elm Creek. If this is the case the LaForme syncline is doubly-plunging.

A northwest-trending fault zone(?) divides the western succession of micaceous quartzite and metavolcanic rocks of the Lardeau Group from the tightly folded quartzites, calcareous phyllites, marbles and black phyllites of the Hamill Group, Mohican, Badshot and Index formations of the eastern half of the map area. In the Downie Creek area to the north, the contact between the Index Formation and the micaceous quartzite and quartz-muscovite schist to the west, has been interpreted by Brown (1991) as a west-verging fault (the Standard Peak fault). Close inspection of this contact has revealed that, in most locations, the Index Formation is gradational into the underlying quartzite assemblage (Logan *et al.*, 1996). The fault does not occur at the contact between black phyllite and quartzite at Standard Peak, although the existence of a fault at this horizon elsewhere cannot be ruled out.

In the LaForme area, the westernmost belt of Index phyllite (Figure 2) is in gradational contact with the quartzite assemblage to the west, and fault contact to the east. North of Maunder Creek, on the ridge separating Maunder Creek and the east tributary of LaForme Creek, the western contact with the underlying micaceous quartzite is exposed. The contact is gradational but the change in metamorphic mineral assemblages is abrupt. Black crenulated calcareous phyllite and lesser interbedded greenstone and metadiorite pass directly into structurally lower biotite-muscovite±garnet bearing schist and quartzite. The eastern contact at this same locale is marked by a narrow (less than 2 metres thick), black, siliceous, manganese and iron carbonate-rich unit, separating the black phyllite unit of the Index Formation from mature white and pink orthoquartzite, micaceous quartzites and interbedded greenstone of the Hamill Group.

Northwestward from Maunder Creek, the fault juxtaposes progressively younger rocks over the black phyllite of the Index Formation. The fault appears to truncate the more northerly-trending Badshot and Mohican stratigraphy in the area of the Lead King and Adair mineral prospects, and the Badshot marble at the Mastodon mine (Figure 2). Bedding/foliation-parallel

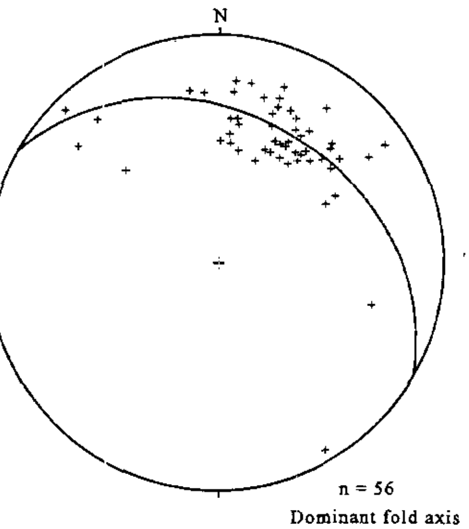

Figure 4. Equal area projection of plunge of minor folds of the dominant phase of deformation.

shear faults are common in the underground developments at the Mastodon mine (White, 1951; Fyles, 1960) and are locally mineralized.

A thrust fault juxtaposes rusty-weathering phyllite and dolostones of the Mohican Formation over black phyllites of the Index Formation, along the east flank of Roseberry Mountain (Figure 3, Logan *et al.*, 1996; Brown, 1991). This fault can be traced southward across McKinnon Creek and up onto the ridge separating McKinnon and Carnes creeks. The contact here between calcareous, rusty-weathering siliceous phyllites of the Mohican Formation and black graphitic phyllite is knife sharp, and it is difficult to envision a fault structure here, but if the structurally lower black phyllite is indeed the Index Formation then stratigraphic relationships require a thrust fault.

The contact between the Early Mississippian Clachnacudainn gneiss and the overlying metasedimentary rocks has been variously interpreted as unconformable, intrusive and faulted. In the LaForme area, Crowley (1992) described the contact as probably intrusive, but he shows a fault (the Lower Standfast Creek) following the contact between the gneiss and metasedimentary rocks. He constrains the upper time limit of motion by the intrusion of a probably mid-Cretaceous granodiorite. No kinematic evidence for ductile deformation was recognized along the contact between the orthogneiss and micaceous quartzite unit in the vicinity of Maunder Creek. We interpreted the contact to be intrusive into the Lower Paleozoic Lardeau Group strata and feel that a fault is not necessary to separate the Clachnacudainn terrane from the Selkirk allochthon in the La Forme Creek area.

The southwest-verging structures are deformed by younger east-trending, gently plunging folds. These structures are well developed farther north in the Goldstream-Downie map areas where they predate emplacement of the mid-Cretaceous Goldstream Pluton (Logan and Colpron, 1995) and postdate the peak of metamorphism. In the LaForme area this younger deformation is limited to the development of crenulation cleavage and small-scale open folds, mainly in phyllites and schists of the Index Formation, and is not reflected in the map pattern. The axial-planar schistosity is vertical to steeply dipping and strikes easterly.

COLUMBIA RIVER FAULT

The Columbia River fault zone separates rocks of the Selkirk allochthon in its hangingwall from rocks of the Monashee Complex in its footwall (Read and Brown, 1981; Figure 1). The structure is a regional normal fault which strikes northwesterly and dips 20° to 40° to the east in the study area. 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). This ductile-brittle fault of Eocene age is superposed on older, amphibolite-grade mylonites that have been attributed to displacement along the ductile Jurassic to Paleocene Monashee décollement (Lane, 1984; Lane *et al.*, 1989; Brown *et al.*, 1992a). The fault migrates from place to place between the lower and upper plates of the décollement.

For the most part, the trace of the fault zone lies in the Columbia River and is not exposed. South of Carnes Creek the fault is exposed in road cuts along Highway 23. At Carnes Creek, rocks in the footwall are silicified mylonitic gneisses, possibly Devono-Mississippian orthogneiss of the Clachnacudainn Complex (Brown *et al.*, 1993). Mafic plagioclase-actinolite-calcite metavolcaniclastic and interlayered dolomitic marble of the Jowett Formation occupy the hangingwall. Discrete late brittle fault zones, less than a metre wide and characterized by ankeritic and clay-altered fault gouge, cut the main fault trace exposed south of the Carnes Creek Road turnoff on Highway 23.

At Sale Creek, amphibolite-grade mylonitic metasedimentary rocks correlative with cover gneisses of the Monashee Complex (Brown *et al.*, 1993) have been mapped in the hangingwall of the Columbia River fault (Murphy, 1980). These are part of a 500-metre thick, post mid-Cretaceous, east-directed mylonite zone interpreted to be part of the Monashee décollement.

METAMORPHISM

Rocks of the Mount LaForme area contain mineral assemblages characteristic of greenschist to amphibolite facies metamorphism. Most of the map area is in the chlorite zone; biotite zone and amphibolite facies rocks are confined to the footwall of the Columbia River fault zone and to a narrow northwest-trending zone which follows the northern contact of the Early Mississippian Clachnacudainn gneiss body.

A metamorphic culmination extends 10 kilometres northwestward from Maunder Creek along the northern contact of the Clachnacudainn orthogneiss to the abandoned Mastodon Mine road. It extends approximately 1 000 to 2 000 metres north from the contact into the structurally overlying metasedimentary rocks. The rocks are garnet-muscovite-biotite-chlorite-andalusite paragneisses and schists. The garnet porphyroblasts are synkinematic with respect to the dominant foliation, which is defined by biotite and muscovite. The garnets commonly have retrograde rims of fine-grained muscovite, chlorite and quartz. Muscovite psuedomorphs andalusite. Calc-silicate horizons contain fine radiating clusters of actinolite arranged in a characteristic 'bow-tie' texture on the dominant foliation surfaces. The metamorphic grade decreases rapidly northeastward, and the gneisses pass structurally upward into biotite and chlorite-zone micaceous quartzite and quartz-muscovite schist. The garnet grade pelitic schist assemblages do not extend beyond the micaceous quartzite-schist unit into the overlying calcareous graphitic phyllite. It is unclear whether the transition between the micaceous quartzites and the phyllite is the result of a fault, decreasing metamorphic grade or compositional controls. The northern contact between the Early Mississippian orthogneiss and micaceous quartzite has been inferred to be a thrust fault (lower Standfast Creek fault; Crowley, 1992). At three separate exposures northwest of Maunder Creek, brittle, minor fault structures cut both the gneiss and its host rocks. No direct evidence for a major fault between the orthogneiss and the Lardeau Group metasedimentary rocks was observed.

Regional relationships and geochronology indicate a Middle Jurassic age for southwest-verging deformation and the peak of regional metamorphism (Archibald *et al.,* 1983; Colpron and Price, 1995b). Accordingly, the age of garnet-grade regional metamorphism at LaForme Creek is inferred to be Middle Jurassic.

An alternative interpretation for the compressed, higher grade metamorphic zones at LaForme Creek, which takes into account the close proximity of the orthogneiss, is that this narrow belt coincides with an older contact metamorphic aureole around the original Early Mississippian granodiorite intrusion. Since the rocks in the aureole were already partially dehydrated, Middle Jurassic regional metamorphism reached a somewhat higher grade than the surrounding rocks which were undergoing metamorphism for the first time. The same spatial association between narrow metamorphic isograds and adjacent Early Mississippian orthogneiss is present in the Downie Creek area (Logan *et al.,* 1996; Logan and Friedman, 1997, this volume), supporting this interpretation.

MINERAL PROSPECTS

In the LaForme area, stratabound zinc and lead mineralization occurs in well-defined bedding parallel fissures in marble and dolostone of the Badshot Formation and phyllite and micaceous quartzite of the Hamill and/or Lardeau groups; and as disseminated replacements of these lithologies. At the Mastodon mine, zinc and lead mineralization occurs as veins along faults and as replacement zones, developed adjacent to the faults. At the J&L deposit, mineralization consists of a tabular stratiform body of precious and base metals (main zone) as well as zinc and lead replacement zones in the hangingwall marble (Yellowjacket zone). The relationship between these two zones is not clear.

J&L

The J&L is a stratiform precious and base metal deposit. It consists of a Main zone, 1.6 metres (true thickness) of massive and disseminated sulphides, developed over 800 metres underground, and traced on surface for over 1850 metres. Probable/possible reserves are 4.77 million tonnes grading 2.7 % lead, 4.3 % zinc, 7.2 grams per tonne gold and 72 grams per tonne silver. The Main zone is described by McKinlay (1987) and summarized by Meyers and Hubner (1989). It is probably an exhalative volcanogenic massive sulphide deposit, akin to Eskay Creek (Logan *et al.,* 1996). The Yellowjacket zone is a lead-zinc deposit hosted in siliceous carbonates in the hangingwall of the Main zone. It was a blind-deposit discovered in 1990 and has probable/possible reserves of 910,000 tonnes grading 7.4 % zinc, 2.6 % lead and 55 grams per tonne silver (Northern Miner - August 5, 1991. The Yellowjacket zone is an epigenetic carbonate replacement deposit.

MASTODON

The Mastodon mine is approximately 5 kilometres south of the J&L mine on the divide separating LaForme and Carnes creeks, at an elevation of 1525 metres. The abandoned and collapsed remains of the main camp and mill site on the north side of LaForme Creek is approximately 6 kilometres east of Highway 23.

The Mastodon showings were discovered in 1898. Mastodon Zinc Mines Ltd. developed the property in the early 1950s and produced a total of 31,204 tonnes averaging 10% zinc, approximately 0.3% lead and 0.04% cadmium during two short periods in 1952 and 1960. The mine was closed in 1960 and the facilities dismantled. The early history and detailed description of the mine workings are summarized in the Annual

Report of the Minister of Mines for 1950 (White, 1951) and 1959 (Fyles, 1960).

The Mastodon orebodies are on the western side of a lenticular mass of northwest-trending limestone of the Badshot Formation (Figure 2). To the west the carbonate is in contact with black, calcareous phyllite and greenstone correlative with the Index Formation. Phyllitic limestone, calcareous micaceous quartzite and grit, and grey phyllite of the Mohican Formation are exposed to the east. The strata are isoclinally folded and strongly sheared. Foliation strikes northwesterly and dips moderately to the northeast. Minor folds plunge north from 20° to 45°, with a Z-shape symmetry (viewed to the north). Fyles (1959) measured minor folds in the underground workings and concluded that two generations of folds are present. One plunges gently northwest and the other plunges northeast down the dip of the foliation. He recognized several foliation-parallel shear zones (strike faults) underground and the primary control they have on the zinc mineralization. The mineralization either occupies these structures or has spread outwards from them into chemically and/or structurally favourable zones. The orebodies dip to the northeast and pitch to the north (Fyles, 1960).

The sulphide assemblage is simple, consisting of disseminations and streaks of honey-coloured sphalerite and minor amounts of fine-grained galena and tetrahedrite (a silver-bearing sulphosalt). Sphalerite replaces limestone, dolostone and to a lesser extent phyllite. Pyrite is notably absent. Mineralization is localized at carbonate-phyllite contacts (predominantly within carbonate rocks) adjacent to faults and concentrated along fold hinges. Bleached alteration zones correspond to shear zones, and zones of silicification and dolomitization of the carbonate. Alteration of the phyllitic rocks is restricted to silicification and sericitization (Fyles, 1960). Partial to complete oxidation of the zinc mineralization, to considerable depths has resulted from groundwater circulation along solution cavities in the calcareous rocks (White, 1951). These ground conditions have proven to be inhospitable to most of the diamond drilling programs initiated on the property.

The age of mineralization is not well constrained. The only intrusive in the area is the Early Mississippian Clachnacudainn orthogneiss south of LaForme Creek. Sulphide textures indicate mineralization has undergone at least some post deposition deformation (probably in the Jurassic). Remobilized quartz and sphalerite fill sigmoidal tension gashes which crosscut early layer-parallel sphalerite replacement and galena-rich layers that contain rounded clasts of sphalerite, quartz, carbonate and phyllite in a fine-grained sulphide matrix (*durchbewegung* texure - a texture common in deformed and metamorphosed massive sulphide deposits). Lead isotopic model ages for the carbonate replacements of the Lower Cambrian Badshot Formation in the area are either Devonian or Jurassic.

Two diamond drill holes were completed on the Mastodon property by Banff Resources Inc. in 1994. Neither intersected economic concentrations of mineralization, but hole 1994-1, collared and drilled 121.39 metres in Index phyllites, intersected a faulted 9.7 metre thick zone containing garnets and minor sulphides. Geochemistry (Christopher, 1994) indicated elevated manganese, but generally lower lead, zinc and copper values than overlying strata. This horizon is geochemically similiar to the "garnet zone" in the hangingwall to the orebody at the Goldstream mine.

The Lead King prospect is located 3 kilometres southeast of the Mastodon Mine. Development work was limited to surface trenching and possibly a shallow adit. The showings are located at the southeastern end of the Mastodon marble lens (Figure 2). The rocks consist of variably silicified dolostone and grey phyllite, the former is locally so siliceous it resembles grey or buff quartzite (Fyles, 1960). Strata is isoclinally folded and sheared; strike is almost easterly and the dip is gentle to the north, into the hill. Galena and sphalerite occur as disseminations and fracture fillings replacing silicified limestone and dolostone. Four or five lenses of sulphides are exposed along the dolostone for about 60 metres (Fyles, 1960).

The Adair adit and trenches are located approximately 1.5 kilometres east of the Lead King prospect. The showings are hosted in grey limestone, grey dolostone and green and grey phyllite, correlated with the Mohican Formation. The rocks strike northwest and dip moderately northward into the hill. Mineralization is hosted in five or six steep to vertical white quartz veins which cut the main foliation at a high angle. The veins are irregular in thickness, continuity and sulphide content (Fyles, 1960). Pyrite, arsenopyrite, pyrrhotite, minor sphalerite, galena and chalcopyrite occur as irregular clusters in boudinaged quartz veins. A second showing about a kilometre to the southeast contains disseminated galena and sphalerite as replacements in limestone and dolostone (Fyles, 1960).

NEW PROSPECTIVE HORIZONS

In the Goldstream area, a distinctive spessartine garnet-bearing, pyrrhotite-rich, thinly laminated graphitic coticule unit, termed the "garnet-zone", is associated with the massive sulphide layer. It is interpreted to be an exhalite manganese-iron-rich seafloor hydrothermal precipitate (Höy *et al.*, 1984). These garnet zones are important exploration targets and mapping this summer recognized two additional iron-manganese-silica-rich horizons in the Mount LaForme area.

The two zones, both forming gossans, were recognized within lower Index Formation black phyllite close to the contact with the Badshot Formation. Both zones contained up to 3 per cent stratabound disseminated and massive sulphides consisting of pyrrhotite and/or pyrite with rare chalcopyrite. Sulphides occurred in zones of tight folding and silicification, and exhibited textures indicative of remobilization. The distribution and base metal content of these zones was not anomalous, and the manganese content was only slightly anomalous.

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NECHAKO NATMAP PROJECT - 1996 OVERVIEW

By D.G. MacIntyre and L.C. Struik (GSC, Vancouver)

A Contribution to the Nechako NATMAP Project

KEYWORDS: Nechako Plateau, NATMAP, multidisciplinary, bedrock mapping, surficial mapping, biogeochemistry, till geochemistry, geochronology, conodonts, radiolarian, geophysics, Babine Porphyry Belt, Eocene extension.

INTRODUCTION

The Nechako NATMAP project, which began in 1995, is a joint mapping and geoscientific research project between the British Columbia Geological Survey Branch (BCGSB) and the Geological Survey of Canada (GSC) that also includes participation by universities and industry (Struik and McMillan, 1996; McMillan and Struik, 1996). The co-cordinators of this project are the authors of this report. Work done by BCGSB field crews is funded wholly by the Energy and Minerals Division of the Ministry of Employment and Investment; GSC funding is from the Cordilleran division in Vancouver supplemented with additional funding from the National Mapping Program (NATMAP).

The project area, which encompasses over 30,000 square kilometres in central British Columbia, includes NTS map sheets 93F, 93K, and parts of 93L, 93M, 93N and 93G (Figure 1). The primary objective of the project is to improve the quality and detail of bedrock and surficial maps while focusing on several geological problems. In particular it will address questions of Tertiary crustal extension, Mesozoic compression and the manner of accretion of exotic terranes, the geological and geophysical definition of the terranes, the sequence of changing Pleistocene glacial ice flow directions, and the character and dispersion of glacial deposits. This new data will be used to better understand structural controls on the distribution of known mineral deposits and to identify target areas favourable for the discovery of new mineral resources by integrating geological, geophysical and geochemical data using a GIS.

In this second field season of the Nechako NATMAP project, mapping crews did 1:50 000 scale bedrock mapping in ten areas and surficial mapping in five areas (Figure 2). This work was enhanced by detailed geophysical and remote sensing surveys and stratigraphic studies based on micro and macro paleontology and radio-isotopic age dating. Stratigraphic studies concentrated on sections within the Cache Creek Group near Fort St. James and mainly volcanic sequences of the Ootsa Lake and Endako groups. Field crews also collected samples of till, silt , lake water and vegetation

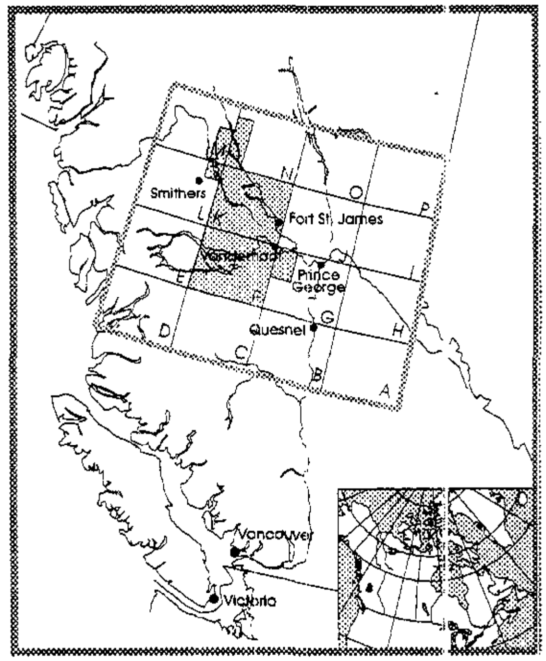

Figure 1. Location of the Nechako Natmap project

in selected areas in order to assess the potential for detecting known and new mineral deposits. Geophysical line surveys included ground-based magnetics, gravity and electromagnetics. Digital GIS projects included final compilations of data on the Quesnel Trough, compilation of mapping data from Placer Dome Incorporated, and cartography of some existing geology maps.

OVERVIEW OF RESULTS TO DATE

Bedrock mapping

Don MacIntyre, Ian Webster and Pat Desjardins of the BCGSB with the assistance of summer students Joseph Schrank and Susan Hand completed 1:50 000-scale geologic mapping of NTS map sheet 93M/1 (Figure 2, D) (MacIntyre *et al.*, 1997, this volume). Bedrock mapping of the Fulton Lake map sheet (93L/16) was completed in 1995 (MacIntyre *et al.*, 1996). The main objective of this work is to acquire a better understanding

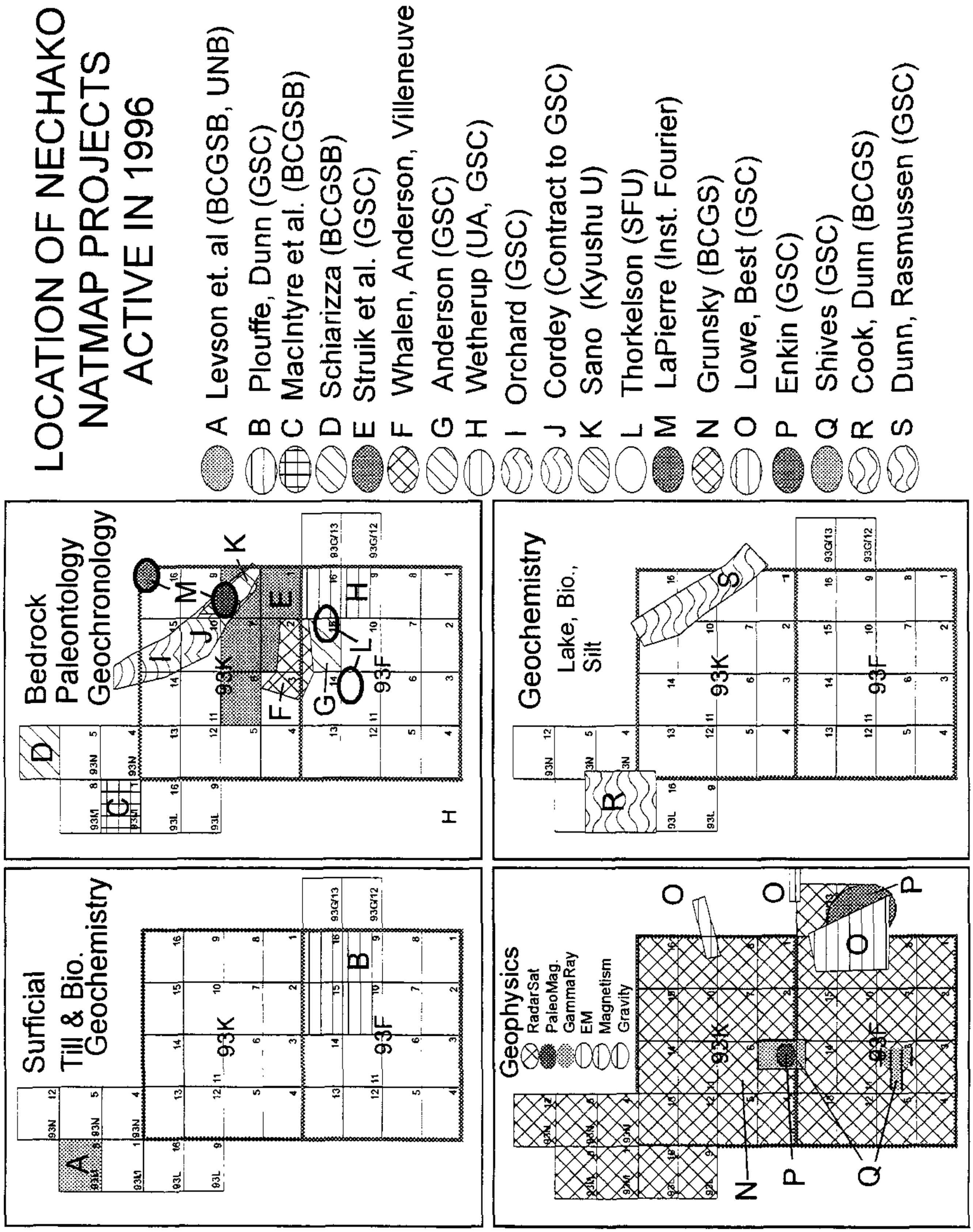

Figure 2. Projects active in the Nechako Natmap project area in 1996. See text for explanation of symbols.

of late Tertiary tectonics in the area and to integrate this with concurrent surficial and geochemical surveys in an attempt to define new exploration targets. Mapping to date, which has focused on new areas of rock exposure created by logging activities, plus new fossil collections and isotopic age dating (Villeneuve and MacIntyre, 1997) has helped to place previous mapping by Carter (1973) and Tipper and Richards (1976) into a modern stratigraphic framework. New mapping has confirmed that rocks ranging from Pennsylvanian to Early Cretaceous (Albian) in age were folded and thrust faulted in a major contractional tectonic event that probably took place in mid Cretaceous time, prior to eruption of Late Cretaceous volcanics of the Kasalka Group. In the Babine Lake area, early Cretaceous and older rocks are unconformably overlain and cut by the Eocene Babine Igneous suite of volcanics and high level intrusions. A preliminary model suggests volcano-plutonic centers were formed as pull-aparts on right lateral transcurrent faults related to an Eocene transtensional tectonic event. Age dating and mapping suggest development of Eocene volcanic basins in the Babine Lake area began with building of stratovolcanoes, followed by emplacement of high level stocks and dikes of biotite-feldspar porphyry and formation of porphyry copper deposits. These basins were further disrupted by late Tertiary block faulting with blocks tilted to the southeast thus truncating the older, north trending volcanic basins. Understanding the late Tertiary extensional tectonics of the area is critical to the delineation of areas favourable for the discovery of new mineral resources and for the successful exploration at existing properties.

Paul Schiarizza and Garry Payie (BCGSB) conducted bedrock mapping on the east side of Takla Lake in the western part of the Manson River map area (93N/12,13). This mapping has resulted in an improved understanding of the stratigraphy and structure of the Sitlika assemblage (Patterson, 1974), and its structural relationships with Cache Creek terrane to the east and Stikine Terrane to the west (Schiarizza and Payie, 1997, this volume). Mapping of the Sitlika belt is supported by U-Pb radiometric dating and geochemical studies carried out by Fiona Childe of MDRU (Childe and Schiarizza, 1997, this volume). The lithology and stratigraphy, Permo-Triassic age, and primitive tholeiitic geochemistry of the Sitlika assemblage support its correlation with the Kutcho Formation of northern British Columbia (Monger *et al.*, 1978), which hosts the Kutcho Creek volcanogenic massive sulphide deposit.

Bert Struik (GSC) and a crew of seven university students conducted bedrock mapping in the southeast quadrant of Fort Fraser map area (93K/1,2,6,7,8; Struik *et al.* 1997; Figure 2, E). The mapping has yielded new stratigraphy for the Tertiary Endako and Ootsa Lake groups, refined the distribution of the metamorphic facies of the Cache Creek Group, better defined the distribution and characterized contact relationships of some of the Mesozoic plutonic bodies and determined the tectonic block fault pattern in some of the Tertiary sequences. Janice Letwin initiated a Bachelors thesis at the University of Alberta (UA) on the geology of the Shass Mountain area underlain primarily by Cache Creek Group ultramafic, mafic and pelagic metasedimentary rocks. As part of the regional mapping of the Cache Creek Group, a contract research project has been conducted by Fabrice Cordey on the radiolarian biostratigraphy (Figure 2, L). This work will assist in defining the age range, paleogeographic setting, biostratigraphy and structures of the Cache Creek Terrane in the central Canadian Cordillera. More detailed results from last summer's sampling are reported in Cordey and Struik (1996). Newly determined age relationships have been used to locate a thrust fault, and have established a Triassic age range for ribbon cherts of the Cache Creek Group in the vicinity of Fort St. James.

Henriette LaPierre of the Universite Joseph Fourier, France (UJF) and Mark Tardy of the Universite de Chambery, France (UCH) sampled upper Paleozoic and Mesozoic volcanic rocks of the Cache Creek and Takla Groups for detailed geochemical analyses and some $^{40}Ar/^{39}Ar$ dating. This study attempts to characterize the source environments, and therefrom, tectonic regimes of the volcanic rocks and their host suites. Some comparisons will be made with existing interpretations of similar aged terranes in the southern Canadian and United States Cordillera.

Joe Whalen (GSC) conducted geochemical sampling of plutonic suites in the Endako/Fraser Lake area (93F/15 north and 93K/2) and characterized their lithological features and contact relationships. At least two plutonic groups were identified, an older penetratively deformed suite and a younger, locally slightly foliated to massive, group of intrusions. Each of these displays mafic to felsic compositional variations. In conjunction with Bob Anderson, petrographic, chemical, and isotopic work in progress will establish the age, petrogenesis and tectonic significance of these plutonic suites. Preliminary Nd isotopic results on samples collected in 1995 from some of the younger intrusions indicate they were derived mainly from juvenile sources (e.g., depleted mantle) rather than by remelting of old continental crust (Struik *et al.*, 1997; Anderson *et al.*, 1997)

Bob Anderson (GSC) with Rob L'Heureux conducted 1:50 000 mapping of the Hallet Lake map area (93F/15, G). Mesozoic and Tertiary volcanic units were distinguished. Mesozoic sedimentary and volcanic sequences are locally overturned to the north-northwest. Jurassic, Early Cretaceous and Late Cretaceous plutonic suites were mapped. Some Early Cretaceous phases, which are correlative with those of the Endako Mine camp, host widespread molybdenite showings. Follow-up mineralogical, chemical and geochronological work will define the composition and age of these suites. Rob L'Heureux's Bachelor's Thesis (UA) concerns the geological, petrological, and geochronological character of the plutonic suites which host the Nithi Mountain Molybdenum showings.

Lithological, textural and structural characteristics of the Eocene Ootsa Lake, Eocene-Oligocene Endako and Miocene Chilcotin groups were documented and contrasted. Mapping and analysis of plutonic rocks suggest at least 5 magmatic episodes whose character, age, distribution, and composition were previously unknown. Many have characteristics typical of plutonism recognized elsewhere in Stikine and Quesnel terranes but Early Cretaceous plutonism is unique to the Nechako NATMAP area and hosts the Endako porphyry molybdenite deposits.

Stephen Wetherup (UA) and Christopher Anderson of the University of British Columbia (UBC) completed mapping of the Nulki Lake (93F/16) and Tatuk Lake (93F/9) map areas. The western and southern bounds of the Vanderhoof Metamorphic complex were delineated (Wetherup, 1997). A clearer idea has been developed of the distribution of dioritic to monzonitic plutons of probable Jurassic and Cretaceous ages, and the contact relationships between the Tertiary volcanic suites. Wetherup's mapping in the Nulki Hills and south to Finger Lake will be part of a Masters thesis (UA) concentrating on the tectonic history of the Vanderhoof Metamorphic Complex.

SURFICIAL MAPPING AND GEOCHEMISTRY

Vic Levson, Dan Meldrum, Erin O'Brien and Craig Churchill (BCGSB) in collaboration with Andrew Stumpf and Bruce Broster from the University of New Brunswick (UNB), Alain Plouffe of the GSC and Brent Ward of the Ministry of Forests. conducted regional surficial mapping, drift geochemical sampling and glacial studies in the Babine Porphyry Belt (93M/8) (Figure 2, A) (Levson *et al.*, 1997, this volume; Stumpf *et al.*, 1997). Time-stratigraphic, 1:50 000, surficial geology mapping, incorporating local and regional ice flow history data, was conducted on 93M/8. This work will extend 1995 mapping on 93L/16 and 93M/1 and will provide a complete overview of the surficial geology of the Babine porphyry copper belt. Ice flow studies in the region show a dominant regional southeasterly flow. Glacial dispersal patterns of mineralized rock in the area reflect this dominant southeasterly flow. Surficial units, in which there is a high potential of tracing mineral anomalies to their bedrock source, as well as deposits such as glacial lake sediments, where the usefulness of soil geochemistry is limited, were identified during the mapping program. Surficial geology data from the Babine area will also be integrated with new bedrock geology mapping in the region.

The main objective of the till geochemical sampling program is to identify potential mineral anomalies in drift covered areas for industry follow-up by producing 1:50 000 regional till geochemistry maps for 93 L/16, 93M/1 and 93M/8. Quaternary stratigraphy studies were conducted in the Bulkley River valley and Nechako Reservoir areas in order to determine the regional Quaternary history. Till stratigraphy, ice flow history and lithologic studies were also conducted to determine regional dispersal patterns in different types of sample media, needed for appropriate design of exploration programs.

Detailed case study investigations were conducted in collaboration with Steve Cook (BCGSB) and industry geologists at the Hearne Hill, Lennac Lake, Nak and Trail Peak porphyry copper prospects. The work included detailed lithologic, sedimentologic and geochemical studies of surficial sediments around areas of known mineralization. Processes of dispersal of mineralized bedrock from different deposit types will be modeled to determine the size and shape of anomalies in various sediment facies and size fractions.

Steve Cook (BCGSB) conducted lake sediment, silt and till sampling for geochemical studies in the area of 93L/16, 93M/1 and 93M/8 (Figure 2, R; Cook, 1997). The Babine regional lake sediment and water geochemistry survey was conducted over the entire Babine porphyry belt. Lake sediments and waters were obtained from 332 sites over the equivalent of four 1:50 000-scale map sheets in areas of ongoing bedrock mapping. In addition, case study investigations were conducted in collaboration with Vic Levson (BCGSB) at the Hearne Hill, Lennac, Nak, Trail Peak and Dorothy prospects. The objective of these investigations is to document the till geochemical expression of the hydrothermal alteration zones associated with these Babine deposits.

Colin Dunn (GSC) also joined forces with Steve Cook to conduct a detailed till and biogeochemical study at the Lennac prospect. In this study the principal biogeochemical sample medium was again Lodgepole pine outer bark, but supplemented with samples of alder. The latter has a propensity to accumulate molybdenum and is useful, therefore, in defining zones of Mo and Cu enrichment. Bark samples were obtained from more than 120 sites over the general vicinity of the Lennac prospects.

Alain Plouffe (GSC), Francois Therrien and Holly Keyes conducted surficial mapping, and till and Lodgepole pine bark sampling throughout the northeast quadrant of the Nechako River map area (Figure 2, B; Plouffe, 1997). The work has more clearly defined the distribution of Glacial Lake Fraser sedimentation in the area. Colin Dunn (GSC) worked with the group to establish and integrate the till and tree bark sampling program. The Lodgepole pine outer bark samples (236 sites) were obtained throughout the same area and at most of the same sites that till samples were collected. The complementary till and biogeochemical data will be used to assist regional mapping of till dispersal and concealed bedrock. In addition, bark analyses to date indicate zones of metal enrichment not previously reported near Nulki Lake (Mo, Cu, Ag), and north of Goldie Creek (Mo, Ba, Sr), both in 93F16. The latter occurrence is in the vicinity of a quarry into layered felsic tuffs that have a tridymite coating on bedding surfaces.

Pat Rasmussen, Colin Dunn and Gwendy Hall (GSC) conducted a preliminary regional biogeochemical and hydrogeochemical survey in the Pinchi Creek area to determine the natural distribution and mobilization of mercury and related trace elements from geological sources to the atmosphere, vegetation and surface waters. Their study was designed to complement previous studies of mercury distribution in till (Plouffe, 1996) and in lake sediments (Steve Cook, personal communication, 1995), both of which provided valuable information for environmental applications.

GEOPHYSICAL STUDIES

Rob Shives (GSC) readied gamma ray, aeromagnetic and very low frequency electromagnetic data collected over the Endako Mine (parts of 93K/3 and 93F/15) and Wolf-Capoose prospect (part of 93F/6) areas (Figure 2, Q) for publication (Shives, in press). The magnetic data clearly show the location of the Casey Fault in the Endako area, and the thorium/potassium ratios highlight the alteration patterns of each of the known large mineral occurrences as well as some unidentified sources.

Eric Grunsky (BCGSB), is p[lanning to do image analysis studies in the Nechako NATMAP area using RADARSAT data. Two standard images (100 x 100 km) and one ScanSAR (500 x 500 km) have been ordered through the Application Development and Research Opportunity Project.

The areas covered are:

- Takla Lake area (93M 01, 08; 93N 04, 05; 93K 12, 13; 93L 09, 16)
- Nechako River (93K 01, 02, 03; 93F 01, 02, 03, 06, 07, 08, 09, 10, 11, 14, 15, 16; 93C 06, 07, 09, 10, 11, 14, 15, 16)
- NATMAP Project Area (93C,F,K,N)

Randy Enkin (GSC) sampled Tertiary plutonic rocks in and around the Endako Mine and near the Vanderhoof Complex to use paleomagnetic techniques to establish the history of Tertiary block movements in these regions (Figure 2, Q). This will test the hypothesis that Tertiary dextral strike-slip and listric extensional faults bound the Vanderhoof Complex and have affected much of the upper plate rock package of the region.

Mel Best and Carmel Lowe from the GSC, with students Michael Heyd and Jason Halko, conducted gravity, magnetic and electromagnetic (EM) surveys along several transects that crossed the Pinchi Fault and the boundary of the Vanderhoof Metamorphic Complex (Figure 2, P). These integrated geophysical surveys were used to map in three dimensions faults, bedrock structures and lithology beneath glacial drift. Preliminary results indicate that drift-covered faults and contacts, and in some instances structural features, were detected using these methods. In addition the EM survey conducted by M. Best provided new information on the southern extent of glacial Fraser Lake sediments. C. Lowe has recently compiled the regional aeromagnetic and gravity data over the entire Nechako NATMAP area and has carried out a preliminary interpretation.

GEOCHRONOLOGY

Mike Orchard (GSC) and Hillary Taylor (GSC) sampled the Mount Pope limestone of the Cache Creek Group near and northwest of Fort St. James (Figure 2, F); this sampling also complemented the detailed stratigraphic studies of Hiroyoshi Sano (KU). This work is a follow up to sampling and conodont determinations done prior to the NATMAP project (Orchard and Struik, 1997) and those that resulted from collections made during 1995 (Orchard, *et al.*, 1997). New conodont data from a transect northeast from Stuart Lake to Pinchi Lake shows that the carbonate youngs from Late Carboniferous, (Bashkirian to Mocovian) to Early Permian (probably Gzhelian-Asselian). The limestone interbedded with basalt that crops out adjacent to Stuart River at Fort St. James is mid Permian (Guadalupian). Anomalous Early Triassic conodonts are mixed with Carboniferous fauna in one collection from the region, implying a younger dissolution history for some of the Cache Creek limestones. Younger Triassic conodont fauna is also now known from west of Stuart Lake at Whitefish Bay.

Mike Villeneuve (GSC) worked closely with each of the mapping projects sampling and isotopically dating plutonic and volcanic suites, to determine the age of compressional and extensional fabrics hosted by some of the rocks, to establish the relationship between plutonism and ore generation, and to correlate Tertiary tectonics and volcanism throughout the project area. Studies continue on dating orthogneiss protoliths, the provenance of detrital zircons and post-crystallization thermal events in the Vanderhoof Metamorphic Complex. The Babine Igneous Suite, hosting porphyry Cu (+/- Au) deposits at northern Babine Lake, have yielded isotopic emplacement ages of 49-52 Ma (Villeneuve and MacIntyre, 1997).

STRATIGRAPHY

Hiroyoshi Sano of Kyushu University, Japan (KU) measured sections of the Cache Creek Group's Mount Pope sequence in detail (Figure 2, K; Sano and Struik, 1997). He has determined some of the possible depositional environments of the unit, and has associated this sequence with deposition on and surrounding oceanic island atolls.

Derek Thorkelson of Simon Fraser University (SFU) did reconnaissance work on Tertiary volcanic sections in the northern Nechako River map area (Figure 2, L). He has examined some unconformities and has found some lithological relationships and sequences that merit further work.

GEOGRAPHIC INFORMATION SYSTEMS

Stephen Williams (GSC) and Eric Grunsky (BCGSB) are working with scientific staff of both the GSC and BCGSB in the compilation of computer geological, geochemical and geophysical data to be published through various digital media (floppy disk, tape, CD-ROM, web site). That data will be integrated with a common GIS platform. A recent CD-ROM product contains information relevant to the Quesnel Trough of central British Columbia including NTS map areas 93K, 93N, 93J, 93O(SW) and 94C (Williams *et al.*, 1996). The computer information on that CD is available in several formats and is accessible with software included with the CD-ROM.

Andrew Harries and Ralph Westera (GSC) completed the digitization of the Placer Dome Inc. geological maps (Kimura *et al.* 1980). These maps were used as guides in the field mapping, and will be included in the compilation of the Nechako project maps.

ACKNOWLEDGMENTS

We would like to thank all those people who worked hard to make this project a reality and for the support of the GSC, BCGSB and geoscience community. We make a special note of thanks to Glen Johnston of Endako Mines for his hospitality and generosity with his ideas and Ed Kimura and Sharon Gardner of Placer Dome Inc. for their contribution to Canadian geoscience community through the donation of their geological maps of the Fort Fraser and Nechako River map areas. In addition we thank the many companies working in the Babine Porphyry Belt for their cooperation and generosity in permitting access to their properties and sharing their geological ideas for the area. Lori and Ken Lindenberger of Pipers Glen RV park provided generous support to the GSC crew throughout June to August.

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BABINE PORPHYRY BELT PROJECT: BEDROCK GEOLOGY OF THE OLD FORT MOUNTAIN AREA (93M/1), BRITISH COLUMBIA

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(British Columbia Geological Survey Branch contribution to the Nechako NATMAP Project)

KEYWORDS: bedrock mapping, Nechako NATMAP, Old Fort Mountain, Babine Porphyry Belt, Eocene extension, Babine Igneous Suite, Babine Intrusions, Newman volcanics, porphyry copper deposits, Bell, Hearne Hill, Morrison, Wolf, Dorothy, Fireweed.

INTRODUCTION

The Babine porphyry belt project is part of the Nechako National Mapping Program (NATMAP), a joint effort of the Geological Survey of Canada and the British Columbia Geological Survey Branch of the Ministry of Employment and Investment (McMillan and Struik, 1996; MacIntyre and Struik, 1997, this volume). This is a multidisciplinary project with separate components for bedrock and surficial geology, till and silt geochemistry. The primary objectives of the Babine Porphyry Belt project are to produce 1:50 000-scale bedrock and surficial geology maps of the Fulton Lake (93L/16), Old Fort Mountain (93M/1) and Nakinilerak Lake (93M/8) map sheets (Figure 1) and to define areas of possible buried metallic mineral deposits using till, lake and silt geochemistry. This report summarizes the results of bedrock mapping completed in 1996 and supplements a previous report on mapping done in the Fulton Lake map sheet in 1995 (MacIntyre *et al.*, 1996).

PROJECT DESCRIPTION

The Babine porphyry belt is located in west-central British Columbia and is centred on the northern third of Babine Lake (Figure 1). The belt is approximately 80 kilometres long and includes twelve significant porphyry copper deposits and prospects including the Bell and Granisle past producers. The mineral potential of the area was ranked the fourth highest of the 97 tracts evaluated in the Skeena-Nass mineral potential project (MacIntyre *et al.*, 1995). The estimated value of known in-ground mineral resources in the area is $1.96 billion and the value of past production is estimated at $1.13 billion (1986 dollars). In spite of the high mineral potential and obvious economic significance of the area, the most recent published geological mapping in the belt was by Carter (1973). Since then there has been extensive logging in the area, providing new access and better bedrock exposure, especially in areas of extensive drift cover. This, coupled with renewed interest in

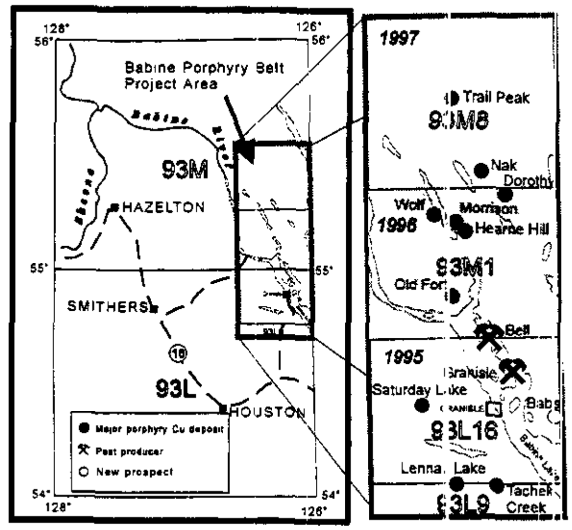

Figure 1. Location of the Babine Porphyry Belt project area, West-central British Columbia. Shaded area was mapped in 1996 and is the subject of this report.

porphyry copper deposits as an exploration target and the need for economic diversification in the economy of the area, make this project particularly timely. It is hoped that new bedrock and surficial mapping, together with regional till and lake geochemistry and airborne geophysical surveys, will stimulate additional exploration in the belt and lead to new discoveries. Drift prospecting, lake geochemistry and airborne geophysics will be especially important in defining new targets in drift-covered areas. The Quaternary geology and till and lake geochemical sampling completed in 1995 and 1996 are discussed in separate reports (Huntley *et al.*, 1996, Stumpf *et al.*, 1996, Levson *et al.* , 1997 (this volume) and Cook *et al.*, 1997 (this volume).

ACCOMPLISHMENTS

The 1996 bedrock mapping crew consisted of Don MacIntyre and Ian Webster accompanied by student field assistants Susan Hand and Joseph Schrank. Additional mapping support was provided by Pat Desjardins and Paul Wojdak. This crew completed 1:50

000-scale geological mapping of the Old Fort Mountain mapsheet (93M/1). In addition to regional bedrock mapping, major mineral deposits and new prospects in the area were mapped and sampled. Samples were also collected for radiometric dating in conjunction with Mike Villeneuve of the Geological Survey of Canada and this information will help to further refine the geology of the area. Major geological accomplishments made during the 1996 field season are summarized below.

- the belt of Lower to Middle Jurassic bimodal volcanics first recognized in the area west of Granisle in 1995 was extended as far northward as Hearne Hill. This volcanic package thickens and becomes more vent proximal northward suggesting a major eruptive center is located in this direction.
- a major ash flow unit of probable Lower to Middle Jurassic age was mapped on the south flank of Hearne Hill. This unit could be up to 1000 metres thick.
- collections were made from 18 fossil localities. Many of these occurrences are new and will provide important stratigraphic control in the map area.
- correlation of Lower Jurassic stratigraphy in the Old Fort Mountain area with the type area of the Telkwa Formation in the Telkwa Range. This suggests the Howson subaerial facies extends much further east than originally thought.
- zones of silicification and quartz veining associated with Eocene rhyolite domes were sampled and may prove to contain precious metal values.
- a Tertiary graben containing carbonaceous Cretaceous strata was located in the northeast corner of the map area. This area may have potential for coal.
- 24 mineral occurrences were located and sampled. Assay results will determine if any of these are significant.
- 16 Ar-Ar and 5 U-Pb radiometric age date samples were collected. These will be processed by Mike Villeneuve of the Geological Survey of Canada, Ottawa.

SUMMARY STATISTICS

A total of 235 person days was required to complete 1:50 000-scale mapping of Fulton Lake map sheet (93L/16). A total of 562 geologic stations were recorded in the 89 000 hectare map area.

FUTURE PLANS

Geoscientific studies are planned for the Babine Lake area in 1997 as part of the Nechako NATMAP program. The target for bedrock mapping in 1997 will be to complete 1:50 000-scale mapping of the Nakinilerak Lake map sheet (93M/8, Figure 1). The major porphyry copper deposits on this map sheet are Nak and Trail Peak, both of which should be active next summer.

PREVIOUS WORK

Geologic mapping and mineral property evaluations by the Geological Survey of Canada and the British Columbia Department of Mines (now Ministry of Employment and Investment) date back to the turn of the century. Earliest reports on the geology of west-central British Columbia are by G.M. Dawson (1881) who described porphyritic flows in the Francois Lake and Skeena River areas. Volcanic rocks in the Hazelton and Smithers area were first described by Leach (1910) who proposed a two-fold subdivision between Jurassic volcanics, which he called the Hazelton Group, and Cretaceous sedimentary strata which he named the Skeena series. Hanson (1925) further subdivided the Hazelton Group into a lower volcanic division, a middle sedimentary division and an upper volcanic division. This division remained unchanged for many years until Armstrong (1944a, 1944b) included the Skeena series with the Hazelton Group

In 1976, the Geological Survey of Canada published Tipper and Richards (1976a) bulletin *Jurassic Stratigraphy and History of North-central British Columbia*. This comprehensive publication included previously unpublished data on numerous fossil localities and measured stratigraphic sections, including several in the Babine Lake area. This bulletin complemented the release of an open file, 1:250 000-scale, geological map of the Smithers (Tipper and Richards, 1976b). The geology of the Hazelton map sheet (93M) was released as open files 720 (Richards, 1980) and 2322 (Richards, 1990).

Tipper and Richards subdivided the Hazelton Group into several different formations. They also resurrected the name Skeena Group for Early Cretaceous coal-bearing, overlap sedimentary strata that Armstrong (1944a, 1944b) originally placed in the Hazelton Group.

Carter mapped the Babine porphyry belt in detail between 1965 and 1972 as part of a British Columbia Ministry of Mines regional study of porphyry deposits in west-central British Columbia. This excellent work was released as Preliminary Map 12 (Carter, 1973) and remains the only published geological map of the belt. Because of improved access via logging roads, better bedrock exposure in clear-cuts and a better understanding of regional stratigraphic relationships, we were able to expand on this earlier mapping and place it in a modern stratigraphic framework.

The Babine porphyry belt is one of the most important mineral camps in British Columbia (Carter *et al.* 1995). Numerous reports have been published on individual deposits. Carson and Jambor (1974), Wilson *et al.* (1980) and Zaluski *et al.* (1994) have discussed hydrothermal alteration and fluid geochemistry in the district; Fahrni et al. (1976), Carson et al. (1976) and Dirom et al. (1995) have described the geology and mineralization at the Granisle and Bell mines; and Carson and Jambor (1976) and Ogryzlo et al. (1995) the Morrison and Hearne Hill deposits.

ACCESS

The main access to the area is from Highway 16, which follows the Bulkley River valley from the town of Houston through Telkwa and Smithers and north to Hazelton (Figure 1). Smithers, located approximately half way between Prince George and Prince Rupert, is the largest town in the area and is a major transportation centre with daily jet service to Vancouver, Terrace and Prince George.

There are two main routes into the study area from Highway 16. The Smithers Landing - Granisle connector route, which leaves Highway 16 south of Smithers and goes through McKendrick Pass on its way to Granisle, is 78 kilometres long and is mainly gravel. The Topley - Granisle road is paved; it leaves Highway 16 at Topley and terminates at Granisle, a distance of 48 kilometres. An extensive network of logging roads provides access to much of the map area, especially east of Babine Lake. The east side of the lake is accessible by private ferry between Mill Bay, just north of Topley Landing, and Nose Bay on the east side of the lake. Crossing time is approximately 20 minutes. The ferry is run by Northwood Lumber Co. based in Houston, and is free to the public with the acquisition of a permit. On the east side of the lake, the Morrison, Hagan, Jinx and Nose Bay haulage roads, which are radio controlled and heavily used by logging trucks, are the main access routes.

PHYSIOGRAPHY

The physiography of the Babine Lake area is characterized by rolling hills and extensive drift-covered areas of low relief. Bedrock exposure is found on the crests of hills and small glaciated knolls, in deeply incised creek valleys and along the shores of Babine and Fulton lakes. Clear-cut logging in the area has also exposed bedrock along road cuts and in areas subject to soil erosion. Huntley et al. (1996) discuss the physiography and Quaternary history of the study area.

TECTONIC HISTORY AND REGIONAL GEOLOGIC SETTING

The Babine Porphyry Belt is entirely within Stikinia, the largest terrane of the Intermontane tectonic belt. This terrane includes Lower Devonian to Middle Jurassic volcanic and sedimentary strata of theAsitka, Stuhini, Lewes River and Hazelton assemblages and related comagmatic plutonic rocks. The oldest rocks are upper Paleozoic carbonates and island-arc volcanic and volcaniclastic rocks locally referred to as the Stikine assemblage (Monger, 1977, Brown et al., 1991). Areas with this assemblage, which east of the Bowser Basin is called the Asitka Group, represent remnants of a tectonically dismembered, shallow-water, island-arc environment with carbonate buildups fringing emergent volcanic islands. Permian and possibly older rocks occur in the study area and these rocks are tentatively correlated with the Asitka Group.

The Paleozoic island-arc regime was followed by a depositional hiatus prior to development of a Late Triassic volcanic arc and eruption of the predominantly basaltic Stuhini Group. By Early Jurassic time the area was part of the regionally extensive Hazelton calcalkaline volcanic arc. The orientation of this arc and the polarity of related subduction zones is still much in debate. However, facies relationships suggest there was a central marine trough that was bounded by northwest-trending island-arcs. This apparent paleogeography is complicated by significant right-lateral displacement of the Hazelton rocks along northeast-trending transcurrent faults. A northeast-dipping subduction zone seems likely for the western part of the Hazelton arc. The basaltic to andesitic island-arc volcanics exposed in the study area can be correlated with the Stuhini and Hazelton groups on the basis of lithology and inferred stratigraphic position.

Collision of Stikinia with the Cache Creek Terrane in Middle Jurassic time resulted in uplift of the Skeena Arch and formation of the Bowser Basin. From Late Jurassic to Early Cretaceous time, continued uplift and erosion of the Skeena Arch and Omineca crystalline belt resulted in deposition of thick molasse deposits in the Bowser Basin, which lies northwest of the study area. Contraction and development of the Skeena Fold Belt began in the latest Jurassic or earliest Cretaceous, accompanied by uplift and magmatism within the Coast Belt and supracrustal shortening in the Bowser Basin (Evenchick, 1990). In the Albian, rocks of the Skeena Group were deposited in a broad, shallow-water basin that may have covered much of West Central British Columbia including the current study area.

A major plate collision in middle Cretaceous time resulted in further uplift of the Coast Mountains and extensive folding and thrust faulting of rocks to the east. Debris from rising metamorphic-plutonic complexes and the evolving Skeena Fold Belt was shed eastward and deposited in the Sustut basin. This was followed by the growth of north-trending, eastward-migrating Andean-type volcanic arcs in late Cretaceous to Eocene time. These arcs are believed to be the result of oblique, eastward subduction of oceanic crust under the leading edge of the North American plate, with volcanic centres localized along zones of extension within a transtensional tectonic regime. Throughout the North American Cordillera this volcano-tectonic event is known as the Laramide orogeny. In West Central British Columbia, calcalkaline volcanic rocks of the

Upper Cretaceous Kasalka Group and Eocene Ootsa Lake Group are the remnants of these arcs which were built on uplifted, folded and eroded blocks of Stikinia and its Upper Jurassic to Lower Cretaceous overlap assemblages. In the Tahtsa lake area late Cretaceous and Eocene volcanics sit with angular discordance on folded early Cretaceous (Albian) sediments of the Skeena group. The unconformity is overlain by an erosional conglomerate suggesting uplift and erosion prior to the onset of continental arc volcanism in late Cretaceous time. In the study area, Eocene porphyritic flows and breccias of the Newman volcanics are correlated with the Ootsa Lake Group; the Kasalka Group is not well represented, being restricted to one small outlier.

The Middle to Late Cretaceous Bulkley intrusions and the Eocene Babine intrusions (Carter, 1981) are the plutonic roots of these younger continental volcanic arcs. Mineral deposits in the study area are associated with emplacement of these intrusions. The most economically important exploration targets are porphyry copper and molybdenum deposits and related mesothermal precious metal veins. Post Eocene (post Laramide) crustal extension and block faulting produced a basin and range geomorphology through the development of grabens and horsts. This complex fault pattern, superimposed on an earlier mid Cretaceous contractional event controls the bedrock map pattern of the area. Locally within the Interior plateau, late Tertiary extension was accompanied by the development of metamorphic core complexes and extensive bimodal volcanism. No metamorphic core complexes are recognized in the northern Babine lake area and there is not an extensive cover of post Eocene volcanics as there is to the south in the Interior plateau. The Babine porphyry belt appears to lie near the northern limit of late Tertiary extension and volcanism.

Extension in the Babine lake area appears to have been accompanied by northeast displacement along right-lateral transcurrent faults and tilting of fault blocks to the southeast. This right-lateral displacement offset earlier northwest-trending grabens and horsts containing Eocene and younger volcanic and sedimentary strata (MacIntyre *et al.*, 1989). Extension of the crust in Miocene time was accompanied by extensive outpouring of continental lava flows of the Endako and Chilcotin groups which now cover large parts of the Interior Plateau to the south.

An important objective of the current project is to reconstruct the paleogeography of the Eocene magmatic arc and associated porphyry copper deposits prior to disruption by late Tertiary block faulting and right lateral transcurrent fault movements. This is important to exploration because many of the porphyry deposits have probably been rotated, tilted and possibly segmented by the late Tertiary tectonism. Such offsets have been documented at the former Bell mine (Carson *et al.*, 1976), and at the Morrison and Hearne Hill deposits (Ogryzlo *et al.*, 1995). The latter may be part of the same volcano-plutonic center, with the Morrison deposit displaced downward and northeastward into the Morrison graben (Ogryzlo *et al.*, 1995). Understanding these movements is critical to mounting successful exploration programs at both known deposits, and in the search for new deposits that may not be exposed at surface.

LITHOLOGIC UNITS

The geology of the study area, based on mapping completed in 1996 and the earlier mapping of Carter (1973), Tipper and Richards (1976) and Richards (1980; 1990), is shown in Figure 2. Figure 3 illustrates our current understanding of the stratigraphic relationships between the different map units; Figure 4 is a cross section across the map area.

The geologic framework of the study area consists of a series of uplifted, tilted and folded fault blocks containing rocks ranging from Triassic to Eocene in age. North-trending grabens centred on Hatchery arm of Babine Lake, Morrison Lake and the Hautête valley are defined by a series of inward dipping, progressively down-dropped fault blocks. Eocene and possibly younger volcanic and intrusive rocks are preserved in these grabens. The grabens are truncated and offset by northeast and northwest-trending dextral shear zones of post Eocene age.

PERMO-TRIASSIC ROCKS

Limestone and mafic volcanics that have previously been mapped as Permian and Triassic in age (Tipper and Richards, 1980) crop out along the southern margin of the map sheet, west of Babine Lake. A series of cliffs along the shore of Babine lake offer the best exposure. Here, limestone is interbedded with mafic volcanics. Bedding attitudes are disrupted by fault imbrications suggesting proximity to a fault zone. These rocks are tentatively correlated with the Western Takla Group based on lithology and apparent age.

LATE TRIASSIC TO EARLY JURASSIC TOPLEY INTRUSIONS (LTrJT)

The Topley intrusions, as defined by Carter (1981), include quartz diorite to quartz monzonite of Late Triassic to Early Jurassic age. Earlier reports (Carr, 1965; Kimura *et al.*, 1976) used the term Topley intrusions for granite, quartz monzonite, granodiorite, quartz diorite, diorite and gabbro intrusions of probable Jurassic age that intrude Triassic volcanic rocks from Babine Lake to Quesnel. Included in this Topley suite were high-potassium intrusions associated with the Endako porphyry molybdenum deposit. However, subsequent K-Ar isotopic dating showed that most of these intrusions were Late Jurassic to Early Cretaceous in age. Consequently, the intrusions around Endako were renamed the Francois Lake intrusions to distinguish them from the older Topley suite.

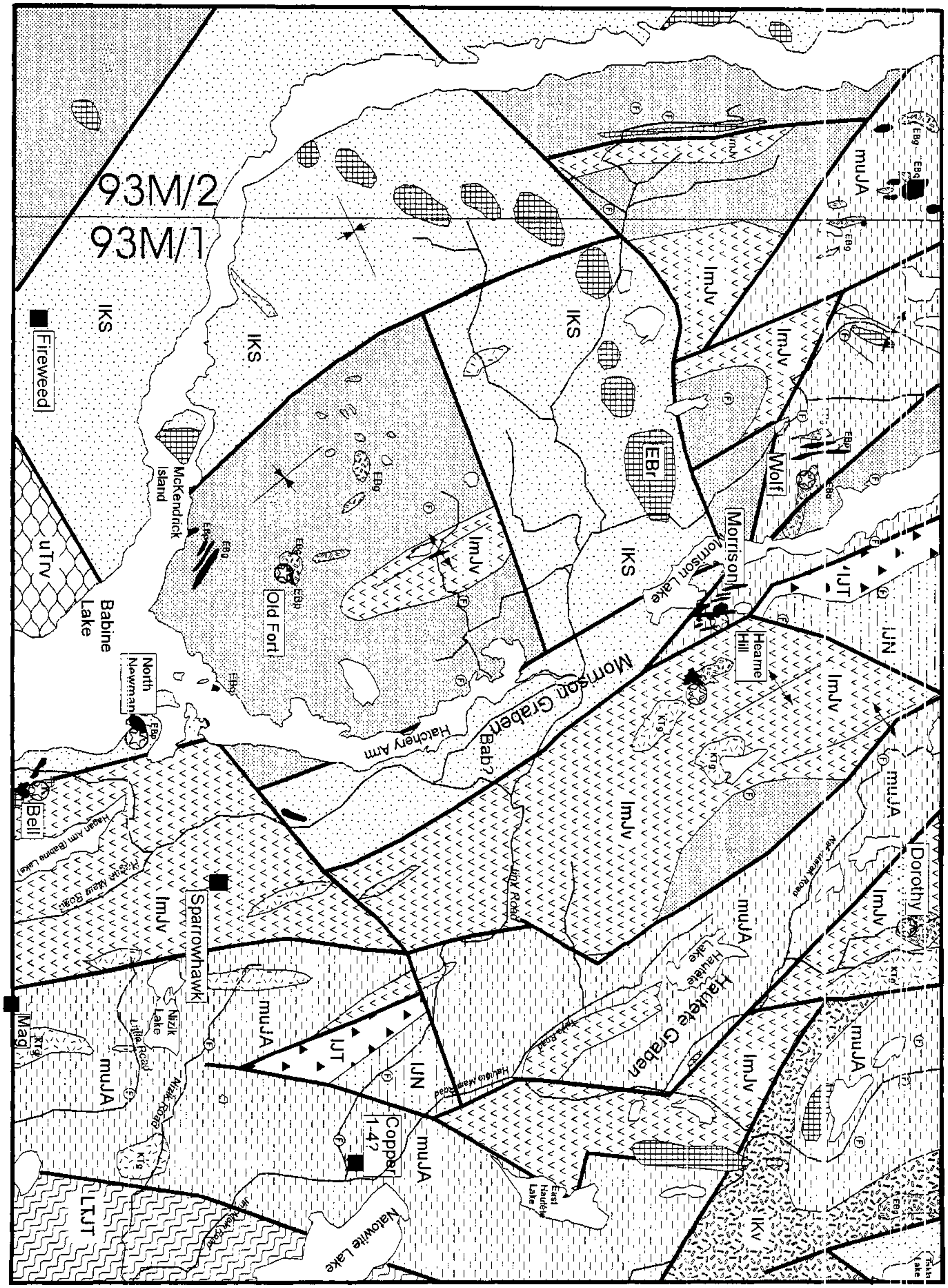

Figure 2. Generalized bedrock geology of the Old Fort Mountain map sheet, 93M/1. See Figure 3 for legend. Stars and solid squares are known occurrences discussed in this report.

Potassium-argon isotopic dates for the Topley intrusions, as defined by Carter (1981), would include ages as young as 178 Ma, but most are between 199 and 210 Ma (Early Jurassic) using the old decay constants. Most of these dates are from large plutons in the Topley area and southwest of Babine Lake. In the current study we restrict the term Topley intrusions to typically pink, potassium feldspar-rich granite and quartz monzonite of apparent Late Triassic to Early Jurassic age. We consider the type area to be the southeast corner of the Fulton Lake map sheet where a large, multiphase intrusive body, the Tachek stock, is well exposed in clear-cuts and along the shores of Babine Lake. The high-potassium composition of these rocks distinguishes them from older and younger plutonic suites that are mainly granodiorite to quartz diorite. Phases of the Topley intrusions, as defined in this study, intrude rocks believed to be correlative with the Permian Asitka and Late Triassic Stuhini groups. The only locality where a Topley intrusion has been observed cutting Telkwa Formation rocks is in a creek exposure 3 kilometres west of Lennac Lake. Here, a fine-grained, pink aplitic dike, typical of the youngest phase of the Topley suite, cuts maroon lapilli tuffs.

The extreme southeast corner of the Old Fort Mountain map sheet is the only area where typical Topley rocks crop out. These rocks are believed to be in fault contact with younger Jurassic volcanics and sediments to the northwest. Exposure is poor and the exact nature of the contact and possible kinematics are not known. The bounding fault is believed to be a southerly extension of the Takla right lateral transcurrent fault system which juxtaposes Jurassic and Cretaceous volcanic and sedimentary strata against older Triassic rocks to the east. Significant displacement along this fault system has been demonstrated to the north; the magnitude of right lateral displacement, if any, is unknown in the Babine Lake area.

Prior to the current study, only two localities in the study area where the Topley intrusions had been dated (Nos 40 and 33, Table 1). A 210 $\pm$9 Ma age (revised) was determined on hornblende extracted from coarse-grained porphyritic monzonite exposed on a small island 8 kilometres north of Topley Landing (Wanless, 1974); a 178 $\pm$7 Ma age (revised) was determined on biotite from a hornblende-biotite-quartz-feldspar porphyry dike at the Tachek porphyry copper prospect (Carter, 1981).

Two new U-Pb age determinations have been done on zircon extracted from rocks collected at two different localites within the Tachek stock (nos. 33 and 41, Table 1). These gave ages of 178.7 $\pm$ 0.5 Ma and 215-230 Ma respectively. Unfortunately both of the U-Pb determinations have problems and their reliability is suspect. In addition, Ar-Ar ages were determined on a porphyritic hornblende diorite stock located east of the Tachek stock near Toncha lake (No. 32, Table 1), biotite granodiorite within the Tachek stock (No 36, Table 1) and a hornblende-feldspar porphyry dike cutting suspected Triassic rocks north of Granisle (No. 37, Table 1) These gave ages of 175.7$\pm$1.7 Ma, 191.1$\pm$1.9 Ma and 193.7$\pm$1.9 Ma respectively, all within the previously determined age ranges for the Topley intrusive suite. These new age determinations combined with previous dating suggest that there are two main magmatic events, one in the 191 to possibly as old as 230 Ma time period, and another more tightly constrained episode around 176 to 179 Ma. Clearly, more work will be needed to confirm the apparent range of ages within the Tachek stock and for other intrusive bodies considered to be part of the Topley suite.

LOWER TO MIDDLE JURASSIC HAZELTON GROUP

The Hazelton Group (Leach, 1910) is a calcalkaline island-arc assemblage that evolved in Early to Middle Jurassic time. Tipper and Richards (1976a) divided the group into three major formations. These are, from oldest to youngest, the subaerial to submarine, predominantly calcalkaline volcanic Telkwa Formation, the marine sedimentary and volcanic Nilkitkwa Formation and the shallow water, marine transgressive Smithers Formation. In the Babine lake area there is also a lower to middle volcanic formation which Richards called the Saddle Hill volcanics. On the Old Fort Mountain map sheet the lower part of the Hazelton succession is not well exposed and the predominant formations are the lower to middle Jurassic Saddle Hill volcanics and the middle Jurassic Smithers and middle to upper Jurassic Ashman formations.

LOWER JURASSIC TELKWA FORMATION (lJT)

The type area for the Telkwa Formation is in the Telkwa Range, where a thick section of Early Jurassic volcanic rocks is well exposed. Regionally, the formation varies from marine to nonmarine and ranges from Sinemurian to early Pliensbachian in age. In the type area the predominant lithologies are air-fall tuffs, volcanic breccias and amygdaloidal basalt flows; these rocks constitute the Howson subaerial facies of the formation (Tipper and Richards, 1976a).

Previous mapping in the type area (MacIntyre *et al.*, 1989) suggests the Telkwa Formation is divisible into three members, each representing a distinct cycle of arc volcanism. These members are characterized by their predominant lithologies, although internal facies variations are common. In ascending stratigraphic order they are: (1) an andesitic pyroclastic member comprised of thick-bedded, massive, maroon andesitic lapilli, crystal and ash tuffs with minor interbeds of siliceous-banded ash flows and grey, welded lapilli tuffs; (2) a basaltic flow member which is predominantly dark green to maroon, amygdaloidal to aphyric basalt; and (3) a felsic pyroclastic member that includes interbedded ash-flow tuff, felsic lapilli and crystal tuff, flow-banded spherulitic rhyolite, volcanic breccia and related epiclastic rocks.

The Telkwa Formation is not well exposed in the Old Fort Mountain map sheet, occurring in only two

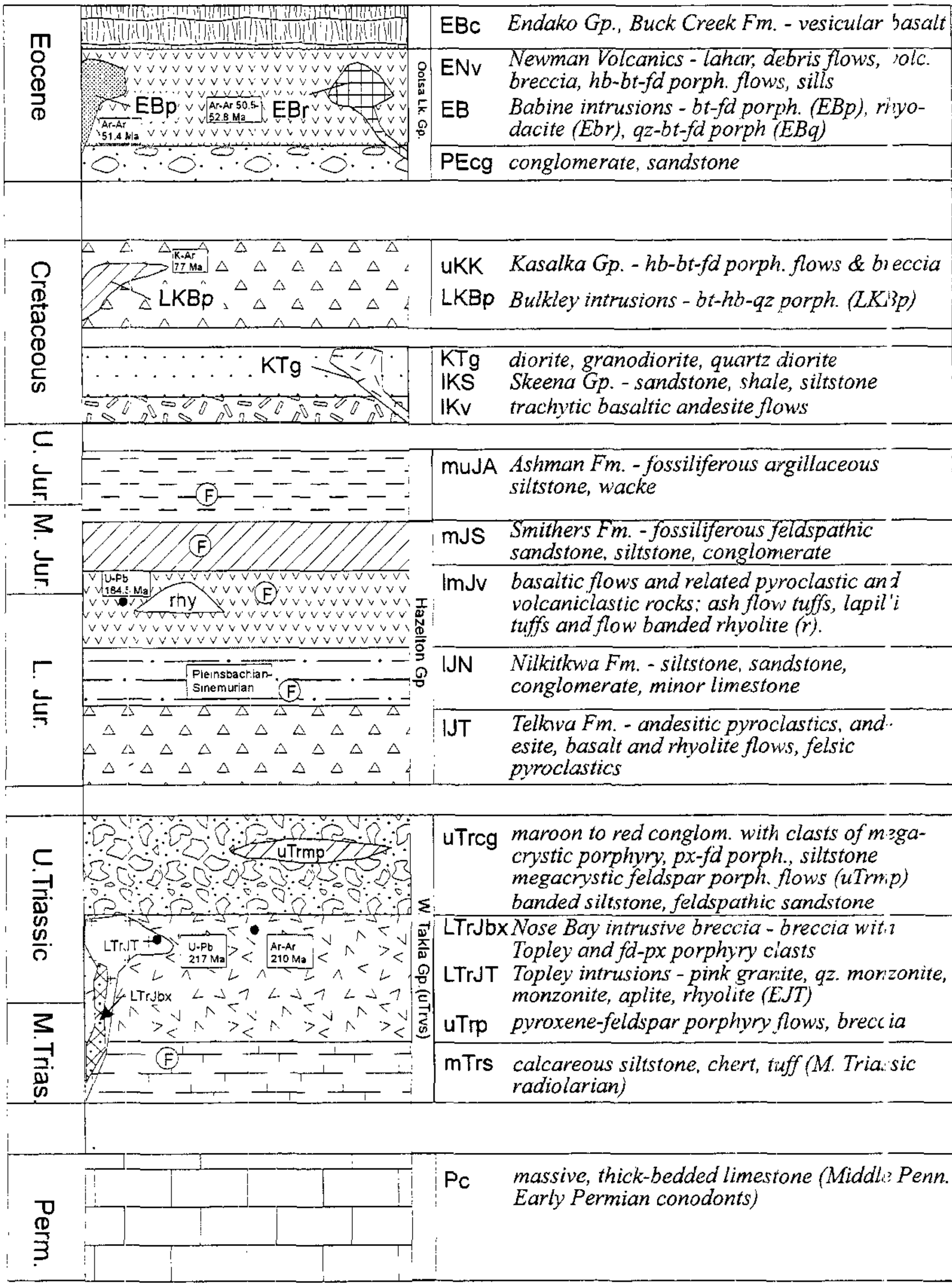

Figure 3. Diagrammatic section showing relationships between map units in the Old Fort Mountain map area (93M/1).

isolated fault blocks, one east of Morrison lake and one northeast of Nizik lake. In both areas only the upper members or the formation are exposed and these rocks, which are typically amygdaloidal basalt flows, are overlain by shallow water marine sedimentary rocks of the Late Sinemurian - Early Pliensbachian Nilkitkwa formation.

LOWER JURASSIC NILKITKWA FORMATION (lJN)

Tipper and Richards (1976a) assigned thick sections of Pliensbachian to Toarcian shale, greywacke, tuff, breccia and minor limestone, that are well exposed in the Nilkitkwa and Bait ranges, to the Nilkitkwa Formation. In the type area the formation is as much as 1000 metres thick. Limestone and chert beds occur in the lower part of the section and help distinguish Nilkitkwa rocks from younger, lithologically similar formations. Shallow-water fossiliferous limestone, interbedded with pebble conglomerate and feldspathic sandstone, is particularly common where Nilkitkwa sediments onlap Telkwa volcanics.

The only known exposures of the Nilkitkwa Formation in the current study area are east of Morrison lake and northeast of Nizik lake along the old Jinx haulage road. In both localities, northeast dipping beds of feldspathic sandstone, siltstone and pebble conglomerate conformably overlie amygdaloidal basalt and maroon lapilli tuff of the Telkwa Formation. Coarse, poorly sorted conglomerate beds often contain subangular pebbles and boulders of amygdaloidal basalt in a limy, sandy matrix. The coarse clastics grade up section into deeper water, finer-grained, more thinly bedded feldspathic sandstones and siltstones. Fossils from these beds include well preserved *Weyla*, a diagnostic Lower Jurassic bivalve commonly found in the lower part of the Nilkitkwa formation. Similar shallow water sediments containing late Sinemurian to early Pliensbachian fossils occur in the Telkwa Range (MacIntyre *et al.*, 1989) and at two localities in the Fulton Lake map sheet (MacIntyre *et al.*, 1996), one on a small island just south of Sterrett Island which is Late Sinemurian (H.W. Tipper, personal communication, 1995) and the other at Broughton Creek which is late Pliensbachian (H.W. Tipper, personal communication, 1995).

LOWER TO MIDDLE JURASSIC SADDLE HILL VOLCANICS (lmJv)

The Old Fort Mountain map sheet is underlain by up to 2000 metres of bimodal, predominantly subaerial, volcanics that are Lower to Middle Jurassic in age. Richards (1990) was the first to recognize volcanics of this age in the Hazelton map area and he named these rocks the Saddle Hill volcanics. Saddle Hill, which is located west of Morrison lake in the current study area, is underlain by maroon to green feldspar rich crystal and lapilli tuffs that are overlain by shallow marine sediments of the Smithers formation. The latter contain ammonites and bivalves of Bajocian age. The volcanic rocks, which underlie the central and northwest corners of the Old Fort Mountain map sheet, are believed to conformably overlie Lower Jurassic marine sedimentary strata of the Nilkitkwa formation although this contact is not well exposed. The Saddle Hill volcanics are therefore lower to middle Jurassic in age based on stratigraphic position.

Rocks lithologically similar to the Saddle hill volcanics crop out in the area west of Granisle and on the Newman Peninsula. The Granisle section was previously mapped as Triassic Takla Group, and the Newman Peninsula section as Lower Jurassic Telkwa Formation. In a previous report (MacIntyre, *et al.* 1996), we suggested the Newman section was probably not Telkwa Formation, based on lithologic differences, and that both the Newman and Granisle sections were probably Triassic, assuming the age shown on previous open file maps for the rocks west of Granisle was correct. However, zircons extracted from a quartz-bearing lapilli tuff bed within the Granisle section subsequently yielded a Jurassic, 184.7$\pm$0.5 Ma U-Pb isotopic age (M. Villeneuve, personal communication) (No. 35, Table 1). This Toarcian age suggests the rocks west of Granisle (and therefore, lithologically similar rocks on the Newman Peninsula) are correlative with the Saddle Hill volcanics, a conclusion supported by lithologic similarities and apparent isotopic age.

The volcanic rocks exposed on Saddle Hill probably represent only the upper part of the total Lower to Middle Jurassic volcanic succession. The lower and middle parts, which include beds of amygdaloidal and aphyric to feldspar-phyric basalt and felsic pyroclastic rocks, crop out as a series of ridges in the clearcut area west of Saddle Hill. However, the best and most continuous exposures of rocks correlated with the Saddle Hill volcanics occur along the north trending ridge that extends from the Newman Peninsula to Hearne Hill. This volcanic sequence, which appears to be thickening northward toward Hearne Hill, includes a lower unit of rhyolitic ash flows and ignimbrites and lesser lapill tuff , a middle unit of greenish grey basaltic flows interbedded with related epiclastic and pyroclastic rocks and an upper unit of maroon feldspathic tuffs, volcanic conglomerates, cherts and epiclastics that grade into fossiliferous, shallow marine sediments of the Smithers Formation.

White-weathering, flow-banded rhyolite and medium to thick-bedded, weakly to intensely welded ash-flow tuff and ignimbrite occur near the bottom of the Saddle Hill volcanic sequence. The ash flow member is well-exposed in the clear cut south of Hearne Hill where it may be up to 1000 metres thick. This section includes light grey to white-weathering, well bedded lapilli tuffs, ash-flow tuffs and volcanic debris-flows. The ash-flow tuffs are unwelded to strongly welded to un-welded and contain light coloured, lapilli-sized clasts that include aphanitic rhyolite, flow-banded rhyolite and scoriaceous tuff in a fine-grained, greyish green, feldspar-phyric matrix. A sample of ash flow from the Hearne Hill section was collected in 1996 and has been submitted for age dating. Debris flows in the section contain clasts of the ash-flow tuffs and are probably locally derived.

The Hearne Hill section is intruded by northwest-trending, vertical, strongly epidotized basaltic dikes that probably feed flows higher up in the section. Younger, Eocene, northeast trending-flow banded, rhyolite dikes cut both the ash-flows and basalt dikes. Flow banding is defined by cream and maroon bands, approximately 1 to 2 millimetres wide. Some of the bands are comprised almost entirely of white spherulites. Elsewhere within the Saddle Hill succession, flow banded rhyolites occur as light grey weathering, discontinuous, lensoidal to dome-like bodies that intrude basaltic flows in the upper part of the Saddle Hill succession. It is not certain whether these rhyolites, which are clearly intrusive, are part of the Lower to Middle Jurassic volcanic sequence or are much younger, the Eocene Babine Intrusive Suite.

A distinctive lithology within the Saddle Hill succession is a heterolithic, clast-supported volcanic breccia or agglomerate that contains white-weathering, subrounded, 25-centimetre to 1-metre bombs of flow-banded rhyolite. The bombs have deep reaction rims indicating that they were hot at the time of lithification. The breccia was probably the result of a phreatic explosion. The fact that the breccia contains flow banded rhyolite clasts suggests the rhyolites are part of the Lower to Middle Jurassic volcanic suite.

Near the top of the lower member is a section consisting of interbedded medium to coarse-grained volcanic wacke, aquagene tuff and autobrecciated, amygdaloidal basalt flows.

The middle member of the Saddle Hill volcanics is comprised of volcanic breccia, aquagene tuff and autobrecciated basaltic flows, interbedded with lapilli tuff, volcanic conglomerate and sandstone. Hyaloclastite is locally present and the massive volcanics typically contain magnetite and specularite. A strong aeromagnetic high is associated with this unit and has been used to map the extent of these volcanics below areas of heavy overburden. The volcanic rocks weather a distinctive orange-tan colour and have a dark green chloritic matrix. The volcanic wackes have poorly defined cross and graded bedding and locally contain poorly preserved bivalves, ammonites and corals (J. Palfy, personal communication) indicating a marine depositional environment. Irregular bodies of light grey, recessive, lime mud are also associated with the fossil bearing beds.

The most distinctive lithology within the middle to upper part of the Saddle Hill succession is a greenish grey to slightly maroon volcanic breccia. The breccia is poorly-sorted and contains lapilli to block-sized, rounded to subrounded volcanic clasts in a greenish grey feldspathic matrix. The clasts vary from light grey to dark green in colour and from dense, aphanitic to feldspar phyric and amygdaloidal. Medium to strong epidote alteration, often with quartz, occurs either pervasively or as veins and clots. Overlying the breccias are basalt flows. The flows are typically amygdaloidal and locally autobrecciated. Intense epidote alteration and veining is common. The flows weather a light brown colour and vary from maroon to greenish grey on fresh surfaces. They appear to be mostly subaerial in origin.

A sequence of greenish grey weathering, autobrecciated basaltic flows and aquagene tuffs occur near the top of the Lower to Middle Jurassic section. The flows vary from aphanitic to intensely amygdaloidal and are locally porphyritic with 35-40%, 5 to 8 millimetre feldspar phenocrysts. Epidote alteration and veining is locally intense. In one locality, an aphanitic flow has a bulbous weathering pattern that is suggestive of pillows.

Feldspar rich maroon to green, medium to thick-bedded volcanic sandstones, debris flows and tuffs occur near the top of the Saddle Hill volcanic section and grade into fossiliferous green to dark grey beds of the Smithers formation. In general there is a change from maroon to green colour up section, suggesting a change from subaerial to submarine conditions.

A minor amount of marine sediment also occurs in the upper half of the section and contains poorly preserved bivalves, ammonites and possible corals. Attitudes are measured from thin tuffaceous sandstone, feldspar crystal tuff and ash tuff beds that are intercalated with the more massive volcanic rocks.

MIDDLE JURASSIC SMITHERS FORMATION (mJS)

The Lower to Middle Jurassic Saddle Hill volcanics are conformably overlain by an interbedded sequence of shallow water, green to maroon feldspathic volcanic sandstone, wacke, siltstone shale, crystal tuff and minor granule to pebble conglomerate of the Smithers Formation. These rocks are very fossiliferous and contain abundant bivalves, ammonites and belemnites that indicate an Early Bajocian age (H. Tipper, personal communication). Several of these localities contain well-preserved *Trigonia*. The Smithers Formation sediments typically contain 25-45 percent feldspar detritus suggesting they are derived from a volcanic source area. Some of the feldspar may be of an air-fall origin. A distinctive dark green colour is also common due to presence of glauconite. Carbonaceous wood impressions and concretions are also common.

The best exposures of the Smithers Formation in the current study area east of the northwest arm of Babine Lake, on a low knoll and in the clear cut areas west of Hatchery Arm, on Old Fort Mountain and along the west side of the Hautête graben (Figure 2).

UPPER JURASSIC TO LOWER CRETACEOUS BOWSER LAKE GROUP

The Smithers Formation grades up section into deeper water, finer-grained siltstones and wackes of the

Table 1. Isotopic Age Dates, Babine Porphyry Belt

No.	Sample #	NTS	Zon	Easting	Northing	Location	Unit	System	in	Age (Ma)		Error	Rock Description	Source
1	GSC 73-43	93L/16	9	677314	6091091	Bear island	Babine intrusions	K-Ar	Bi	45.1	±	2	bt-fd porphyry	Wanless et al., 1974
2	GSC 73-37	93L/16	9	665878	6094217	Turkey Mtn.	Newman volcanics	K-Ar	Bi	46.8	±	2.7	hb-fd porphyry flow	Wanless et al., 1974
3	NC-68-10	93M/ 8	9	668795	6144179	Trail Peak	Babine intrusions	K-Ar	Bi	49.8	±	1.5	bt-fd porphyry	Carter, 1974, 1981;
4	DMA95-200	93L/16	9	679350	6090650	Newman Pen.	Newman volcanics	Ar/Ar	Hb	49.9	±	0.6	hb-fd porphyry with rare bt	this study
5	NC-67-1	93M/ 1	9	670285	6105244	Old Fort Mtn.	Babine intrusions	K-Ar	Bi	50.0	±	2	bt-fd porphyry	Carter, 1974
6	GSC 73-39	93L/16	9	662856	6089781	Saturday Lk.	Newman volcanics	K-Ar	Hb	50.2	±	3	hb-bt-fd porphyry, flow or neck	Wanless et al., 1974
7	GSC 73-40	93L/16	9	662856	6089781	Saturday Lk.	Newman volcanics	K-Ar	Bt	50.2	±	3	hb-bt-fd porphyry, flow or neck	Wanless et al., 1974
8	NC-67-22	93L/16	9	677036	6096223	Bell mine	Babine intrusions	K-Ar	Bi	50.7	±	2.1	bt-fd porphyry, weakly mineralized	Carter, 1974
9	NC-69-8	93L/16	9	682022	6091781	Granisle mine	vein	K-Ar	Bi	51.0	±	2.1	qtz-cpy-bn-apatite-biotite vein	Carter, 1974
10	DDH70-11	93L/16	9	682000	6092000	Granisle mine	Babine intrusions	Ar/Ar	Bi	51.2	±	0.6	medium-grained hb-bt-fd porphyry	this study
11	KBE95-43	93L/16	9	666136	6094717	Turkey Mtn.	Newman volcanics	Ar/Ar	Hb	51.2	±	0.5	hb-bt-fd porphyry	this study
12	DMA95-177	93L/16	9	680526	6092845	Newman Peninsula	Newman volcanics	Ar/Ar	Hb	51.3	±	0.6	hb-bt-fd porphyry	this study
13	DMA95-106	93L/16	9	663556	6086574	Saturday Lk.	Newman volcanics	Ar/Ar	Bi	51.5	±	0.5	hb-bt-fd porphyry, flow or neck	this study
14	NC-67-23	93L/16	9	677036	6096223	Bell mine	Babine intrusions	K-Ar	Bi	51.5	±	3	bt-fd porphyry, mineralized	Carter, 1974
15	NC-68-1	93L/16	9	682022	6091781	Granisle mine	Babine intrusions	K-Ar	Bi	51.5	±	2	bt-fd porphyry, late dyke	Carter, 1974
16	NC-67-5	93L/16	9	682022	6091781	Granisle mine	Babine intrusions	K-Ar	Bi	51.6	+	2	bt-fd porphyry, late dyke, unmineralized	Carter, 1971
17	N95-1-152	93M8	9	675100	6130050	NAK property	Babine intrusions	Ar/Ar	Bi	51.7	±	0.5	hb-bt-fd porphyry	this study
18	DMA95-106	93L/16	9	663556	6086574	Saturday Lk.	Babine intrusions	Ar/Ar	Hb	51.9	±	0.7	hb-bt-fd porphyry, flow or neck	this study
19	73-10-318	93L/16	9	668000	6084750	Saturday Lk.	Babine intrusions	Ar/Ar	Hb	52.3	±	0.6	hb-fd porphyry	this study
20	DMA-95-24	93L/16	9	666318	6121851	Wolf property	Babine intrusions	Ar/Ar	Bi	52.4	±	0.5	granodiorite	this study
21	NC-67-43	93L/16	9	679391	6090746	Newman Peninsula	Newman volcanics	K-Ar	Hb	52.4	±	1.9	hb-fd porphyry	Carter, 1974
22	DMA95-270	93L/16	9	663750	6090750	Turkey Mtn.	Newman volcanics	Ar/Ar	Hb	52.6	±	0.6	medium to fine-grained hb-bt-fd porphyry	this study
23	IWE95-275	93L/16	9	668900	6096950	Turkey Mtn.	Newman volcanics	Ar/Ar	W	52.7	±	0.6	augite phyric basalt plug	this study
24	NC-67-2	93M/ 1	9	670356	6103390	S. of Old Fort	Babine intrusions, sill	K-Ar	Bi	53.0	±	2	bt qz monzonite	Carter, 1974
25	NC-67-40	93M/ 1	9	669718	6120076	Morrison	Babine intrusions	K-Ar	Bi	53.0	±	2.1	bt-fd porphyry	Carter, 1974
26	NC-67-4	93L/16	9	682022	6091781	Granisle mine	Babine intrusions	K-Ar	Bi	55.8	±	3	bt-fd porphyry, mineralized	Carter, 1974
27	NC-72-1	93L/ 9	9	671768	6066311	Lennac Lake	Bulkley intrusions	K-Ar	Bi	78.3	±	2.5	qz-hb-bt-fd porphyry, mineralized	Carter, 1974
28	DMA95-134	93L/16	9	671530	6070262	Lennac Lake	Bulkley intrusions	Ar/Ar	Bi	78.3	±	0.8	coarse grained bt-plagioclase porphyry	this study
29	NC-69-1	93M/ 8	9	668795	6144179	Trail Peak	Bulkley intrusions?	K-Ar	Bi	105	±	4	qz diorite, granodiorite	Carter, 1974
30	DMA95-181	93L/16	9			Newman Peninsula	Rocky Ridge volc.?	U/Pb	Zr	107.8	±	0.5	plag-K-spar porphyritic dacite	this study
31	MAC-CORE	93K/13	10			MAC property	Francois intrusions	Ar/Ar	Bi	142.5	±	1.4	bt-hb porphyry stock	this study
32	KBE95-161	93K/13	10	311900	6085500	Toncha Lk.	Topley intrusions?	Ar/Ar	Hb	175.7	±	1.7	porphyritic hb-fd diorite to monzonite	this study
33	NC-69-4	93L/16	9	681279	6070396	Tachek Crk.	Topley intrusions?	K-Ar	Bi	178	±	7	hb-bt-qz fd porphyry, mineralized	Carter, 1974
34	KBE95-145	93L/16	9			E. of Babine Lk.	Topley intrusions	U/Pb	Zr	178.7	±	0.5	granite, bt monzogranite	this study
35	IWE95-111	93L/16	9			W. of Granisle	Hazelton Group	U/Pb	Zr	184.7	±	0.5	fd-qz phyric rhyolitic lapilli tuff	this study
36	KBE95-71	93L/16	9	687749	6087797	E. of Babine Lk.	Topley intrusions	Ar/Ar	Bi	191.1	±	1.9	granodiorite	this study
37	DMA95-275	93L/16	9	673700	6089950	N. of Granisle	Topley intrusions	Ar/Ar	Hb	193.7	±	1.9	bt-hb-fd porphyry	this study
38	GSC 73-44	93L/ 9	9	681368	6056103	Mahtzehtzel Mt.	Topley intrusions	K-Ar	Bi	199	±	8	qz monzonite	Wanless et al., 1974
39	DMA 95-146	93L/16	9	669421	6080872	N. of Fulton Lk.	W. Takla Group	Ar/Ar	Hb	208	±	2	pyroxene hb-fd porphyry flow	this study
40	GSC 73-45	93L/16	9	683883	6082888	Babine Lake	Topley intrusions	K-Ar	Hb	210	±	9	monzonite, slightly foliated	Wanless et al., 1974
41	DMA95-180	93L/16	9			W. of Babine Lk.	Topley intrusions	U/Pb	Zr	215-230		???	K-spar-bt granite, weakly foliated	this study
42	KBE95-11	93K13	10	309600	6093500	W. of Toncha Lk.	??	Ar/Ar	Hb	219	±	2	foliated hb diorite	this study

Middle to Upper Jurassic Ashman Formation. The Ashman Formation has been included by previous workers as part of the Bowser Lake Group, based on an apparent disconformity as indicated by a gap in the fossil record. In the current study area, the Ashman Formation, like the Smithers Formation, is locally very fossiliferous with abundant bivalves, ammonites and belemnites. The formation varies. The lower part is coarse-grained, poorly sorted shallow water marine granule and pebble conglomerate interbedded with maroon and greenish grey sandstone and siltstone and containing abundant bivalves, ammonites, belemnites and fossilized wood debris. It changes to deeper water, well-bedded, sparsely fossiliferous shaly argillaceous siltstones and greywackes. The finer-grained, presumably deeper water rocks are well-exposed in road cuts north and south of Nizik Lake. Small, carbonaceous bivalves collected in 1995 from a road cut southeast of Nizik Lake were identified by the Geological Survey of Canada as *Vaugonia doroschini* (Eichwald)(?) and *Plagiostoma*(?) sp. indicating a Late Bathonian or Callovian through to Early Oxfordian age (Paleontology Subdivision, Calgary, collection number C-211602). In 1996, ammonites and bivalves were collected from several new localities, including outcrops in a clear cut northwest of Saddle Hill, a road cut northeast of Nizik Lake, road cuts along the west side of the Hautête graben and outcrops in clear cuts north of MacDougall Creek in the northeast corner of the map area (Figure 2). Preliminary examination of these fossil collections by Jozsef Palfy suggests an age range for the Ashman Formation from as old as Late Bajocian or Bathonian, for beds directly overlying Smithers Formation along the Nakinilerak Lake road, to as young as Oxfordian for beds exposed along road cuts north of MacDougall Creek. The latter are shallow water sediments with abundant wood and volcanic debris, suggesting a facies change from deeper water fine-grained basinal sediments to coarse-grained, shallow water near shore sediments going from Nizik lake in the south central part of the map area to the northeast corner.

LOWER CRETACEOUS SKEENA GROUP (lKS)

The Skeena Group (Leach, 1910) is characterized by well-bedded, quartz, feldspar and muscovite-bearing, marine sedimentary rocks that overlap Jurassic and older rocks along the southern margin of the Bowser Basin. The main Skeena lithologies are dark grey shaly siltstone, greywacke, carbonaceous mudstone and chert-pebble conglomerate These sediments were deposited in a fluviodeltaic, near-shore to shallow marine environment (Basset, 1991). Although fossils are rare, the Skeena Group appears to be range from Hauterivian to late Albian or early Cenomanian in age. The Skeena rocks were folded, uplifted and eroded during a mid to late Cretaceous contractional event related to evolution of the Skeena Fold Belt.

Richards (1990) subdivides Skeena Group rocks in the Hazelton map area (93M) into six formations or mappable units. These are from oldest to youngest the Kitsuns Creek Formation, Kitsumkalum shale, Hanawald conglomerate, unnamed subaqueous volcanics and volcaniclastics, Rocky Ridge Formation and Red Rose Formation. Skeena Group sedimentary rocks in the Old Fort Mountain map sheet have previously been correlated with the Kitsuns Creek Formation or mapped as undivided Skeena Group. A small area in the northeast corner of the map area, around Wedge Mountain has been mapped as Rocky Ridge Formation. In the Hazelton map area the Kitsuns Creek Formation includes feldspathic and volcanic sandstone, siltstone, shale, polymictic, volcaniclastic conglomerate, coal and carbonaceous sediments; the Rocky Ridge Formation includes subaerial, alkaline basaltic-andesitic augite-feldspar porphyry flows, tuff, breccia, lahar and intercalated volcaniclastic sediments (Richards, 1990).

In the current study area, Skeena Group sedimentary rocks are generally poorly exposed because they are only preserved in downdropped fault blocks or grabens which tend to be low-lying areas with extensive cover. Areas where Skeena Group rocks are exposed or have been intersected in drilling, include the northwest shores of the Newman Peninsula, the low lying area between Turkey and Old Fort mountains, the low lying area north of Old Fort Mountain, the area along the east shore of Hatchery Arm and the southeast end of Morrison Lake, and in road cuts in a new clear cut east of Wedge Mountain in the northeast corner of the map area. The main Skeena Group lithologies are medium to coarse-grained, grey quartzo-feldspathic sandstone, dark grey siltstone and dark grey to black carbonaceous mudstone. These rocks are folded and have a moderate to steep dip especially near intrusive bodies.

LATE CRETACEOUS BULKLEY INTRUSIONS (LKBp)

The term Bulkley Intrusions was first used by Kindle (1954) for granitic rocks near Hazelton. This suite is Late Cretaceous in age and includes large porphyritic and equigranular stocks of quartz monzonite, granodiorite and quartz diorite and smaller plutons and dikes of feldspar porphyry, hornblende-biotite-quartz-feldspar porphyry and quartz porphyry. Potassium argon isotopic ages range from 70 to 84 Ma (Carter, 1976). The plutons define a north-trending belt that extends from north of the Babine River south to the Eutsuk Lake area. They are believed to be the roots of an eastward-migrating magmatic arc that formed during a major transtensional tectonic event in Middle to Late Cretaceous time. The only intrusions in the Babine Lake area that are known to be part of this suite are exposed at the Lennac Lake porphyry copper prospect (MacIntyre *et al.*, 1996). One of these intrusions was dated using the laser Ar-Ar technique and gave a 78.3 ± 0.8 Ma age date(No 28, Table 1), identical to a previous 78.3 ± 2.5 K-Ar age date determined by Carter (1973). There are no known occurrences of Bulkley Intrusions in the Old Fort Mountain map area.

CRETACEOUS-TERTIARY INTRUSIONS (KTg)

Correlation of these intrusions with the Babine Intrusions is based on a spatial association and should be considered tentative; none of these bodies has yet been dated. These intrusions could be older and unrelated to the Babine intrusions. In places the stocks are very coarse-grained with 3 to 4 centimetre long, crudely aligned, hornblende phenocrysts.

Numerous stocks of medium to coarse-grained greenish grey hornblende diorite, quartz diorite and gabbro crop out in the map area. The best exposures occur along the ridge east of the Morrison Graben, especially between Hearne Hill and south of Nizik Lake, where northerly elongate bodies cut Lower to Middle Jurassic volcanics and younger sedimentary rocks of the Ashman Formation. They range from dikes less than 10 metres wide to stocks 2 to 3 kilometres long and 0.5 to 1 kilometres wide. For the most part the intrusions have been emplaced passively with little disruption of regionally bedding attitudes. Zones of biotite hornfels are locally present, especially around larger bodies. In places the diorite has a porphyritic texture with hornblende needles and laths up to 3 or 4 centimetres in length. Generally the diorite is weakly to moderately chloritized and in places has poorly developed mineral lineation. Compositionally these intrusions range from gabbro to granodiorite, but most are probably true diorites.

The age of diorite intrusions in the map area is uncertain. They are found cutting rocks ranging from Lower Jurassic through to Lower Cretaceous in age. Therefore, assuming there is only one episode of dioritic magmatism, these intrusions must be Lower Cretaceous or younger. The only radiometric date on any of these intrusions is consistent with this conclusion, giving a K-Ar of 105±4 Ma (no.29, Table 1). on biotite from a quartz diorite or granodiorite at Trail Peak. It is possible, however, that some of the diorite intrusions are Eocene, and represent the earliest, least differentiated phases of the Babine Intrusions.

EOCENE BABINE IGNEOUS SUITE

The Babine Igneous Suite includes 3 major units all of which are believed to be early Eocene in age. These units are: the porphyritic to equigranular diorite to granodiorite Babine intrusions (Carter, 1976; 1981); the extrusive equivalent of these intrusions, the Newman volcanics; and a series of flow-banded rhyolite domes and dikes which may or may not be related to the two previous units.

BABINE INTRUSIONS (EBp, EBq, EBg)

The Babine Intrusions include small plugs and dikes of crowded biotite±hornblende feldspar porphyry (EBp), quartz±biotite feldspar porphyry (EBq) and equigranular hornblende-biotite granodiorite to quartz diorite (EBg) that occur as multi-phase intrusive centres in a north-trending belt that extends from Fulton Lake to Trail Peak (Figure 1). Also included with the Babine Intrusions but not restricted to being a phase within major intrusive complexes are domes and dikes of flow-banded to aphanitic rhyolite (EBr). Potassium-argon isotopic ages biotite and hornblende phyric phases range from 49 to 55 Ma (50.2 to 55.8 using new decay constants, see Table 1) indicating the intrusions are early Eocene in age. The intrusions, which are believed to be the subvolcanic roots of a calcalkaline magmatic arc, cut volcanic and sedimentary strata ranging in age from Triassic to Early Cretaceous. The Newman volcanics are the extrusive equivalents of the intrusions, and these rocks are preserved close to intrusive centres on the Newman Peninsula and at Saturday Lake. The fact that the volcanic edifices have not been completely removed by erosion is further evidence that the Babine intrusions and associated porphyry copper deposits, such as Bell and Granisle, are exposed at a subvolcanic level.

Compositionally, the Babine intrusions and Newman volcanics are very similar to the older Bulkley intrusions and Kasalka volcanics found further to the west. This suggests similar, transtensional, volcanic environments prevailed during the Late Cretaceous and, Eocene, with the locus of volcanism moving progressively eastward with time.

Biotite-hornblende quartz diorite to granodiorite (EBg)

Stocks of medium-grained, equigranular to sub-porphyritic biotite-hornblende quartz diorite to granodiorite are exposed on Old Fort Mountain, north of Saddle Hill on the Wolf property, north of Hearne Hill, and at the Dorothy property (Figure 2). The stocks are typically cut by dike-like bodies of biotite-feldspar porphyry which have associated porphyry copper mineralization. Zones of biotite hornfels and disseminated and fracture controlled pyrite up to several hundred metres in width enclose the equigranular stocks, particularly on Old Fort Mountain and at the Wolf Property. The Old Fort Mountain stock also has a very strong aeromagnetic response. Although the equigranular phase of the Babine intrusions can host low-grade copper mineralization, better grades are typically associated with younger porphyritic phases. The absence of any significant amount of the early equigranular phase at properties such as Morrison, Bell and Granisle is interpreted to reflect a shallower level of exposure at these properties. It is assumed that these bodies exist at depth according to the model shown in Figure 3.

Biotite-feldspar porphyry (EBp)

The most abundant rock type of the Babine intrusive suite is a crowded, dark grey biotite-feldspar porphyry that typically occurs as small plugs and dikes. This rock type contains 40 to 60%, 2 to 3-millimetre phenocrysts of biotite, plagioclase and rarely hornblende and quartz, in a finer grained groundmass of plagioclase, quartz, biotite and minor potassium feldspar. The porphyries are quartz diorite to granodiorite in composition and are typical of plutonic rocks found in a continental calcalkaline magmatic arc environment.

Quartz-biotite-feldspar porphyry and quartz feldspar porphyry (EBq)

Quartz-phyric intrusions with or without biotite post-date the main phase of stockwork mineralization at the Bell mine and apparently cut the earlier biotite-feldspar porphyry phase (Dirom *et al.*, 1995). The quartz-phyric rocks are weakly mineralized relative to the biotite-feldspar porphyry phase and contain partially resorbed quartz phenocrysts. This intrusive phase is most common around the Bell pit but also occurs as small stocks and dikes in the northwest corner of the map area (Figure 2). One north trending dike is 10 to 20 metres thick and can be traced for up to 3 kilometres.

Rhyolite dikes and domes (EBr)

White to cream weathering, locally flow-banded, aphanitic to feldspar phyric rhyolitic dikes and domes are common in the map area. These siliceous rocks are resistant and tend to form topographic highs. The largest bodies are located north of Old Fort Mountain, where the rhyolite occurs as an arcuate belt of resistant knolls rising from a relatively flat plateau. The knolls are comprised of rusty weathering, white to cream weathering aphanitic to flow-banded rhyolite that is intrusive into Cretaceous Skeena Group sedimentary rocks. Both the flow banding in the rhyolite domes and bedding in the surrounding sedimentary strata have a shallow to moderate south to southeasterly dip suggesting the emplacement of the rhyolite might have been controlled in part by bedding in the sedimentary succession. The rhyolite domes may also have been emplaced along an inward dipping ring dike structure centered on Old Fort Mountain. As mentioned earlier numerous intrusions are exposed on Old Fort Mountain suggesting the presence of a major volcano-plutonic center.

Northerly elongate rhyolite intrusions also occur in the northeast corner of the map area, in the vicinity of McDougall Creek. These domes are at the southern end of a long, narrow chain of rhyolite domes that extends northward into the 93M/8 map sheet.

The rhyolite domes in the Babine Lake area were probably formed when silica rich fluids escaped from partially crystallized magma reservoirs. Emplacement of the highly viscous magma was controlled by faults in the surrounding country rock. Formation of rhyolite domes may have been accompanied by collapse of underlying magma chambers and formation of caldera like structures.

EOCENE OOTSA LAKE GROUP

The Ootsa Lake Group, as defined by Duffell (1959), is a succession of continental calcalkaline volcanic rocks with minor nonmarine sedimentary interbeds. In the type area around Ootsa Lake, the volcanic members are differentiated andesites, dacites and rhyolites. The dacites and rhyolites occur both as flows and flow-breccia dome complexes of limited areal extent; the andesites and tuffs are more extensively distributed. Several dates determined in the Whitesail Lake area indicate that the Ootsa Lake volcanics erupted 50 million years ago for a period as short as 1 million years (Diakow and Mihalynuk, 1987). In the study area, hornblende-biotite-phyric andesite flows, breccias and lahars of the Newman volcanics yield similar ages and are therefore mapped as part of the Ootsa Lake Group.

NEWMAN VOLCANICS (ENv)

In the Babine Lake area, calc-alkaline, hornblende-biotite-feldspar porphyry flows, breccias and lahars sit with angular discordance on folded Triassic, Jurassic and Lower Cretaceous volcanic and sedimentary rocks. These volcanic rocks were given the name Newman volcanics by Tipper and Richards (1976a) because they are well exposed on both sides of the Newman Peninsula. Similar rocks crop out sporadically along the western shore of Babine Lake and on Bear Island. Here the Newman Volcanics are restricted to the north trending Granisle graben which is centered on Babine Lake. The volcanics within the graben are in fault contact with older rocks indicating formation of the graben post-dates volcanism. The Newman Volcanics also occur as a subcircular volcanic plateau southeast of the current map area. This plateau, which is locally known as Turkey Mountain, may be the eroded remains of a large volcanic cone (MacIntyre *et al.*, 1996).

In the Old Fort Mountain map sheet, outcrops of Newman volcanics are restricted to the north end of the Newman Peninsula. Scattered outcrops of hornblende-biotite-feldspar porphyry do occur within the Morrison graben but most of these are probably resistant knolls representing volcanic necks or dikes that intrude recessive Lower Cretaceous Skeena Group sedimentary strata. The Newman volcanics have probably been removed by erosion within the Morrison graben.

The Newman volcanics are Early Eocene based on previous K-Ar dating which ranges from 44.3±2 to 51.5±1.9 Ma (45.1 to 52.4 using new decay constants, Table 1). These ages overlap those determined for lithologically identical porphyries of the Babine Intrusions and the volcanics are, therefore, considered to be the extrusive equivalent of these rocks (Villeneuve and MacIntyre, 1997).

The Newman volcanics can be subdivided into three units or members. The lowest member is mainly columnar to sheet-jointed hornblende-biotite-feldspar porphyry flows and/or sills that are lithologically similar to biotite-feldspar porphyries of the Babine intrusions. These rocks are overlain by a middle member which is mainly volcanic breccia composed of angular clasts identical to the underlying porphyries. Towards the top of the section lahars, debris flows and volcanic-pebble conglomerate predominate. A gently east dipping, heterolithic conglomerate exposed in Tachek Creek, and sitting with angular discordance on Triassic volcanic rocks, may be the basal member of the Newman volcanics.

STRUCTURE

The structure of the Babine Lake area reflects the effects of at least four major tectonic events. The oldest took place in mid to late Jurassic time when rocks of the Hazelton and Takla Groups were folded and uplifted. This was followed in mid Cretaceous time by a contractional event that produced northwest-trending folds and northeast directed thrust faults. Rocks as young as Albian were involved in this folding whereas the Late Cretaceous volcanics of the Kasalka Group were not. Crustal extension and development of north trending grabens and horsts took place in Late Eocene or younger time as both the Babine intrusions and Newman volcanics have been truncated and displaced by movement on faults bounding the grabens. The latest event which may be as young as Miocene involved tilting of fault blocks to the southeast along northeast trending faults. In general, because of the Eocene and younger movement of fault blocks younger rocks typically occur at lower elevations within north trending valleys while older rocks are found at higher elevations on the ridges bounding the valleys.

MINERAL OCCURRENCES

The most important mineral occurrences in the Babine Lake area are porphyry copper deposits associated with the Eocene Babine intrusions and Late Cretaceous Bulkley intrusions (Carter, 1981; Carter *et al.*, 1995). The Bell past producer and the Morrison, Hearne Hill, Dorothy, Old Fort and Wolf (Double R) are the main porphyry copper prospects in the 1996 study area (Table 2). In addition, the Fireweed epithermal prospect occurs near the southern boundary of the map area.

BELL (MINFILE 93M 001)

The Bell porphyry copper deposit is located on the Newman Peninsula and straddles the boundary between the 93L/16 and 93M/1 mapsheets (Figure 2). The geology and production history of the Bell deposit, which was a producing mine from 1972 to 1992, has recently been reviewed by Dirom *et al.*, 1995 and in a previous report by Carson *et al.*, 1976. Zaluski (1992), and Zaluski *et al.* (1994) have recently described the results of stable isotope studies at Bell and other deposits in the district which indicate the presence of both magmatic and mixed magmatic-meteoric fluid sources.

The Bell ore body is associated with a multi-phase intrusive complex, covering an area of approximately 1200 metres by 600 metres, that includes from oldest to youngest biotite-feldspar porphyry, rhyolite to rhyodacite, quartz-feldspar porphyry and explosion breccia. Several small, elongate stocks of biotite-feldspar porphyry and rhyolite occur around the main intrusive complex. The intrusions, which are probably the subvolcanic roots of a stratovolcano, are believed to have been emplaced along zones of dilation associated with extensional faulting during the early stages of formation of the Granisle graben. The intrusive complex is located along the north-trending Newman fault, which is located along the eastern boundary of the Granisle Graben. To the east of the fault the Bell intrusions cut volcanics believed to be correlative with the Lower to Middle Jurassic Saddle Hill volcanics; to the west of the fault they cut sedimentary strata of the Lower Cretaceous Skeena Group. Another fault occurs 1000 metres west of the Newman fault and juxtaposes Skeena Group rocks against Eocene Newman Volcanics. The Newman volcanics, which are the extrusive equivalents of the porphyry intrusions, are

Table 2. Mineral Occurrences

No.	Property Name	Status	Metals	Hosts	Type
001	Bell	PAPR	Cu,Ag,Au	EBp,EBqEBr,lKS, lmJv	Porph
002	Mag	SHOW	Pb,Zn,Cu	muJA	Vein
003	Snoopy	SHOW	Cu	lmJv	?
004	Old Fort	SHOW	Cu	EBg,mJS	Porph
005	Jake	SHOW	Cu	lmJv	?
006	Kofit, Hearne Hill	DEPR	Cu,Au,Ag	lmJv, EBp, EBg	Porph
007	Morrison	DEPR	Cu,Au	EBp, muJA	Porph
008	Wolf	PROS	Cu,Mo	EBg, EBp	Porph
009	Dorothy	DEPR	Cu,	EBg, EBp	Porph
121	Mast	SHOW	Cu	KTd,lmJv	Porph
127	Bab	SHOW	Cu	EBp	Shear
144	Fort	SHOW	Cu	mJS, EBp	Porph
151	Fireweed	DEPR	Ag,Pb,Zn	lKS	Epith.
159	Newman North	SHOW	Cu	EBp, lKs	Porph
160	Sparrow-hawk	SHOW	Cu	lmJv	Vein
162	Copper 1-4	SHOW	Cu	muJA	Vein

PAPR - past producer; DEPR - developed prospect; PROS - prospect; SHOW - showing well exposed southwest of the deposit. The close proximity of these extrusive rocks to the Bell intrusive complex suggests the intrusive complex is exposed at a subvolcanic level.

Mineralization at Bell is typical of high level porphyry copper systems. Pyrite, chalcopyrite, minor bornite and trace molybdenite occur as disseminations, fracture coatings and in quartz veinlet stockworks within all phases of the intrusive complex. Gold occurs as electrum associated with copper mineralization. One of the unusual features at Bell was a zone of chalcocite supergene enrichment which originally capped the deposit and extended to depths of 70 metres.

Extensive zones of hydrothermal alteration are associated with the porphyry copper mineralization at Bell. The earliest alteration, which was produced by high temperature magmatic fluids according to the stable isotope studies of Zaluski *et al.* (1994), produced a core zone of potassic alteration comprised of secondary biotite, magnetite and minor K-feldspar centered on the intrusive complex and an outer zone of propylitic alteration comprised of chlorite and carbonate. Influx of meteoric water during the later stages of alteration resulted in overprinting of feldspar destructive sericite-carbonate-quartz alteration on the earlier potassic and propylitic alteration zones (Zaluski *et al.*, 1994)

Initial ore reserves at Bell were 116 million tonnes averaging 0.48 percent copper. Production from the Bell mine totalled 77.2 million tonnes averaging 0.47 percent copper with an average waste to ore ratio of 0.98:1. Total recovered metals were 303 277 tonnes copper, 12 794 kilograms gold and 27 813 kilograms of silver (Dirom *et al.*, 1996).

MAG (MINFILE 93M 002)

The MAG showing is located near the northern limit of the Red property, which is 6 kilometres north of the Granisle mine-site in an area of very limited outcrop. Granby Mining Company Limited first explored the property in the mid 1960's followed in 1966 by Bethex Explorations Ltd. Bethex drilled nine holes in 1967. Canadian Superior Exploration Limited and Quintana Minerals Corporation completed induced polarization and geochemical surveys in 1972. The property was restaked by Gerard Auger in 1984 and he subsequently optioned it to Anglo Canadian Mining Corporation. Anglo in turn optioned the property to Equity Silver Mines Limited. In 1987; Equity completed 963 metres of diamond drilling in seven inclined holes. An additional 914 metres was drilled in six holes in 1989.

The MAG showing is the only mineral occurrence exposed on surface. It is a 0.3 metre wide quartz-carbonate vein with galena, sphalerite and chalcopyrite, in sheared, rusty sedimentary rocks near the northwest corner of the property. Elsewhere on the property, the main target is a pyrite-pyrrhotite zone that produces a strong geophysical conductor. The zone has been drill-tested over a strike length of 220 metres. Drill intersections with core lengths of between 30 and 50 metres have contained massive and stringer sulphides with elevated copper, zinc, lead, silver and gold values (N.C. Carter, personal communication, 1995). Host rocks are Middle to Upper Jurassic Ashman Formation argillaceous siltstones and greywackes with interbedded felsic and intermediate volcanic rocks. One outcrop of the sedimentary rocks occurs in a south-flowing creek gully on the west side of the property. Here, the beds strike north and dip moderately to the west. A Cretaceous to Teritiary diorite stock crops out in the large clear-cut on the north end of the property.

SNOOPY (MINFILE 93M 003)

The Snoopy copper showing is reported to be located 1.6 kilometres northwest of Nizik Lake and 7.5 kilometres northeast of the Bell mine. It is apparently associated with a Cretaceous to Tertiary dioritic intrusion. The exact location of the showing is uncertain.

OLD FORT (MINFILE 93M 004)

The Old Fort showing is located on the southeast slope of Old Fort Mountain, in an area of heavy tree cover. The property was staked in 1965 following a soil sampling program. In 1966, Falconbridge Nickel Mines Limited built a tractor road from Hatchery Arm to the property, completed geologic mapping, and drilled 17 holes totalling 1113 metres (3652 feet). Falconbridge in conjunction with several joint venture partners did additional exploration, including trenching, magnetics, induced polarization and electromagnetic surveys between 1966 and 1976. Additional work was done by Pearl Resources in 1982 and 1983. The main target of interest on the property is an elliptical stock of hornblende-biotite quartz diorite approximately 1000 metres in diameter that is cut by a northeast trending body of biotite quartz monzonite and dikes of biotite-hornblende-feldspar porphyry. Carter (1974) reports that biotite collected from one of these dikes gave a K-Ar isotopic age of 49 Ma (50.0 ± 2 Ma using revised decay constants) (No. 5, Table 1). The quartz diorite intrudes marine sediments of probable Middle Jurassic age. A broad zone, up to 1000 metres wide, of hard, dense, rusty weathering, biotite-hornfels with variable amounts of disseminated pyrite and pyrrhotite surrounds the stock. Chalcopyrite and minor bornite occur with magnetite as disseminations and fracture coatings in both the quartz diorite and hornblende-biotite-feldspar porphyry dikes. Molybdenite occurs in some fractures associated with K-feldspar veinlets.

JAKE (MINFILE 93M 005)

The Jake copper showing is reported to be located 5 kilometres northeast of the north end of Hatchery Arm. The showing is described as minor pyrite, chalcopyrite and malachite in stratified andesitic and rhyolitic volcanic rocks of the Lower to Middle Jurassic Saddle Hill volcanics. The showing was not located during the current mapping program and its location can not be verified.

HEARNE HILL (KOFIT) (MINFILE 93M 006)

The geology and exploration history of the Hearne Hill property has recently been reviewed by Ogyzlo *et al.* (1995). The Hearne Hill showing was first explored by Trojan Consolidated Mines and Buttle Lake Mining in 1967. In 1968, Texas Gulf Sulphur Company optioned the property and drilled 12 holes totalling 1942 metres. This work defined the presence of low grade (0.2 percent copper) porphyry copper deposit associated with a multi-phase intrusive body similar to other porphyry prospects in the district. The property was optioned to Canadian Superior Exploration who did diamond drilling and percussion drilling in 1968 and 1969 respectively. Discouraged by low grades, the option was dropped and the property was not explored again until 1989 when in was acquired by Dave Chapman. Chapman did some trenching on the property and located the Chapman breccia zone in an area where high grade breccia boulders had originally been found back in 1967. Noranda subsequently optioned the property in 1989 and drilled 6 holes totalling 468 metres in an attempt to define the geometry of the breccia zone. The best intersection from this drilling was 42.5 metres averaging 3.61 percent copper. In 1990, Noranda further explored the Chapman breccia by drilling 5 vertical NQ holes, totalling 856 metres. These drill holes intersected both the well mineralized breccia and younger, post mineral quartz-feldspar porphyry dikes which resulted in lower overall grades. In 1991, the owner, Dave Chapman, drilled 7 more holes totalling 550 metres into the breccia body, with the best intersection being 50 metres assaying 2.3 percent copper, including a 3 metre section assaying 0.401 oz/tonne gold. Booker Gold optioned the property in 1992 and did diamond drilling in 1994, 1995 and 1996. This work resulted in the discovery of the Peter Bland breccia zone, northeast and up slope from the Chapman breccia body. To date, Booker has competed over 70 drill holes on the property, most of these targeting the Chapman and Peter Bland breccia zones. In addition, a detailed till geochemical program was done on the property in 1996 and follow-up work based on the results of this survey are in progress at the present time.

There are two distinctive styles of copper mineralization at Hearne Hill. The earliest and most widespread is typical of porphyry copper deposits in the district and is comprised of fracture controlled and disseminated pyrite, chalcopyrite, minor bornite and molybdenite. This mineralization occurs in hornfelsed volcanics, equigranular biotite quartz diorite and dikes of biotite-feldspar porphyry. Late syn and post mineral dikes cut the mineralized zone and have diluted the overall grade of the deposit. In general higher copper grades occur in hornfelsed rocks of the Lower to Middle Jurassic Saddle Hill volcanic succession.

The second style of mineralization at Hearne Hill, and the one which has been the focus of recent exploration by Booker Gold, is comprised of northeast elongate, steeply southeast dipping ellipsoidal breccia bodies that contain high grade copper and associated gold and silver values. To date, two breccia bodies, the original Chapman zone, which is 68 metres long and up to 26 metres wide, and the more recently discovered Peter Bland zone which is of similar size, are known and appear to be on strike along the same northeast-trending structure that cuts through the Hearne Hill porphyry system. The breccias are clast-supported with angular clasts showing a preferred orientation parallel to the current erosion surface. The mineral concentration within these breccias, which has characteristics of low temperature epithermal systems, occurs as coarse, nearly massive chalcopyrite, pyrite and marcasite cement in the interstices between clasts. Superimposed on the sulphides is a younger cement of calcite, dolomite and chalcedony. Open cavities are still common within the breccias, which are believed to have formed by collapsed of wallrock into porous zones created by intense hydrothermal leaching of silicates. The collapse breccias grade outward into intensely fractured wall rock which can also contain significant copper mineralization as fracture fillings.

The fluid inclusion geothermometry studies of Ogryzlo (1994) suggest the breccias at Hearne Hill formed from low temperature, low salinity meteoric fluids at a minimum depth of less than 100 metres. The stockwork porphyry system, on the other hand, apparently formed from higher temperature, higher salinity magmatic fluids at a minimum depth of 4 kilometres plus or minus 1 kilometre. The magmatic stockwork mineralization, which occurs within both the porphyry intrusions and surrounding volcanics, is characterized by the occurrence of disseminated and fracture controlled chalcopyrite and minor bornite with associated very fine-grained secondary biotite and K-feldspar. Argillic alteration, which is common within the breccias, has been superimposed on these potassically altered rocks, and is probably related to a lower temperature epithermal event during the waning stages of hydrothermal alteration. Some supergene replacement of sulphides by limonite is observed in surface exposures. Booker Gold has estimated that the high grade core centered on the breccia bodies contains up to 28 million tonnes of potentially ore grade rock (Sampson and Weary, 1996)

MORRISON (MINFILE 93M 007)

The Morrison deposit, like Hearne Hill was discovered in 1962 when Noranda's Norpex Group did a follow-up on anomalous silt samples. The deposit, which has been described by Carter (1967), Carson and Jambor (1976) and Oryzlo *et al.* (1996), occurs on the east side of the north-trending Morrison graben which underlies Morrison Lake and Hatchery Arm (Figure 2). Although outcrop within the graben is limited, rocks near the deposit are more resistant due to hornfelsing and silicification and tend to crop out as small north trending ridges that are surrounded by low-lying areas covered by thick glacio-lacustrine deposits.

Subsequent drilling by Noranda at Morrison resulted in delineation of a porphyry copper deposit which is estimated to contain 190 million tonnes grading 0.40 percent copper and 0.2 grams per tonne gold using a cutoff grade of 0.30 percent copper (Ogryzlo *et al.*, 1995). Noranda still owns the Morrison deposit.

At Morrison, as at other deposits in the district, chalcopyrite, pyrite and minor amounts of bornite and molybdenite occur as fracture coatings, disseminations and quartz veinlet stockworks within and peripheral to a small, northwest elongate, multi-phase stock of biotite-hornblende-feldspar porphyry, typical of the Babine intrusions. Carter (1974) reports that biotite from this intrusion gave a K-Ar isotopic age of 52.1 ± 2.1 Ma (53.0 ± 2.1 Ma using revised decay constants, No.25, Table 1). The stock, which is 900 metres long and up to 300 metres wide, and a series of peripheral north-trending dikes of similar composition intrude Middle to Upper Jurassic argillites and siltstones of the Ashman Formation. A small amount of well-sorted conglomerate cut by dacite sills, unconformably overlies the Ashman Formation and may be Cretaceous or Eocene in age. Near the main stock, the sediments are typically hornfelsed and contain disseminated and fracture controlled pyrite and chalcopyrite.

Alteration at Morrison is arranged in annular zones about the main stock. The main zone of copper mineralization occurs within a central zone of intense secondary biotite and magnetite which defines the potassic zone. Stable isotope studies indicate this alteration is predominantly of a magmatic origin (Zaluski *et al.*, 1994). Enclosing the potassic zone is a zone of propylitic alteration characterized by the presence of chlorite and carbonate. Unlike Bell and Granisle, there is no extensive overprinting of early magmatic alteration with phyllic and argillic alteration although this type of alteration does occur in some of the biotite-hornblende feldspar porphyry dikes.

The Morrison deposit has been affected by Eocene or younger extension and dextral shearing. To the east of the deposit is the Morrison fault which forms the eastern boundary of the Morrison graben. This fault may be dipping westward and, if so, the Morrison Deposit may be the downwardly displaced upper part of the Hearne Hill porphyry system, an idea put forth by Ogyzlo (1992). A north-trending, post-mineral shear zone with up to 330 metres of dextral offset cuts and displaces the main stock and zone of copper mineralization. This shear zone, which typically has intense clay-carbonate alteration and local breccia development, is also mineralized with marcasite, sphalerite and arsenopyrite occurring in quartz-carbonate veinlets and vugs.

Another northwest trending dextral shear zone truncates the southern part of the Morrison intrusive center. Intrusions on the Wolf property, some 4.5 kilometres to the northwest, may be the displaced southern part of the Morrison intrusive system.

WOLF (MINFILE 93M 008)

The Wolf prospect is located north of Saddle Hill and west of Morrison Lake. This area was first staked and explored by Kerr Addison who located an EM conductor and low grade copper in granodiorite along the west shore of Morrison Lake. Tro-Buttle Exploration and Canadian Superior Exploration explored the property in 1967 and 1968 and complete 5 diamond drill holes totalling 182 metres in the vicinity of the EM conductor. It was concluded this conductor was due to the presence of graphitic siltstone. Cities Services optioned the property in 1976 and did 19 kilometres of IP survey. This was followed by Noranda in 1979 who drilled a single 152 metre hole, again near Morrison Lake. Noranda did a small soil sampling program on the property in 1988 and in 1989 the claims were allowed to lapse. In 1992, R. McMillan staked the property as the Double R and in 1993 Phelps Dodge completed six diamond drill holes totalling 781 metres on the northeast slope of a small ridge on the west side of the property. This drilling, which was on 200 metre centers, was done to test a coincident soil and magnetic anomaly. The drill holes intersected low grade copper mineralization associated with biotite-feldspar porphyry dikes that cut a biotite granodiorite stock. Chalcopyrite and pyrite occur as disseminations and fracture coatings and locally as stockwork veinlets. The best drill intersection was 16 metres of 0.25 percent copper.

The biotite granodiorite stock at Wolf intrudes and has hornfelsed siltstones of the Middle to Upper Jurassic Ashman Formation. The contact zone, which is strongly pyritic is exposed near the crest of a north trending ridge. Biotite extracted from the granodiorite gave an Ar-Ar isotopic age of 52.4 ± 0.5 Ma confirming these intrusions are part of the Babine suite (No. 20, Table 1). The granodiorite stock underlies the area northeast of the ridge and, near Morrison Lake, is truncated and offset by a dextral shear zone that is probably a splay of the Morrison fault. Movement on this shear zone is clearly Eocene or younger. The same shear zone truncates the Morrison intrusive complex several kilometres to the east and the granodiorite on the Wolf property may be an offset and uplifted portion of the Morrison system. Outcrops of rhyolite and basalt occur northeast of the shear zone and these rocks are near the top of the Lower to Middle Jurassic Saddle Hill volcanic succession.

DOROTHY (MINFILE 93M 009)

The Dorothy property, which is located northeast of Hautête Lake, was first staked in 1965. After completion of induced polarization, magnetometer, electromagnetic and geochemical surveys in 1970, the property was tested by diamond drilling in 1971. This work defined an inferred resource of 45 million tonnes averaging 0.25 percent copper and 0.01 percent molybdenum. Little work has been done on this property since 1971. However, a new logging road (the Highland Main) now cuts through the deposit and low grade copper mineralization in the form of disseminated and fracture-controlled pyrite and chalcopyrite is exposed in road cuts over a distance of 1800 metres. Examination of these exposures reveals that the mineralization occurs in a multi-phase stock comprised of crowded biotite-feldspar porphyry and equigranular to subporphyritic granodiorite or quartz diorite. Some of the biotite-feldspar porphyry is dark grey due to abundant secondary biotite alteration. Elsewhere the porphyry has moderate to intense quartz-sericite-pyrite alteration. The latter appears to be overprinting the earlier biotite alteration. Although the Dorothy stock has not been dated it is almost certainly part of the Babine Igneous Suite.

East of the Dorothy stock is a large, north trending body of hornblende diorite which may or may not be part of the Babine suite. Contact relationships are not clear but it appears the Dorothy stock intrudes the diorite. To the west the stock intrudes volcanics of probable Lower to Middle Jurassic age.

MAST (MINFILE 93M 121)

The Mast copper showing is apparently located southeast of the Dorothy porphyry copper deposit. The exact location of the showing is uncertain and consequently it was not examined during the 1996 field program. The showing is described as disseminated pyrite and minor chalcopyrite in silicified andesitic volcanic rocks and diorite of probable Late Cretaceous to Tertiary age. The deposit is classified as a porphyry deposit.

BAB (MINFILE 93M 127)

The Bab showing is described as being located 2 kilometres east of the north end of Babine Lake. A number of hornblende-biotite-feldspar porphyry intrusions of the Babine suite are reported to occur in this area. These intrusions cut Lower to Middle Jurassic volcanics of the Saddle Hill succession. Mineralization in the form of pyrite and chalcopyrite with sericite and secondary biotite occurs in a narrow, northwest-trending shear zone that cuts relatively fresh porphyry. The location of the Bab showing is uncertain and it was not visited during the 1996 field program.

FORT (MINFILE 93M 144)

The Fort showing is on the west side of Old Fort Mountain. It is described as pyrite and minor chalcopyrite occurring within and adjacent to a small plug of biotite-feldspar porphyry. The showing was not examined in 1996.

FIREWEED (MINFILE 93M 151)

The Fireweed property is a relatively recent discovery in the Babine Porphyry Belt and is an example of the type of epithermal mineralization that is associated with the Babine Igneous Suite. The geology of the property has been described in a recent report by Mallott (1992).

The Fireweed property, which was staked in 1987 after float with anomalous gold was found by prospectors, is located in a low-lying clear cut area southeast of Smithers Landing. Follow-up work discovered two mineralized outcrops in an area covered by up to 40 metres of glacio-lacustrine clay. In 1988, Canadian United Minerals drilled 32 holes to test geophysical targets. This worked showed that the property is underlain by a northeast trending graben that contains moderate to steeply northwest and southeast dipping beds of the Lower Cretaceous Skeena Group. The graben is bounded by Jurassic and possibly Triassic volcanic rocks.

The main showings on the property are the Mn, Sphalerite and West Zone (Mallott, 1992). These occur in the Lower Cretaceous Skeena Group, which here is mainly interbedded carbonaceous sandstone, siltstone and mudstone. There are three types of mineralization observed in drill core and limited bedrock exposure. These include: breccia zones healed with fine to coarse-grained massive pyrite-pyrrhotite and lesser amounts of sphalerite, chalcopyrite; fine to very fine-grained disseminated pyrite, marcasite, sphalerite, galena and minor tertrahedrite interstitial to sand grains in manganiferous coarse sandstones; and fine-grained, banded, massive sulphides that contain rounded quartz-eyes and sedimentary clasts. The massive sulphides are comprised of alternating beds of pyrite-pyrrhotite and sphalerite-galena. The best grades of mineralization occur in the coarser-grained, more permeable sandstone beds within the carbonaceous sandstone-siltstone-mudstone succession. The best drill intersection was 7.9 metres averaging 635.3 grams per tonne silver, 2.26 percent lead and 3.02 percent zinc (Mallott, 1992). Although intrusive rocks are not exposed on surface, several drill holes have cut sills and dikes of strongly altered feldspar porphyry and latite that are probably part of the Eocene Babine Igneous Suite.

The style and tenor of mineralization on the Fireweed property suggests a near surface epithermal environment of formation. Circulation of hydrothermal fluids through the permeable Skeena beds produced near massive sulphide mineralization in places. Heat for the hydrothermal system was probably supplied by

Eocene dikes and sills which cut the sedimentary succession.

Other areas underlain by Skeena Group rocks and cut by Eocene intrusions should also be considered prospective for epithermal deposits similar to the Fireweed. These areas, which are typically recessive and lack outcrop, occur north of Old Fort Mountain and in the Morrison Graben (Figure 2). In 1996, Booker Gold drilled two holes into the Morrison Graben, southwest of the Hearne Hill deposit. These holes intersected carbonaceous Skeena Group sediments that are cut by numerous biotite-feldspar porphyry dikes. Bands of fine-grained massive pyrite and possibly marcasite often associated with strongly carbonaceous sediments were observed in the drill core. This mineralization may also be epithermal in origin and suggests there may be potential for deposits similar to the Fireweed within the Morrison Graben.

NEWMAN NORTH (MINFILE 93M 159)

The Newman North showing is located on a point at the northwest tip of the Newman Peninsula, approximately 4 kilometres northwest of the Bell mine. A small stock of biotite-feldspar porphyry intrudes steeply dipping Skeena Group sediments just west of the Newman Fault. The showing was discovered and drilled at the same time as the Bell deposit. The showing is comprised of disseminated and fracture-controlled pyrite and minor chalcopyrite. A strong aeromagnetic anomaly is associated with the intrusion which may be larger at depth.

SPARROWHAWK (MINFILE 93M 160)

The Sparrowhawk showing is located 7 kilometres north of the Bell mine and 3.5 kilometres northeast of Hagan Arm. The showing was discovered in 1989 during a regional reconnaissance program initiated by Noranda. Examination of exposures along road cuts and trenches on the property indicate the host rocks are part of a westward dipping succession of Lower to Middle Jurassic Saddle Hill volcanics. A north trending zone of bleaching, pyritization and carbonate alteration appears to be centered on a fault zone that parallels the east side of the Morrison Graben. Showings on the property include minor chalcopyrite associated with magnetite veins in altered vesicular basalt and chalcopyrite and bornite in a 10 centimetre wide quartz vein that cuts rhyolite. These showings appear unrelated to alteration along the fault zone and may be of a volcanogenic origin.

COPPER 1-4 (MINFILE 93M 162)

This showing, which was discovered in 1986, is reported to be located 2.5 kilometres west of Natowite Lake, in a gravel pit. Galena and sphalerite are present as pods, veinlets and stringers within a 10 to 20 centimetre wide, east-northeast trending shear zone that cuts argillaceous sediments of the Middle to Upper Jurassic Ashman Formation. The best assay reported by Canyon City Resources Inc. in their 1987 prospectus was 713.7 grams per tonne silver, 23 percent lead, and 13.5 percent zinc across 10 centimetres of vein and 5 centimetres of wall rock.

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British Columbia Geological Survey
Geological Fieldwork 1996

U-PB GEOCHRONOLOGY, GEOCHEMISTRY AND ND ISOTOPIC SYSTEMATICS OF THE SITLIKA ASSEMBLAGE, CENTRAL BRITISH COLUMBIA

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(MDRU contribution 82)
(British Columbia Ministry of Employment and Investment contribution to the Nechako National Mapping Program)

KEYWORDS: Sitlika assemblage, U-Pb geochronology, Permian, Early Triassic, tonalite, rhyolite, bimodal, tholeiitic, Kutcho Assemblage

INTRODUCTION

Rocks of the Sitlika assemblage occur within the eastern Sitlika Range and adjacent parts of the Hogem Ranges, east of Takla Lake in central British Columbia (Figs. 1 and 2). The Sitlika assemblage is currently the focus of a two year 1:50,000 scale mapping project headed by one of the authors of this report (Schiarizza and Payie, 1997; Schiarizza *et al.*, 1997). This report presents U-Pb zircon geochronology for felsic volcanic and intrusive rocks, major and trace element analyses for the principal igneous lithologies of the Sitlika assemblage and Nd isotopic and rare earth analyses for rocks dated in this study.

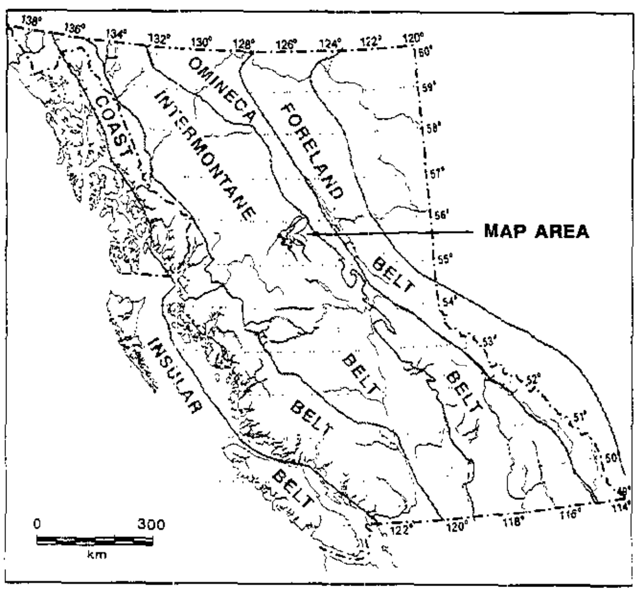

Figure 1. Location of the Sitlika assemblage, northcentral British Columbia.

PREVIOUS WORK

Volcanic and sedimentary rocks, directly east of the Takla Fault, were originally correlated with the Cache Creek Group (Armstrong, 1949). Further mapping by Paterson (1974) identified the presence of three principal lithologies within and south of the Sitlika Range: argillite, volcanic rock and greywacke. Based on the occurrence of felsic volcanic and volcaniclastic rocks within this sequence, Paterson (1974) concluded that these rocks were not part of the Cache Creek Group, and hence informally named them the Sitlika assemblage.

On the basis of similarities in lithologies and structural style Monger *et al.* (1978) suggested that the Sitlika assemblage may represent an offset portion of the Kutcho Assemblage, a fault-bounded volcano-sedimentary sequence which lies some 300 km north of the Sitlika assemblage. The Kutcho Assemblage is host to the Kutcho Creek volcanogenic massive sulphide deposit, with reserves of 17 Mt, grading 1.6% Cu and 2.3% Zn, 29 g/t Ag and 0.3 g/t Au (Bridge *et al.*, 1986); the identification of displaced slivers of the Kutcho Assemblage in the Cordillera has implications for base metal exploration. Recent studies have documented the precise age and geochemical characteristics of the Kutcho Assemblage and provide a basis for comparison between the Kutcho and Sitlika assemblages (Childe and Thompson, 1995; Thompson *et al.*, 1995; Childe and Thompson, submitted). One of the most distinctive characteristic of the Kutcho Assemblage is the Permo-Triassic to earliest Triassic age of magmatism (Childe and Thompson, submitted). This time period is typically characterized by a regional unconformity in terranes of island-arc affinity in the Cordillera (Gabrielse and Yorath, 1991).

GEOLOGY

The Sitlika assemblage comprises greenschist facies metavolcanic and metasedimentary rocks in the central part of the Intermontane Belt. They are in fault contact

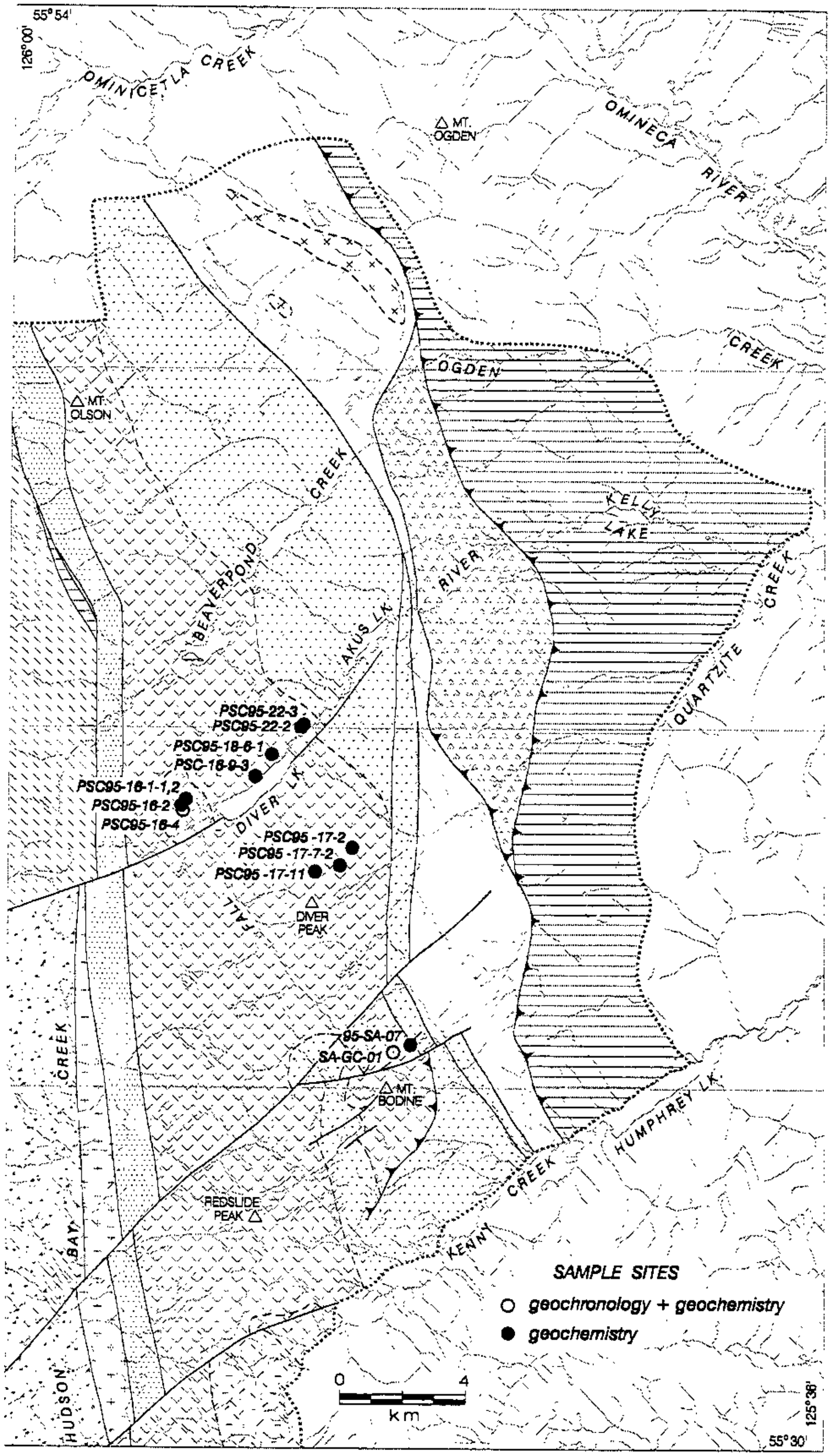

Figure 2. Generalized geology of the Kenny Creek - Mount Olson area (after Schiarizza and Payie, 1997), showing geochemistry and geochronology sample locations.

Upper Cretaceous

Sustut Group

Tango Creek Formation: polymictic conglomerate; sandstone, shale

Jurassic or Cretaceous (?)

Medium to coarse grained biotite granodiorite

STIKINE TERRANE

Lower to Middle Jurassic

Hazelton Group

Medium to dark green, brownish-weathered andesite, basalt and associated breccias and tuffs; commonly feldspar or feldspar-pyroxene-phyric; lesser amounts of volcanic conglomerate, sandstone and siltstone

Late Triassic to Early Jurassic (?)

Topley Intrusions(?): Red to pink, fine to medium-grained granite; lesser amounts of feldspar porphyry

SITLIKA ASSEMBLAGE

Middle to Upper Jurassic (?)

Western clastic unit: dark grey phyllite and slate; foliated chert-pebble conglomerate and chert-grain sandstone; lesser amounts of foliated limestone and grey phyllite containing flattened sedimentary and volcanic-lithic granules

Triassic (?)

Eastern clastic unit: variably foliated siltstone, sandstone and conglomerate containing felsic volcanic and plutonic clasts; medium to dark grey slate and phyllite; locally includes foliated limestone, limestone conglomerate and green chloritic phyllite

Early Triassic

Light grey, medium to coarse-grained tonalite; medium green, medium-grained tonalite to quartz diorite

Late Permian or Early Triassic

Medium grained epidote-chlorite-feldspar schist to semischist; sericite-chlorite-feldspar schist; weakly foliated chloritized hornblende diorite

Permian to Early Triassic

Volcanic unit: medium to dark green chlorite schist, fragmental chlorite schist and pillowed metabasalt; chlorite-sericite schist containing felsic metavolcanic fragments; lesser amounts of quartz-sericite schist, quartz-feldspar porphyry, metasandstone and metachert

CACHE CREEK TERRANE

Pennsylvanian to Triassic

Cache Creek Group

Sedimentary unit: light to medium grey quartz phyllite, platy quartzite and metachert; lesser amounts of recrystallized limestone, dark grey phyllite, massive to pillowed greenstone, fragmental greenstone and chlorite schist; minor amounts of metasandstone

Mafic unit: Medium to dark green, massive to pillowed greenstone, fragmental greenstone and chlorite schist; minor amounts of metagabbro, amphibolite, serpentinite, listwanite, slate, ribbon chert and metasandstone

Ultramafic unit: serpentinite, serpentinized ultramafite and serpentine-magnesite-talc schist; serpentinite melange containing knockers of greenstone, diabase, amphibolite, chert and limestone; locally includes mariposite-quartz-magnesite-altered rock and nephrite

Legend to accompany Figure 2.

with the Stuart Lake Belt of the Cache Creek terrane to the east, and juxtaposed against unmetamorphosed volcanic and sedimentary rocks of the Stikine terrane to the west, across the Late Cretaceous or Early Tertiary Takla fault. In the Kenny Creek - Mount Olson area, the Sitlika assemblage is subdivided into three units, corresponding to the divisions originally defined by Paterson (1974) (Fig. 2). The volcanic unit comprises mafic to felsic flow and fragmental rocks, along with comagmatic intrusions. Mafic rocks are dominant and include thoroughly reconstituted actinolite-epidote-chlorite schists, as well as more massive greenstone with variable preservation of vesicles, plagioclase phenocrysts and pillow structures. The subordinate felsic volcanic rocks include quartz-sericite schists, with or without relict quartz and feldspar phenocrysts, as well as massive feldspar porphyry and quartz-feldspar porphyry. Light grey felsic volcanic rocks also constitute the dominant clast type in fragmental sericite-chlorite schists that are common within the unit. These fragmental rocks generally interfinger with pillowed mafic volcanic rocks, and may represent mass flow deposits derived from adjacent felsic volcanic buildups. Mafic to intermediate composition intrusive rocks within the volcanic unit include fine- to medium-grained feldspar-chlorite schist and semischist, derived from sills, dykes and small plugs of diabase, gabbro, and diorite. Felsic intrusive rocks include widespread dykes and sills of variably foliated quartz-feldspar porphyry, as well as a small multiphase tonalite stock that intrudes pillowed volcanic rocks and fragmental schist west of Diver Lake (Fig. 2).

Clastic sedimentary rocks that outcrop mainly east of the volcanic unit correspond to Paterson's (1974) greywacke division. These rocks rest stratigraphically above the volcanic unit in sections exposed north of Beaverpond Creek and west of Mount Bodine; the contact is abrupt but structurally concordant with the underlying volcanics. The basal part of the eastern clastic unit comprises conglomerate and coarse sandstone, overlain by green chloritic phyllite containing lenses of recrystallized limestone and dolostone. Conglomerates contain mainly felsic volcanic clasts, with some felsic plutonic clasts, limestone clasts and mafic volcanic clasts. The volcanic and plutonic clasts are lithologically similar to rocks found within the Sitlika volcanic unit. Higher stratigraphic levels consist mainly of dark grey slate intercalated with thin to thick, massive to graded beds of volcanic-lithic sandstone and siltstone. The eastern clastic unit is not dated, but is presumed to be Early Triassic and/or younger as it overlies the volcanic unit.

Clastic metasedimentary rocks that outcrop west of the Sitlika volcanic unit are equivalent to Paterson's (1974) argillite division, and consist of dark grey phyllite, chert-pebble conglomerate, chert-quartz sandstone, and limestone. These rocks are not well exposed, but apparently form a narrow continuous belt that occurs east of the Takla fault over the full length of the map area (Fig. 2). The contact with the adjacent Sitlika volcanic unit is not well exposed, but is inferred to be a fault. The western clastic unit is not dated, but is tentatively correlated with the Middle to Upper Jurassic

Ashman Formation at the base of the Bowser Lake Group (Tipper and Richards, 1976). This correlation is based on their general lithologic similarity, and in particular on the predominance of chert clasts in the coarser clastic intervals, which are not common in older clastic rocks found in this part of the central Intermontane Belt.

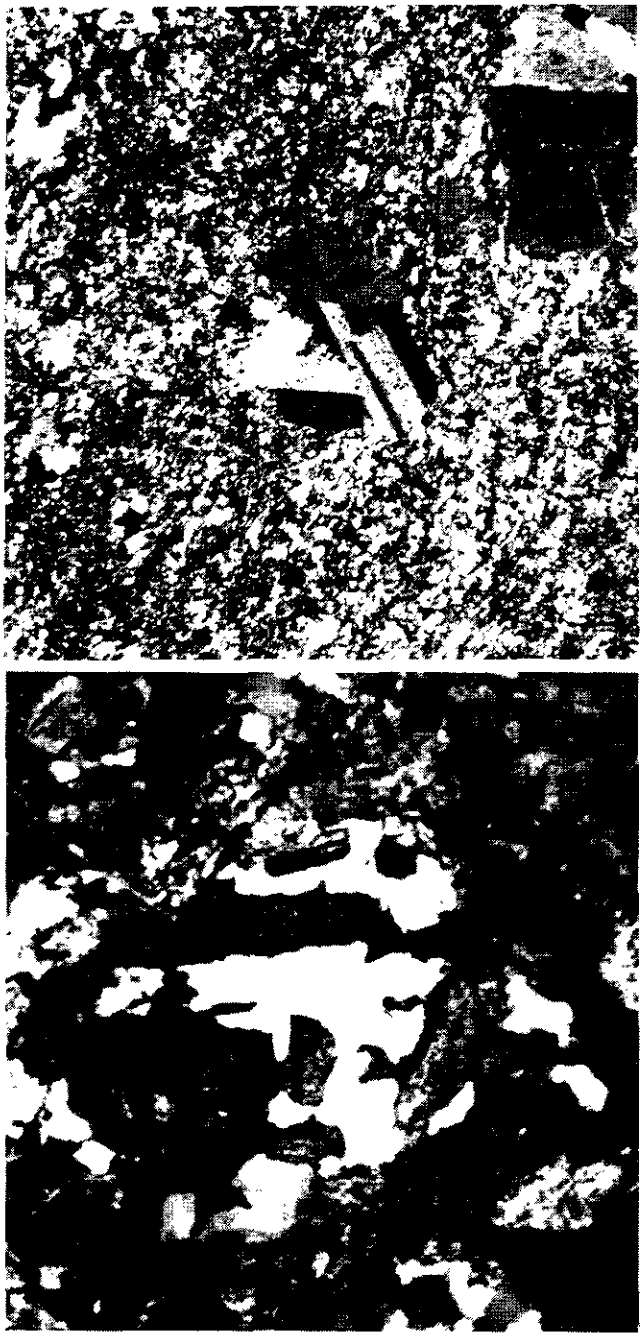

Figure 3. a-upper) photomicrograph of quartz-plagioclase glomerocryst in a quartzo-feldspathic groundmass, Mount Bodine rhyolite, sample SA-GC-01 (field of view = 5 mm); b-lower) photomicrograph of intergrown quartz and plagioclase grains, tonalite, sample PSC95-16-4 (field of view = 5 mm)

All three units of the Sitlika assemblage are characterized by a single penetrative cleavage or schistosity defined by the preferred orientation of metamorphic minerals and variably flattened clastic grains or volcanic fragments. This metamorphic foliation is axial planar to folds that are most commonly observed in the eastern clastic unit. The folds are upright, with axes that plunge north to northwest or south to southeast. North of Beaverpond Creek, the volcanic unit and lower portion of the overlying eastern clastic unit comprise a moderately east-dipping homocline cut by steeply east-dipping cleavage. Farther east, the eastern clastic unit is repeated across several upright folds. The wide outcrop expanse of the eastern clastic unit thins dramatically to the south, apparently due to truncation along the fault system that marks the Sitlika - Cache Creek contact. The volcanic belt is correspondingly wider in the south, in part due to internal folding, as indicated by a faulted anticline and adjacent syncline that repeat the volcanic unit and overlying eastern clastic unit south and west of Mount Bodine.

The Sitlika assemblage is bounded to the east by a unit of serpentinite melange that is included in the Cache Creek Group. Metasedimentary and metavolcanic rocks comprising the bulk of the Cache Creek Group farther east rest structurally above the serpentinite melange unit across an east-dipping thrust fault (Paterson, 1974). Limited structural data suggests that the Sitlika - Cache Creek contact (specifically, the contact between the Sitlika assemblage eastern clastic unit and the serpentinite melange) is a steeply dipping dextral strike-slip fault that postdates the contractional deformation within the Cache Creek Group (Schiarizza and Payie, 1997).

U-PB GEOCHRONOLOGY

Two samples were collected for U-Pb zircon geochronology. These consisted of a tonalite from the Diver Lake area, with abundant 3-6 mm glassy quartz phenocrysts set in a fine-grained crystalline groundmass (PSC95-16-4), and a rhyolite from the Mount Bodine area, with 1-2 mm quartz and plagioclase phenocrysts (SA-GC-01) (Figs. 3 a and b).

Analytical Techniques

Sample preparation and U-Pb analyses were carried out at the Geochronology Laboratory of the University of British Columbia. The samples were 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). 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

TABLE 1. U-PB ZIRCON ANALYTICAL DATA

Fraction[1]	Wt.	U	Pb[2]	$^{206}Pb/^{204}Pb$[3]	Pb[4]	^{208}Pb[5]	Isotopic ratios($\pm 1\sigma$,%)[6]			Isotopic dates(Ma,$\pm 2\sigma$)[6]		
	mg	ppm	ppm		pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
Mount Bodine rhyolite SA-GC-01												
A,m,M1,p	0.120	77	3	1730	14	9.7	0.04082±0.13	0.2892±0.29	0.05138±0.23	257.9±0.7	257.9±1.3	257.8±10.5
B,f,M1,p	0.122	60	2	604	29	8.9	0.03680±0.13	0.2603±0.43	0.05129±0.34	233.0±0.6	234.9±1.8	253.9±15.7
C,f,M1,p	0.102	53	2	917	14	8.1	0.03782±0.12	0.2671±0.35	0.05123±0.28	239.3±0.6	240.4±1.5	251.0±12.7
J,f,M2,p	0.052	67	2	579	15	8.5	0.03714±0.14	0.2632±0.48	0.05140±0.40	235.1±0.7	237.2±2.0	258.7±18.2
Diver Lake tonalite PSC95-16-4												
A,c,N1,p	0.099	194	7	2469	19	7.8	0.03801±0.22	0.2682±0.31	0.05112±0.19	240.5±1.0	241.2±1.3	248.8±8.3
B,c,N21p	0.035	174	7	1254	12	8.6	0.03807±0.18	0.2689±0.40	0.05122±0.32	240.9±0.8	241.8±1.7	250.9±14.6
C,m,N1,p	0.140	244	9	4202	19	7.7	0.03771±0.11	0.2652±0.21	0.05100±0.13	238.6±0.8	238.8±0.9	240.7±5.9
D,c,M1,p	0.285	230	37	6801	23	8.1	0.03816±0.12	0.2689±0.21	0.05111±0.11	241.4±0.6	241.8±0.9	245.7±5.0
E,c,N1,p	0.196	199	32	3925	24	7.5	0.03816±0.10	0.2686±0.21	0.05105±0.13	241.4±0.5	241.6±0.9	243.0±6.2

[1]All fractions are air abraded; Grain size, smallest dimension: c= +134μm, m=-134μm+74μm, f=-74μm;
Magnetic codes: Franz magnetic separator sideslope at which grains are nonmagnetic; e.g., N1=nonmagnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: p=prismatic.
[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).

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.

Analytical Results

The Diver Lake tonalite (PSC95-16-4) contained abundant coarse-grained, prismatic zircon with few inclusions and good clarity. Analysis of five fractions yielded $^{207}Pb/^{206}Pb$ ages of 241 to 251 Ma. Fraction E was concordant with a $^{206}Pb/^{238}U$ age of 241.4 Ma, while fraction D slightly overlapped concordia, with a $^{206}Pb/^{238}U$ age of 241.4 Ma (Figure 4a). An Early Triassic age of 241 +/-1 Ma, which is based on the $^{206}Pb/^{238}U$ age and associated errors of fractions E and D, is considered to be the best estimate for the age of this rock.

The Mount Bodine rhyolite (SA-GC-01) contained a small quantity of fine-grained prismatic zircon with few inclusions and good clarity. Zircon from this rock was characterized by extremely low U concentrations (53 to 77 ppm), which is in part reflected in low $^{206}Pb/^{204}Pb$ ratios (Table 1). All of the zircon recovered from this rock was divided into four fractions, analyses yielded $^{207}Pb/^{206}Pb$ ages of 251 to 259 Ma. Fraction A was concordant, with a $^{206}Pb/^{238}U$ age of 257.9 Ma (Figure 4b). A Permian age of 258 +10/-1 Ma based on the $^{206}Pb/^{238}U$ age and $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ errors of fraction A, is considered to be the best estimate of the age of this rock.

GEOCHEMISTRY

Major and Trace Elements

A suite of thirteen igneous rock samples from the Sitlika assemblage were analyzed for major and trace element abundances. Based on these analyses, the Sitlika assemblage has a roughly bimodal distribution of compositions, containing basalt (47-50% SiO_2) and dacite to rhyolite, and their intrusive equivalents (62-85% SiO_2) (Table 2). The Mount Bodine rhyolite (SA-GC-01) has a high SiO_2 concentration (85%), combined with relatively low concentrations of other major elements (Al_2O_3, Fe_2O_3, CaO, Na_2O) which indicates silicification of this rock, and is consistent with field observations. In a plot of SiO_2 vs. K_2O (Pecerrillo and Taylor, 1976), unaltered rocks from the Sitlika

Table 2. Major and trace element data.

sample number	lithology	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	Na2O %	K2O %	P2O5 %	LOI	Total	BaO ppm
SA-GC-01	rhyolite	85.25	0.16	8.40	1.58	0.02	0.00	0.15	4.53	0.23	0.02	0.25	100.59	<d/l
95-SA-07	dacite	67.86	0.70	11.37	5.93	0.26	2.46	0.44	3.04	0.55	0.19	4.35	100.31	103
PSC95-16-1-1	tonalite	74.47	0.30	13.45	2.55	0.05	0.65	1.95	5.09	0.69	0.06	0.99	100.28	181
PSC95-16-1-2	QFP	66.42	0.65	16.01	4.72	0.11	1.35	3.66	5.56	0.30	0.18	1.34	100.33	170
PSC95-16-2	QFP to tonalite	65.18	0.74	16.12	5.17	0.10	1.56	3.72	5.34	0.34	0.18	1.82	100.30	116
PSC95-16-4	tonalite	74.43	0.31	13.92	2.09	0.03	0.71	2.45	5.16	0.62	0.06	0.87	100.69	258
PSC95-16-9-3	pillowed metabasalt	49.00	2.17	16.40	12.62	0.19	4.79	5.08	5.38	0.04	0.24	3.85	99.85	191
PSC95-17-2	biot-chl. schist	48.53	1.81	14.64	15.65	0.24	5.56	6.37	3.79	0.45	0.11	3.42	100.67	257
PSC95-17-7-2	chlorite schist	62.09	1.38	15.02	8.18	0.17	2.53	2.68	7.23	0.18	0.20	0.98	100.68	132
PSC95-17-11	chlorite schist	46.98	1.53	16.15	12.36	0.19	5.04	9.05	4.24	0.07	0.28	4.70	100.67	135
PSC95-18-6-1	pillowed metabasalt	49.89	1.42	15.64	13.91	0.22	4.92	7.70	4.38	0.12	0.14	2.56	100.98	138
PSC95-22-2	chl-ser-qtz schist	74.14	0.12	14.68	1.29	0.04	0.35	0.31	7.05	1.28	0.02	0.82	100.13	125
PSC95-22-3	chlorite schist	43.91	1.35	17.13	11.78	0.18	6.84	7.89	4.20	0.22	0.18	6.68	100.46	119
Detection Limits (ppm):		60	35	120	30	30	95	15	75	25	35			17

sample number	Co ppm	Cr2O3 ppm	Cu ppm	Ni ppm	V ppm	Zn ppm	Ga ppm	Nb ppm	Pb ppm	Rb ppm	Sr ppm	Th ppm	U ppm	Y ppm	Zr ppm
SA-GC-01	47	<d/l	7	<d/l	<d/l	68	9.8	5.3	<d/l	<d/l	23.1	<d/l	<d/l	40.0	180.3
95-SA-07	18	<d/l	83	<d/l	83	1219	19.0	3.3	160.9	4.6	35.6	<d/l	<d/l	50.2	166.0
PSC95-16-1-1	54	<d/l	5	<d/l	25	57	13.9	4.1	<d/l	8.8	132.5	<d/l	4.3	27.4	139.3
PSC95-16-1-2	36	<d/l	4	<d/l	56	60	16.6	3.9	<d/l	2.7	200.2	<d/l	4.5	40.4	131.0
PSC95-16-2	14	<d/l	3	<d/l	68	59	15.0	4.1	<d/l	3.9	217.0	<d/l	4.4	42.7	117.8
PSC95-16-4	60	<d/l	4	<d/l	27	43	13.7	3.9	<d/l	5.4	110.9	<d/l	4.2	29.4	127.3
PSC95-16-9-3	44	66	46	11	402	136	20.1	3.6	2.3	<d/l	106.4	4.2	6.7	43.6	121.1
PSC95-17-2	45	35	32	<d/l	490	117	18.1	3.4	2.1	5.7	118.9	5.1	7.1	30.6	46.5
PSC95-17-7-2	19	<d/l	12	<d/l	164	111	19.5	4.0	1.0	1.0	73.9	1.3	5.8	53.2	268.1
PSC95-17-11	37	217	27	45	253	118	18.0	2.8	1.8	<d/l	133.2	4.0	6.6	37.6	109.9
PSC95-18-6-1	37	<d/l	53	3	391	126	19.2	3.0	1.6	<d/l	125.0	4.7	7.0	37.4	106.6
PSC95-22-2	30	<d/l	23	9	<d/l	60	17.2	8.2	<d/l	8.5	25.6	<d/l	4.0	85.5	233.7
PSC95-22-3	47	271	89	62	288	124	14.9	3.8	1.9	2.6	73.5	3.0	6.6	28.0	74.6
Detection Limits (ppm):	10	15	2	3	10	2	1	1	1	1	1	1	1	1	1

Table 3. Rare earth element data.

sample number	Au ppb	Ag ppm	As ppm	Br ppm	Cs ppm	Hf ppm	Hg ppm	Ir ppb	Sb ppm	Sc ppm	Se ppm	Ta ppm	W ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm
SA-GC-01	<d/l	<d/l	<d/l	<d/l	<d/l	<d/l	<d/l	<d/l	0.1	6.4	<d/l	1.4	251	6.6	23	16	4.4	0.8	1.0	4.4	0.6
PSC95-16-4	<d/l	<d/l	<d/l	<d/l	<d/l	4.5	<d/l	<d/l	0.6	6.1	0.8	1.6	302	5.8	<d/l	16	2.3	0.9	0.6	3.1	0.5
PSC95-18-6-1	<d/l	<d/l	2.0	<d/l	<d/l	2.9	<d/l	<d/l	0.6	39.1	<d/l	<d/l	15	4.3	<d/l	16	3.6	1.4	0.9	3.6	0.5
Detection	2	2	1	0.5	0.2	0.2	1	1	0.1	0.1	0.5	0.3	1	0.1	1	1	0.01	0.05	0.1	0.05	0.01
Limits:	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm

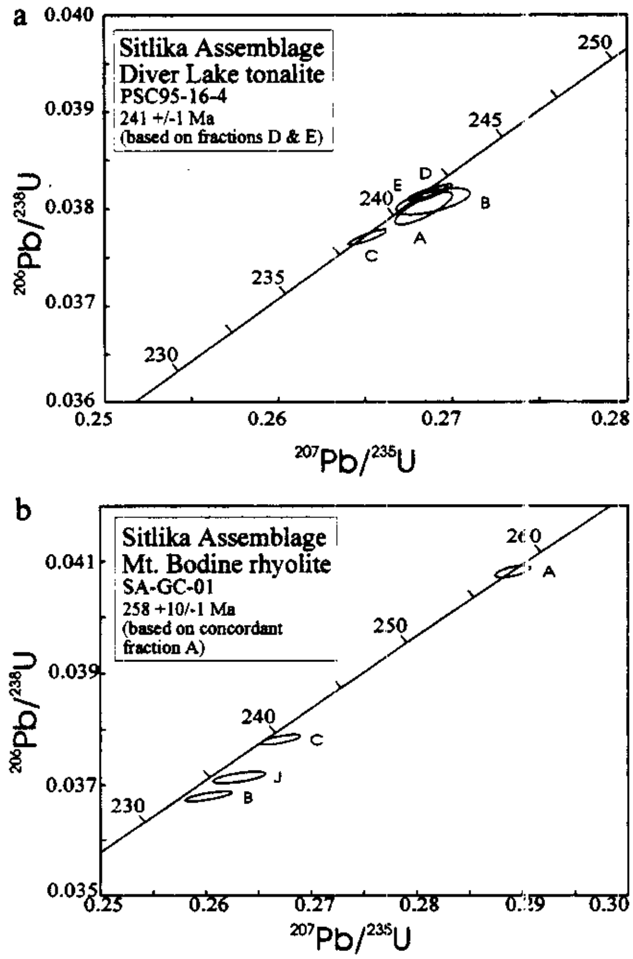

Figure 4. U-Pb concordia diagrams for a) Diver Lake tonalite (PSC95-16-4); and b) Mount Bodine rhyolite (SA-GC-01).

assemblage lie within the field for low-K magmas (Fig. 5a).

A plot of Zr vs. Y indicates that intrusive and volcanic rocks of the Sitlika assemblage have a predominantly tholeiitic magmatic affinity, with Zr/Y ratios of 1.5 to 5.0 (Fig. 5b and Table 3).

Rare Earth Elements

Rare earth element (REE) concentrations were determined for samples of rhyolite, tonalite, and basalt from the Sitlika Assemblage (Table 4 and Figure 6a and b). All three rocks are characterized by low REE abundances and near-flat REE patterns. A small negative europium anomaly for the rhyolite is consistent with fractionation of plagioclase in this unit. With the exception of the europium anomaly, the patterns for the rhyolite and tonalite are extremely similar (Figure 6a). The low overall REE concentrations and near-flat REE patterns for rocks of the Sitlika Assemblage suggest derivation from primitive magmatic sources.

Table 4. Nd Isotopic Data

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	meas. $^{143}Nd/^{144}Nd$ (error x 10^{-6}, 2σ)	ε_{Nd} [2] (present day)	age [1] (Ma)	ε_{Nd} [2] (initial)
Mount Bodine rhyolite SA-GC-01	4.77	16.12	0.1789	0.513029 (6)	+7.6	258	+8.2
Diver Lake tonalite PSC95-16-4	2.61	9.99	0.16158	0.512723 (19)	+1.7	241	+2.7

[1]used for the calculation of ε_{Nd} (initial).
[2]error = ± 0.5 ε_{Nd} units.

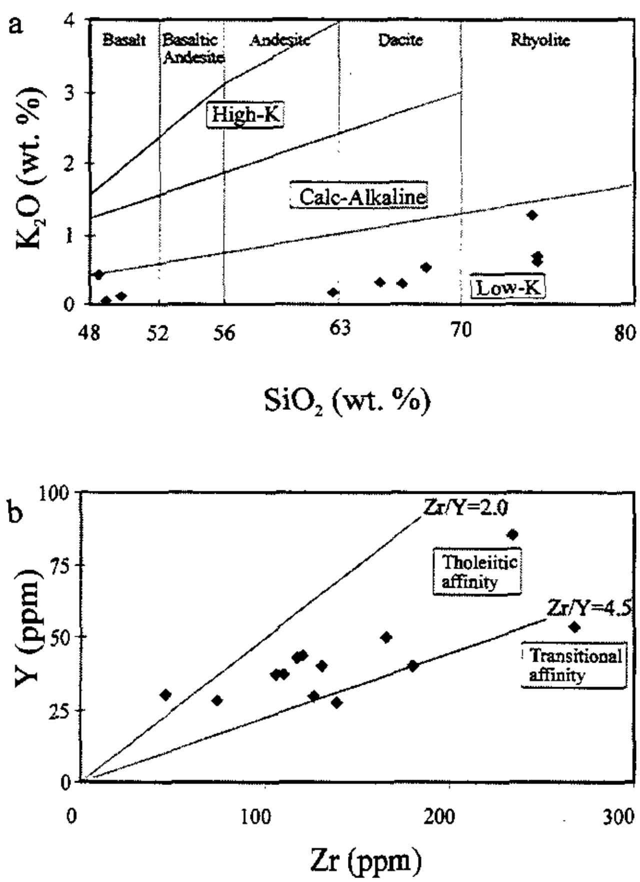

Figure 5. a) SiO_2 vs. K_2O diagram for unaltered rocks of the Sitlika Assemblage (fields from Peccerillo and Taylor, 1976); b) Zr vs. Y diagram for all samples from the Sitlika Assemblage (fields from Barrett and MacLean, 1994).

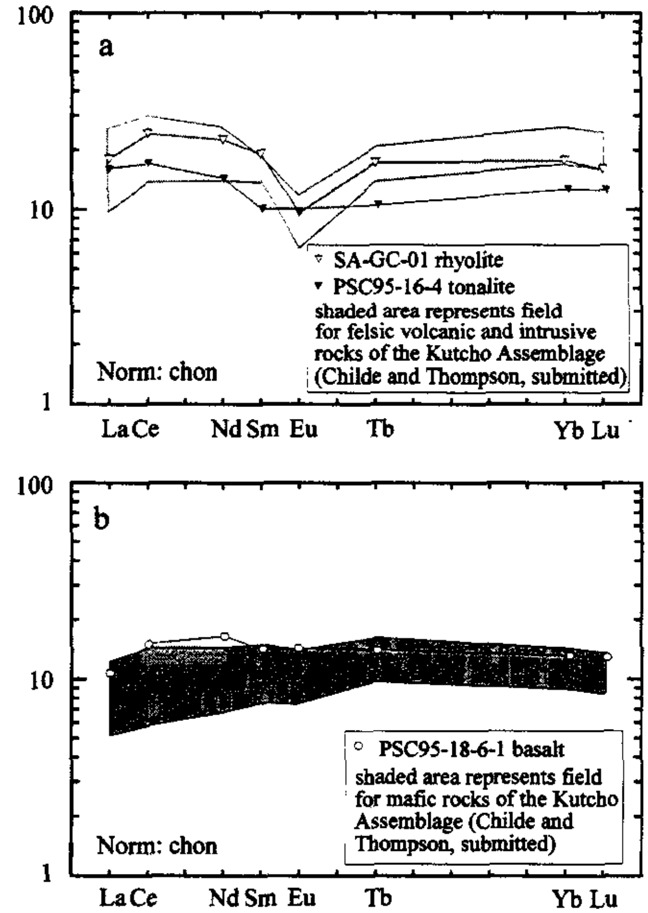

Figure 6. Chondorite-normalized rare earth element diagram for a) rhyolite (SA-GC-01) and tonalite (PSC95-16-4), showing the field for felsic volcanic and intrusive rocks of the Kutcho Assemblage (Childe and Thompson, submitted), and b) basalt (PSC95-18-6-1) from the Sitlika Assemblage, showing the field for mafic volcanic rocks of the Kutcho Assemblage (Childe and Thompson, submitted).

ND ISOTOPIC SYSTEMATICS

The Nd isotopic ratio of rhyolite and tonalite dated in this study were determined to further constrain the degree of evolution of this magma. Isotopic analysis of the rhyolite was conducted by R. Thériault at the Geochronology Laboratory of the Geological Survey of Canada; analysis of the tonalite was conducted at Memorial University. Analytical procedures are described by Thériault (1990). Abundances of Sm and Nd determined by isotope dilution have an uncertainty of 1% or less. Uncertainty for calculated ε_{Nd} values is ± 0.5 ε_{Nd} units. Neodymium analytical results are presented in Table 4.

An initial ε_{Nd} value of +8.2 for the Mount Bodine rhyolite is one of the highest values reported for a felsic rock within the Cordillera and indicates derivation of this magma from primitive, unenriched magmatic sources, with no evidence for contamination by old, isotopically evolved sialic crust. An initial ε_{Nd} value of +2.7 for tonalite that intrudes the Sitlika assemblage indicates that this unit is also derived from primitive magmatic sources.

DISCUSSION

Ages of 258 +10/-1 Ma and 241 +/-1 Ma, determined for rhyolite and tonalite, respectively, indicate that magmatic activity in the Sitlika assemblage was occurring in the Permo-Triassic, and in part overlapped in time with magmatism in the Kutcho Assemblage. Major and trace element chemistry shows that the Sitlika assemblage is composed of low-K intrusive and bimodal volcanic rocks with a tholeiitic magmatic affinity. Rare earth element chemistry and Nd isotopic systematics indicate derivation from primitive magmas, uncontaminated by old, evolved crust.

Rocks of the Sitlika assemblage formed in the same time period as the Kutcho Assemblage, and the principal lithologies are indistinguishable from those of the Kutcho Assemblage. As such, this region represents a viable exploration target for Kutcho Creek-equivalent VMS mineralization in the Cordillera.

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GEOLOGY OF THE SITLIKA ASSEMBLAGE IN THE KENNY CREEK - MOUNT OLSON AREA (93N/12, 13), CENTRAL BRITISH COLUMBIA

By Paul Schiarizza and Garry Payie

(British Columbia Ministry of Employment and Investment contribution to the Nechako National Mapping Program)

KEYWORDS: Sitlika assemblage, Cache Creek Group, Hazelton Group, Sustut Group, Takla fault, Vital fault, Mount Bodine, Mount Olson, volcanogenic massive sulphides, gold-quartz veins, listwanite, nephrite.

INTRODUCTION

The Sitlika assemblage was named by Paterson (1974) for greenschist facies metavolcanic and metasedimentary rocks that outcrop east of Takla Lake, between the Takla fault and the Stuart Lake belt of the Cache Creek Group (Figure 1). Monger *et al.* (1978) recognized a strong lithologic and structural similarity between the Sitlika assemblage and the Kutcho Formation, which occurs in the eastern part of the King Salmon allochthon in northern British Columbia. They suggested that the King Salmon allochthon and structurally overlying Atlin belt of Cache Creek Terrane had been displaced northward from the Sitlika assemblage and adjacent Stuart Lake belt, on Late Cretaceous or early Tertiary dextral strike-slip faults. Gabrielse (1985) accepted this correlation, and suggested that restoration of about 300 kilometres of dextral offset, distributed on the Kutcho, Finlay, Ingenika and Takla faults, would match the Atlin belt and King Salmon allochthon with the Stuart Lake belt and Sitlika assemblage (Figure 2).

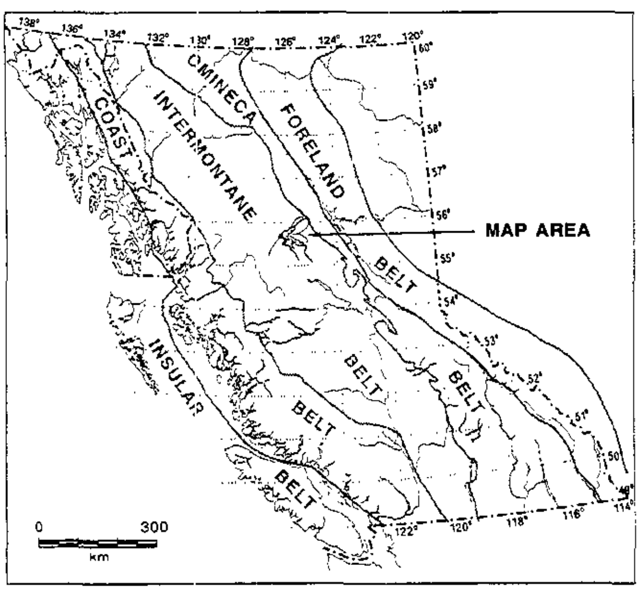

Figure 1. Location of the Sitlika project area.

The Kutcho Formation is host to the Kutcho Creek volcanogenic massive sulphide deposit, with reserves of 17 Mt grading 1.62% Cu, 2.32% Zn, 29.2 g/t Ag and 0.3 g/t Au in the main sulphide lens, and an additional 11 Mt of variable grade in two smaller lenses (Bridge *et al.*, 1986). Correlation of the Sitlika assemblage with the Kutcho Formation suggests that the Sitlika assemblage has potential to host similar volcanogenic massive sulphide mineralization. The Sitlika bedrock mapping project, part of the Nechako Natmap program, was therefore designed to update the geologic database for the western Manson River map area and, in particular, to determine the stratigraphy and structure of the Sitlika assemblage, the validity of its correlation with the Kutcho Formation, and its potential to host volcanogenic massive sulphide mineralization. Recent work on the Kutcho Creek deposit, by the Mineral Deposit Research Unit of the University of British Columbia, has established a Permo-Triassic age for volcanic and intrusive rocks of the Kutcho Formation, and documented their geochemical characteristics (Childe and Thompson, 1995; Thompson *et al.*, 1995). This new database provides some quantitative constraints with which to test the Kutcho - Sitlika correlation.

This report summarizes the findings from the first year of regional mapping within and adjacent to the Sitlika belt, carried out from late June to the end of August, 1996. It also incorporates data from 9 days of reconnaissance mapping and sampling by the senior author in August 1995. The map area covers the northern part of the Sitlika assemblage where it was originally studied and defined by Paterson (1974). It is planned to continue mapping southward along the Sitlika belt in the 1997 field season (*see* Figure 3).

The Kenny Creek - Mount Olson map area is situated mainly within the Hogem Ranges (including parts of the Sitlika and Vital ranges) of the western Omineca Mountains. The lowlands bordering Takla Lake in the southwestern corner of the area comprise part of the northern end of the adjacent Nechako Plateau. Access to the southwestern part of the area is provided by a network of logging and Forest Service roads that originates at Fort St. James, 160 kilometres to the southeast. A major logging road also extends eastward through the map area along the Fall River, and a seasonal four-wheel-drive road follows Kenny Creek along the area's southeastern boundary. Access to other parts of the area was by helicopter, facilitated by a seasonal base established by Pacific Western Helicopters at Rustad Limited's Lovell Cove logging camp, 5 kilometres west of the map area.

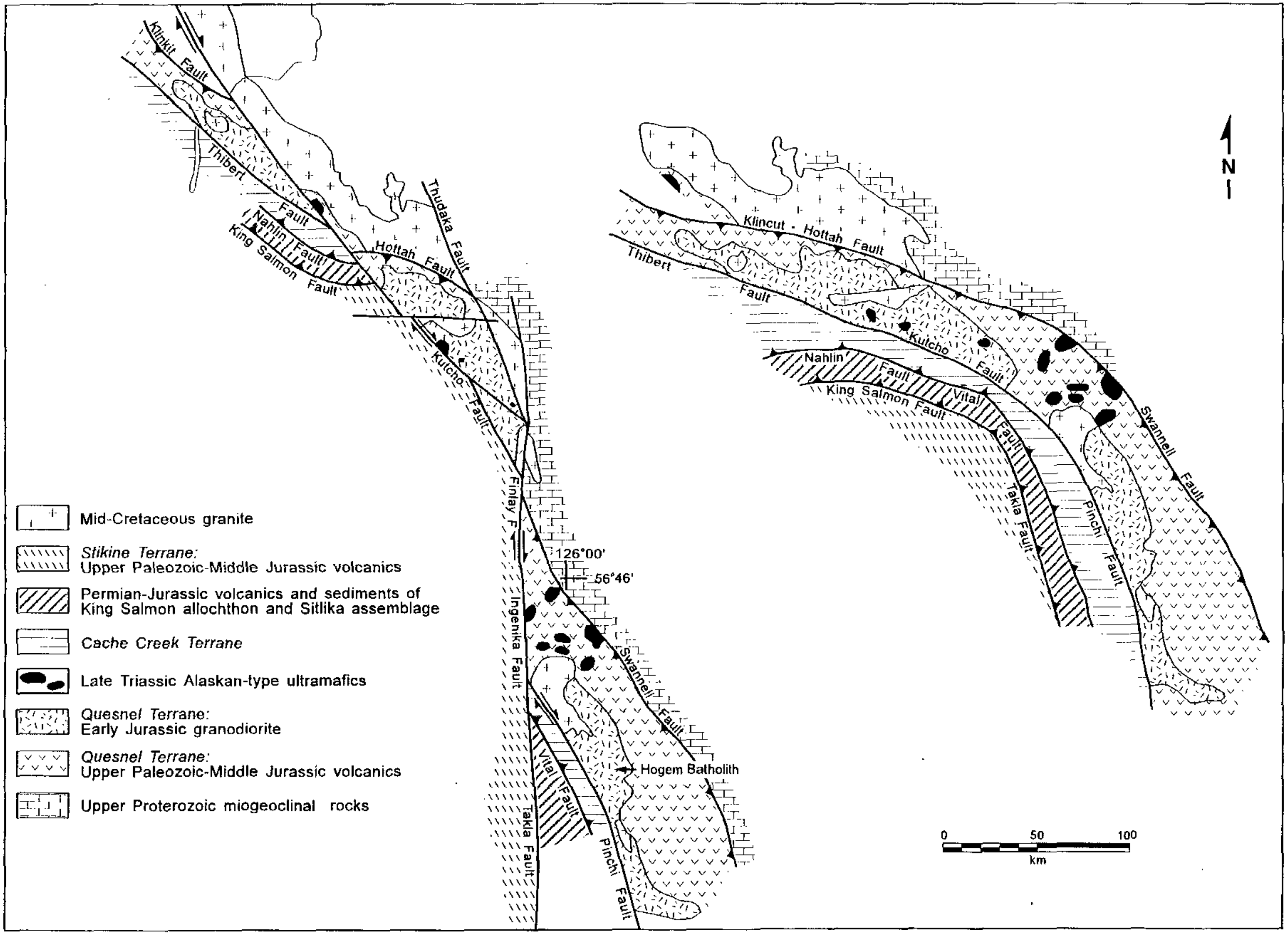

Figure 2. Major fault systems in the Intermontane Belt of central & northern British Columbia; right-hand diagram shows restoration matching Sitlika assemblage & King Salmon allochthon after removing about 300 kilometres of dextral displacement distributed on the Kutcho, Findlay, Ingenika and Takla faults. After Figures 9A and 9D of Gabrielse (1985).

The only permanent settlement in the area is the village of Takla Landing, located just beyond the southwest corner of the map area.

REGIONAL GEOLOGIC SETTING

The Kenny Creek - Mount Olson map area is situated within the eastern to central part of the Intermontane Belt. At this latitude the eastern Intermontane Belt includes early to mid-Mesozoic arc volcanic and plutonic rocks of the Quesnel Terrane flanked to the west by late Paleozoic and early Mesozoic oceanic rocks of the Cache Creek Terrane (Figure 3). The two terranes are separated by the Pinchi fault, which has had a long history, possibly beginning as an early Mesozoic subduction zone and/or transform plate boundary between the Cache Creek accretionary wedge and the Quesnel Terrane magmatic arc (Paterson, 1977; Ghent *et al.*, 1996). Latest movement is inferred to be dextral strike-slip of Tertiary age, based on occurrences of deformed and altered sedimentary rocks resembling the Late Cretaceous and Paleocene Sifton Formation within strands of the fault (Paterson, 1977; Struik, 1993).

The Cache Creek Group within and adjacent to the Kenny Creek - Mount Olson map area was referred to as the Stuart Lake Belt by Armstrong (1949) in order to distinguish it from a separate belt of rocks that he also included in the Cache Creek Group farther to the east. The latter, which he referred to as the Manson Creek belt, includes rocks that are presently assigned to Cassiar, Slide Mountain and Quesnel terranes (Ferri and Melville, 1994). The Stuart Lake belt can be traced southward for 400 kilometres into the type area of the Cache Creek Group in southern British Columbia (Wheeler and McFeely, 1991). It includes polydeformed chert, siliceous argillite, limestone, phyllite, slate, siltstone, sandstone, and mafic metavolcanic and meta-intrusive rocks. Thick limestone units contain fusulinids, corals, brachiopods, bryozoans, gastropods and conodonts that are Pennsylvanian and Permian in age (Armstrong, 1949; Thompson, 1965; Orchard and Struik, 1996); radiolarian chert and cherty mudstone range from Early Permian to earliest Jurassic in age (Cordey and Struik, 1996a,b). Ultramafic rocks within the Stuart Lake belt were referred to as the Trembleur intrusions by Armstrong, who interpreted them to be intrusive bodies cutting the Cache Creek sedimentary and volcanic rocks. These rocks are now included within the Cache Creek Group, and interpreted to be tectonically emplaced upper mantle and lower crustal portions of dismembered ophiolite sequences (Paterson, 1977; Ross, 1977; Whittaker, 1983; Ash and Macdonald, 1993; Struik *et al.*, 1996).

The Sitlika assemblage consists of greenschist facies metavolcanic and metasedimentary rocks that outcrop west of the Cache Creek Group (Figure 3). Rocks assigned to this assemblage in the Manson River map sheet were included in the Cache Creek Group by Armstrong (1949). They were named the Sitlika assemblage by Paterson (1974), who noted that they were structurally and lithologically distinct from the Cache Creek Group, and separated from the main belt of Cache Creek rocks to the east by a zone of serpentinite melange. Rocks correlated with the Sitlika assemblage were subsequently mapped as a narrow belt that extends northwestward through the northeastern corner of the Hazelton map area and into the southern McConnel Creek map area (Figure 3; Richards, 1990; Monger, 1977). The southern extent of the Sitlika assemblage is not well defined, as the area around central and southern Takla Lake has not been remapped since the unit was defined by Paterson. On Figure 3 it is shown to occur west of a discontinuous belt of ultramafic rocks that may correlate with those that mark the Sitlika - Cache Creek contact to the north (Bellefontaine *et al.*, 1995). It is possible, however, that the areas shown to be underlain by Stuhini and Cache Creek groups in the vicinity of southern Takla Lake include rocks of the Sitlika assemblage.

The Sitlika assemblage and Cache Creek Group are faulted to the west against the Stikine Terrane, which includes three successive assemblages of arc-derived volcanic, sedimentary and plutonic rocks that are assigned to the Lower Permian Asitka Group, the Upper Triassic Stuhini (formerly Takla) Group and the Lower to Middle Jurassic Hazelton Group (Tipper and Richards, 1976; Monger, 1977; MacIntyre *et al.*, 1996). These arc successions are overlain by predominantly marine clastic sedimentary rocks of the upper Middle Jurassic to Lower Cretaceous Bowser Lake and Skeena Groups, which in turn are overlapped by Upper Cretaceous to Eocene nonmarine clastic sedimentary rocks of the Sustut Group or age-equivalent continental arc volcanic rocks of the Kasalka and Ootsa Lake groups. Stikine Terrane and overlying clastic basin and continental arc assemblages cover the western two-thirds of the Intermontane Belt at the latitude of the study area, extending westward to the Coast Mountains.

The earliest deformation documented within Cache Creek Terrane in central British Columbia is related to subduction, probably beneath adjacent magmatic arc rocks of Quesnel Terrane, as indicated by blueschist facies rocks that yield Late Triassic K-Ar and Ar-Ar cooling dates (Paterson and Harakal, 1974; Paterson, 1977; Ghent *et al.*, 1996). Subsequent uplift of Cache Creek Terrane is recorded by chert-rich clastic detritus that was shed westward into the basal part of the Bowser Lake Group in late Middle Jurassic to Late Jurassic time. This uplift may relate to the early stages of a deformational episode that generated greenschist facies metamorphism and penetrative deformation within the Cache Creek Terrane and the Sitlika assemblage, and ultimately resulted in Cache Creek Terrane being thrust westward over Stikine Terrane (Monger *et al.*, 1978). Monger *et al.* suggest that the final stages of this contractional episode occurred in latest Jurassic to earliest Cretaceous time, based on the involvement of Oxfordian strata in west-directed thrusting to the northwest of the present study area, and a 110±4 Ma K-Ar date on synkinematic metamorphic biotite from a sample of the Sitlika assemblage collected in Ominicetla Creek. Younger deformation in the region involved dextral strike-slip and related extension, and occurred in Late

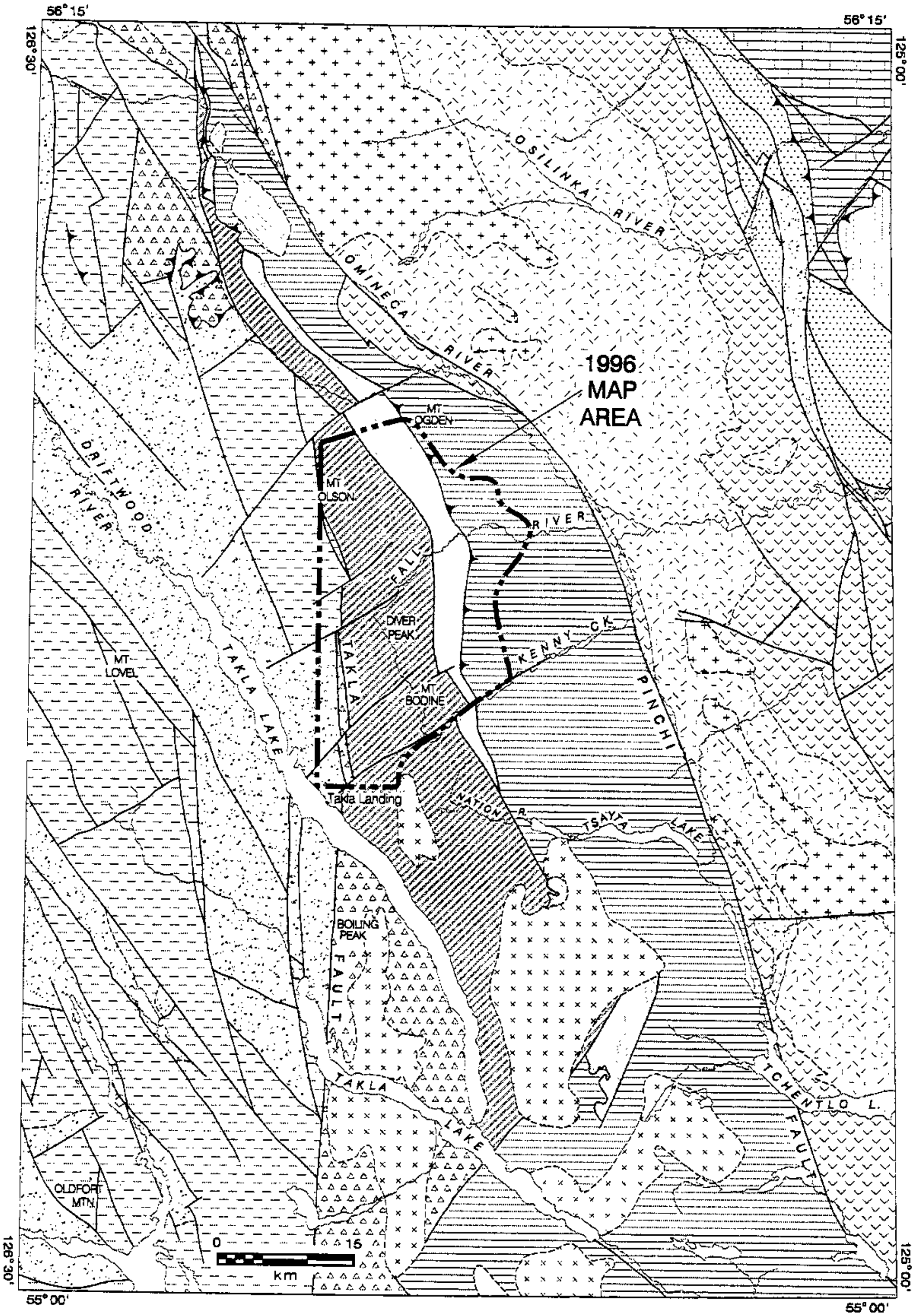

Figure 3. Geologic Setting of the Kenny Creek - Mount Olson map area. Modified from compilations by MacIntyre *et al.* (1994, 1995) and Bellefontaine *et al.* (1995).

Cretaceous to Eocene

Marine to nonmarine conglomerate, sandstone, shale; dacite, rhyolite; includes Skeena, Sustut and Ootsa Lake groups west of Takla fault; Sifton and Uslika formations east of Pinchi fault.

Cretaceous

Granite; local quartz syenite and alaskite.

Axelgold intrusions: layered gabbro.

Jurassic to Cretaceous

Granodiorite, quartz diorite, diorite.

STIKINE TERRANE

Lower to Upper Jurassic

Hazelton and Bowser Lake groups: mafic to felsic flows, tuffs and breccias; sandstone, siltstone, shale, conglomerate.

Permian and Upper Triassic

Mainly mafic to intermediate flows, tuffs, breccias & associated sedimentary rocks of the Upper Triassic Stuhini Group; locally includes basalt, rhyolite, tuff, chert, argillite and limestone of the Lower Permian Asitka Group, or granite of the Topley intrusions.

SITLIKA ASSEMBLAGE

Permian to Jurassic

Basalt, dacite, rhyolite, sandstone, slate, conglomerate; locally includes limestone, diorite, tonalite.

CACHE CREEK TERRANE

Pennsylvanian to Triassic

Quartz phyllite, chert, argillite, limestone, sandstone, greenstone, gabbro

Variably serpentinized harzburgite, dunite and ultramafic cumulates; serpentinite melange; greenstone, gabbro, amphibolite; local chert and limestone.

QUESNEL TERRANE

Late Triassic to Early Jurassic

Hogem batholith: monzonite, quartz monzonite, granodiorite, monzodiorite, diorite; locally includes gabbro, pyroxenite, syenite, quartz syenite.

Middle Triassic to Lower Jurassic

Takla Group: mafic volcanic flows, tuffs and breccias; conglomerate, sandstone, siltstone, limestone.

Mississippian to Permian

Lay Range assemblage: siltstone, argillite, slate, sandstone, chert, conglomerate; basalt, tuff, agglomerate; locally includes gabbro and serpentinite.

SLIDE MOUNTAIN TERRANE

Nina Creek Group: chert, argillite, basalt, breccia, gabbro.

CASSIAR TERRANE

Hadrynian to Permian

Sandstone, siltstone, shale, conglomerate, limestone, dolostone; local tuff

Legend to accompany Figure 3.

Cretaceous(?) to early Tertiary time (Monger *et al.*, 1978; Gabrielse, 1985; Struik, 1993; Wetherup and Struik, 1996).

LITHOLOGIC UNITS

Sitlika Assemblage

In the Kenny Creek - Mount Olson area (Figure 4), the Sitlika assemblage is subdivided into 3 units, corresponding to the 3 divisions originally defined by Paterson (1974). These are informally referred to as the volcanic unit (equivalent to Paterson's volcanic division), the eastern clastic unit (equivalent to Paterson's greywacke division) and the western clastic unit (equivalent to Paterson's argillite division). Volcanic and plutonic rocks within the volcanic unit are, at least in part, of Permian and Early Triassic age, and are readily correlated with the Kutcho Formation. The eastern clastic unit rests depositionally above the volcanic unit and contains detritus that was probably derived from it. It can also be correlated with rocks in the King Salmon allochthon, including the conglomerate unit of the upper Kutcho Formation and correlative or younger limestone, conglomerate and sandstone of the Sinwa and Inklin formations. The western clastic unit occurs as a narrow belt adjacent to the Takla fault. It is inferred to be in fault contact with the volcanic unit, and is of unknown stratigraphic relationship to the other two units of the assemblage. It includes chert pebble conglomerates which, together with its other lithologic components, suggest that it may correlate with Middle to Upper Jurassic rocks in the lower part of the Bowser Lake Group.

VOLCANIC UNIT

The volcanic unit of the Sitlika assemblage comprises mafic to felsic flow and fragmental rocks, along with co-magmatic intrusions. Mafic rocks are dominant, and include thoroughly recrystallized actinolite-epidote-chlorite schists as well as more massive greenstones with variable preservation of vesicles, plagioclase phenocrysts and pillow structures. Felsic volcanic rocks are distinctly subordinate, and typically occur as narrow intervals, from a few metres to several tens of metres thick, overlain and underlain by mafic rocks. They include quartz-sericite schists, with or without relict quartz and feldspar phenocrysts, as well as massive to flow-banded feldspar porphyry and quartz-feldspar porphyry. Although the internal stratigraphy of the volcanic unit is not well understood, felsic rocks seem to be thickest and most abundant in the upper part of the unit.

Schistose fragmental volcanics are a common and widespread component of the volcanic unit. Mafic fragmental rocks, in part derived from pillow breccias, occur locally. Most fragmental units, however, consist of light grey to green, variably flattened felsic volcanic clasts within a sericite-chlorite schist matrix. In places the schists with felsic fragments grade into non-fragmental felsic volcanics. More commonly, however, they form thick units that interfinger with pillowed mafic volcanics.

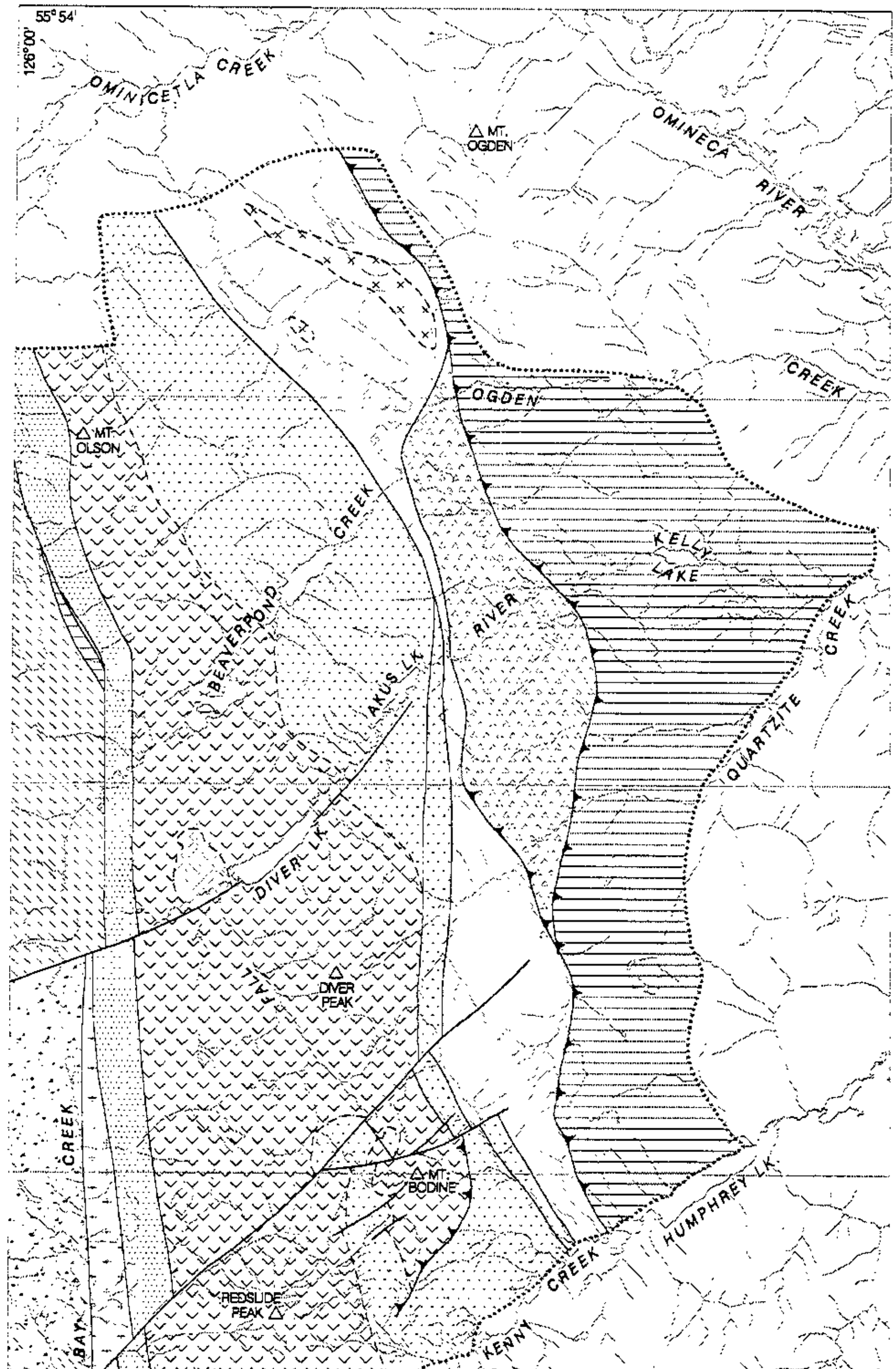

Figure 4. Generalized geology of the Kenny Creek - Mount Olson map area.

Upper Cretaceous

Sustut Group

Tango Creek Formation: polymictic conglomerate; sandstone, shale

Jurassic or Cretaceous (?)

Medium to coarse grained biotite granodiorite

STIKINE TERRANE

Lower to Middle Jurassic

Hazelton Group

Medium to dark green, brownish-weathered andesite, basalt and associated breccias and tuffs; commonly feldspar or feldspar-pyroxene-phyric; lesser amounts of volcanic conglomerate, sandstone and siltstone

Late Triassic to Early Jurassic (?)

Topley Intrusions(?): Red to pink, fine to medium-grained granite; lesser amounts of feldspar porphyry

SITLIKA ASSEMBLAGE

Middle to Upper Jurassic (?)

Western clastic unit: dark grey phyllite and slate; foliated chert-pebble conglomerate and chert-grain sandstone; lesser amounts of foliated limestone and grey phyllite containing flattened sedimentary and volcanic-lithic granules

Triassic to Jurassic (?)

Eastern clastic unit: variably foliated siltstone, sandstone and conglomerate containing felsic volcanic and plutonic clasts; medium to dark grey slate and phyllite; locally includes foliated limestone limestone conglomerate and green chloritic phyllite

Early Triassic

Light grey, medium to coarse-grained tonalite; medium green, medium-grained tonalite to quartz diorite

Late Permian or Early Triassic

Medium grained epidote-chlorite-feldspar schist to semischist; sericite-chlorite-feldspar schist; weakly foliated chloritized hornblende diorite

Permian to Early Triassic

Volcanic unit: medium to dark green chlorite schist, fragmental chlorite schist and pillowed metabasalt; chlorite-sericite schist containing felsic metavolcanic fragments; lesser amounts of quartz-sericite schist, quartz-feldspar porphyry, metasandstone and metachert

CACHE CREEK TERRANE

Pennsylvanian to Triassic

Cache Creek Group

Sedimentary unit: light to medium grey quartz phyllite, platy quartzite and metachert; lesser amounts of recrystallized limestone, dark grey phyllite, massive to pillowed greenstone, fragmental greenstone and chlorite schist; minor amounts of metasandstone

Mafic unit: Medium to dark green, massive to pillowed greenstone, fragmental greenstone and chlorite schist; minor amounts of metagabbro, amphibolite, serpentinite, listwanite, slate, ribbon chert and metasandstone

Ultramafic unit: serpentinite, serpentinized ultramafite and serpentine-magnesite-talc schist; serpentinite melange containing knockers of greenstone, diabase, amphibolite, chert and limestone; locally includes mariposite-quartz-magnesite-altered rock and nephrite

Legend to accompany Figure 4.

These may represent mass flow deposits derived from adjacent felsic volcanic buildups.

Sedimentary rocks occur rarely, but are a very minor component of the volcanic unit. Dark grey phyllite is most common, and is locally intercalated with thin beds of feldspathic tuffaceous(?) sandstone. Narrow intervals of light grey to green thin-bedded chert and siliceous phyllite also occur, as do intervals of light grey, thin-bedded, laminated to crosslaminated siltstone and fine-grained sandstone.

Mafic to intermediate intrusive rocks within the volcanic unit include fine to medium-grained feldspar-chlorite schist and semischist, derived from sills, dikes and small plugs of diabase, gabbro and diorite. Felsic intrusive rocks include widespread dikes and sills of variably foliated quartz-feldspar porphyry, as well as a small multiphase tonalite stock west of Diver Lake that intrudes pillowed volcanics and fragmental schists (Figure 4). The dominant phase within this stock has abundant glassy quartz phenocrysts, 3 to 6 millimetres in size, within a fine to medium grained, massive to weakly foliated groundmass of intergrown quartz, plagioclase and chloritized mafic grains. An older phase has sparse, small phenocrysts of quartz and plagioclase within a fine-grained groundmass that includes these same minerals, as well as abundant metamorphic chlorite and epidote.

Zircons from a weakly foliated quartz-plagioclase-phyric rhyolite north of Mount Bodine have yielded a U-Pb date of 258 +10/-1 Ma, and the tonalite plug that intrudes metabasalts and fragmental schists east of Diver Lake has been dated at 241 ±1 Ma by the same method (Childe and Schiarizza, 1997). These dates indicate that magmatism within the Sitlika volcanic unit occurred in Permian to Early Triassic time. Childe and Schiarizza also present geochemical and Nd isotopic data indicating that the Sitlika volcanic and intrusive rocks have a low-K tholeiitic magmatic affinity, and were derived from primitive magmas uncontaminated by old, evolved crust.

EASTERN CLASTIC UNIT

The eastern clastic unit of the Sitlika assemblage is best exposed in a wide outcrop belt north of the Fall River (Figure 4). Its contact with the adjacent volcanic rocks is well defined, although not quite exposed, on two adjacent ridges southeast of Mount Olson. There, it appears to be a stratigraphic contact, marked by a basal conglomerate, across which the eastern clastic unit overlies the volcanic unit. South of the Fall River, this stratigraphic contact is truncated by the northerly-striking fault bounding the Cache Creek ultramafic unit, although the eastern clastic unit apparently continues southward as a narrow fault-bounded lens along this fault system. The eastern clastic unit is repeated across a faulted anticline and adjacent syncline south and west of Mount Bodine. The stratigraphic contact is locally exposed on the east limb of the syncline, west of Mount Bodine, where it is marked by a basal conglomerate similar to the one north of the Fall River.

The basal part of the eastern clastic unit comprises several tens of metres of moderately to strongly schistose pebble to cobble conglomerate, in shades of green, grey or maroon. The conglomerates contain mainly felsic volcanic clasts, but also include clasts of limestone, mafic volcanic rocks, felsic plutonic rocks and phyllitic rocks of possible sedimentary origin. The volcanic and plutonic clasts are lithologically similar to rocks found within the Sitlika volcanic unit, from which they were presumably derived. In the sections north of the Fall River, conglomerates in the upper part of the basal conglomerate unit are intercalated with lenses of gritty sandstone and purple or green phyllite. These rocks pass up-section into green chloritic phyllite containing layers and lenses of buff to rusty dolomitic marble, which in turn pass up-section into grey phyllite containing lenses and layers of grey marble and silty calcarenite. This calcareous interval is several tens of metres thick and is overlain by predominantly thin-bedded sandstone and dark-grey slate, typical of much of the eastern clastic unit. Similar calcareous rocks are present locally west of Mount Bodine, but seem to be absent in some sections in the southern part of the area.

Most of the eastern clastic unit, above the basal conglomerate and overlying calcareous rocks, consists of dark grey slate intercalated with thin to thick, massive to graded beds of volcanic-lithic sandstone, siltstone and calcarenite. The internal stratigraphy and thickness of this part of the unit is not known, as the top is not exposed and it is repeated by numerous folds where it is best exposed north of the Fall River. Conglomerate, similar in composition to the basal conglomerate unit, occurs locally, as do beds and lenses of grey marble and calcarenite. Calcareous rocks are particularly abundant in highly folded and faulted sections exposed on the ridge 3.5 kilometres northeast of Mount Olson. In one section on this ridge, limestone beds up to 5 metres thick are intercalated with schisty sandstone, calcarenite and slate over a stratigraphic interval of about 40 metres. Some of the carbonate units are conglomeratic, containing flattened clasts of felsic volcanic rock and grey phyllite. The stratigraphic position of this interval is not known, and it is possible that it might be a structural repeat of the basal part of the unit.

The eastern clastic unit is not dated. It appears to be structurally concordant with the underlying volcanic unit, but the contact is abrupt, and the clastic rocks contain volcanic and plutonic detritus that was probably derived from the underlying unit. This suggests that the contact might be a disconformity or an unconformity. In any case, the eastern clastic unit apparently postdates the Permian to Early Triassic magmatism recorded in the underlying volcanic unit, and is therefore Early Triassic or younger. The possibility that the contact is disconformable or unconformable, coupled with a lithologic similarity to the Lower Jurassic Inklin Formation which overlies the Kutcho Formation, suggests that parts of the unit may be as young as Jurassic.

WESTERN CLASTIC UNIT

The western clastic unit of the Sitlika assemblage consists of dark grey slate, chert-pebble conglomerate, sandstone and limestone. It is nowhere well exposed, but apparently forms a continuous belt, from less than a kilometre to 1.5 kilometres wide, that occurs east of the Takla fault over the full length of the map area (Figure 4). Foliated chert-pebble conglomerate is the dominant and most characteristic lithology within the belt. It consists of moderately to strongly flattened clasts within a foliated sandy matrix of flattened chert and quartz grains with or without metamorphic sericite and chlorite. Pebbles are typically a few centimetres or less in longest dimension, but range up to 10 centimetres. They are almost entirely chert, but clasts of limestone, quartz, white felsite and chert-quartz sandstone, the latter of probable intraformational origin, also occur. Stratification within the conglomerates is locally defined by discontinuous narrow lenses of chert-quartz sandstone. Locally, similar sandstone dominates intervals up to 10 metres thick, where it occurs as thin planar beds separated by thinner interbeds or partings of grey slate.

Dark grey slate or phyllite is also a common component of the western clastic unit, but typically forms poor rubbly outcrops. The slate is commonly pyritic, and locally displays thin beds or laminae of slaty siltstone or fine-grained sandstone. In exposures south of Mount Olson, strongly fissile dark grey phyllite contains abundant light grey patches, from 1 to 10 millimetres across, that may be completely flattened lithic grains.

Carbonate was observed within the western clastic unit at one locality, about 3 kilometres west of Diver Lake. It forms an isolated outcrop about 30 metres wide, consisting of foliated, dark grey, finely recrystallized limestone containing patches and lenses of light grey marble. This outcrop is about 400 metres east of exposures of chert pebble conglomerate typical of the unit, and several hundred metres west of the inferred contact with the Sitlika volcanic unit.

None of the rocks within the western clastic unit are dated. Furthermore, it is apparently bounded by faults, so its stratigraphic relationship, if any, to the other units of the Sitlika assemblage is unknown. The most likely correlation, based solely on lithology, is with the Middle to Upper Jurassic Ashman Formation of the Bowser Lake Group, which includes dark grey shale, feldspathic to quartzose sandstone, chert-pebble conglomerate and local lenses of limestone (Tipper and Richards, 1976).

REGIONAL CORRELATION OF THE SITLIKA ASSEMBLAGE

The volcanic unit of the Sitlika assemblage resembles the Kutcho Formation in its bimodal character, the presence of comagmatic intrusions, and the Permo-Triassic age of magmatism. This correlation is fully supported by the geochemical and Nd isotopic characteristics reported by Childe and Schiarizza (1997). It is also supported by the strong lithologic similarity between the eastern clastic unit of the Sitlika assemblage and clastic rocks overlying the Kutcho volcanics. The latter include conglomerates that are included in the upper part of the Kutcho Formation, as well as rocks that have been included in the Sinwa and Inklin formations

(Pearson and Panteleyev, 1975; Panteleyev and Pearson, 1977a,b; Thorstad and Gabrielse, 1986). Similar features include the presence of a basal conglomerate unit containing clasts derived from the underlying volcanic rocks; an overlying limestone unit gradational with the conglomerates (Sinwa Formation) and an upper interval of slate, siltstone and calcareous greywacke with local conglomerate intervals (Inklin Formation).The Kutcho Formation and Sitlika assemblage also share a similar structural relationship to the Cache Creek Group, leaving little reason to doubt that the two units are correlative.

The age of the western clastic unit is unknown, as is the stratigraphic relationship to the volcanic and eastern clastic units. As discussed above, its lithologic attributes, and in particular the presence of chert-pebble conglomerates, suggest that it may correlate with the Middle to Upper Jurassic Ashman Formation of the Bowser Lake Group. The Bowser Lake Group was deposited on Middle Jurassic and older rocks of the Stikine Terrane, but contains detritus eroded from Cache Creek Terrane. Monger *et al.* (1978) suggest that the Cache Creek Terrane, the Sitlika assemblage and the Stikine Terrane, including overlying Bowser Lake Group, were imbricated by westerly-directed thrust faults in Late Jurassic or Early Cretaceous time. Correlation of the western clastic unit with the Bowser Lake Group is consistent with this interpretation, and suggests that the Sitlika assemblage is essentially a structural - metamorphic entity that formed during this major episode of contractional deformation.

The volcanic unit and overlying eastern clastic unit of the Sitlika assemblage may also correlate with an assemblage of rocks that is in thrust contact beneath the Cache Creek Group in the northeastern part of the Taseko Lakes map area, 450 kilometres to the south. There, Read (1992, 1993) documented a succession of Upper Permian metadacite flows and tuffs, overlain by meta-andesite and metabasalt flows and intruded by a Late Permian leucoquartz monzonite pluton. The dacitic volcanics have yielded a U-Pb date of 259±2 Ma (Read, 1993), almost identical to the date from the Sitlika rhyolite north of Mount Bodine (Childe and Schiarizza, 1997), and the associated leucoquartz monzonite pluton has been dated at 254±1.2 Ma. Correlation of this succession with the Sitlika volcanic unit is based on similarities in age, general lithologic character (mafic and felsic metavolcanic rocks plus comagmatic intrusions) and structural position along the western margin of the Cache Creek Group. Furthermore, the Upper Permian volcanic succession in the northeastern Taseko Lakes map area is depositionally(?) overlain by Lower Jurassic siltstone and sandstone containing felsic volcanic detritus that is inferred to have been derived from the underlying volcanics. These clastic rocks (Unit lJs of Read, 1993) may correlate, at least in part, with the eastern clastic unit of the Sitlika assemblage, as well as with the Inklin Formation of the King Salmon allochthon.

Childe *et al.* (1996, 1997) suggest that the Kutcho and Sitlika successions may also correlate with one or more fault-bounded panels of felsic and mafic volcanic rocks that are juxtaposed against the Cache Creek Group in the Ashcroft map area, south of the town of Cache Creek. They report that a tonalitic body that intrudes volcanic rocks in one of these panels has yielded a preliminary U-Pb zircon age of 242±2 Ma, which correlates with the age of magmatism in the Kutcho Formation, and with the dated tonalite body in the Sitlika assemblage.

Cache Creek Group

ULTRAMAFIC UNIT

The westernmost element of the Cache Creek Group in the Kenny Creek - Mount Olson map area is a belt of ultramafic rocks and serpentinite melange, up to 5 kilometres wide, that was first described by Paterson (1974), and is here referred to as the ultramafic unit. This unit is dominated by serpentinite and talc-magnesite schists, but also includes lenses and knockers of greenstone, amphibolite and metasedimentary rocks. It rests structurally beneath other units of the Cache Creek Group across east-dipping thrust faults; its contact with the Sitlika assemblage to the west is, at least in part, a younger dextral strike-slip fault.

The ultramafic unit is dominated by sheared and foliated serpentinite, locally containing metre-scale lenses of relatively massive ultramafite. Although grains of relict pyroxene could be discerned locally, even the relatively massive lenses are sufficiently serpentinized that protolith compositions are generally not apparent. Rusty-weathered talc-magnesite schist is also a common component of the ultramafic unit. In places it is restricted to narrow, linear zones in sharp contact with enclosing serpentinite, but elsewhere it occurs over broad areas and is gradational with the associated serpentinite. Orange-weathered zones of quartz-carbonate-mariposite-altered serpentinite (listwanite) are also fairly common, but are restricted to relatively narrow, linear zones that are, at least in part, fault-controlled. Rodingite and nephrite are likewise restricted to narrow alteration zones, typically along contacts between serpentinite and other rock types.

Greenstone forms discontinuous lenses and knockers within the ultramafic unit, ranging from a few metres to more than a kilometre in size. Although some of the greenstone was derived from mafic volcanic rocks, as indicated by relict pillows and pillow breccia, a larger proportion appears to have been derived from fine to finely-medium grained diabasic rock. In some large knockers, fine to medium-grained diabasic to gabbroic greenstone with an isotropic igneous(?) texture grades into foliated amphibolite. Similar moderately to strongly foliated, fine to medium grained amphibolite occurs as discrete knockers, ranging up to several tens of metres in size. The amphibolite facies metamorphism of these rocks is presumed to predate the mid-Mesozoic(?) greenschist facies metamorphism that characterizes the Cache Creek and Sitlika rocks within the map area. It might be related to Late Paleozoic construction of oceanic crust, or to early Mesozoic subduction or obduction tectonics.

Sedimentary rocks are not common within the ultramafic unit, but bedded chert, quartz phyllite and limestone occur locally, either as discrete knockers within serpentinite or as components of larger composite lenses comprising both metasedimentary rock and greenstone. At one locality, bedded chert within a mafic knocker occurs as an isolated raft enclosed by diabasic greenstone.

MAFIC UNIT

Rocks assigned to the mafic unit of the Cache Creek Group form a lens, 15 kilometres long by 4 kilometres wide, that outcrops between the ultramafic and sedimentary units north and south of the Fall River (Figure 4). Exposures within this lens are predominantly massive and pillowed greenstones, locally associated with fragmental greenstones probably derived from pillow breccias. Although most of the greenstones are of volcanic origin, relict textures suggest that some were derived from diabasic intrusive phases. Also included in the mafic unit are rare occurrences of amphibolitic metagabbro, serpentinite, listwanite-altered ultramafic rock and metasedimentary rock. The metasedimentary rocks are mainly interbedded chert and slate, but include rare exposures of quartz-feldspar-lithic sandstone that occurs as thin beds, with graded bases and laminated tops, intercalated with slate.

The western contact of the mafic unit was observed at one place, east of Diver Lake, where it is an east-dipping thrust(?) fault that separates it from the underlying ultramafic unit. The eastern contact was not observed. The mafic unit is dominated by greenstones of both extrusive and intrusive origin, similar to those that form knockers and lenses within the ultramafic unit. It is therefore thought to be more closely related to the ultramafic unit than the sedimentary unit, and may essentially be a very large lens within the former, as the map pattern suggests (Figure 4). In detail, however, greenstones within the mafic unit are dominantly of volcanic origin, whereas those that form knockers within the ultramafic unit are dominantly intrusive. This suggests that the mafic unit represents a slightly higher stratigraphic level within the crustal section of an original ophiolite stratigraphy, from which the ultramafic and mafic units were presumably derived.

SEDIMENTARY UNIT

Easternmost exposures in the Kenny Creek - Mount Olson map area are assigned to the sedimentary unit of the Cache Creek Group. This unit is dominated by grey platy quartz phyllites, but also includes metachert, cherty argillite, slate, limestone, greenstone, chlorite schist and metasandstone. Reconnaissance mapping to the east indicates that similar rocks dominate the Cache Creek Group all the way to the Pinchi fault (*see* Figure 3).

The sedimentary unit is dominated by light to dark grey platy quartz phyllites, comprising plates and lenses of fine-grained recrystallized granular quartz, typically a centimetre or less thick, separated by phyllitic mica-rich partings. Locally these platy rocks grade into less siliceous and more homogeneous medium to dark grey phyllites. Less commonly, they include intervals of light to medium grey bedded chert, comprising beds and lenses of cryptocrystalline cherty quartz, from 1 to 5 centimetres thick, separated by phyllitic partings. Also present are fragmental phyllites consisting of siliceous rock fragments within a green to grey phyllite matrix. The fragments typically range from a few millimetres to a few centimetres in size, but locally include narrow lenses up to 50 centimetres long that resemble broken beds. The fragmental intervals may have been derived from thin-bedded siliceous sedimentary units that were fragmented during soft-sediment slumping.

Light to dark grey recrystallized limestone occurs as intervals ranging from a few metres to a few tens of metres thick. These are in apparent depositional contact with bedded chert and platy quartz phyllite, or in fault contact with quartz phyllite or greenstone. Much thicker, light-grey weathered limestone units are visible in the mountains northeast of the study area, north of Ogden Creek (Armstrong, 1949). Paterson (1974) reports that fusulinids from these thick limestone exposures are of early Late Permian age. Macrofossils were not seen in limestones in the Kenny Creek - Mount Olson area; samples are being processed for microfossils, but the results are not yet available.

Mafic metavolcanic rocks, including chlorite schist, pillowed greenstone and fragmental greenstone, occur as intervals ranging up to many tens of metres thick within the sedimentary unit. These are widespread, but comprise less than 10 per cent of the unit. The mafic metavolcanic rocks typically form lenses parallel to the synmetamorphic foliation and transposed compositional layering in surrounding metasedimentary intervals. Locally they are associated with weakly foliated, fine-grained chlorite-feldspar semischists that were probably derived from mafic dikes or sills.

Clastic rocks are a very minor component of the sedimentary unit in the Kenny Creek - Mount Olson area, although narrow intervals of thin-bedded sandstone or siltstone occur locally within sections of grey phyllite. The unit also includes rare exposures comprising contorted thin beds and fragments of green tuffaceous(?) siltstone within dark grey slaty argillite.

The sedimentary unit is juxtaposed above the ultramafic unit across an east-dipping thrust fault in the northern and southern parts of the map area. A similar structure may separate it from the mafic unit in the intervening area, but the contact is not exposed. The thrust fault at the base of the unit may have formed in the Late Jurassic, as one component of a protracted event that resulted in greenschist facies metamorphism of the Cache Creek Group and its westward translation above the Sitlika assemblage and the Stikine Terrane (Monger *et al.*, 1978). This deformation apparently postdated its early to mid-Mesozoic (and older?) accumulation as an accretion-subduction complex. It is not clear from what part of the Cache Creek complex the adjacent ophiolitic rocks of the mafic and ultramafic units were derived, or when they attained their present structural position along the western margin of the Cache Creek belt.

INTRUSIVE ROCKS CUTTING THE CACHE CREEK GROUP

Felsic plutonic rocks of probable Jura-Cretaceous age are common only in the eastern part of the map area, where they cut the Cache Creek Group. The largest of these intrusive bodies is an elongate stock of coarse grained, biotite±muscovite granodiorite that occurs within the Cache Creek ultramafic unit in the northern part of the area, southwest of Mount Ogden (Figure 4). Similar granodiorite forms a small plug 2 kilometres southwest of the main stock, and occurs as dikes and pods elsewhere in this part of the ultramafic unit.

Dikes of light grey felsite and aplite occur locally within all three units of the Cache Creek Group, but are most common in the sedimentary unit in the southern part of the area. They range from less than a metre to about 10 metres in thickness. Most are massive, but some display a foliation parallel to the schistosity in the enclosing schists. A swarm of gently-dipping dikes within the western part of the sedimentary unit on the ridge above Kenny Creek is truncated by the east-dipping thrust fault that separates the metasedimentary rocks from the underlying ultramafic unit. This relationship, combined with the foliated to massive nature of the dikes, suggests that they were intruded during the late stages of synmetamorphic contractional deformation in this part of the Cache Creek Group.

CACHE CREEK ROCKS SOUTH OF MOUNT OLSON

Rocks tentatively included in the Cache Creek Group also occur west of the Sitlika assemblage, in a fault-bounded lens of limited extent that crops out about 5 kilometres south of Mount Olson. The eastern part of this lens comprises several tens of metres of serpentinite and quartz-carbonate-mariposite-altered serpentinite that are juxtaposed against dark grey phyllites of the Sitlika western clastic unit. To the west, these ultramafic rocks are in contact with a metasedimentary interval consisting mainly of dark grey slate with discontinuous, contorted lenses of greenish slaty siltstone to fine grained sandstone, and local lenses of contorted chert to cherty argillite. The metasedimentary rocks are in turn bounded to the west by an interval of strongly foliated chlorite-sericite-feldspar schist, which grades westward into weakly foliated, medium grained chloritized metagabbro.

The serpentinite, metasedimentary rocks and metagabbro described above, which are lithologically similar to parts of the extensive belt of Cache Creek rocks exposed east of the Sitlika assemblage, were observed over an area less than 150 metres wide. Their contact with the adjacent Sitlika assemblage is fairly well constrained, although not exposed, but they are separated from rocks of the Hazelton Group to the west (Richards, 1990) by more than a kilometre of Quaternary cover. This poorly-defined western boundary is inferred to be the main strand of the Takla fault, which is well defined about 8 kilometres to the south. The contact with the Sitlika assemblage to the east is also inferred to be a fault. It may be an older structure, related to structural imbrication of the Sitlika assemblage and Cache Creek Terrane in early to late Mesozoic time, and analogous to structures that separate the Kutcho Formation from structurally underlying lenses of Cache Creek Group that occur locally along the base of the King Salmon allochthon (Thorstad and Gabrielse, 1986). Alternatively, it may be a splay from the Takla fault. In this interpretation, the Cache Creek lens might have been derived from the vicinity of southern Takla Lake, where a major splay of the Takla fault system apparently marks the western boundary of Cache Creek Terrane (Figure 3).

Stikine Terrane

GRANITE ALONG THE TAKLA FAULT

Sparse exposures of red to pink-weathering granite in the southwestern part of the map area define a narrow, linear belt that separates the Sitlika assemblage from the Sustut Group to the west. The granite is a fine to medium grained equigranular rock consisting of pink K-feldspar, lesser amounts of grey-green saussuritic plagioclase, 10 to 20 per cent quartz, and 5 to 10 per cent chloritized mafics. Pink to brown-weathering feldspar porphyry locally occurs as narrow dikes cutting the granite, or as larger, isolated exposures of massive to flow-banded rock within the same belt.

The granite is highly fractured, and rarely displays a weak foliation. It apparently forms a narrow fault-bounded lens along the Takla fault. It is tentatively correlated with the lithologically similar Late Triassic to Early Jurassic Topley intrusions, which outcrop on either side of Babine Lake, 25 to 50 kilometres to the south (Carter, 1981; MacIntyre *et al.*, 1996).

HAZELTON GROUP

The Hazelton Group comprises Lower to Middle Jurassic submarine to subaerial arc volcanic rocks and related sedimentary rocks that are a widespread component of Stikine Terrane in central and northern British Columbia (Tipper and Richards, 1976; Marsden and Thorkelson, 1992). Following Paterson (1974), volcanic and sedimentary rocks that occur east of the Takla fault in the northwest corner of the map area are included in the group. These rocks are poorly exposed and are not dated within the present map area, but are continuous with better exposed rocks to the west, which Richards (1990) assigns to the Lower Jurassic Telkwa Formation of the Hazelton Group.

Rocks assigned to the Hazelton Group in the Kenny Creek - Mount Olson map area lack the penetrative foliation that characterizes the adjacent Sitlika assemblage. Most exposures consist of chlorite-epidote-altered, medium to dark green or mottled green/maroon andesitic or basaltic volcanics. Feldspar phenocrysts are commonly present, and chloritized pyroxene phenocrysts are evident locally. Most of the volcanics were apparently derived from massive flows, although monolithic flow(?) breccias also occur. Sedimentary rocks of uncertain relationship to the volcanics are also present, and include well indurated, thin to medium-bedded feldspar-lithic sandstone intercalated with siltstone and cherty argillite, purple concretionary siltstone, and red to purple, vaguely stratified volcanic breccia or conglomerate. The latter rock type consists of angular to amoeboid-shaped clasts of mainly felsic to intermediate volcanic rock, up to 6 centimetres across, within a gritty sandstone to siltstone matrix of similar composition.

SUSTUT GROUP

The Sustut Group (Lord, 1948; Eisbacher, 1974) consists of Upper Cretaceous to Eocene nonmarine clastic sedimentary rocks and intercalated tuffs that were deposited above Stikine Terrane and overlying Bowser Lake Group in central and northern British Columbia. Exposures of Upper Cretaceous conglomerate west of the Takla fault in the southwestern corner of the map area were assigned to the group by Armstrong (1949). These rocks occur near the south end of a belt that extends northwestward through the Hazelton map area (Richards, 1990) to the type area of the group along the Sustut River in the McConnell Creek map area (Lord, 1948).

Exposures of Sustut Group rocks in the Kenny Creek - Mount Olson map area are entirely sedimentary, and parts of the succession along Takla Lake just to the south have yielded collections of Cenomanian plant fossils (Armstrong, 1949). These rocks are therefore assigned to basal unit of the group, the Tango Creek Formation, as defined by Eisbacher (1974). The dominant lithology is light brownish-weathering, well-indurated conglomerate containing clasts of mafic to felsic volcanic rock, chert, cherty argillite and a wide variety of plutonic clasts, including granite, granodiorite and monzonite. White vein quartz is a conspicuous clast component in most exposures, and clasts of strongly foliated quartz-rich tectonite occur locally. The conglomerates are generally poorly to moderately sorted, comprising rounded to subrounded cobbles and pebbles within a gritty sandstone matrix of similar composition. There is no stratification apparent in many exposures, whereas in others the conglomerate forms medium to thick beds that locally display cross stratification and channeling. Medium to coarse-grained sandstone and gritty sandstone commonly forms thin to medium lenticular beds within these stratified intervals. Green concretionary siltstone to fine grained sandstone, commonly with fossil plant remains, occurs locally as intervals that are up to several metres or more thick. No basal contacts of this distinctive lithofacies were observed; upper contacts are sharply defined by overlying conglomerates.

STRUCTURE

Structure of the Sitlika Assemblage

All three units of the Sitlika assemblage are characterized by a single penetrative cleavage or schistosity defined by the preferred orientation of metamorphic minerals and variably flattened clastic grains or volcanic fragments. Metamorphic mineral assemblages reported by Paterson (1974) indicate lower to mid greenschist facies metamorphic grade; his observations are supported by the present study, although this report was written prior to a thorough petrographic examination of thin sections. The metamorphic foliation dips steeply to the east-northeast or west-southwest throughout the Sitlika belt. It is axial planar to upright folds of bedding, most commonly observed in the well-bedded eastern clastic unit, with axes that plunge north-northwest or south-southeast. Bedding was only rarely observed in the volcanic and western clastic units, where it typically dips more gently than, and in the same direction as, the associated schistosity.

The contact between the western clastic unit and volcanic unit is tightly constrained on the west flank of Mount Olson and on the ridge 1.5 kilometres to the south. There, it appears to be an east-dipping ductile fault contemporaneous with the steeply-east-dipping schistosity in both units. Bedding in both units dips at moderate angles eastward. This relationship, steeply east-dipping schistosity cutting more gently east-dipping bedding, apparently persists eastward across the entire width of the volcanic belt, and across the stratigraphic contact into the basal part of the overlying eastern clastic unit. The wide expanse of eastern clastic unit farther east, however, is repeated across numerous upright, north-northwest trending folds.

The outcrop width of the volcanic unit is considerably greater in the south than it is in the Mount Olson area. This is in part due to internal folding, as indicated by a faulted anticline and adjacent syncline that repeat the contact between the volcanic unit and overlying eastern clastic unit south and west of Mount Bodine (Figure 4). The contact between the volcanic unit and western clastic unit is not exposed anywhere south of the Mount Olson area, but is constrained to be essentially parallel to the adjacent Takla fault. Structural trends within the southern and central parts of the volcanic unit strike northwesterly, at a shallow angle to this contact (Schiarizza *et al.*, 1997). This suggests that the northward narrowing of the volcanic unit is due to a gradual truncation along this contact. It is suspected, therefore, that the southern and central parts of the volcanic/western clastic contact is a relatively young fault, related to the adjacent Takla fault, that has been superimposed on the east-dipping ductile fault that marks the contact at Mount Olson. In a similar fashion, the wide expanse of folded eastern clastic unit exposed north of the Fall River thins dramatically southward due to its truncation along the relatively young dextral strike-slip fault system that defines the contact between the Sitlika assemblage and the adjacent Cache Creek Group (Figure 4).

Structure of the Cache Creek Group

The Cache Creek Group comprises greenschist facies rocks that are of comparable metamorphic grade to the Sitlika assemblage, but contrast markedly in structural style (Paterson, 1974). Mesoscopic structures are best displayed in the sedimentary unit, where compositional layering has been transposed into parallelism with a prominent metamorphic foliation. This schistosity is deformed by a pervasive set of second-generation structures characterized by east-verging folds with moderately west-dipping axial surfaces, commonly marked by a crenulation or fracture cleavage. The axes of these folds, along with associated crenulation lineations, plunge gently north to north-northwest. Metamorphic minerals that define the first generation schistosity are, at least in part, bent and kinked by these younger structures, indicating that the second phase of deformation postdates most of the metamorphism.

Although their orientation is locally highly variable due to later folding, the schistosity and compositional layering within the Cache Creek Group most commonly dip to the east. This east dipping foliation is parallel to east-dipping faults that were observed to mark the contact between the sedimentary unit and underlying ultramafic unit in the northern and southern parts of the area. A similar east-dipping fault separates the mafic unit from the ultramafic unit where the contact was observed east of Diver Lake. Asymmetric fabrics within east-dipping shear zones in the immediate footwall of the fault that separates the sedimentary unit from the ultramafic unit in the southern part of the area indicate thrust movement. The synmetamorphic deformation within the Cache Creek Terrane may therefore by related to an episode of west-directed thrusting. Although structures within the Sitlika assemblage are not easy to relate to those within the Cache Creek Group, the east-dipping synmetamorphic fault that separates the volcanic unit from the western clastic unit at Mount Olson may be a correlative structure.

Contact Between the Cache Creek Group and the Sitlika Assemblage

Monger *et al.* (1978) referred to the contact between the Cache Creek Group and Sitlika assemblage as the Vital fault, which they described as "a zone of imbricated alpine-type peridotite and basalt up to 3 kilometres wide with fault planes dipping easterly at about 50 degrees". This fault zone corresponds to the Cache Creek ultramafic unit of this report. As described above, east-dipping faults, one with documented thrust movement, mark the contacts between the ultramafic unit and the overlying mafic and sedimentary units, and east-dipping outcrop-scale faults were also observed internally within the ultramafic unit. However, the contact between the Cache Creek ultramafic unit and the adjacent Sitlika assemblage is well defined only on the north face of an east-trending ridge 3.8 kilometres east of Diver Lake. There, the fault contact strikes northerly and dips steeply. For about 200 metres east of the fault contact, most mesoscopic faults within serpentinite of the ultramafic unit are vertical or dip steeply west, and most display gently plunging mineral fibres or slickensides. One such fault zone contains several discrete faults which enclose domains of sigmoidally disposed foliation that indicate dextral strike-slip movement. Farther east, steeply-dipping, north-striking faults and zones of listwanite alteration appear to cut across east-northeast-dipping foliation and related fault zones along and beneath the contact with the overlying mafic unit.

Shear bands indicating dextral strike slip were also observed within the western part of the ultramafic unit about 5 kilometres north-northeast of Mount Bodine, although there, the actual contact with the adjacent Sitlika assemblage is not well defined. Nevertheless, these relationships suggest that within all or parts of the Kenny Creek - Mount Olson map area, the eastern boundary of the Sitlika assemblage is a system of dextral strike-slip faults that postdates the east to northeast-dipping contractional structures within the adjacent Cache Creek Group. This dextral fault system is inferred to be Tertiary in age, and broadly contemporaneous with the Takla fault to the west, and latest movement on the Pinchi fault to the east. It may be a relatively local feature that here crosscuts a regional west-directed thrust system that places Cache Creek Group above the Sitlika assemblage and its correlatives. This thrust system is mapped in the western Axelgold Range at the north end of the Stuart Lake belt (Monger, 1977; Monger *et al.*, 1978), in northern British Columbia where it separates the Cache Creek Group from the Sitlika-correlative King Salmon allochthon (Nahlin fault: Monger *et al.*, 1978; Thorstad and Gabrielse, 1986), and in southern British Columbia where it separates the Cache Creek Group from Sitlika-correlative rocks in the northeastern Taseko Lakes map area (Read, 1992, 1993).

Takla Fault

The Takla fault (Armstrong, 1949; Paterson, 1974) marks the western boundary of the Sitlika assemblage, and juxtaposes it against volcanic, sedimentary and plutonic rocks of Stikine Terrane. It is not exposed, but its north-striking trace is fairly well defined in the southern part of the map area, where it separates the Sitlika assemblage from an elongate lens of pink granite that is correlated with the Topley intrusions of Stikine Terrane. This granite is in contact with the Sustut Group to the west, across an inferred fault that may also be part of the Takla system. The trace of the Takla fault is also well constrained for a few kilometres north of the northeast striking Diver Lake fault, where it juxtaposes the Sitlika assemblage against unmetamorphosed volcanic and sedimentary rocks of the Hazelton Group (Figure 4). It is not well defined farther to the north, where the main strand of the fault is inferred to mark the western boundary of Cache Creek Group rocks exposed south of

Mount Olson. As discussed previously, this lens of Cache Creek Group may have been emplaced along the Takla fault, or it might be part of an older fault slice imbricated with the Sitlika assemblage and then truncated by the Takla fault.

Monger *et al.* (1978) and Gabrielse (1985) suggest that the Takla fault is part of a Late Cretaceous to early Tertiary dextral strike-slip fault system that may have a cumulative displacement of about 300 kilometres (Figure 2). In this interpretation, the Takla fault would correlate with the Glenlyd - Ingeneka fault of the McConnell Creek map area, with which it can be matched after restoring 15 to 20 kilometres of dextral offset on the Pinchi - Two Lake Creek fault system as mapped by Monger (1977) which is equivalent to the Omineca fault of Lord (1948). Relationships within the Kenny Creek - Mount Olson map area provide little direct evidence bearing on the nature of movement on the Takla fault, although a northwest plunging anticline that is documented in the Sustut Group directly west of the fault (Schiarizza *et al.*, 1997) is of an appropriate orientation (Wilcox *et al.*, 1973) to be related to Late Cretaceous or Tertiary dextral movement on the fault. This study does, however, support correlation of the Sitlika assemblage with the King Salmon allochthon, and this correlation forms the main basis for the dextral strike-slip interpretation.

Northeast Striking Faults

Prominent topographic lineaments along Diver Lake, the creek north of Redslide Peak, and Kenny Creek coincide with northeast striking faults that mark apparent dextral offsets of the Takla fault system. The Diver Lake fault also truncates the Hazelton Group and juxtaposes it against the Sustut Group to the south. Northeast striking faults that coincide with minor dextral offsets of the contact between the Sitlika volcanic unit and overlying eastern clastic unit were also mapped southeast of Mount Bodine, and an east-northeast striking fault north of the mountain marks a one kilometre sinistral offset of the fault separating the Sitlika assemblage from the adjacent serpentinite melange unit. These northeast striking faults are relatively young features, as they offset the Takla fault and related structures which are probably of Tertiary age. They might be broadly related to strike-slip faulting on the Takla system, or might reflect a discrete younger event.

MINERAL OCCURRENCES

Eureka (MINFILE 93N 179)

The Eureka showing occurs within the Sitlika assemblage about 1.5 kilometres north-northeast of Mount Bodine. It comprises a pod of mineralized quartz, measuring about 60 centimetres high by 40 centimetres wide, within a vertical, northwest-striking shear zone. The quartz contains patches and disseminations of pyrite and chalcopyrite, as well as malachite and manganese oxide staining. The shear zone cuts variably quartz-pyrite-altered schists, apparently derived from a dominantly felsic succession within the volcanic unit a short distance west of the fault(?) contact with the eastern clastic unit. Watkins (1980, sample 430) reports that a channel sample across the mineralized pod returned 1.3% Cu, 106 ppm Pb, 6450 ppm Zn, 22 ppm Ag and 70 ppb Au. A 127.5 metre drill hole was collared to the northeast of the Eureka showing in 1989, and inclined to the southwest in order to test the mineralization and an associated IP anomaly at depth (Campbell, 1990). The hole encountered variably pyritic felsic flows and fragmental rocks, locally cut by veinlets and stringers of quartz±pyrite. Traces of chalcopyrite and sphalerite were recorded from the upper part of the hole, where one 3.8 metre section contained 0.44% Zn, and a separate 1.7 metre section contained 0.40% Cu (Campbell, 1990).

The Eureka showing appears to represent epigenetic mineralization, possibly related to the system of northwest-striking faults that separate the Sitlika volcanic unit, eastern clastic unit, and Cache Creek ultramafic unit in this area. However, evidence for syngenetic sulphide deposition within the Sitlika volcanic unit comes from 500 metres to the west, at a locality referred to as the Crystal showing (Figure 5). There, several centimetres of laminated pyrite and chert, of probable exhalative origin, occur within a zone of rubbly subcrop dominated by massive jasperoidal quartz containing patches of specular hematite and stringers of magnetite. These rocks occur at the contact between a succession of west-dipping sericite-chlorite schists and fragmental schists, and an overlying unit of relatively massive silicified rhyolite. The footwall schists contain chlorite-rich stringers and patches that have been interpreted as zones of pre-metamorphic chlorite alteration, related to the hydrothermal activity that deposited the overlying banded sulphide and chert (Watkins, 1980; D. Bohme, personal communication 1995). A sample of the laminated pyrite/chert submitted for assay by Watkins (1980, sample 445) did not yield anomalous base or precious metal concentrations.

Don Showing (New)

The Don showing comprises a system of mineralized quartz veins that occur within the Sitlika volcanic unit about a kilometre southwest of Mount Bodine (Figure 5). The veins are exposed, although not easily accessible, over a distance of about 200 metres in the south wall of the cirque basin west of the mountain. Veins just below the ridge crest at the east end of the system occur on either side of a northeast-striking fault that defines a 300 metre apparent dextral offset of the contact between the volcanic and eastern clastic units. They range from a few centimetres to about a metre in width, and most dip at moderate to shallow angles to the southeast. Most of the thicker veins contain patches, up to several centimetres across, of limonite-altered pyrite, locally with chalcopyrite, malachite and azurite. A sample of mineralized material from one of these thick veins contained 2.17% Cu, 380 ppb Au and 1.8 ppm Ag (Table 1, Sample 96PSC-28-12-2). Veins farther west within the system are in part marked by gossanous zones, but were not examined.

Silica-Pyrite Alteration Zones within the Sitlika Assemblage

Gossanous areas of pyritized and silicified rock are scattered throughout the Sitlika volcanic unit, mainly as narrow zones associated with felsic volcanic rocks. The most visible gossans occur on the southeast shoulder of Mount Olson and the two ridges to the south, and on the low slopes north-northeast of Mount Bodine (Figure 5). These alteration zones comprise intervals of variably pyritic sericite-quartz schist, platy pyrite-quartz semischist and, locally, talc-quartz schist. The intensely altered rocks are interleaved with layers and lenses of variably pyritic metadacite to metarhyolite, as well as chloritic schists that were probably derived from basalts. However, the relative proportion of mafic to felsic volcanics is generally obscure due to the pervasive nature of much of the alteration. Samples from these alteration zones commonly show elevated concentrations of zinc, but are not appreciably anomalous with respect to other base or precious metals (Table 1).

A significant new discovery of a hydrothermal breccia and associated alteration zone was made by L.B. Warren in the summer of 1995, and staked as the Vent claims. The discovery outcrop occurs in a narrow canyon in the lower portion of an unnamed Creek, about 500 metres east of Diver Lake (Figure 5). It includes a vertical outcrop face, about 6 metres long, made up of a hydrothermal breccia consisting of angular, white, silicified rock fragments held together by a matrix of granular fine-grained pyrite and grey quartz. This breccia grades northward into highly fractured pyritic and silicified rock that can be traced for about 200 metres downstream. It is abruptly truncated to the southeast by a moderately northwest-dipping brittle fault that juxtaposes the breccia against a medium green, rusty-weathered rock with ghosts of small feldspar phenocrysts. This green feldspar-phyric unit is about one metre thick; it is structurally underlain, across an abrupt but apparently unfaulted west-northwest-dipping contact, by a pale grey silicified rock containing disseminated pyrite. This rock passes southeastward into variably silicified chlorite-sericite schists that were derived from a felsic volcanic protolith. These felsic schists were traced for 2 kilometres along the creek to the southeast. They apparently form a relatively narrow unit, perhaps as much as 100 metres wide, enclosed by metabasalt. What may be the same felsic unit is also exposed on Fall River logging road to the north, but is offset from the Vent unit by about 500 metres of apparent dextral displacement across the inferred trace of the northeast trending Diver Lake fault. Grab samples from the Vent hydrothermal breccia and associated pyritic rocks just to the south did not yield anomalous base or precious metal values, and a sample from quartz-pyrite-altered rock to the north contained only a slightly elevated concentration of zinc (Table 1). Nevertheless, this occurrence clearly warrants further exploration.

Source (MINFILE 93N 110)

The Source occurrence is a narrow, gold-bearing quartz vein within the Cache Creek ultramafic unit, 3.7 kilometres east-northeast of Mount Bodine (Figure 5). It was discovered in June 1989 and subsequently staked as the Source claims by L.B. Warren of Smithers. Grexton (1990) reports that the vein is 25 centimetres wide and was traced as subcrop for more than 100 metres in an east-west direction. It locally contains very fine visible gold which occupies minute, discontinuous fractures within the quartz. The best assay result reported by Grexton had 7.27 grams per tonne gold and 89.8 grams per tonne silver.

The Source vein is within an east-trending zone of mariposite-quartz-magnesite (listwanite) alteration, 10 to 20 metres wide, that cuts across the north-northwest-striking foliation of talc-magnesite schists containing knockers of greenstone and amphibolite. Where best exposed, just to the west of the Source vein, individual listwanite zones are 2 to 3 metres wide and separated by similar widths of schist. A sample of listwanite collected from this exposure in 1996 contained 12 ppb Au (Table 1, Sample 96PSC-23-9-2); Culbert (1985) reports that a sample of silicified rock from the same listwanite-altered zone contained 45 ppb Au and 2.6 ppm Ag.

A prominent zone of listwanite alteration also occurs along the contact between the ultramafic unit and the Cache Creek sedimentary unit, where it appears to postdate fabrics related to west-directed thrusting within serpentine-magnesite-talc schist. A sample of listwanite from this contact, collected on the ridge crest 600 metres north-northeast of the Source vein, contained 94 ppb Au (Table 1, Sample 96PSC-23-17). Macfarlane (1984b) reports soil anomalies of 780, 550 and 35 ppb Au from adjacent sample sites along strike approximately 1 kilometre to the north, and a nearby stream sediment silt sample collected by Culbert (1985) yielded 315 ppb Au. More recent work has yielded a soil anomaly of 135 000 ppb Au from the same area (L.B. Warren, personal communication, 1996).

The eastern contact of the Cache Creek ultramafic unit is not well exposed for a considerable distance to the north, but the entire outcrop width of the unit is exposed 9 kilometres north of the Source showing, east of Diver Lake. There, the serpentinite melange unit is only about 600 metres wide, and northerly-striking zones of listwanite alteration, locally associated with extensive quartz veining, occur within its central and eastern parts. One sample of listwanite from the central part of this belt yielded 36 ppb Au (Table 1, Sample 96PSC-11-9).

Shane Showing (New)

The Shane showing is a mineralized quartz vein that was discovered within the Cache Creek ultramafic unit

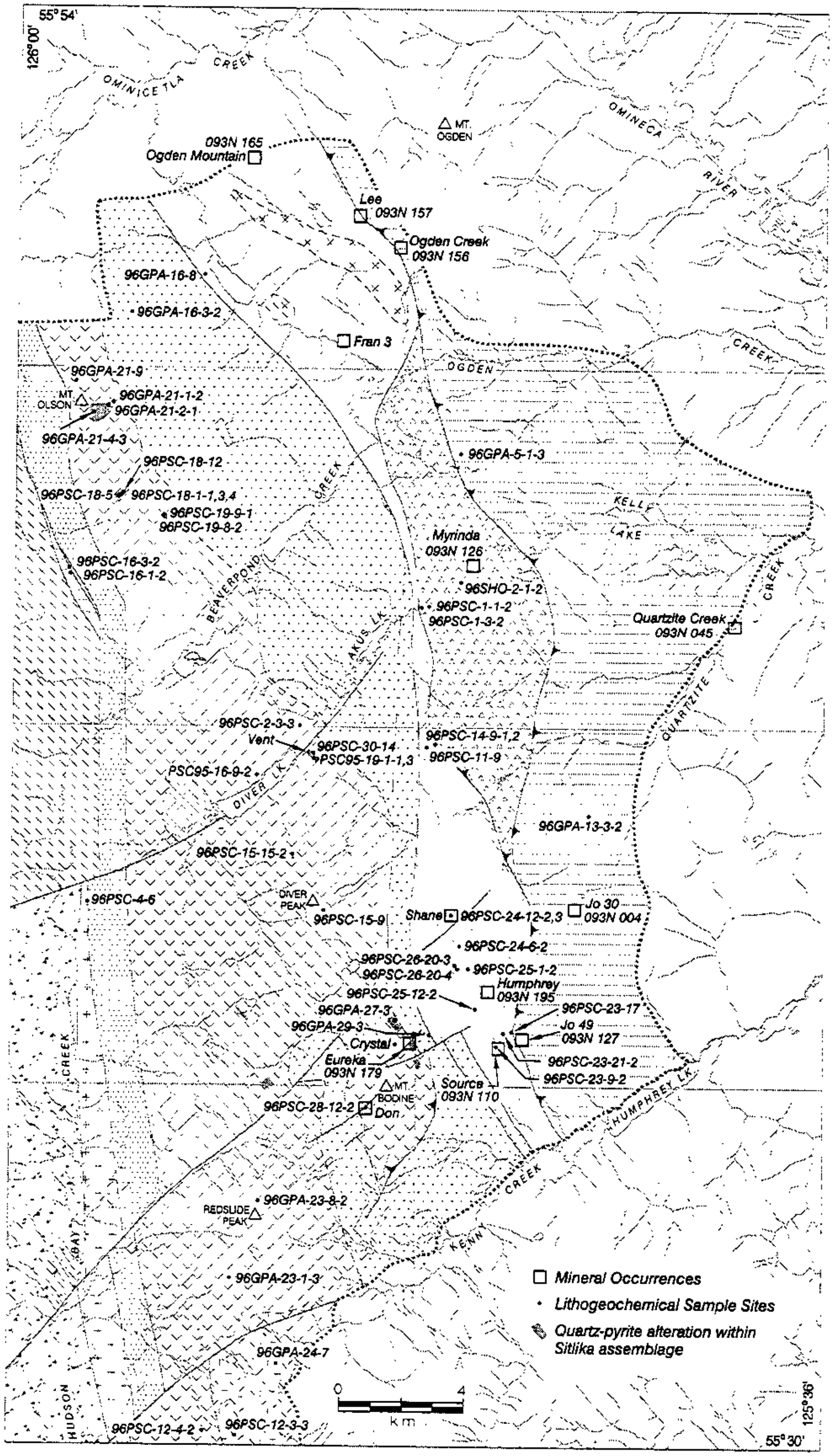

Figure 5. Locations of mineral occurrences and lithogeochemical sample sites in the Kenny Creek - Mount Olson map area.

TABLE 1. ANALYTICAL RESULTS FOR ROCK SAMPLES COLLECTED IN THE KENNY CREEK-MOUNT OLSON MAP AREA

Field No.	Element	Au	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U	Th	Sr	Cd	Sb	Bi	V	Cr	Mg	Ba	Ti	B	Al	W
	Units	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	%	ppm	%	ppm
	Method	INA	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP	AICP
	Detection limit	2	1	1	3	1	0.3	1	1	2	0.01	2	5	2	1	0.2	2	2	1	1	0.01	1	0.01	3	0.01	2
Field No.	**Description**																									
PSC95-16-9-2	pyritic schist	3*	7	178	20	398	0.5	52	13	323	20.97	< 2	< 5	2	13	4.2	< 2	< 2	89	74	0.6	6	0.07	< 3	0.8	< 2
PSC95-19-1-1	qtz-py altd	2*	1	6	< 3	< 1	< .3	4	1	27	2.18	4	< 5	2	14	< .2	< 2	< 2	5	146	0.03	2	0.1	< 3	0.47	< 2
PSC95-19-1-3	silic py breccia	3*	3	1	5	< 1	< .3	4	2	14	17.14	29	< 5	< 2	2	0.8	< 2	< 2	1	90	< .01	3	< .01	< 3	0.08	< 2
96PSC 1-1-2	limonite altd	-2	3	67	< 3	84	< .3	67	33	1012	6.03	29	5	3	148	0.5	2	< 2	67	58	2.36	63	< .01	14	0.73	< 2
96PSC 1-3-2	rusty carb alt	-2	2	20	3	88	< .3	18	21	1358	5.74	12	6	< 2	252	0.7	< 2	< 2	47	12	3.3	58	< .01	8	0.34	< 2
96PSC 2-3-3	qtz-lim altd	2	9	16	10	43	0.3	12	1	86	2.22	33	< 5	< 2	8	0.4	3	< 2	22	22	0.05	31	0.01	< 3	0.23	6
96PSC 4-6	qtz-carb alt	9	6	71	4	94	0.3	32	24	3739	6.22	15	< 5	4	71	0.2	< 2	< 2	87	27	0.67	143	< .01	16	1.05	< 2
96PSC 11-9	listwanite	36	2	13	< 3	14	< .3	1509	78	619	3.71	5	< 5	< 2	9	< .2	4	< 2	22	469	17.36	398	< .01	7	0.08	3
96PSC 12-3-3	qtz float with cpy	-2	4	71	< 3	10	< .3	10	1	619	1.12	< 2	< 5	< 2	58	0.2	2	< 2	7	21	0.26	50	0.01	< 3	0.18	8
96PSC 12-4-2	pyritic schists	-2	4	53	3	173	< .3	24	11	1349	7.85	< 2	< 5	< 2	15	0.4	2	< 2	127	21	2.37	31	0.53	< 3	2.87	< 2
96PSC 14-9-1	list. with qtz+py	-2	8	6	5	62	< .3	822	54	892	5.27	456	< 5	< 2	229	0.3	4	< 2	18	193	15.29	40	< .01	3	0.16	2
96PSC 14-9-2	magnesite + qtz	-2	4	6	< 3	19	< .3	245	12	206	1.73	56	< 5	< 2	15	< .2	4	< 2	8	73	3.33	10	< .01	3	0.09	10
96PSC 15-9	pyritic schist	7	2	14	< 3	138	< 3	26	4	281	6.36	10	< 5	< 2	9	0.2	4	< 2	138	154	1.59	18	0.57	< 3	2.53	< 2
96PSC 15-15-2	pyritic gossan	-2	3	47	< 3	84	< .3	38	11	972	6.23	< 2	< 5	< 2	4	0.2	< 2	< 2	147	174	3.38	13	0.66	< 3	2.78	< 2
96PSC 16-1-2	rusty qtz-carb vn	-2	3	26	< 3	48	< .3	22	16	1501	5.54	20	< 5	< 2	74	0.2	2	< 2	98	25	2.22	12	0.01	< 3	1.42	2
96PSC 16-3-2	list with qtz veins	-2	2	21	< 3	23	< .3	1392	64	1158	5.68	379	< 5	< 2	42	0.4	4	< 2	14	419	15.53	13	0.01	< 3	0.13	3
96PSC 18-1-1	pyritic schist	-2	2	22	< 3	235	< .3	17	3	1751	4.4	< 2	< 5	< 2	5	< .2	< 2	< 2	157	68	5.59	7	< .01	< 3	4.41	< 2
96PSC 18-1-3	lim. stringers (py)	3	3	38	< 3	141	< .3	6	8	1699	7.58	2	< 5	< 2	6	< .2	5	< 2	155	10	3	5	0.37	< 3	3.12	< 2
96PSC 18-4	pyritic qtz schist	-2	3	6	< 3	24	< .3	10	< 1	140	1.67	8	< 5	< 2	2	< .2	3	< 2	2	20	0.39	8	< .01	< 3	0.48	8
96PSC 18-5	pyritic schist	-2	3	14	7	149	< .3	11	16	2752	6.71	7	< 5	< 2	4	0.3	4	< 2	304	40	3.45	6	0.14	< 3	3.69	< 2
96PSC 18-12	pyritic qtz schist	2	2	32	< 3	156	< .3	11	17	2472	7.01	< 2	10	2	2	< .2	< 2	< 2	234	16	4.32	1	0.01	< 3	3.27	< 2
96PSC 19-8-2	py-qtz alt. rock	-2	5	5	< 3	3	< .3	8	1	71	1.84	< 2	< 5	< 2	1	< .2	< 2	< 2	5	15	0.05	1	< .01	< 3	0.18	4
96PSC 19-9-1	pyritic schist	-2	4	6	< 3	1	< .3	9	2	38	2.27	< 2	< 5	< 2	4	< .2	3	< 2	2	15	0.02	26	< .01	< 3	0.1	4
96PSC 23-9-2	listwanite zone	12	3	14	< 3	31	< .3	781	40	725	3.74	60	< 5	< 2	69	0.3	5	< 2	10	289	15.53	6	< .01	3	0.09	3
96PSC23-17	listwanite zone	94	2	17	< 3	19	< .3	739	52	554	3.61	75	< 5	< 2	138	< .2	2	< 2	14	448	15.2	7	< .01	< 3	0.12	4
96PSC 23-21-2	rusty alt +qtz vn	-2	2	4	< 3	14	< .3	30	5	327	1.38	< 2	< 5	< 2	11	< .2	3	< 2	28	39	0.36	7	< .01	< 3	0.22	7
96PSC 24-6-2	pyritic gossan	-2	3	71	< 3	87	< .3	73	38	690	5.74	< 2	5	< 2	11	0.5	< 2	< 2	167	156	1.88	30	0.46	10	3.32	< 2
96PSC 24-12-2	qtz vns with cpy	-2	3	878	24	43	< .3	19	2	93	0.81	6	< 5	< 2	3	0.2	2	< 2	8	30	0.07	2	< .01	3	0.09	9
96PSC 24-12-3	pyritic carb altd	-2	1	68	< 3	105	< .3	52	32	1568	6.93	14	8	< 2	111	0.7	< 2	< 2	56	42	4.38	6	< .01	3	0.28	< 2
96PSC 25-1-2	goss rock w. po	-2	1	75	< 3	143	< .3	92	40	934	7.3	< 2	7	< 2	13	0.8	2	< 2	92	90	1.92	8	0.78	< 3	2.01	< 2
96PSC 25-12-2	list. and qtz veins	-2	3	5	< 3	7	< .3	456	27	363	1.77	3	< 5	< 2	20	< .2	3	< 2	8	510	6.87	1	< .01	< 3	0.15	6
96PSC 26-20-3	qtz vein	-2	2	353	< 3	48	< 3	21	5	300	1.65	10	< 5	< 2	4	< .2	6	< 2	17	28	0.18	2	0.01	3	0.18	6
96PSC 26-20-4	rusty qtz-carb vn	-2	2	5	< 3	23	< .3	26	2	466	1.46	4	< 5	< 2	14	< .2	2	< 2	12	24	0.75	2	< .01	3	0.12	7
96PSC 28-12-2	qtz vein w. py/cpy	380	5	21714	< 3	107	1.8	17	86	347	7.01	121	< 5	< 2	3	1.7	383	< 2	7	33	0.02	7	< .01	< 3	0.09	14
96PSC 30-14	silic. schist w, py	-2	4	28	5	166	< .3	37	27	361	4.31	36	7	< 2	7	1.3	3	< 2	80	47	0.67	50	0.4	< 3	1.06	< 2
96SHO 2-1-2	qtz/carb alt (list)	9	1	50	5	110	< 3	170	42	1403	6.99	170	16	2	236	0.8	14	< 2	45	92	3.97	45	< .01	14	0.54	< 2
96GPA 1-9-3	py ritic chert layer	20	45	36	4	10	0.6	7	1	49	11.44	9	< 5	4	1	< .2	4	4	2	9	0.02	25	< .01	5	0.07	3
96GPA 5-1-3	limonitic qtz vein	8	3	38	< 3	29	0.3	20	5	213	2.59	7	5	3	4	< .2	< 2	2	25	18	0.09	43	< .01	3	0.26	7
96GPA 13-3-2	limonitic qtz vein	-2	3	27	10	10	0.5	14	2	126	0.95	2	11	3	4	0.3	2	< 2	5	21	0.14	13	< .01	< 3	0.35	5
96GPA 16-3-2	limonitic qtz vein	10	3	29	22	11	0.7	16	4	116	0.93	3	< 5	3	3	< .2	3	2	4	20	0.07	22	0.01	4	0.13	7
96GPA 16-8	pyritic listwanite	-2	1	23	< 3	19	< .3	2301	147	551	6.9	14	< 5	3	10	< .2	< 2	< 2	25	1304	17.85	6	< .01	4	0.45	< 2
96GPA 21-1-2	silic pyritic rock	-2	4	41	6	538	0.7	6	2	1482	3.29	< 2	< 5	3	1	< .2	< 2	2	68	26	3.42	2	0.24	< 3	2.49	< 2
96GPA 21-2-1	silic. pyritic rock	-2	3	9	< 3	38	0.4	19	1	190	2.09	< 2	11	3	3	< .2	< 2	2	5	23	0.43	5	0.06	< 3	0.45	3
96GPA 21-4-3	silic. pyritic rock	-2	[illegible]	8	[illegible]	43	< .3	9	2	198	3.18	< 2	< 5	2	3	< .2	< 2	< 2	40	23	0.88	7	0.06	< 3	0.94	7
96GPA 21-9	altd pyritic rock	-2	21	59	< 3	22	< .3	111	18	165	14.15	53	< 5	5	13	0.2	< 2	< 2	62	174	1.17	11	0.33	< 3	1.27	< 2
96GPA 23-1-3	lim-py-qtz altd	-2	3	51	3	17	0.4	13	9	224	3.08	77	< 5	< 2	23	< .2	2	3	84	31	0.37	25	0.68	< 3	0.92	< 2
96GPA 23-8-2	lim-py-qtz altd	-3	1	15	< 3	31	< .3	26	7	314	4.3	< 2	< 5	2	7	0.2	< 2	8	76	156	1.3	11	0.52	3	1.61	2
96GPA 24-7	pyritic intrusive	-2	< 1	41	< 3	22	< .3	4	4	442	4.17	< 2	< 5	2	33	< .2	< 2	< 2	128	11	1.82	20	0.33	< 3	2.24	< 2
96GPA 27-3	lim-qtz-py volc	-2	1	16	11	413	< .3	4	< 1	1285	2.43	< 2	< 5	2	7	0.2	< 2	< 2	5	7	1.42	26	0.01	< 3	1.26	< 2
96GPA 29-3	talc,magnesite,py	-2	< 1	10	< 3	20	< .3	1174	22	657	3.92	5	5	2	30	0.3	< 2	< 2	9	521	11.61	8	< .01	< 3	0.12	< 2

Abbreviations: AICP = Aqua regia digestion-ICPES; INA = Instrumental Neutron Activation; alt = alteration; altd = altered; carb = carbonate; cpy = chalcopyrite; lim = limonite; list = listwanite; goss = gossan; qtz = quartz; po = pyrrhotite; silc = silicified; volc = volcanic rock; vn(s) = vein(s); w = with; * = fire assay about 6 kilometres north-northeast of Mount Bodine (Figure 5). It occurs within a large lens of greenstone to amphibolite that measures about one kilometre in its longest, north-northwest dimension. The vein is about a metre wide, dips steeply to the south, and was traced for several tens of metres along its east-west strike. The white quartz contains local cavities lined with small quartz crystals, and is separated into discontinuous sheets by partings of chlorite and rusty carbonate. The partings are oriented approximately parallel to the vein walls, and some contain slickensides or mineral fibres that pitch at moderate angles to the east. Wallrocks are variably altered with rusty carbonate and pyrite for one to two metres beyond the vein. Mineralization within the vein consists of scattered blebs of chalcopyrite and pyrite. A single grab sample of vein material yielded 878 ppm Cu and 24 ppm Pb, but did not contain anomalous concentrations of Au or Ag. (Table 1, Sample 96PSC-24-12-2). A sample of altered wallrock did not contain significantly anomalous base or precious metal concentrations (Sample 96PSC-24-12-3).

East to northeast-striking quartz and quartz-carbonate veins occur throughout the Cache Creek ultramafic unit between the Shane and Source occurrences, but are not particularly abundant. Most of the veins occur in relatively large greenstone or amphibolite knockers, although some are within serpentinite or magnesite-talc schist. Some of the veins contain pyrite, although base metal sulphides were observed only at the Shane occurrence. However, one 80-centimetre-wide quartz vein on the ridge crest 1.5 kilometres south of the Shane showing contained abundant limonitic vugs and selvages, and yielded 353 ppm Cu (Table 1, Sample 96PSC-26-20-3). None of the quartz veins sampled in this area contained anomalous precious metal values.

Jo 49 (MINFILE 93N 127)

The Jo 49 MINFILE occurrence is 800 metres east-northeast if the Source vein, within the Cache Creek sedimentary unit about 200 metres east of its contact with the ultramafic unit. It was discovered on the Jo 49 claim during a regional exploration program for gold in the Vital Range, carried out in 1983 and 1984, but is presently within the Source claim group, staked by L.B. Warren in 1989. The area is underlain by phyllites and platy quartz phyllites cut by abundant aplite dikes and sills. The occurrence comprises a number of gold anomalies, including values of 4000 and 2500 ppb Au, reported by Macfarlane (1984b) from rock chip samples collected over a linear zone about 200 metres long, parallel to and 200 metres east of the Vital fault. Re-sampling of the area by Culbert (1985) confirmed the presence of anomalous gold, but failed to repeat the highest values reported by Macfarlane; he reports 5 different samples with gold values ranging from 340 to 695 ppb Au.

The anomalous gold concentrations at the Jo 49 occurrence are within narrow, discontinuous, north-striking quartz veinlets that occur within a relatively large, irregular aplitic body (Culbert, 1985). Although similar aplite is abundant within the Cache Creek metasedimentary rocks for a considerable distance to the east, the gold-bearing veinlets are apparently restricted to the area adjacent to the fault contact with the ultramafic unit. The veinlets are therefore inferred to have formed during some stage of movement on the fault, which originated as a west-directed Jurassic(?) thrust, but may have been overprinted by dextral strike-slip in the early Tertiary. Their presence predominantly within a large aplite body may reflect the contrast in competency and ability to develop open fractures between this body and the host Cache Creek phyllites.

Jo 30 (MINFILE 93N 004)

The Jo 30 occurrence is within the Cache Creek sedimentary unit near the headwaters of Quartzite Creek, 8 kilometres northeast of Mount Bodine. The mineralization is reported as "skarn with chalcopyrite, pyrite, manganese and quartz veining" (Macfarlane, 1984a), apparently within Cache Creek metasedimentary rocks adjacent to a felsic dike. Macfarlane reports that one rock chip sample of this mineralization contained 2850 ppb Au, while two other samples did not yield anomalous gold values. The Jo 30 mineralization was discovered during a regional exploration program carried out in 1983 and 1984, aimed at locating the source rock for the placer gold deposits found along Quartzite Creek and other creeks draining the Vital Range to the south and southeast. No subsequent work has been reported in the area, and the Jo claim group has lapsed.

Quartzite Creek (MINFILE 93N 045)

The Quartzite Creek occurrence is a past-producing placer mine on the lower reaches of Quartzite Creek (Figure 5), which at this point flows over Cache Creek phyllites and schists containing numerous, apparently barren, quartz veins (Lay, 1934). This creek has been worked intermittently from the late 1800s to the present, but the only recorded production was between 1931 and 1945, when 13 530 grams of gold were extracted (Holland, 1950). Lay (1934) reports that mining efforts were directed at both post-glacial gravels above rock benches and an older buried channel. The placer working have also yielded boulders of rhodonite and jade (Leaming, 1973).

Nephrite Occurrences (MINFILE 93N 126, 156, 157, 165)

Nephrite jade was produced from boulders and *in situ* occurrences on the southwest slopes of Mount Ogden from 1967 to 1992. As reported by Price (1973, 1988), good quality jade was first discovered by W.L. Owen and S.E. Porayko in the upper reaches of Ogden Creek and two of its tributaries in the summer of 1967 (Ogden Creek occurrence; MINFILE 93N 156). Jade was produced from these placer leases in 1967, 1968 and 1969, at which time

Owen and Porayko discovered and staked a high grade *in situ* showing at the head of Lee Creek, one of the nephrite-bearing tributaries of Ogden Creek. This lens, along with several other *in situ* nephrite lenses subsequently discovered nearby (Price, 1988), are collectively referred to as the Lee occurrence (MINFILE 93N 157). New World Jade Ltd. was formed in 1970 to explore and produce nephrite from this property, and operated until 1974 when the assets were acquired by B.C. Gem (H.K.) Ltd. The claims were acquired by The Continental Jade Ltd in 1976, and production continued until at least 1992, in part under the direction of operator Jade West Resources Ltd.

Nephrite occurrences contiguous with the Lee occurrences to the north-northwest are collectively referred to as the Mount Ogden occurrence (MINFILE 93N 165). These include a number of *in situ* nephrite lenses of various sizes and quality, associated colluvial blocks, and alluvial boulders in Squawkbird Creek and the unnamed creek to the east (Price, 1973). Placer leases were first located along Squawkbird Creek by L.D. Barr in 1968, and *in situ* nephrite was discovered the following year. Mineral claims and additional placer leases covering these occurrences were staked by Barr for Far North Jade Ltd. which began producing nephrite from the property in 1970.

According to MINFILE, the nephrite production from the three occurrences southwest of Mount Ogden totaled about 1700 tonnes between 1967 and 1992. It is uncertain how much production there has been since that time, but there was no mining or exploration activity apparent during our mapping program in 1996. The claims covering both the Lee and Mount Ogden occurrences are currently held by The Continental Jade Ltd.

The nephrite occurrences southwest of Mount Ogden are within the eastern part of the Cache Creek ultramafic unit. The initial *in situ* nephrite discovery at the head of Lee Creek is along the fault contact with structurally overlying platy quartz phyllites of the Cache Creek sedimentary unit. The contact zone is up to 30 metres wide (Leaming, 1978), and includes a narrow zone of talc schist which passes downward into rodingite containing lenses of nephrite. The other significant area of production on the Lee occurrence is about 700 metres to the south-southwest. There, narrow bands of high quality nephrite occur along the contact between serpentinite and the large granodiorite body that intrudes it (Price, 1988); additional nephrite lenses occur within altered serpentinite a short distance northeast of the contact (Leaming, 1978). At the Mount Ogden occurrence to the northwest, nephrite typically occurs along contacts between serpentinite (or talc-magnesite schist) and enclosed lenses of altered greenstone or siliceous metasedimentary rock (Price, 1973).

The Fran 3 claim covers a nephrite lens within the Cache Creek ultramafic unit about 3.5 kilometres south of the Lee occurrence. The nephrite there occurs along the contact between serpentinite and structurally overlying metachert and greenstone. N. Scafe, owner of the claim, and L. Warren extracted about 90 tonnes of low quality nephrite from this locality in the mid 1980s (L. Warren, personal communication, 1996).

The Myrinda nephrite occurrence (MINFILE 93N 126) is within the Cache Creek mafic unit, about 10 kilometres south-southeast of the Mount Ogden occurrences. The nephrite occurs as a narrow lens along a northeast-striking fault a few hundred metres north of the Fall River. It was tested by three short drill holes in 1985, which showed the jade to be of low quality and unsuitable for any commercial purpose (Makepeace, 1986). Other jade occurrences were reportedly uncovered a short distance away during the drill program, but these were not drill-tested and the Myrinda claim has subsequently lapsed.

Humphrey (MINFILE 93N 195)

The Humphrey MINFILE occurrence refers to talc and chrysotile veinlets mentioned by Macfarlane (1984b), and talc-ankerite alteration described by Culbert (1985), in their descriptions of the Cache Creek ultramafic unit northeast of Mount Bodine. However, although talc is a common metamorphic constituent of the ultramafic rocks, and asbestiform serpentine occurs locally, the unit has not apparently been explored for either commodity.

SUMMARY OF MAIN CONCLUSIONS

The 1996 mapping program covered most of the Sitlika assemblage where it was originally defined by Paterson (1974). This has resulted in an improved understanding of the composition, distribution and mutual relationships of Paterson's three divisions of the assemblage, and an improved understanding of the structural relationships between the Sitlika assemblage and terranes to the east and west. Following are some of the main conclusions derived from this mapping and supporting radiometric dating and geochemical analyses reported by Childe and Schiarizza (1997).

- The volcanic unit of the Sitlika assemblage is readily correlated with metavolcanic rocks of the Kutcho Formation on the basis of lithology (mafic and felsic volcanics with associated intrusions), Permo-Triassic age, and primitive tholeiitic geochemistry. Clastic metasedimentary rocks of the eastern clastic unit (greywacke division of Paterson, 1974) rest stratigraphically above the volcanic unit and contain felsic volcanic and plutonic clasts that were probably derived from the underlying unit. These clastic rocks are likely correlative with metasedimentary rocks that comprise the upper part of the Kutcho Formation and/or the overlying Sinwa and Inklin formations.
- Rocks correlative with volcanic and plutonic rocks of the Kutcho Formation and Sitlika assemblage also occur in southern British Columbia, where they are likewise in structural contact with the Cache Creek Group. These assemblages are distinct from volcanic arc rocks in adjacent Stikine

Terrane in both the age of magmatism and their primitive geochemical and isotopic signatures (Childe *et al.*, 1996). They may comprise remnants of primitive arc sequences that developed on oceanic crust in western Cache Creek Terrane or as part of a previously unrecognized terrane to the west.

- The western clastic unit of the Sitlika assemblage (argillite division of Paterson, 1974) consists of dark grey phyllite and chert-pebble conglomerate, with lesser chert-quartz sandstone and minor limestone. It is faulted against the volcanic unit along the western margin of the Sitlika belt, and is of unknown stratigraphic relationship to the other two units of the assemblage. The western clastic unit is included in the Sitlika assemblage on the basis of similar metamorphic grade and structural style, but is tentatively correlated, on the basis of lithology, with the upper Middle Jurassic to Upper Jurassic Ashman Formation of the Bowser Lake Group, which was deposited above Stikine Terrane to the west. Therefore, although the Sitlika assemblage consists largely of a distinctive stratigraphic succession correlative with the Kutcho Formation, it is primarily a structural - metamorphic entity, possibly analogous with the King Salmon allochthon of northern British Columbia.
- The Sitlika assemblage is bounded to the west by the northerly-trending Takla fault system, which juxtaposes the western clastic unit against volcanic rocks of the Lower to Middle Jurassic Hazelton Group in the north, and against undated granite and adjacent Upper Cretaceous clastic rocks of the Sustut Group in the south. The Takla fault system is not well exposed, but the presence of a northwest-trending fold in the adjacent Sustut Group is consistent with previous interpretations that it is a Late Cretaceous to early Tertiary dextral fault system.
- The eastern boundary of the Sitlika assemblage is, at least in part, a steeply-dipping, north to northwest-striking dextral fault system that is probably of early Tertiary age. It juxtaposes the eastern clastic unit against serpentinite melange that outcrops along the western limit of Cache Creek Terrane. The dextral strike-slip fault apparently postdates east-dipping thrust faults that occur within the serpentinite melange and define its eastern contacts with structurally overlying sedimentary and mafic units of the Cache Creek Group. Regionally, similar east-dipping thrust faults separate the Cache Creek Terrane from underlying Sitlika assemblage and its correlatives, and separate the latter assemblages from structurally underlying Stikine Terrane. Tentative correlation of the Sitlika western clastic unit with Middle to Upper Jurassic rocks of the Bowser Lake Group supports the Late Jurassic to Early Cretaceous timing proposed by Monger *et al.* (1978) for this west-directed contractional deformation and related metamorphism in central British Columbia.
- The Sitlika volcanic unit is a bimodal assemblage of mafic and felsic rocks that has potential to host volcanogenic massive sulphide mineralization. The upper part of the unit may be most prospective as it contains a relatively high proportion of felsic volcanic rocks and has prominent gossanous pyrite-silica alteration zones in several areas. This part of the assemblage includes the newly discovered Vent hydrothermal breccia and alteration zone east of Diver Lake, as well as a narrow interval of laminated pyrite-chert of probable exhalative origin (Crystal showing) north of Mount Bodine.
- Previously known and newly discovered metallic mineral occurrences within the map area are mainly vein systems that occur within the Sitlika assemblage and adjacent Cache Creek Terrane in a band that trends northeasterly from the vicinity of Mount Bodine. These veins occur where the fault separating the Sitlika assemblage from the Cache Creek Group changes from its regional north-northwest trending orientation to a northerly trend. As latest movement on this fault system appears to be dextral strike-slip, the northerly trending segment of the fault system, which persists from the Mount Bodine area to the Fall River, marks an extensional jog in the system (*see* Figure 3), and is therefore a favourable site for syn-faulting mineral deposition (Sibson, 1987). It is suspected, therefore, that the vein systems in the Mount Bodine area are relatively young occurrences related to movement along this dextral fault system. Alternatively, some of the occurrences in the Cache Creek Group, such as the Jo 49, may have formed during the late stages of the earlier episode of synmetamorphic west-directed Jurassic(?) thrusting.
- Nephrite occurrences within the Cache Creek ultramafic unit are restricted to the area north of Beaverpond Creek, where the unit is intruded by stocks and dikes of granodiorite. In detail, the intrusive rocks are not spatially associated with most of the *in situ* nephrite lenses, and were not considered by Leaming (1978) to be an important factor in their genesis. However, the general spatial relationship suggests that the intrusive rocks may have been a source of heat and/or fluids that helped drive the metasomatic processes that produced nephrite.

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GEOLOGY OF THE SWANNELL RANGES IN THE VICINITY OF THE KEMESS COPPER-GOLD PORPHYRY DEPOSIT, ATTYCELLEY CREEK (NTS 94E/2), TOODOGGONE RIVER MAP AREA

By Larry J. Diakow and Paul Metcalfe

KEYWORDS: Toodoggone River map area, Kemess South, copper-gold porphyry, Black Lake intrusive suite, Asitka Group, Stuhini Group, Toodoggone formation.

INTRODUCTION

The Toodoggone-McConnell project was intitiated in 1996. The main objective is to improve understanding of the geological setting of copper-gold porphyry prospects along the tract of Mesozoic volcanic and plutonic rocks in the Swannell Ranges that extends southeastward from the Toodoggone River (94E), through McConnell Creek (94D) into the Mesilinka River (94C) map areas. The Kemess South copper-gold porphyry deposit, situated along this belt in the southern Toodoggone River map area, was discovered in the late 1980's and currently is at an early stage of mine development with production anticipated in 1998. The Kemess South orebody has estimated reserves of 200 million tonnes grading an average of 0.224% copper and 0.63 g/t gold (Royal Oak Mines Inc., 1995).

During 1996, 400 square kilometres in the vicinity of the Kemess mine was mapped at 1:20 000 scale (Figure 1). This work refines and supplements earlier regional mapping in the Toodoggone River area (Gabrielse *et al.*, 1975; Diakow *et al.*, 1993). Also in 1996, a regional geochemical survey (RGS) program was conducted in McConnell Creek and Toodoggone River map areas, covering more than 18 500 square kilometers outside of Spatsizi and Tatlatui provincial parks. Survey results are scheduled to be released in July, 1997.

Access into the study area is by fixed wing from either Prince George or Smithers to an airstrip along the Sturdee River. A system of Forest Service roads originating at either Fort St. James or Windy Point on Highway 97, north of Prince George, join the Omineca Resource Access Road and together they serve as a seasonal transportation link to a number of active mineral prospects in the Swannell Ranges. The drive from either point of origin to the Kemess minesite covers more than 400 kilometres and requires about 10 hours.

The area has been glaciated and varies from subdued, rounded hills to steep terrain at elevations between 1200 metres and 2100 metres. Rock exposure is sporadic along the major drainages but improves significantly above tree line, at about 1600 metres elevation.

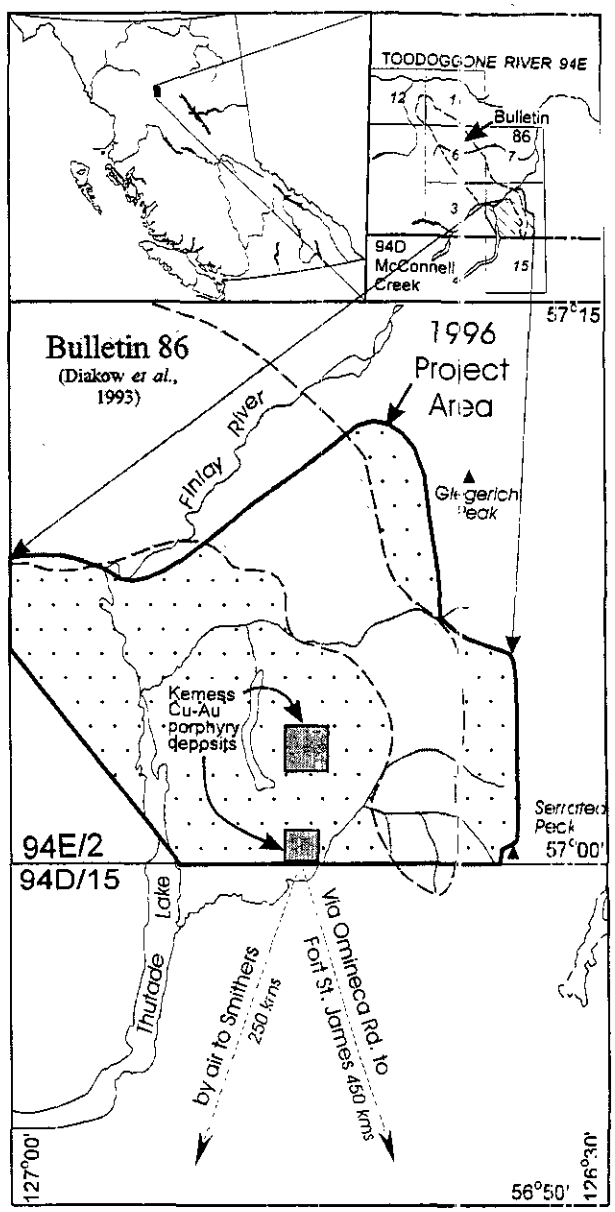


Figure 1. Location of the study within Attycelley Creek map area (94E/2).

LOCAL GEOLOGY

The study area is located near the eastern margin of the Intermontane Belt, where dextral strike-slip faults of the northerly trending Finlay-Ingenika fault system separate rocks in Stikinia to the west from slivers of Quesnellia to the east (Figure 2). These Late Paleozoic and Mesozoic volcanic arc terranes lie along the western border of older, comparatively more intensely deformed and metamorphosed pericratonic rocks of the Cassiar Terrane in the Omineca Belt. Farther west in the Stikine Terrane, the arc assemblages are largely concealed by Middle Jurassic to Late Cretaceous sedimentary strata that underlie the Bowser and Sustut successor basins.

Rock units underlying the southern part of the Toodoggone River map area at about 57° latitude are dominated by volcanic and lesser sedimentary rocks that range in age from Paleozoic to Early Jurassic. The general distribution of lithostratigraphic units in the study area comprises a relatively young, medial Jurassic belt that passes outward into bordering Triassic and Paleozoic strata. Towards the western border of the study area, the older units disappear beneath a thick cover of Upper Cretaceous sedimentary strata.

Paleozoic rocks along parts of the northeastern margin of Stikinia, which have been mapped as the Lower Permian Asitka Group (Gabrielse *et al.*, 1975; Monger, 1977), consist of andesitic and rhyolitic volcanic rocks with locally prominent sections of interbedded limestone and chert. Upper Triassic rocks of the Stuhini Group are more widespread and characterized by a proponderance of clinopyroxene-bearing basalts, andesitic volcanic rocks and associated epiclastic rocks. They are difficult to distinguish solely on lithology from some of the more mafic Paleozoic volcanic rocks. Locally the Lower Jurassic Toodoggone formation of the Hazelton Group rests directly on strata of the Stuhini Group. The contact, where exposed, is a gently inclined non-erosional unconformity. The Toodoggone formation is composed mainly of volcanic units readily distinguished by the presence of modal quartz, biotite and hornblende in rocks of andesite to dacite composition.

Most rocks in the study area display mineralogy typical of the zeolite grade of regional metamorphism. The exceptions are metavolcanic rocks of amphibolite and greenshist grade found in the thermal aureoles of several small Alaskan hornblende gabbro and pyroxenite bodies. Probable Early Jurassic intrusive rocks of the Black Lake suite underlie much of the Swannell Ranges in the eastern Toodoggone River (94E) and McConnell Creek (94D) map areas. In the Toodoggone River area, Early Jurassic calc-alkaline plutons and coeval volcanic rocks of the Toodoggone formation represent an important arc magmatic event. This event coincides with development of an elongated volcano-tectonic depression that is endowed with numerous precious metal-bearing occurrences. During the 1980's the Toodoggone mining camp was intensely explored for epithermal gold and silver mineralization, and resulted in production from the Baker and Lawyers mines. A general shift of exploration toward copper-gold porphyry targets related to Early Jurassic plutons is more recent.

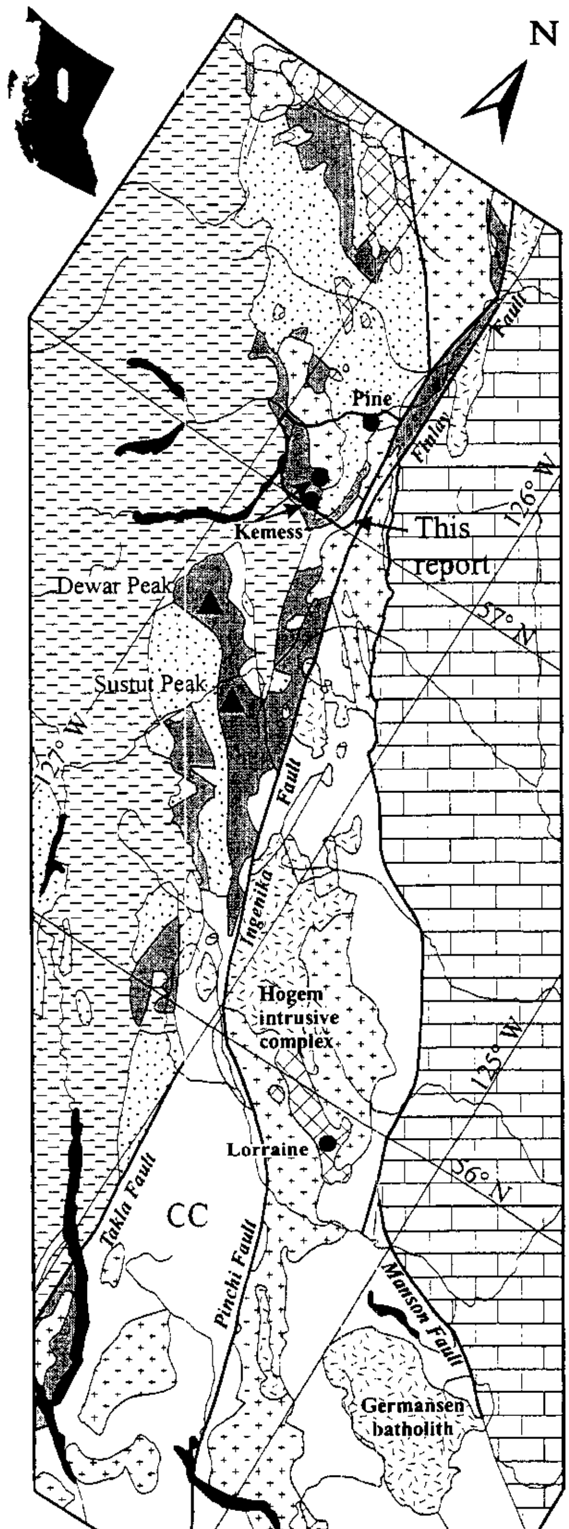
LITHOSTRATIGRAPHIC UNITS

Paleozoic Rocks

Limestone, chert and volcanic rocks, mainly basalt and andesite, but with local rhyolitic ash-flow tuff are interpreted to be Late Paleozoic in age. In isolated outcrops the more basic rocks of this map unit are easily confused for lithologically similar rocks of the Upper Triassic Stuhini Group. Relatively undeformed Paleozoic rocks underlie much of the valley bottom adjacent to the northern end of Thutade Lake and extend eastward to the flat-topped ridge (herein called the Duncan Lake ridge) that borders Duncan Lake in the west. Near Serrated Peak, in the southeast part of the study area, Paleozoic strata are locally folded and presumably thrust over Jurassic volcanic rocks. Paleozoic rocks also crop out, generally at lower elevations in several valleys incising a mountain located between Attycelley Creek and the Finlay River. The upper contact of the Paleozoic succession is an unconformity with overlying rocks of the Upper Triassic Stuhini Group.

Paleozoic rocks are most widespread and probably thickest in the region adjacent to Thutade Lake. The sequence there appears to be gently inclined towards the west with probable flextures causing strata to locally deviate from this general trend. Although no contacts were observed in the scattered outcrops west of Thutade Lake, a consistent spatial relationship implies a crudely bedded stratigraphy that comprises a lowermost rhyolitic ash-flow tuff overlain successively by andesite flows then limestone with interbedded chert. Conglomerate, which is sporadically exposed, marks the top of the Paleozoic unit and it stratigraphically underlies the first exposure of pyroxene phyric flows of the Stuhini Group. The conglomerate is between 3 and 20 metres thick and consists of subangular and angular pebbles and cobbles supported by a finer sandy matrix. The most abundant clasts are fine-grained feldspar porphyry; less common clast varieties include limestone, chert, siltstone, welded tuff, and rare biotite-quartz-feldspar phyric granitoid. With the exception of the granitic clasts, these lithologies resemble local outcrops of the Paleozoic unit. No mafic volcanic clasts were found.

Pyroclastic flows in the lower part of the succession near Thutade Lake are readily distinguished by flattened, chlorite-altered fragments between 1 and 8 centimetres long that are in a light green siliceous groundmass. Although other lithic pyroclasts are present they are recrystallized and silicified. Light green and maroon ash tuff, with rare intervals of accretionary lapilli tuff, form scarce, well bedded, air-fall tuff deposits up to 20 metres thick within otherwise massively bedded ash-flow tuff. The ash-flow member is conformably overlain by a unit with massively bedded andesite and some aphanitic basalt



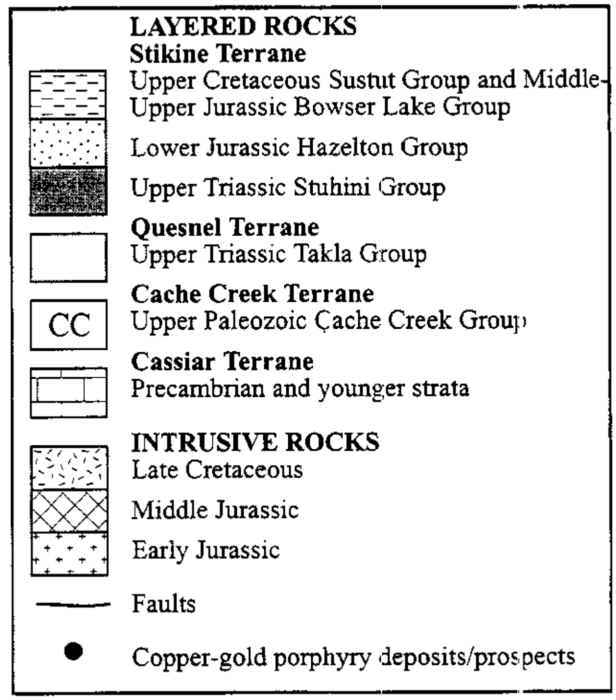


Figure 2. Regional geologic setting of the study area and important copper-gold porphyry prospects associated with Early Jurassic plutons in Stikine and Quesnel terranes. The study area is near the eastern boundary of Stikinia. Rocks exposed include: Upper Paleozoic Asitka Group, Upper Triassic Stuhini Group, equivalent to the Takla Group of Monger (1977), Lower Jurassic Toodoggone formation, overlain by Upper Jurassic and Upper Cretaceous Bowser Lake and Sustut groups (modified after Wheeler and McFeely, 1991).

flows that locally contain sandstone and granule conglomerate beds about 1 metre thick at the base. The andesite contains between 20 and 25% plagioclase phenocrysts up to 4 millimetres in diameter and microphenocrysts of clinopyroxene set in a medium green groundmass. East of Thutade Lake aphanitic basalt flows become more common and predominate along sections of the west facing slope on the Duncan Lake ridge. The basalt is a dark green, almost black rock with lustrous chloritic fracture and cleavage surfaces. At several localities similar aphanitic basalt flows occupy intervals up to 20 metres thick within an overlying limestone-chert member.

Limestones interlayered with chert are perhaps the most readily recognizable of the Paleozoic lithologies. They stratigraphically overlie the andesite-basalt flow member on Duncan Lake ridge, however, the actual contact has not been observed. Here, the limestone is more than 120 metres thick and forms rounded knolls across the ridge crest in the north; it thins dramatically southward in a series of bluff-forming exposures along the east-facing slope. West of Thutade Lake, where limestone underlies an area of 2.5 km^2 along a low-lying ridge, it appears to be bound on all sides by steeply dipping faults that juxtapose it against the andesite flow member. In this area the limestone is typically massive, weathering light grey or streaky grey-black and internally it is white with a recrystallized fine-grained texture. The relative proportion of chert and limestone is quite variable, ranging from isolated chert layers within massive limestone to chert-dominant sections more than 60 metres thick. Generally the chert, which is off-white, light green, or less commonly pink or purple, forms beds from several centimetres to 30 centimetres thick, sometimes alternating with limestone.

Solitary corals occur with bryozoans, crinoid and brachiopod fragments in a number of localities of the bedded limestone and chert unit. At a fossil site on the Duncan Lake ridge, massive carbonate is stratigraphically overlain by a steeply inclined section about 60 metes thick, composed of aphanitic basalt at the base that passes upward to alternating coral-bearing limestones, calcareous ash tuff and lesser lapilli tuff beds. The coral population appears to have been extinguished periodically during explosive volcanic episodes only to be reestablished during lulls in volcanism that are marked by deposition of limestone interbeds up to one-half metre thick. Fusulinids are well preserved locally within some reworked lapilli tuff beds. Microfossil collections for conodonts have been made from relatively scarce limy argillite interbeds in limestone and for radiolarians from a number of chert localities. Fossil identifications will facilitate age assignment and subdivision of Paleozoic rocks in the study area. In addition, the felsic welded tuff near Thutade Lake, which appears to be stratigraphically beneath limestone, was sampled for a U-Pb zircon date. At present, the presumed late Paleozoic succession in the study area is tentatively correlated with the Lower Permian Asitka Group. Monger (1977) describes three subdivisions in a stratotype of the Asitka Group near Dewar Peak, located about 50 kilometres south of the study area. There volcanics are also prominent in the section, varying in composition from basalt to rhyolite, and they are intercalated with cherts, limestones and some argillite. Fusulinaceans and sponges collected from the Dewar Peak area all indicate that the Asitka Group was deposited during Early Permian time (Ross and Monger, 1978; Rigby, 1973).

Triassic Rocks

Following current usage, rocks of presumed Triassic age in the area are assigned to the Stuhini Group, although the closest Triassic rocks which occur south of the study area and in the same tectonostratigraphic province are assigned by Monger (1977) to the Takla Group of Quesnellia. It is these which will be used for comparison and regional correlation.

Volcanic rocks in the study area, that are interpreted to be part of the Stuhini Group, are lithologically similar to those described by Monger (1977). They form an assemblage at present unconstrained by paleontological data or by isotopic age measurement and grouped entirely on the basis of their lithological homogeneity. A complete section is not present in the area and the thickness of the unit is therefore not known. Their outcrop distribution, shown in Figure 3, is peripheral to overlying units identified by Diakow *et al.* (1993) as the Lower Jurassic Toodoggone formation. The package is underlain by the presumed Paleozoic stratigraphic assemblage described above. The lower contact with the limestone-volcanic sequence of inferred Paleozoic age is apparently disconformable and is exposed on the Duncan Lake ridge. In this section, a limestone-chert unit with associated volcanic siltstones is overlain by a relatively thin bedded unit of clastic sedimentary rocks which are probably volcanogenic and are in turn overlain by a thick succession of fragmental units, incorporating blocks exclusively of volcanic material. This transition in depositional style is identified as the contact, in the absence of paleontological data. Elsewhere, the contact is not exposed. The upper contact of the Stuhini Group is exposed in the centre of the study area, east of the Saunders-Wrich fault and south of Attycelley Creek. The contact is another disconformity, marked by the occurrence of an extremely coarse Triassic volcanic conglomerate, overlain by a distinctly different conglomerate of the Toodoggone formation. Elsewhere the upper contact is covered or faulted.

The main exposures of Stuhini Group rocks are to the north and west of Thutade Lake; immediately south of the Firesteel River; on an unnamed peak immediately southeast of the confluence of the Firesteel and Finlay rivers; to the east along the margin of the Giegerich pluton; on the Duncan Lake ridge and in the immediate vicinity of the Kemess North and Kemess South deposits. Rocks which may also correlate with this Stuhini succession are exposed in the southeast, near Serrated Peak.

The Stuhini Group is dominated by mafic volcanic rocks and by significant thicknesses of derived volcanogenic clastic rocks. Diagnostic phenocryst phases

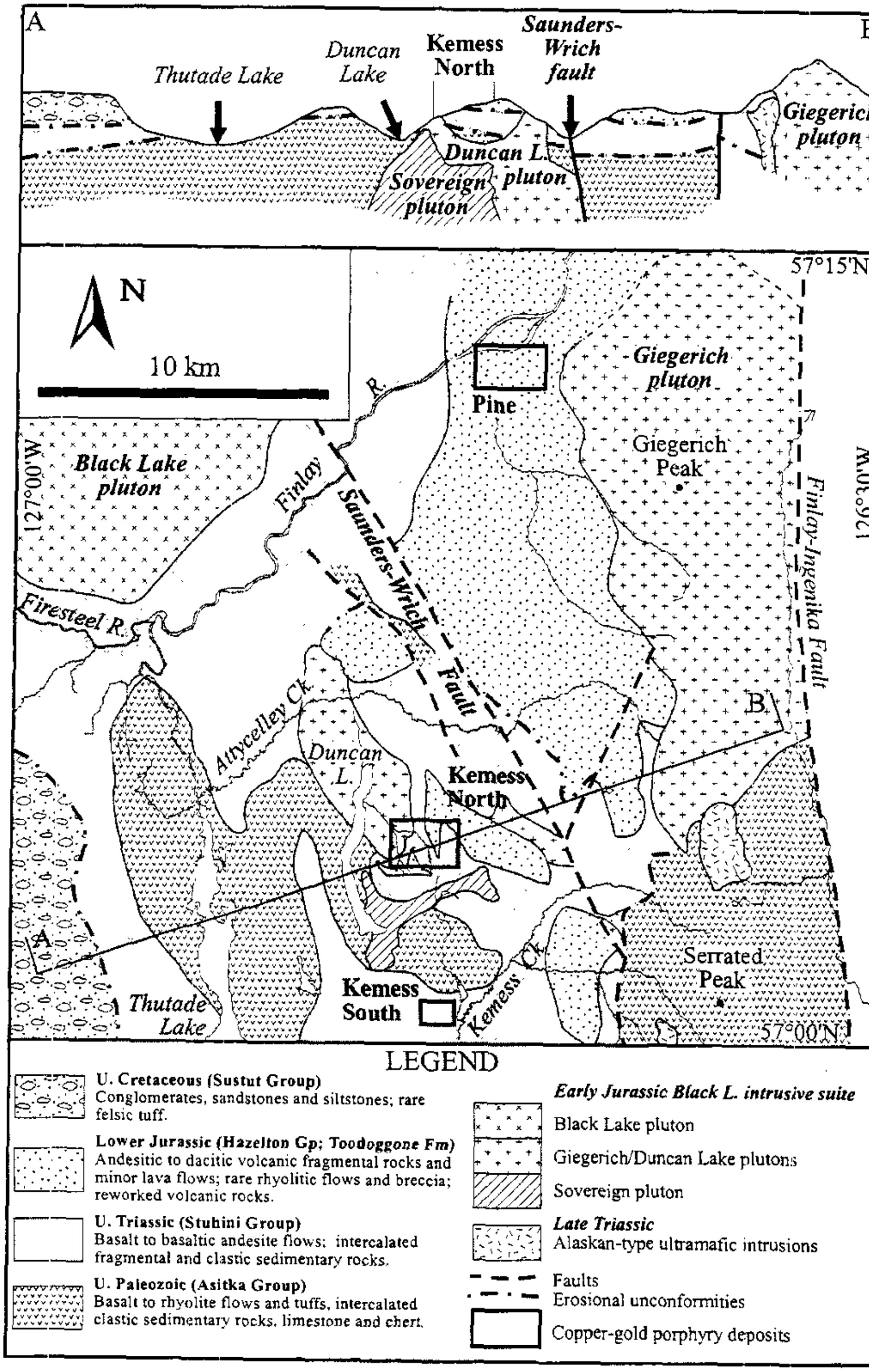


Figure 3. Generalized geology of the Attycelley Creek map area.

for this assemblage are clinopyroxene and plagioclase; the volcanic rocks are characterized by an absence of quartz phenocrysts. Plagioclase and augite are also the dominant detrital minerals in the immature clastic sedimentary rocks and frequently show subhedral crystal forms; this easily leads to misidentification of the rocks as volcanic flows, especially where lichen obscures sedimentary textures that are often visible on clean, weathered outcrops. Similarly, the monomictic nature of both matrix and clasts, together with the occurrence of very large clasts in massive breccias and conglomerates, may cause misidentification of these units as flows.

Basaltic flows in the Stuhini Group are typically dark green or greenish grey on fresh surfaces, maroon or dark green on altered surfaces and weather to a medium grey, grey-green or brown. The flows are commonly porphyritic, containing euhedral to subhedral phenocrysts of plagioclase and/or augite. Olivine is rare or absent. Either phenocryst phase may be as abundant as 15%, but total phenocryst content rarely exceeds 25%. Both phases are 1 to 3 millimetres and rarely exceed 6 millimetres in size. Tabular subhedral plagioclase is generally more abundant and commonly shows weak to moderate epidote alteration; euhedral to subhedral prismatic augite is characteristically very fresh, even in moderately altered rocks. Although traces of olivine may also be present in the phenocryst assemblage (Monger, 1977), these are partially or completely replaced.

Flows may be weakly to locally moderately vesicular; vesicles are subrounded to irregular, as much as 1 centimetre in size and may be partially filled with iron hydroxides. A distinctive lithology, characteristic of the Triassic rocks in the vicinity of Sustut Peak (Monger, 1977) also occurs in the present study area. It comprises lava flows containing large bladed phenocrysts of plagioclase. These are as much as 2 centimetres in length and as abundant as 25% of the rock. Augite phenocrysts are locally present. Monger noted that this rock type occurred as pillowed lava flows, as well as being represented by abundant fragments in volcanic-derived coarse clastic rocks elsewhere. Bladed plagioclase porphyry flows in the study area lack pillows, hyaloclastite or other evidence of hydromagmatic brecciation and are, moreover, very fresh. They are interpreted to be subaerial equivalents of the plagioclase-megaporphyritic pillow lavas to the south.

A large part of the Stuhini Group in the study area consists of coarse reworked volcanic material. This material comprises clasts and crystals derived almost exclusively from basaltic volcanic rocks and is included as the dominant component of massive breccias, cobble conglomerates and boulder conglomerates. Clasts are typically homolithic or monomictic, subrounded and as large as 50 centimetres across. These coarse fragmental rocks are matrix-supported or, less commonly, clast-supported. Matrix and clasts are difficult to distinguish except on clean, weathered surfaces. The rocks are interpreted as forming from reworked pyroclasticentimetresaterial or the distal, brecciated portions of basaltic lava flows. In either case, their large clast size and lack of sorting indicates that they are proximal.

Well-bedded sections of finer grained volcanogenic sedimentary rock are neither common nor laterally persistent in the area. Bedding is usually planar and graded bedding is common in the bedded sections. The composition of the finer grained clastic rocks is lithic arkose or wacke and feldspathic siltstone; quartz is rare. The wackes and siltstones are crystal-rich, often massive and show only vestigial rounding of crystal grains, resembling volcanic rocks. Near-aphanitic siltstones, except where bedded, resemble aphanitic basalts. The composition of the finer clastic rocks is lithic arkose or wacke; quartz is rare. The composition of the finer clastic rocks is lithic arkose or wacke; quartz is rare.

The thickest bedded section of Stuhini Group epiclastic rocks crops out on the east-facing slope of the Duncan Lake ridge. Two to three hundred metres of massive reworked volcanic material overlie a partially bedded section approximately 50 metres thick. The bedded section comprises massive to thinly bedded lithic arkose and thinly bedded to thickly laminated siltstone, immediately overlying a limestone-chert sequence of presumed Paleozoic age. The basal bedded units are volcanic sedimentary rocks and are overlain by coarse reworked volcanic fragmental rocks, with subrounded clasts of augite basalt as large as 25 centimetres, clast and matrix supported in a matrix rich in subhedral plagioclase crystals. The top of this unit was not observed, nor is the unit present on the west side of the ridge; either it is not laterally persistent or terminates against a fault.

Another well exposed section of Stuhini Group clastic volcanogenic sedimentary rocks is found on the banks of the Firesteel River, approximately 2 kilometres upstream from its confluence with the Finlay River. The section is about 100 metres thick and consists of relatively flat-lying thinly to medium bedded, graded, matrix-supported conglomerates and probable reworked lapilli tuffs intercalated with more massive cobble and boulder conglomerates. Overlying rocks consist of coarse augite-phyric basalts, sporadically exposed to the south of the river.

Argillaceous rocks rarely occur in the Stuhini Group in the study area; the finest-grained clastic rocks are usually siltstones. Southwest of the headwaters of Kemess Creek, on a ridge extending northwest from Serrated Peak, a black, thickly laminated pyritic shale unit, approximately 20 metres thick, underlies massive augite-bearing volcanic and subordinate clastic sedimentary rocks.

Rocks south of Attycelley Creek in the centre of the study area, which we assign to the Stuhini Group, have an upper unconformable contact with the basal member of the Toodoggone formation. The top of the Stuhini Group exposed in this area comprises approximately 150 metres of coarse clastic sedimentary rocks, including clast-supported boulder conglomerates containing clasts derived exclusively from the underlying Stuhini Group flows. Boulders are as large as 50 centimetres in diameter, most are subrounded to subangular. The matrix is distinctively maroon weathering; it contains grains of plagioclase and augite but quartz is absent, distinguishing these rocks from similar rocks in the Toodoggone formation, where quartz is ubiquitous.

A fragmental unit, locally marking the top of the Stuhini Group is exposed east of the Saunders-Wrich fault and south of Attycelley Creek. The unit is generally massive, with rare interbeds of normally graded coarse sandstone. It has a regional strike ranging from east-southeast to southeast and dips are moderate. The unit youngs to the northeast and is overlain by a Toodoggone conglomerate containing clasts of quartz-bearing dacite and grains of quartz in the matrix. This contact between the Stuhini Group and the Toodoggone formation is not well exposed.

A probable variant of the Stuhini Group is found to the south of Kemess Creek, in low country initially planned as the site for the Kemess South mill and also along Kemess Creek, immediately south of the Kemess South deposit. The two areas are separated by a low ridge that is underlain by massive augite-porphyritic basalt of the Stuhini Group. Rocks underlying the initial mill site area are highly friable, non-foliated and maroon-weathering volcanogenic fragmental rocks. Conglomerates containing plagioclase-phyric clasts are part of this unit; phenocrysts in clasts, or reworked subhedral grains in the matrix include 10-15% plagioclase, 1 to 4 millimetres in size. Both equant and elongate mafic phenocrysts are present in amounts as great as 10% in clasts and matrix. Complete replacement by chlorite is common, but subvitreous hornblende is present in some samples. The sequence contains, near its top, a non-calcareous fine-grained sandstone and siltstone unit of indeterminate thickness; neither top nor base are exposed. The unit is cream or pale green weathering, thinly bedded to thickly laminated and contains small delicate bivalves, at least one vertebrate fossil and plant debris. Rocks exposed along Kemess Creek are intensely oxidized and are interpreted as reworked pyroclastic units, containing subrounded pebbles or cobbles of plagioclase-porphyritic volcanic rocks. Clasts are monomictic, of similar composition to that of the friablematrix and both clasts and matrix contain relic subhedral plagioclase, partially replaced by zeolite.

Upper Triassic strata are regionally extensive and have been locally mapped in detail near Sustut Peak, south of the study area (Monger, 1977; Figure 2). Monger subdivided the Triassic stratigraphy into three formations. The basal Dewar Formation, comprises well-bedded volcanic sandstone, tuff and argillite; the middle Savage Mountain Formation, comprises augite and plagioclase porphyritic basaltic flows, volcanic breccias and minor volcanogenic clastic sedimentary rocks. In either formation, both the sedimentary and volcanic rocks are characterized by grains of augite and plagioclase. Overlying these units is the Moosevale Formation, it contains volcanic breccias and derived coarse clastic sedimentary rocks dominated by intermediate feldspar porphyry and augite basalt clasts. The sedimentary rocks contain diagnostic Triassic, late Carnian and early Norian, fossils.

The sections of augite- and plagioclase- phyric flows in the study area are correlated with Monger's (1977) Savage Mountain Formation because of the dominance of augite in the rocks. It is possible, however, that the basal, clastic sedimentary beds of this succession, which overlie the chert and limestone sequence west of Duncan Lake, correlate with the Dewar Peak Formation; finer grained lithologies are less common than in the type area but, as Monger notes, the Dewar Peak Formation is probably the distal, basinward equivalent of the Savage Mountain Formation, therefore a range of clastic sedimentary rocks will be present in the region. Units correlative with Monger's (1977) uppermost pyroclastic Moosevale Formation are either poorly represented or absent from the study area. Correlative rocks in the study area might be represented by the hornblende-bearing lithologies described above, in the initial mill site area and, friable volcaniclastic epiclastic rocks exposed along Kemess Creek.

The abundance of extremely coarse clastic sedimentary rocks, the lack of pillowed or hyaloclastic successions and the prevalence of maroon-weathering sequences suggest that most if not all the volcanism associated with the Stuhini Group in the study area was subaerial.

Jurassic Rocks

Lower Jurassic rocks underlie a northwest trending belt in the central part of the Toodoggone River map area. They are unconformable on volcanogenic rocks of the Upper Triassic Stuhini Group and in turn are overlain unconformably by continental sedimentary rocks of the middle and Upper Cretaceous Sustut Group. Part of the Jurassic succession in the Toodoggone River map area was mapped at 1:50 000 scale and subdivided into six members that comprise the Toodoggone formation (Diakow *et al.*, 1993); a stratigraphic division of the Hazelton Group. The Toodoggone formation records two major eruptive cycles separated by deposition of epiclastic rocks during local uplift and erosion of Triassic volcanic and earliest Jurassic plutonic rocks. The formation records subaerial arc volcanism in an extensional setting along the leading edge of the Stikine Terrane between 196 and 193 Ma.

Within the map area, Toodoggone stratigraphy is most complete south of the Finlay River, between the Saunders-Wrich fault and the Giegerich pluton. In this region, three, relatively flat lying members of the Toodoggone formation disconformably overlie a locally eroded surface on Upper Triassic strata. The Adoogacho member, which is the bottom of the formation, the Metsantan member, erupted at the end of the lower volcanic cycle, and the Saunders member, which comprises the uppermost division of the formation. In the immediate area of Attycelley Creek, a substantial thickness of pyroclastic rocks, conservatively estimated at greater than 500 metres thick, crop out between distinctive ash-flow tuffs units of the Adoogacho and Saunders members. However, because this volcanic pile is composed of numerous varieties of crystal-rich tuffs that exhibit only small compositional and mineralogic variations, it is difficult to subdivide the unit. Previously they have been mapped as the Attycelley member, however, this member is now considered to comprise a lower subdivision of the Saunders member. Together they record highly explosive eruptions that culminated volcanism of the Toodoggone formation. The Toodoggone formation apparently thins southwest of the Saunders-Wrich fault, where the uppermost, Saunders member rests directly on uplifted Upper Triassic volcanic rocks.

The unconformable contact that separates underlying Stuhini Group strata from some of the oldest rocks of the Toodoggone formation crops out at several localities in the vicinity of Kemess Creek. At the most southerly exposure of the Toodoggone formation, recessive, crumbly weathered reddish crystal-ash tuffs underlie a flat-topped plateau. The morphology of this plateau is believed to reflect a relatively thin capping of gently inclined bedded pyroclastic units from the basal Adoogacho member. Although there is a 10 metre gap in outcrop, underlying rocks of the Stuhini Group consist of aphanitic basaltic flows with moderate north dipping interbeds of calcareous siltstone and rare, thin, grey limestone. Rocks of the Adoogacho member are most widespread northeast of the Saunders-Wrich fault between Kemess and Attycelley creeks. They consist exclusively of fragmental rocks dominated by crystals admixed with lapilli-size accessory lithics and, in places, blocks. Thin, well bedded intervals with concentrations of crystal and lithic fragments may be due to reworking of the tuffs near their original site of deposition. Although most of the tuffs lack welding, there are weak to moderately welded zones that commonly form resistant bluffs, characterized internally by flattened and aligned pyroclasts.

Regionally, the Adoogacho member is sharply overlain by the Metsantan member. The Metsantan member is composed mainly of trachyandesite flows, intercalated debris flows, finer intraformational epiclastic beds, and some thinly bedded maroon ash and crystal tuffs. Rocks resembling the Metsantan member underlie a series of interconnected ridges southwest of Giegerich Peak. They cover an area of about 10 square kilometres, and are in fault contact with the western margin of the Early Jurassic(?) Giegerich pluton. Lava flows predominate. They are relatively homogeneous light grey-green andesites containing up to 35% phenocysts. The phenocrysts, listed in order of abundance, include: 20 to 30% subhedral plagioclase between 2 and 4 millimetres, 3 to 7% prismatic chloritized hornblende up to 6 millimetres long, scarce chloritized biotite, up to 3 millimetres in diameter, and rare quartz. A variety of epiclastic rocks and fine tuffs comprise sporadic crudely bedded intervals of variable thickness between the monotonous massive flows. The coarsest epiclastic deposits are typically unstructured and contain poorly sorted subangular and subrounded monolithic fragments up to one-half metre in diameter, that are derived from the enclosing andesite flows, supported by a matrix of plagioclase grains and mud. These deposits may have originated as debris flows, however, because there are conglomerate layers dominated by well rounded clasts and also interspersed sandstone and siltstone beds; they evidently attest to periodic reworking of loose debris mantling the flows. Tuff beds are uncommon, but those present consist of relatively thin, ash and crystal-rich varieties.

Strata of the Metsantan member apparently wedge out across a broad valley to the west and southwest from the main area of exposure. The most southerly outcrops of the Metsantan member are sporadically exposed on the lower, north-facing slope of the east trending ridge immediately north of Attycelley Creek. Here it is represented by cobble and boulder conglomerate composed of clasts that closely resemble the texture and composition of flows diagnostic of the Metsantan member. These deposits appear to pass topographically upwards into overlying tuffs assigned to the Attycelley member.

The Attycelley member, as stated previously, resembles conformably overlying rocks of the Saunders member in mineralogy and genesis; both are products of a presumably continuous explosive eruptive event. In this report, however, the Attycelley member is considered to be a subdivision of the Saunders member, comprising the lower of two divisions.

The lower division of the Saunders member is a heterogeneous succession of tuffs and reworked tuffs that crop out adjacent to the central part of Attycelley Creek. Locally they rest with angular discordance on a thick succession of bedded conglomerates and finer clastic rocks that directly overlie the Stuhini Group. Where the lower division is apparently thickest, north of central Attycelley Creek, it is conformably overlain by ash-flow tuffs characterizing the upper division of the Saunders member. Farther west and southwest, towards Duncan Lake and Kemess Creek, the lower division is absent, presumably due to a depositional pinch-out. However, ash-flow tuffs of the upper division apparently thicken, forming a resistant caprock directly overlying the Stuhini Group. In the vicinity of the Kemess North deposit, these rocks are intensely altered adjacent to the Early Jurassic Duncan Lake granodiorite.

The stratigraphic base of the lower Saunders division is locally exposed in the area northeast of the Saunders-Wrich fault between Attycelley and Kemess creeks. The contact is placed at the first occurrence of tuffs that locally have an angular unconformable relationship with the underlying oxidized red conglomerates, sandstone and siltstones that mark a major erosional surface developed on the Stuhini Group. The conglomerates along this paleosurface may be absent, in which case biotite and quartz-bearing tuffs of the lower division disconformably overlie pyroxene phyric flows of the Stuhini Group. Elsewhere correlative epiclastic rocks which are particularly well exposed locally along a northeast striking fault that intersects the Saunders-Wrich fault in the southwest, occupy an intact section more than 250 metres thick. It is composed of two lithologically distinct conglomeratic units. The lower conglomerate, approximately 30 to 50 metres thick, and massively bedded consists exclusively of red oxidized rounded clasts, some as large as 1.5 metres in diameter, in a relatively scant, but well indurated matrix. The clasts are predominantly basalts resembling those of the Stuhini Group, and include bladed feldspar porphyry, aphanitic and amygdaloidal varieties and pyroxene-plagioclase porphyry. This conglomerate is sharply overlain above a sharp disconformable contact by a sequence composed of planar bedded alternating conglomerates, sandstones and siltstones more than 175 metres thick. This sequence is distinguished from the lower conglomerate by its pronounced stratification and the ubiquitous presence of small amounts of quartz, with or without biotite in both the fragmental volcanic clasts and the matrix. Typically the clasts are well rounded, ranging from granules to cobbles and rarely up to 2 metres across. They are dominantly crystal tuffs and lithic-rich tuffs similar to rocks of the Toodoggone formation. Near the base of the upper conglomerate, rare reworked clasts of the underlying Stuhini Group conglomerate are present. Large boulders are sometimes concentrated in lenses that occupy broad channels cut into the underlying planar beds. The conglomerates are generally poorly sorted, alternating or grading upwards into finer grained clastic beds. The upper contact of this sedimentary section is a profound angular unconformity locally with fragmental rocks of the lower Saunders division.

Between Attycelley and Kemess creeks, the lower division of the Saunders member is predominantly recessive, dark grey-green to maroon lapilli tuff, crystal-lithic tuff, tuffite and a subordinate volume of volcanic breccia. Lava flows are virtually absent from the succession. Most of the rocks are rich in crystals, dominated by plagioclase with much less abundant hornblende, biotite and quartz. In rocks containing both mafic minerals, hornblende generally exceeds biotite and together they may account for 5 to 7 volume percent of the rock. Quartz in the rock rarely exceeds 3 volume percent; typically it forms angular grains 1 to 2 millimetres in diameter. Lithic fragments are commonly of lapilli size and make up less than 20 volume percent of most tuffs. They consist mainly of brick red-brown aphanitic and green to maroon porphyritic andesites. The porphyritic fragments generally contain either hornblende or biotite and quartz, and most are dacitic. Rare bedding in the tuffs is generally defined by a change in pyroclast volumes or a variation in grain size, or, in some instances, incipient welded textures. Epiclastic interbeds locally provide superb stratigraphic markers within the monotonous tuffs. For example, south of central Attycelley Creek an interval of volcanic sandstones, siltstones and fine grained conglomerate 30 metres thick is traceable continuously for about 4 kilometres.

The recessive, crudely bedded friable tuffs of the lower division readily distinguish it from more competent, cliff-forming ash flows of the upper division. The contact between divisions is abrupt and best observed north of central Attycelley Creek. There tuffs of the lower division form pink weathering scree capped by ash-flow tuffs of the upper division which form craggy cliffs. Regionally the ash-flow tuff appears to be a single homogeneous cooling unit which is characterized by uniform incipient welding and devitrification that weathers to yield well indurated angular blocks. The rock is dacitic, composed of 30 to 35% broken crystals and comparatively few lithic clasts. The crystals include plagioclase, sanidine, hornblende, biotite and quartz in varying proportions; most are 2 to 4 millimetres in diameter. Quartz, one of the more diagnostic components in the ash flow is commonly resorbed or bipyramidal; abundance varies from 1 to 7 volume percent. The grey-green groundmass of the rock is composed of a fine grained anhedral quartz and feldspar, formed as product of devitrification, along with vestiges of primary glass fragments devitrified to coalescing spherulites. The "classic grey dacite", as it is called in the field, contains cognate vitrophyric pyroclasts which are typically compressed to define a distinctive compaction fabric in the ash flows. Moderately welded rocks containing these fragments crop out mainly north of central Attycelley Creek. In less welded exposures to the west and southwest accidental lithic pyroclasts predominate, consisting mainly of basaltic lithologies derived from the Stuhini Group and lesser pink granitoids. The lithic fragment have subrounded to subangular outlines, form blocks up to one-half metre in diameter and occur in concentrations that range from sporadic to up to 30% of the rock. Rare bedded sandstones and siltstones conformably overlie the upper division These were seen at a single locality on the southwest side of the Saunders-Wrich fault, at Kemess Creek. Detritus in these rocks suggest a nearby Toodoggone formation source.

The range of isotopic ages determined for the Toodoggone formation are summarized in Diakow *et al.*, (1993). Within the study area, previous K-Ar dates indicate the duration of volcanism extended from roughly 204 to 182 for the Adoogacho and upper division of the Saunders member, respectively. Subsequent $^{40}Ar/^{39}Ar$ dating compressed this timing somewhat to 196 and 193 Ma. Additional samples have been collected to better determine the onset of Saunders volcanic activity and to constrain the duration of an Early Jurassic erosional event which separates the two discrete volcanic cycles that regionally comprise the Toodoggone formation.

MAJOR INTRUSIONS

Figure 2 shows the regional distribution of Mesozoic intrusions along the eastern margin of Stikinia and adjacent Quesnellia. The economic importance of these suites is illustrated by their association with copper-gold porphyry deposits. Known mineralized prospects include the Mount Milligan deposit (299 Mt; 0.45 g/t Au; 0.22% Cu; Sketchley *et al.*, 1995), the Lorraine deposit (10 Mt; 0.34 g/t Au; 0.7% Cu; Bishop *et al.*, 1995) and, in the study area, the Kemess South (200 Mt; 0.63 g/t Au; 0.224% Cu) Kemess North (no mineral inventory; Rebagliati *et al.*, 1995a) and Pine (40 Mt; 0.57 g/t Au; 0.15% Cu) deposits (Rebagliati *et al.*, 1995b).

The Kemess and Pine deposits are associated with Early Jurassic (*ca.* 202 to ~190 Ma) calc-alkaline intrusions of the Black Lake intrusive suite, which cut Triassic and older strata along the eastern margin of Stikinia (Woodsworth *et al.*, 1992). Diakow *et al.* (1993) described the Black Lake stock as a pink granodiorite to quartz monzonite with coarse to medium grained hypidiomorphic-granular texture. Modal mineralogy of the rock comprises plagioclase, orthoclase, quartz, hornblende and biotite with accessory apatite, zircon and magnetite. The important Kemess South copper-gold porphyry deposit is associated with a monzonitic intrusive body, the Maple Leaf intrusion, of presumed Early Jurassic age. The Kemess North porphyry deposit occurs between the Duncan Lake pluton and the Sovereign pluton; intrusive bodies of similar composition. The absolute ages of these intrusions is integral to interpreting the age of mineralization and alteration at Kemess North. By contrast, copper-gold porphyry mineralization at the Mount Milligan and Lorraine deposits to the south occurs in alkaline intrusions, at or near the western margin of Quesnellia (Figure 2; McMillan *et al.*, 1995). Mount Milligan is hosted by small monzonite intrusions that yield U-Pb dates of about 182 to 183 Ma. (Sketchley *et al.*, 1995). Like Mount Milligan, the Lorraine deposit (Bishop *et al.*, 1995) is associated with alkalic intrusions which are phases of the Hogem batholith, an intrusive complex that yields Early Jurassic to Early Cretaceous radiometric dates (Garnett, 1978).

Giegerich Pluton

The Giegerich pluton is a dominantly granodioritic intrusion which forms craggy topography throughout the north-eastern part of the study area. Many smaller intrusions in the study area have very similar texture and modal mineralogy, but there is no evidence to indicate that they are comagmatic. Stock and batholith-size intrusions have apparently intruded structurally prepared country rocks, indicated by elongate bodies with steeply dipping faulted contacts.The Giegerich pluton itself cuts Stuhini Group sedimentary and volcanic rocks in this area (Figure 3). The trend of the contact is rectilinear, with alternating 020° and 140° azimuth orientations, progressing northward; these directions are subparallel to the general trends of regional fault sets, the latter direction typified by the Saunders-Wrich fault. Faults with these trends host and may have, to some extent, channelled mineralizing fluids. Rebagliati *et al.* (1995b) noted a northeasterly elongation of an induced polarization anomaly on the Pine property, interpreted as the effect of a northeasterly trending fault, approximately 1.5 kilometres from the margin of the Giegerich pluton.

The Giegerich batholith is an homogeneous biotite-hornblende granodiorite. The rock is typically equigranular, with a grain size of 2-3 millimetres. It contains 10-15% mafic minerals, dominantly subhedral hornblende and subordinate, euhedral to subhedral biotite. Subhedral plagioclase forms as much as 15% of the rock; crystals are as large as 5 millmetres. The equigranular interlocking groundmass consists of 30% plagioclase, 15% intersertal potassium feldspar and as much as 10% intersertal quartz. A more mafic, finer grained rock contains as much as 30% anhedral hornblende and is a possible border phase. Texturally and compositionally, the intrusion is very similar to the Black Lake stock, north of the Finlay River. The intrusion is unfoliated, except along its western contact, where aligned hornblende crystals locally define a weak fabric that is commonly perpendicular to the orientation of the contact.

A sample of granodiorite collected near the centre of the pluton is being analysed for a U-Pb zircon date.

Duncan Lake Pluton

The area immediately east and west of the northern end of Duncan Lake is underlain by intrusive rocks very similar in texture and composition to that of the Giegerich pluton. The Duncan Lake pluton apparently extends northward, across the valley of Attycelley Creek; exposed below treeline on the southwest facing slope of a mountain. The pluton is faulted against Paleozoic rocks west of Duncan Lake and to the east, the intrusion appears to plunge southeastward beneath the Kemess North deposit; altering adjacent dacitic ash-flows that form the stratigraphic top of the Lower Jurassic Toodoggone formation. Similar alteration in both the intrusion and the Jurassic country rocks, co-spatial to the deposit, suggests the mineralizing hydrothermal fluid system may be a syn to post 193 Ma event. This event is inferred from previously published K-Ar and $^{40}Ar/^{39}Ar$ dates determined for cooling of the Duncan Lake pluton (Cann and Goodwin, 1980) and crystallization of correlative ash-flow tuffs (Diakow et al., 1993). During this study samples from both the Duncan Lake pluton and the ashflows were collected for U-Pb zircon age determinations in order to refine the timing of events at Kemess North.

The Duncan Lake stock is an homogeneous, equigranular to weakly porphyritic hornblende-biotite granodiorite that weathers to crumbly talus with a distinctive salmon pink to sandy brown colour. It is composed of 40-45% subhedral tabular plagioclase; including rare phenocrysts up to 7 millimetres long, 10-15% subhedral prismatic hornblende, with rare phenocrysts as large as 7 millimetres, and 5-10% subhedral to euhedral, tabular to prismatic biotite that form rare phenocrysts as large as 6 millimetres. The mafic minerals usually do not exceed 20% of the whole rock and although they appear to be first-formed, smaller hornblende crystals are also intergrown with plagioclase. The mafic minerals are commonly replaced by felted aggregates of chlorite; less commonly, plagioclase is partially epidotized. Intersertal phases consist of 15-20% white potassium feldspar and 5-10% grey quartz. Trace amounts of prismatic apatite and 5-10% microcrystalline magnetite occur in the groundmass of the granodiorite.

Sovereign Pluton

The Sovereign pluton crops out sporadically to the south of the Kemess North deposit. It is a hornblende-biotite granodiorite with a U-Pb date of 202.7 +1.9 -1.6

Ma. (J.K. Mortensen, personal communication, 1996). The age of this intrusion is important because of altered and mineralized rocks of the Saunders member (*ca.* 193 Ma) adjacent to the Kemess North deposit. This suggests that the mineralizing episode may be unrelated to the Sovereign intrusion or possibly, there are overprinting hydrothermal events. The Sovereign intrusion is unaltered except for a moderately strong envelope of epidote and pyrite alteration present near its intrusive contact with volcanic rocks of the Stuhini Group.

The composition of the Sovereign pluton is very similar to that of the Giegerich and Duncan Lake intrusions, described above. The rock is porphyritic and light brownish grey on fresh surfaces, weathering to light brown or beige. Phenocrysts comprise 25-30%, 1 to 6 millimetre subhedral plagioclase; 5-10%, 1 to 4 millimetre subhedral to doubly terminated quartz, and 10% euhedral to subhedral hornblende and biotite. Potassium feldspar occurs entirely as a microcrystalline phase in the groundmass.

The only significant petrographic difference apparent in hand specimen between the Sovereign pluton and the Giegerich and Duncan Lake intrusions is the presence of quartz phenocrysts in the former; quartz also occurs in abundance in the other intrusions; but, as an intersertal phase. The possibility of a comagmatic origin cannot therefore be rejected on the basis of modal mineralogy alone. The chemical variations and petrogenesis of the three intrusions lie outside the scope of this report, but Cann and Godwin (1980) noted that the single sample taken from the quartz-phyric Sovereign pluton did not lie on the Rb-Sr isochron obtained for the Duncan Lake stock, strongly suggesting that the Sovereign pluton is part of a discrete isotopic and chemical system.

Maple Leaf Sill at the Kemess South Deposit

The Kemess South deposit is hosted by the Maple Leaf sill, which intrudes Stuhini Group volcanic rocks. The intrusion is completely covered by overburden, encountered only in diamond drilling. Rebagliati *et al.* (1995a) describe the Maple Leaf intrusion as a plagioclase-porphyritic quartz monzodiorite to quartz monzonite, containing 40-60% plagioclase, 5-10% potassium feldspar, and 5-15% quartz, and, with scarce mafic minerals and accessory sphene, rutile, zircon and apatite.

The intrusion from the hypogene ore test pit, located at the eastern margin of the orebody was sampled for zircons and a U-Pb age determination. The sampled rock displays strong replacement of original minerals by aphanitic potassium feldspar. Because of the intensity of alteration primary textures in the supposed plutonic rock are obscured and, in places the mineralized rock resembles sparsely quartz-phyric volcanics of the Toodoggone formation.

Quartz Monzonite North of Serrated Peak

Near Serrated Peak a quartz monzonite intrusion, which is coarser grained and more potassic than other plutons in the study area, forms an elongate body with subvertical faulted contacts that are roughly parallel to the Finlay-Ingenika fault, immediately to the east. The western margin is a steep, north trending fault which brings the intrusion against a foliated, amphibolite grade metavolcanic border to an Alaskan-type hornblende gabbro stock. The eastern margin is also a steeply dipping fault that juxtaposes the intrusion against a greenstone-chert-limestone sequence of probable Paleozoic age. These faults are evident as distinct linear features on airphotos.

The rock is coarse grained, equigranular and non-porphyritic. Mottled purplish pink and grey on fresh surfaces, it weathers to pale pink or white. All mineral phases are anhedral with a grain size of 3 to 5 millimetres in interlocking non-foliated fabric. They comprise 45-50% plagioclase, 30-35% potassium feldspar, 10-15% quartz and 2-5% chloritized hornblende. Weak, to locally moderate pervasive epidote alteration is present near the contacts.

The quartz monzonite is intruded by two types of dikes. Most are between 2 and 20 metres wide, but on the ridge immediately north of Serrated Peak, a dike is up to 100 metres wide. The older phase of dikes are porphyritic; phenocrysts comprise 25-30% subhedral plagioclase between 3 and 6 millimetres in diameter, 5-10% subhedral hornblende between 1 and 2 millimetres and several percent chloritized biotite. In turn these dikes are locally cut by weakly augite-porphyritic to aphanitic basaltic dikes up to 1.5 metres in diameter. Isotopic age measurements are not available for the quartz monzonite, but we speculated it may be as young as Cretaceous.

Hornblende Gabbro and Hornblende-Biotite-Olivine Clinopyroxenite Near Serrated Peak

Coarse grained mafic and ultramafic rocks that closely resemble Alaskan-type ultramafic bodies intrude Stikinian Upper Triassic and Paleozoic rocks 4 kilometres to the north and on a ridge 2 kilometres southwest of Serrated Peak (Figure 3). The northernmost and larger of these mafic plutons underlies an area greater than 2 km^2. It comprises coarse to medium-grained hornblende gabbro, composed of anhedral plagioclase occupying irregular interstices between randomly oriented subhedral to euhedral prismatic hornblende phenocrysts. Grain size is usually between 2 and 4 millimetres, but an almost pegmatitic variant of the pluton contains hornblende phenocrysts as long as 6 centimetres. The southern and southwestern parts of the pluton are in intrusive contact with amphibolite facies metavolcanic rocks. Based on the preponderance of pyroxene-bearing mafic flows and sparse, coarse bladed plagioclase phyric flows in the metavolcanic assemblage bordering the pluton, the protolith is believed to be the Upper Triassic Stuhini Group.

The mafic intrusion exposed at the southern locality may underlie a much larger area, since it was only briefly examined along the crest of a northwest trending ridge. On this ridge, the northwest contact appears to be a steep fault with a chert-limestone-argillite succession of probable Paleozoic age. Amphibolite facies metavolcanic rocks, similar to those described above, locally form a narrow border to the intrusion. The intrusion is classified as wehrlite, comprising 50-55% anhedral to subhedral clinopyroxene, 20% relict olivine and up to 30% antigorite, pseudomorphous after the olivine. Biotite is present as minute grains ranging from trace to 2%. Grain size is approximately 4 millimetres.

DIKES

Dikes of mafic to felsic composition are more commonly solitary, although swarms may be present, particularly near the northwest margin of the Giegerich pluton. Most of the dikes have either a northwest or northeast trend and dip steeply, parallel to the main structural fabric of the study area. The dikes are grouped roughly on their bulk composition and/or phenocryst assemblage.

Feldspar ±Quartz Porphyry

Volumetrically, feldspar porphyry dikes, with or without quartz phenocrysts are the most common small intrusion and bear a strong resemblance to larger granodiorite plutons (*e.g.*, Giegerich, Duncan Lake and Sovereign) in the map area. The density of these dikes is highest cutting the Toodoggone formation near the northwestern contact of the Giegerich pluton and transecting ridges underlain by the Stuhini Group east and southeast of the Kemess North deposit. In both areas they typically intrude along vertical extensional faults that trend northwest.

The dikes are typically light pink to red and vary in width from 1.5 to 8 metres. Phenocrysts comprise up to 35 volume percent of the rock, dominated by subhedral plagioclase 2 to 6 millimetres in diameter. Two to seven percent subhedral hornblende up to 6 millimetres long and several percent biotite, averaging 2 millimetres in diameter, are nearly always present and partly replaced by chlorite. Potassium feldspar is found locally as scarce phenocrysts. Quartz, which commonly occurs as small sparse phenocrysts, may locally be present as grains averaging 3 millimetres in diameter, in volumes up to 7%.

Basaltic Dikes

Dark green basaltic dikes consist of aphanitic and porphyritic varieties that locally cut the feldspar-quartz porphyry dikes. Typically they are narrow, between 0.5 and 2 metres wide and intruded along structures with general trends of 030° and 140° azimuth. Porphyritic dikes characterized by euhedral augite phenocrysts intrude the Paleozoic and Upper Triassic sequences. Because of the close mineralogic resemblance of these dikes to augite phyric flows of the Stuhini Group they may represent feeders for the basaltic volcanism. The youngest mafic dikes have an aphanitic texture and locally intrude strata of the Toodoggone formation. They are aphyric with plagioclase microlites and a chloritized mafic phase which was probably small anhedral augite.

Megaphyric Quartz Porphyry

Dikes containing conspicuous quartz phenocrysts as large as 1.5 centimetres in diameter are exposed in the cirque headwall south of the Kemess North deposit, immediately to the north of the Kemess South deposit, and at two isolated localities near the northern end of Thutade Lake, and along the Firesteel River. With the exception of the dike at Thutade Lake which is about 15 metres wide, dikes at the other localities vary from 30 metres to more than 100 metres wide. The rock contains as much as 20% subhedral grey quartz phenocrysts in a pale grey or pale green porcellaneous groundmass.

The largest of these intrusives near Kemess North intrudes along a fault that separates ash-flow tuffs of the Toodoggone formation from bladed plagioclase-phyric and clinopyroxene phyric basalts of the Stuhini Group. The dike is mineralized with as much as 5% disseminated pyrite and is locally pervasively epidotized which suggests that it predates mineralization at Kemess North, but postdates some northerly faults that may have channelled the mineralizing solutions.

STRUCTURE

Structures within the map area are dominated by a system of high-angle normal faults, and possibly contractional faults that are mapped mainly in the vicinity of Serrated Peak. The magnitude of motion on most faults is believed to be minor. Minor dislocations within solitary map units are indicated by abrupt changes in bedding attitudes and lateral discontinuity of lithologically distinct rocks. The most prominent high angle faults trend between 120° and 150° azimuth with conjugate sets of secondary faults trending from 20° to 40° and 60° to 80° azimuth. This pattern of faulting is documented regionally in the Toodoggone River map area where it has locally imparted primary control on the deposition and distribution of the Lower Jurassic Toodoggone formation, aided high-level emplacement of comagmatic plutons and provided sites for precious metal-bearing epithermal deposits (Diakow *et al.*, 1993).

Several major faults in the map area are associated with topographic lineaments, as in the case of the Saunder-Wrich fault. The Saunders-Wrich fault is a regional-scale structure traceable imtermittantly for over 30 kilometres northward to the Toodoggone River valley and possibly beyond (Diakow *et al.*, 1993). South of the Finlay River this structure coincides with three valleys aligned to the northwest but separated by Attycelley and Kemess creeks. This fault places the youngest rocks of the Toodoggone formation against Upper Triassic and older strata. Similar granodiorite bodies exposed across the fault near Kemess Creek are interpreted to represent displaced segments of a solitary intrusion. If this assumption is correct, up to 4 kilometres of right lateral strike-slip movement is indicated. The southeastern extent of the Saunder-Wrich fault presumably occurs at an inferred intersection with a younger thrust fault(?)west of Serrated Peak that carries Permian and Triassic rocks and places them against the Toodoggone formation. This is contrary to an earlier interpretation (Diakow *et al*, 1993), in which the trace of the Saunders-Wrich fault was extrapolated to the southeast through the valley southwest of Serrated Peak and beyond, to its terminus at the northerly trending Finlay-Ingenika fault.

Other important northwesterly trending faults are mapped along the cirque headwall of the Kemess North deposit. Here steeply dipping faults with slickenslides that indicate dip-slip movement place locally intensely oxidized and altered rocks of the Stuhini Group against comparatively unaltered rocks of the Toodoggone formation. Steep faults oriented towards the northeast are also numerous in the map area; however, their timing relative to the northwest faults is generally ambiguous, suggesting periodic reactivation of one or the other structures.

Together these more or less orthogonally oriented extensional faults provide structural control for a variety of intrusive rocks in the map area. There importance as a fundamental control for larger plutons is exemplified by the Giegerich pluton. The western contact of this pluton is essentially an interconnected series of steeply dipping faults juxtaposed with slivers of the Stuhini Group, which in turn are faulted against more widespread stratigraphic units of the Toodoggone formation. The contact displays a pronounced rectilinear configuration that approximates the regional structural fabric. Moreover, this inherent control in the country rocks bordering the pluton is manifest in local dike swarms of pink, feldspar phyric, with of without, quartz porphyry and aphanitic basalt, which maintain a consistent northwest trend.

Prominent north striking faults delimit the eastern margin of the Giegerich pluton and juxtapose it against presumably younger quartz monzonite and Paleozoic strata near Serrated Peak (Gabrielse *et al.*, 1977). These faults represent probable en echelon strands of the right lateral strike-slip Finlay-Ingenika fault system. The Finlay-Ingenika fault presumably coincides with the broad valley trending north, in part, along the eastern margin of the Giegerich pluton and, farther north, along the north flowing segment of the Finlay River. It marks a tectonic boundary along the eastern side of the study area that separates mainly brittly deformed, zeolite grade rocks in Stikinia to the west from penetratively deformed greenschist to amphibolite grade rocks in Quesnellia and ancestral North America to the east. Movement along this and other interconnected major right-lateral faults in the northern Canadian Cordillera occurred in Cretaceous and Early Tertiary time (Gabrielse, 1985).

Paleozoic and Triassic rocks, near Serrated Peak, comprise a structural panel apparently thrust locally to the west-northwest onto relatively flat lying Lower Jurassic rocks of the Toodoggone formation. Axial planes in locally folded Lower Permian(?) chert generally trend to the northeast, and dip moderately to the southeast. Bedding attitudes in the hanging wall strata vary markedly, disrupted by numerous high-angle faults that strike to the northeast, subparallel to a prominent regional set of older extensional faults. The outcrop area of the Adoogacho member of the Toodoggone formation narrows south of Kemess Creek, possibly the consequence of local contraction faults.

COPPER-GOLD PORPHYRY DEPOSITS

Copper-gold porphyries related to Early Jurassic plutons are the principal exploration target in the study area and along the tract of Mesozoic arc volcanic and plutonic rocks that extend southeastward into the McConnell Range. The Kemess South and Kemess North deposits are significant examples of this style of mineralization and both deposits are located within the study area. A history of development of the deposits is described in detail by Rebagliati *et al.* (1995a); a brief synopsis of these deposits is given here in addition to observations made during this study.

Kemess South (MINFILE 94E 094)

The Kemess South deposit consists of a supergene zone, containing native copper in a hematite-rich hostrock and hypogene ore zone, with pyrite, chalcopyrite and minor molybdenite lining fractures in variably clay altered and potassium enriched rocks.

The deposit is hosted mainly by the Maple Leaf monzodiorite sill which underlies an area of about 2 square kilometres, but is concealed by a thin veneer of glacial till. The sill is 75 to 175 metres thick in the vicinity of the deposit, with a base that is gently undulose in its eastern part and gently inclined towards the southwest at its western edge. To the south it thins to less than 30 metres and to the north the North Block Fault truncates and juxtaposes the sill against probable Paleozoic chert and argillite overlain by Stuhini Group volcanic rocks. Further study of the fault and its motion is integral to future exploration for a possible northern extension of the ore body.

Rocks exposed in the hypogene test pit, located near the eastern edge of the orebody contain subtle quartz phenocrysts, which has led to the possible presence of altered and mineralized volcanic rocks resembling the Toodoggone formation. The closest rocks of the Toodoggone formation are exposed 5 kilometres north at the Kemess North deposit. They are sparsely quartz phyric ash-flow tuffs which represent the stratigraphic highest unit of the Toodoggone formation that yields Ar-Ar dates of about 193 Ma, elsewhere to the north. Uranium-lead zircon geochronometry on a sample from the hypogene zone will provide a relative age date for mineralization at the Kemess South orebody and test its contemporaneity with intrusive and mineralizing events at Kemess North.

Chert-bearing clastic sedimentary rocks of the Cretaceous Sustut Group, exposed as a thick succession west of the study area, may have extended to cover the Kemess South deposit, but no supporting field evidence was found during the course of the study. Our work indicates that the hanging wall strata exposed to the south of the deposit are friable maroon weathering volcanic rocks, covered to the south and west by progressively greater thicknesses of Pleistocene fluvioglacial boulder- and cobble-bearing gravels.

Kemess North (MINFILE 94E 021)

The Kemess North porphyry prospect is six kilometres north of the Kemess South deposit. Copper and minor molybdenum mineralization is centred on a northeast trending swarm of porphyritic dikes of intermediate composition concealed by a broad gossan which lies along the periphery of two isolated granodiorite intrusions that locally cut and alter volcanic rocks of the Stuhini Group and Toodoggone formation.

The gossan is crudely defined by an oxidized halo with pyrite and inner , alternating argillic and phyllic zones, dominated by clay minerals, quartz, sericite and pyrite. Pervasive alteration has overprinted all primary minerals in the country rocks near the deposit. The Stuhini Group volcanic and sedimentary rocks are moderately to strongly epidotized and chloritized, and have patchy areas of complete replacement by fine-grained grey silica. The altered Toodoggone volcanic rocks contain pervasive argillic and phyllic alteration but can still be distinguished by their infrequent quartz phenocrysts. To the south, the alteration becomes patchy in Stuhini and Toodoggone rocks underlying the headwall of the Kemess North cirque and to the north, an area of poor exposure separates the alteration zone from the Duncan Lake stock.

The Sovereign pluton located south of the deposit has a U-Pb zircon age of 203 Ma. Emplacement of this intrusion may predate the hydrothermal event at Kemess North. Hornblende-biotite granodiorite of the younger(?) Duncan Lake stock is exposed to the north of the deposit. It apparently plunges southeastward beneath the mineralized zone and gossanous country rocks. The Duncan Lake intrusion yields a Rb-Sr isochron date of 190±4 Ma, which is interpreted as the time of cooling and hydrothermal alteration (Cann and Goodwin, 1980). The Saunders member of the Toodoggone formation is about 193 Ma old and the dacite is pervasively altered and locally mineralized with chalcopyrite near the deposit. Field relationships coupled with geochronology indicate that hydrothermal alteration and hypogene mineralization events at Kemess North postdate deposits of the Toodoggone formation, supporting the contention of Cann and Goodwin (1980) for a circa 190 Ma mineralizing event.

SUMMARY

Regional mapping in the Attycelley Creek map area documents three main lithostratigraphic successions. The oldest unit, widely exposed between Thutade Lake and the Kemess minesite, consist of probable Upper Paleozoic chert, limestone, basaltic and rhyolitic volcanic rocks. Upper Triassic augite phyric volcanic and associated sedimentary rocks of the Stuhini Group are extensively exposed but remain undivided; they represent mainly subaerial deposits. Lower Jurassic volcanic rocks of the Toodoggone formation unconformably overlie Upper Triassic strata. They are readily distinguished by fragmental dacitic volcanic rocks containing quartz,with or without, hornblende and biotite. The distribution of the Toodoggone formation narrows to the south where they locally appear to be overridden by a west-northwest verging thrust fault carrying Paleozoic and Upper Triassic rocks in the hangingwall. Elsewhere in the map area the structural fabric is defined by prominent high-angle extensional faults trending northwest and conjugate structures trending north-northeast.

Copper-gold porphyry mineralization is associated with an Early Jurassic plutonic suite of granodiorite to monzonite composition. The Maple Leaf intrusion, a sill-like body which hosts the Kemess South deposit, intrudes probable Upper Paleozoic chert and Upper Triassic volcanics, the latter locally form a deeply weathered profile gradational at depth into supergene ore. The protolith of potassically altered and mineralized country rocks, exposed in the hypogene ore test pit, at the eastern margin of the deposit may be correlative with the Toodoggone formation. The Kemess North deposit is situated between two granitic bodies, the Duncan Lake granodiorite and the Sovereign granodiorite. Field relationships suggest that the Duncan Lake stock may be younger, altering the youngest, Saunders member of the Toodoggone formation near the main zone of mineralization. U-Pb zircon dating of the various plutons is in progress.

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EVIDENCE FOR EARLY TRIASSIC FELSIC MAGMATISM IN THE ASHCROFT (92I) MAP AREA, BRITISH COLUMBIA

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(MDRU contribution 81)

KEYWORDS: U-Pb geochronology, geochemistry, Early Triassic, tonalite, rhyolite crystal tuff, tholeiitic, REE, Kutcho Assemblage, Nicola Group

INTRODUCTION

This report presents U-Pb geochronology, and major, trace and rare earth element data for a package of felsic to intermediate composition volcanic and intrusive rocks. These rocks, previously correlated with the Nicola Group, occur within the western portion of the Ashcroft (92I) map area in southwestern British Columbia (Figure 1).

Rocks examined in the current study include silicic ash and crystal tuffs, and an intrusion of dioritic to tonalitic composition. These units are lithologically similar to volcanic rocks of the Kutcho Assemblage and contemporaneous plutonic bodies which intrude the Kutcho Assemblage, 950 km to the north (Marr, pers. comm., 1995; Childe and Thompson, 1995b). The objectives of this study were to obtain precise age and geochemical data for these rocks, to determine if they could represent an offset portion of the Kutcho Assemblage.

NICOLA GROUP

The Nicola Group is a Late Triassic to Early Jurassic island arc assemblage within the Quesnel terrane. It is comprised of submarine to subaerial, predominantly mafic volcanic and volcaniclastic rocks, their intrusive equivalents and associated clastic and chemical sedimentary rocks (Preto, 1977; Monger *et al.*, 1991). The Nicola Group has been broadly divided into western, central and eastern belts on the basis of lithology and lithogeochemistry (Mortimer, 1986; Monger *et al.*, 1991). Variation from calc-alkaline to shoshinitic compositions from west to east has been interpreted to reflect eastward dipping subduction in the Nicola arc (Mortimer, 1986).

Mafic and lesser felsic volcanic and intrusive rocks previously assigned to the western belt of the Nicola Group have been mapped in the Ashcroft (92I) and Hope (92H) map areas by Preto (1977), Grette (1978), Travers (1978), Shannon (1982), and Monger and McMillan (1984).

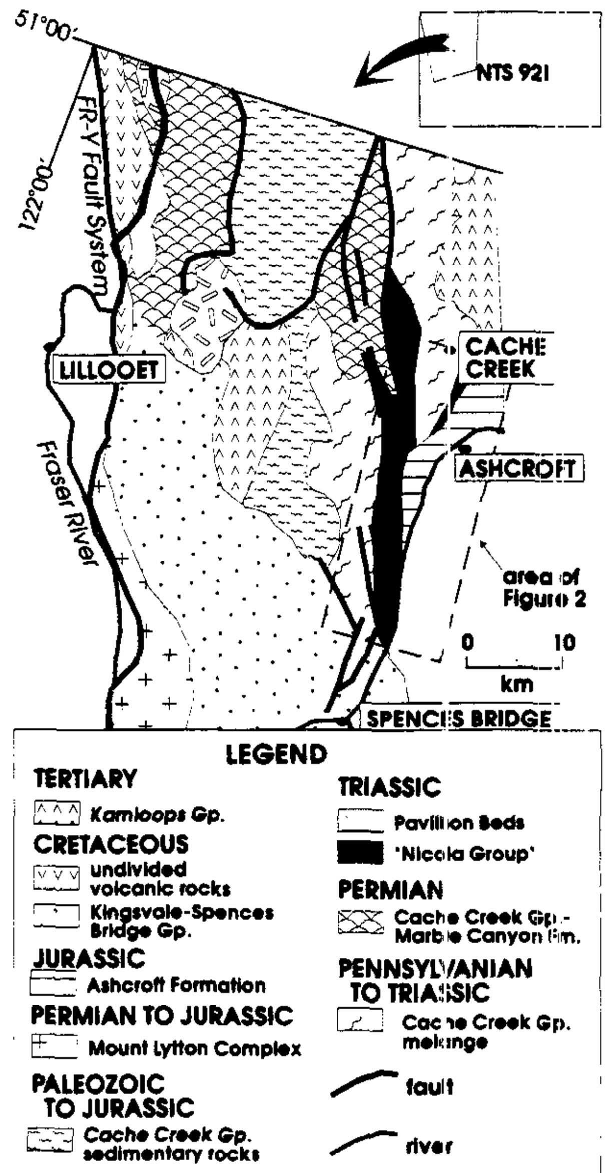

Figure 1. Generalized geology between Lillooet and Ashcroft, the outlined area is detailed in Figure 2 (FR-Y = Fraser River - Yalakom); (modified from Monger et al., 199).

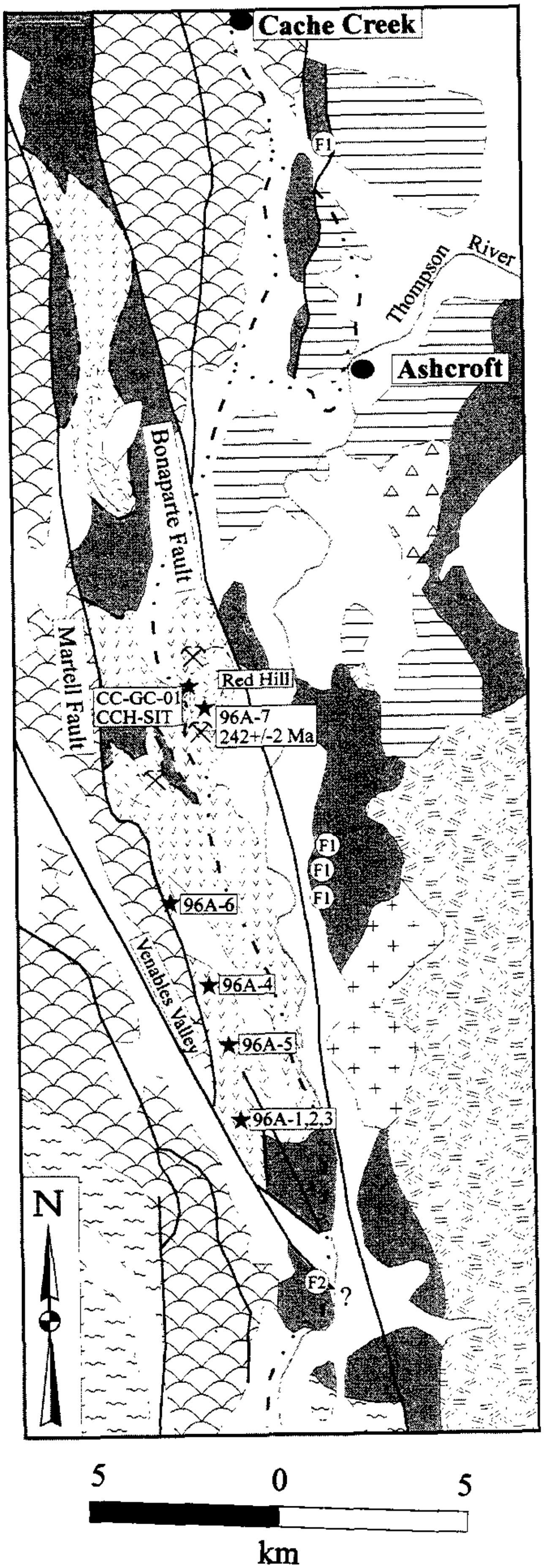

Figure 2. Geology of the Spences Bridge - Cache Creek area (modified from Ladd, 1981; Monger and McMillan, 1984).

KUTCHO ASSEMBLAGE

The Kutcho Assemblage, in north-central British Columbia, forms the lowermost unit in the fault-bounded King Salmon Allochthon. It is composed of tholeiitic bimodal volcanic rocks and sedimentary rocks and is intruded by contemporaneous, probably comagmatic plutonic rocks (Gabrielse, 1979; Thorstad and Gabrielse, 1986; Childe and Thompson, 1995a and b, submitted). Magmatism occurred in the Latest Permian to Early Triassic (Childe and Thompson, 1995a and b). The Kutcho Assemblage is host to the Kutcho Creek volcanogenic massive sulphide deposit, with reserves of 17 Mt, grading 1.6% Cu, 2.3% Zn, 29 g/t Ag and 0.3 g/t Au (Bridge *et al.*, 1986).

GEOLOGY

The current study examines felsic volcanic and intrusive rocks formerly assigned to the Nicola Group between the Martell and Bonaparte Faults, in the Venables Valley and Red Hill areas (Figure 2). Within the Venables Valley area, Grette (1978) divided rocks into three main units. From inferred oldest to youngest these units are: (1) mafic to felsic volcanic rocks, related intrusive rocks, and volcanic derived sedimentary rocks; (2) thick, massive to bedded limestone; and (3) argillite and thin bedded limestone, with minor volcanic rocks.

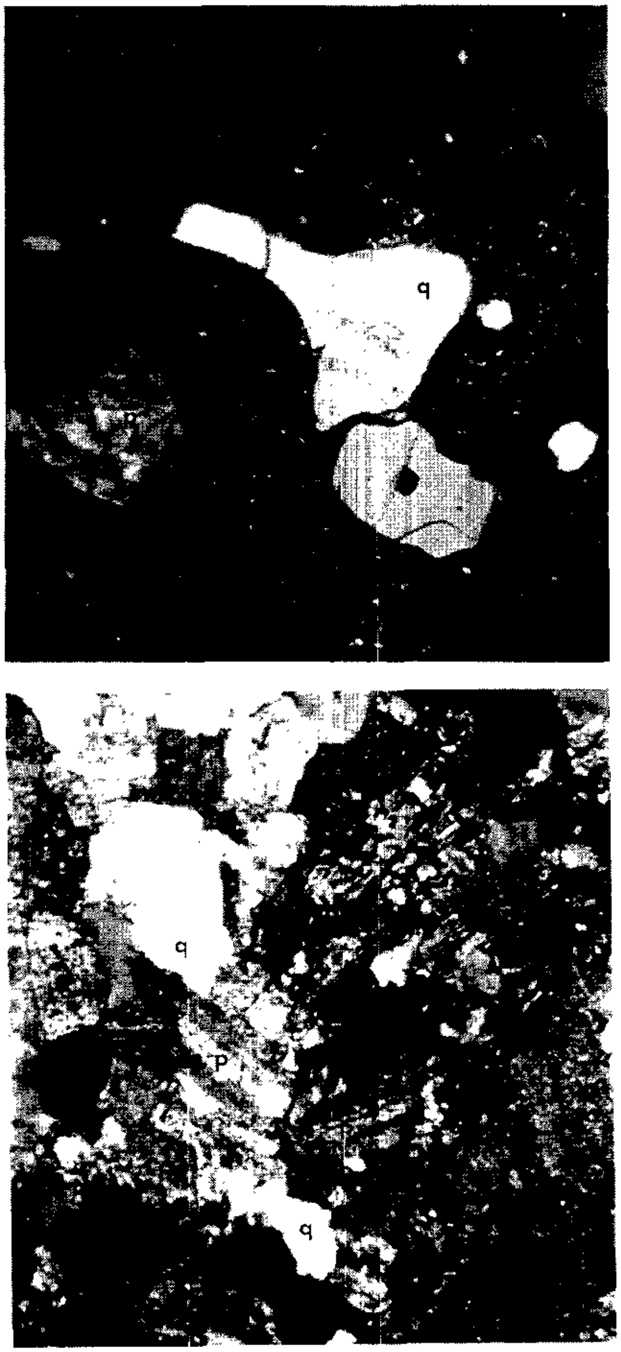

Figure 3. a) photomicrograph of rhyolite crystal tuff (96A-2) showing a broken quartz grain (photograph width 5 mm), b) photomicrograph of tonalite (96A-7) showing equigranular texture (photograph width 5 mm), p = plagioclase, q = quartz.

To the north, in the Red Hill area, Ladd (1981) proposed four subdivisions for volcanic rocks, thought to be interbedded, and hence of contemporaneous age, which were assigned to the Nicola Group. These are (1) felsic crystal tuffs characterized by large quartz grains; (2) chlorite-rich mafic schist, with relict phenocrysts; (3) silicified greenstone; and (4) altered massive chloritic basalt. On Red Hill, Ladd (1981) mapped felsic tuffs cross cut by a series of fine- to coarse-grained granodioritic to tonalitic plutons. Three kilometers southwest of Red Hill, Ladd (1981) observed trondhjemite grading into rhyolite tuffs, and suggested that the intrusion was hypabissal, with the volcanic and intrusive units being emplaced in the same magmatic event.

Felsic volcanic rocks from the Venables Valley and Red Hill consist of massive to bedded crystal to ash tuffs. Crystal tuffs are characterized by 2 to 5 mm diameter glassy quartz and/or plagioclase phenocrysts within a fine-grained quartzo-feldspathic matrix. Quartz and plagioclase commonly occur as broken grains, reflecting the pyroclastic nature of these rocks (Figure 3a). The crystal tuffs contain scattered flow-banded, aphanitic clasts and sporadic layers of wispy chlorite, which may be remnants of flattened pumice fragments. Ash tuffs are characterized by a fine-grained quartzo-feldspathic matrix with rare 1 to 2 mm diameter quartz and plagioclase crystals.

The diorite to tonalite body that intrudes the volcanic rocks on Red Hill has a medium-grained granitic texture, and contains varying proportions of plagioclase, hornblende and quartz, with minor secondary calcite and epidote (Figure 3b).

Biochronological constraints from south, east and north of the study area consist of probable Late Triassic conodonts from limestone (Grette, 1978), Late Triassic ammonites and pelecypods from argillite (Monger and McMillan, 1984), and middle Norian ammonites from sediments overlain by mafic volcanic rocks of the Nicola Group (Travers, 1978) (Figure 2). However, these age determinations do not assist in constraining the age of felsic magmatism, as the dated sedimentary rocks are not found in conformable contact with the felsic rocks.

Grette (1978) obtained an Early Jurassic Rb-Sr whole rock isochron age of 196 +/-15 Ma. with a Sr_i of 0.7043 ($\pm$0.0002) from felsic volcanic and intrusive rocks within the study area; Grette attributed the elevated Sr_i to contamination by seawater Sr. The isochron is highly dependent on a sample of altered dacite. Hydrothermal alteration has the potential to perturb Rb-Sr systematics (Shirey, 1991). Regardless of the mechanism of isotopic disturbance, the validity of this age determination is suspect.

U-PB GEOCHRONOLOGY

One sample of tonalite (96A-7) and three samples of crystal tuff (96A-1, 96-A3, and CC-GC-01) were collected and processed for U-Pb zircon analysis, as described below. Of the four samples, only the tonalite contained sufficient zircon for U-Pb analysis. The low Zr concentrations in the crystal tuffs (65-91 ppm), along with the relatively fine grain size may be responsible for the scarcity of recoverable zircon in the tuffs.

analytical techniques

Sample preparation and U-Pb analyses were carried out at the Geochronology Laboratory of the University of British Columbia. The samples were 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). 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). Age designations were based on the time scale of Harland *et al.* (1990) and the revised age of the Permo-Triassic boundary by Renne *et al.* (1995). 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.

analytical results

The tonalite (96A-7) contained abundant coarse-grained tabular to prismatic zircon with few colourless baguette-shaped inclusions and good clarity. Analysis of four fractions of zircon yielded $^{207}Pb/^{206}Pb$ ages of 238 to 244 Ma. The error ellipse of fraction C slightly overlaps the concordia curve, with a $^{206}Pb/^{238}U$ age of 236 Ma, which provides a minimum age for this rock. However, an Early Triassic age of 242 +/-2 Ma, based on the weighted mean $^{207}Pb/^{206}Pb$ age of all four fractions, is considered the best estimate of the age of this rock.

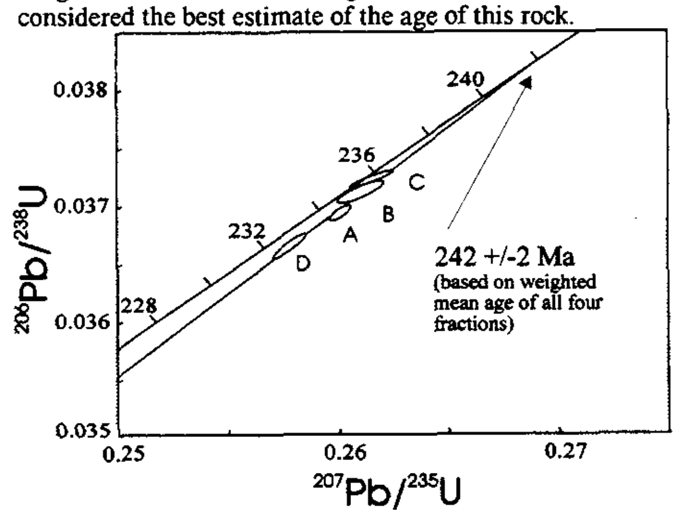

Figure 4. U-Pb concordia diagram for tonalite sample 96A-7.

Table 1. U-Pb zircon analytical data

Fraction[1]	Wt.	U	Pb[2]	^{206}Pb[3]	Pb[4]	^{208}Pb[5]	Isotopic ratios($\pm1\sigma$,%)[6]			Isotopic dates(Ma,$\pm2\sigma$)[6]		
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
tonalite 96A-7												
A,c,N1,t	0.455	183	7	7528	26	8.3	0.03694±0.09	0.2601±0.09	0.05107±0.06	233.8±0.4	234.8±0.4	244.0±2.7
B,c,N1,t	0.204	139	5	8223	8	7.3	0.03712±0.13	0.2610±0.20	0.05100±0.11	235.0±0.6	235.5±0.8	240.9±5.2
C,c,N1,t	0.226	135	5	7877	9	7.6	0.03723±0.10	0.2615±0.19	0.05095±0.10	235.7±0.5	235.9±0.8	238.4±4.8
D,m,N1,t	0.265	169	6	8496	12	7.8	0.03666±0.14	0.2578±0.15	0.05101±0.05	232.1±0.7	232.9±0.6	241.2±2.5

[1]All fractions are air abraded; Grain size, smallest dimension: c= +134μm, m=-134μm+74μm
Magnetic codes: Franz magnetic separator sideslope at which grains are nonmagnetic; e.g., N1=nonmagnetic at 1°;
Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: t=tabular
[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 (1975) model Pb composition at the $^{207}Pb/^{206}Pb$ age of fraction, or age of sample)

Table 2. Major and trace element data

sample number	lithology	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	Na2O %	K2O %	P2O5 %	LOI	Total	BaO ppm
96A-1	qtz+plag crystal tuff	69.76	0.30	12.12	2.77	0.15	1.54	3.79	3.18	1.70	0.06	4.21	99.63	309
96A-2	qtz+plag crystal tuff	79.63	0.22	11.88	0.78	0.02	0.41	0.27	6.26	0.07	0.05	0.53	100.13	28
96A-3	qtz+plag crystal tuff	77.90	0.19	10.00	1.72	0.10	0.70	2.40	4.45	0.22	0.04	2.45	100.19	95
96A-4	plag crystal tuff	60.80	0.60	15.24	8.61	0.16	3.64	1.53	6.00	0.05	0.11	3.43	100.21	64
96A-5	siliceous ash tuff	76.77	0.26	9.78	2.79	0.10	1.22	2.00	4.95	0.20	0.07	2.36	100.52	37
96A-6	qtz+plag crystal tuff	75.58	0.26	12.18	1.96	0.08	0.63	1.27	6.15	0.20	0.06	1.66	100.04	46
96A-7	tonalite	62.54	0.62	15.59	7.11	0.13	2.78	4.83	3.27	1.61	0.09	1.97	100.61	433
CC-GC-01	qtz crystal tuff	76.79	0.24	13.70	0.57	0.01	1.12	0.23	4.46	1.45	0.04	1.30	99.95	251
CCH-SIT	qtz+plag crystal tuff	76.51	0.27	13.65	1.23	0.00	0.20	0.27	5.90	0.92	0.03	1.03	100.03	137
Detection Limits (ppm):		60	35	120	30	30	95	15	75	25	35			17

sample number	Co ppm	Cr2O3 ppm	Cu ppm	Ni ppm	V ppm	Zn ppm	Ga ppm	Nb ppm	Pb ppm	Rb ppm	Sr ppm	Th ppm	U ppm	Y ppm	Zr ppm
96A-1	23	17	11	7	26	103	13	3.4	1.1	20.7	170.1	<d/l	4.5	35.6	84.0
96A-2	44	<d/l	<d/l	<d/l	<d/l	51	10	3.7	<d/l	<d/l	111.1	<d/l	3.6	34.2	108.1
96A-3	44	27	6	11	<d/l	72	10	3.0	<d/l	2.8	163.5	<d/l	3.8	33.7	91.4
96A-4	36	<d/l	6	4	197	104	16	4.3	2.7	<d/l	91.9	<d/l	5.2	25.6	27.8
96A-5	28	16	7	<d/l	49	67	8	3.8	<d/l	<d/l	82.8	<d/l	4.1	27.4	60.7
96A-6	36	20	<d/l	7	23	61	10	4.7	<d/l	1.6	69.2	<d/l	3.9	21.5	79.1
96A-7	31	47	68	9	150	97	14	3.1	2.5	36.4	155.6	3.3	5.5	36.8	112.2
CC-GC-01	30	<d/l	4	<d/l	23	45	15	7.6	<d/l	14.5	61.6	<d/l	<d/l	11.9	65.0
CCH-SIT	44	<d/l	12	<d/l	17	40	13	5.5	<d/l	7.9	75.4	<d/l	<d/l	32.2	88.8
Detection Limits (ppm)	10	15	2	3	10	2	1	1	1	1	1	1	1	1	1

Table 3. Rare earth element data

sample number	Au ppb	Ag ppm	As ppm	Br ppm	Cs ppm	Hf ppm	Hg ppm	Ir ppb	Sb ppm	Sc ppm	Se ppm	Ta ppm	W ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm
96A-3	<d/l	<d/l	<d/l	<d/l	<d/l	3.3	<d/l	<d/l	0.4	10.8	<d/l	0.9	212	5.5	14	9	2.64	0.80	0.7	3.17	0.44
96A-6	<d/l	<d/l	1	<d/l	<d/l	2.3	<d/l	<d/l	0.5	7.9	<d/l	1.0	150	4.4	11	7	1.66	0.51	0.4	1.79	0.25
96A-7	<d/l	<d/l	2	<d/l	1.1	4.5	<d/l	<d/l	0.6	23.1	<d/l	<d/l	108	6.5	19	11	3.18	0.86	0.8	3.48	0.48
Detection Limits	2 ppb	2 ppm	1 ppm	0.5 ppm	0.2 ppm	0.2 ppm	1 ppm	1 ppm	0.1 ppm	0.1 ppm	0.5 ppm	0.3 ppm	1 ppm	0.1 ppm	1 ppm	1 ppm	0.01 ppm	0.05 ppm	0.1 ppm	0.05 ppm	0.01 ppm

GEOCHEMISTRY

major and trace elements

A suite of one intrusive and eight volcanic rock samples were analyzed for major and trace element abundances, using x-ray fluorescence at McGill University in Montreal, Quebec. Volcanic rocks range in composition from dacite to rhyolite (61-80% SiO_2, 0.19-0.30% TiO_2), whereas the intrusive rock has a tonalitic composition (63% SiO_2, 0.62% TiO_2) (Figure 5a and Table 2). All samples have relatively low K_2O (0.05-1.70%) and high Na_2O (3.18-6.26%) concentrations.

Volcanic and intrusive rocks analyzed in this study have Zr/Y ratios of 1.1 to 5.5 (Table 2). Using the limits defined by Barrett and MacLean (1994), these rocks have a predominantly tholeiitic magmatic affinity (Figure 5b).

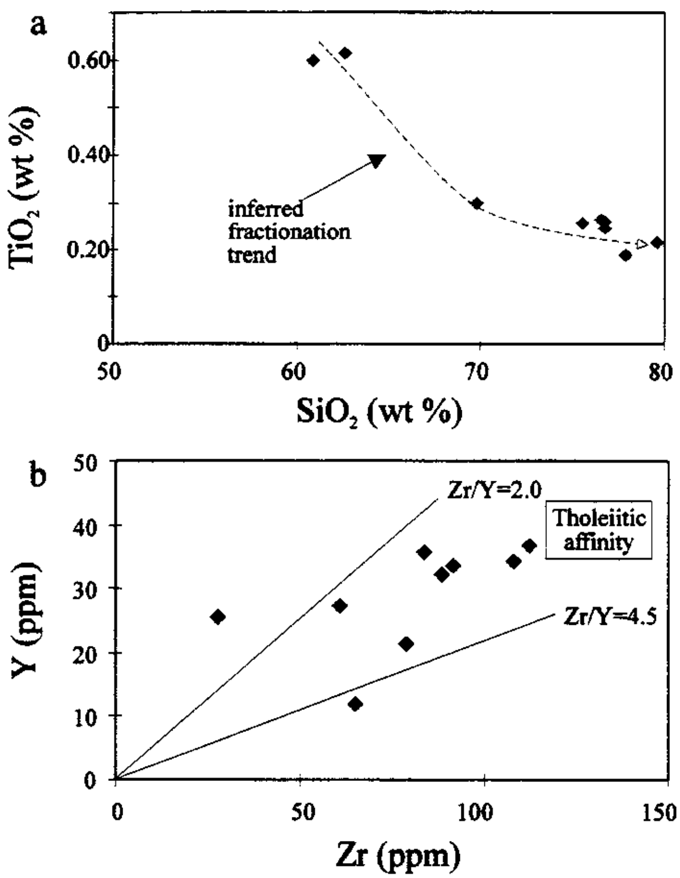

Figure 5. a) TiO_2 versus Al_2O_3 diagram b) Zr versus Y diagram (Barrett and MacLean, 1994) for samples of volcanic and intrusive rocks.

rare earth elements

Rare earth element (REE) concentrations were determined for samples of two rhyolite crystal tuffs and the tonalite by neutron activation analysis at Actlabs in Ancaster, Ontario. All samples are characterized by near-flat patterns (Figure 6 and Table 4). These patterns, combined with low REE concentrations indicate derivation of the rhyolite tuffs and tonalite from primitive magmatic sources.

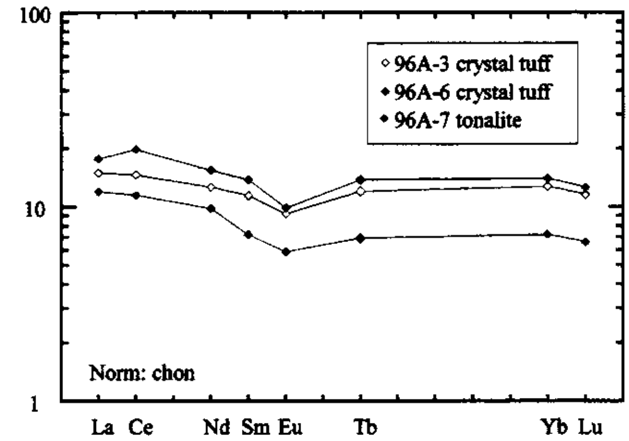

Figure 6. Rare earth element diagram for one tonalite and two rhyolite crystal tuffs.

DISCUSSION AND TECTONIC IMPLICATIONS

An Early Triassic age of 242 +/-2 Ma for the tonalite dated in this study is older than rocks of the Nicola Group and contemporaneous plutonism, but is indistinguishable from rocks of the Kutcho Assemblage (McMillan et al., 1982; Monger and McMillan, 1984; Childe and Thompson, 1995a and b).

The strong similarity between the REE patterns of the rhyolites and tonalite suggests that the volcanic and intrusive rocks were derived from the same magmatic source, and are probably of similar age. The low-K tholeiitic chemistry of these rocks is comparable to those of the Kutcho Assemblage, and dissimilar from the calc-alkaline to shoshinitic chemistry characteristic of the Nicola Group (Mortimer, 1986; Thompson *et al.*, 1995; Barrett et al., in press).

Based on the data presented in this paper, felsic volcanic and intrusive rocks which occur between the Martell and Bonaparte Faults, near Ashcroft, are tentatively correlated with the Permo-Triassic Kutcho Assemblage, rather than the Late Triassic to Early Jurassic Nicola Group. Mafic volcanic rocks assigned to the Nicola Group occur both to the east and west of the Bonaparte Fault (Figure 2). The presence of Late Triassic fossils imply that this correlation is valid for basaltic rocks which occur east of the Bonaparte Fault. However, the age of basaltic rocks that occur west of the Bonaparte Fault, in proximity to, and possibly interbedded with rhyolite tuffs, is not constrained. These basaltic rocks may be contemporaneous with the Early Triassic felsic rocks, rather than the younger Nicola Group lavas. Detailed mapping and geochemistry, accompanied by additional U-Pb geochronology are necessary in order to determine the extent of Early Triassic age rocks with primitive arc affinity in this region.

VMS POTENTIAL

The presence of rocks of Kutcho Assemblage age and affinity within the Ashcroft map area raises the potential for Kutcho Creek-equivalent Cu-Zn volcanogenic massive sulphide mineralization.

A number of copper occurrences are known within the Venables Valley - Red Hill area. The Red Hill showing (B.C. MINFILE 092INW042) contains chalcopyrite, chalcocite, and secondary Cu minerals that occur within chlorite and sericite altered pyritic greenstone, in proximity to Early Triassic rhyolite tuffs and tonalite. Also on Red Hill are unnamed gossans containing malachite and azurite (Ladd, 1981). Rhyolite tuff-hosted mineralization includes two unnamed copper occurrences, which occur approximately 1 km east of the trondhjemite body, southwest of Red Hill (Ladd, 1981). Based on the correlation of these rocks with the Kutcho Assemblage proposed in this paper, mineralized occurrences within this area should be explored for Cu-Zn VMS potential.

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British Columbia Geological Survey
Geological Fieldwork 1996

GEOLOGY OF THE NORTHERN KECHIKA TROUGH (NTS 94L/14, 15; 94M/3, 4, 5, 6, 12, 13; 104P/8, 9, 15, 16)

By Filippo Ferri, Chris Rees, JoAnne Nelson and Andrew Legun

KEYWORDS: Northern Rocky Mountains, Rabbit Plateau, Liard Plain, Kechika Trough, Hyland Group, Cambrian, Kechika Group, Road River Group, Earn Group, Sedimentary Exhalative, Barite, Lead, Zinc.

INTRODUCTION

This paper summarizes 1996 fieldwork on the Gataga Mapping Project that covered the northern part of the Kechika Trough in northern British Columbia (Figure 1). The Kechika Trough is a lower Paleozoic sedimentary off-shelf basin (Figure 2) characterized, in part, by numerous sedimentary exhalative Ba-Pb-Zn deposits of various ages. The most significant of the known deposits occur within the Devono-Mississippian Earn Group. The aim of this project is to produce a detailed geologic database for the portion of the trough with the highest mineral potential. This mapping project, which began in 1994, is in conjunction with several British Columbia Geological Survey Branch - funded Regional Geochemical Surveys covering most of the 1994 to 1996 project areas. The Branch recently released results from a regional stream sediment survey covering the Gataga River (1994) and Gataga Mountain (1995) field areas of the Gataga Mapping Project (Jackaman *et al.*, 1996). A regional lake sediment survey covered the 1996 bedrock map area during the course of the summer and this data will be released later this year (Jackaman *et al.*, 1997).

Mapping during the 1996 field season completed planned coverage of the northern part of the Kechika Trough. The work continued from the northern termination of the 1995 map area and extended to the British Columbia - Yukon border. This area covers the equivalent of approximately five 1:50 000 scale map sheets. Traverse density is less than that of typical 50 000 scale mapping, as carried out in the 1994 and 1995 field seasons, but is significantly greater than traditional 250 000 scale regional mapping. The very small amount of outcrop in the northern half of the map area led to efforts being concentrated in the southern part of the map area.

The southern border of the map area lies midway between the mouth of Horneline Creek and Terminus Mountain. The western map boundary follows the Northern Rocky Mountain Trench and its northwestward projection toward the British Columbia - Yukon border (Figure 3). The Trench is easily discernible in the southern half of the map area but effectively ends farther

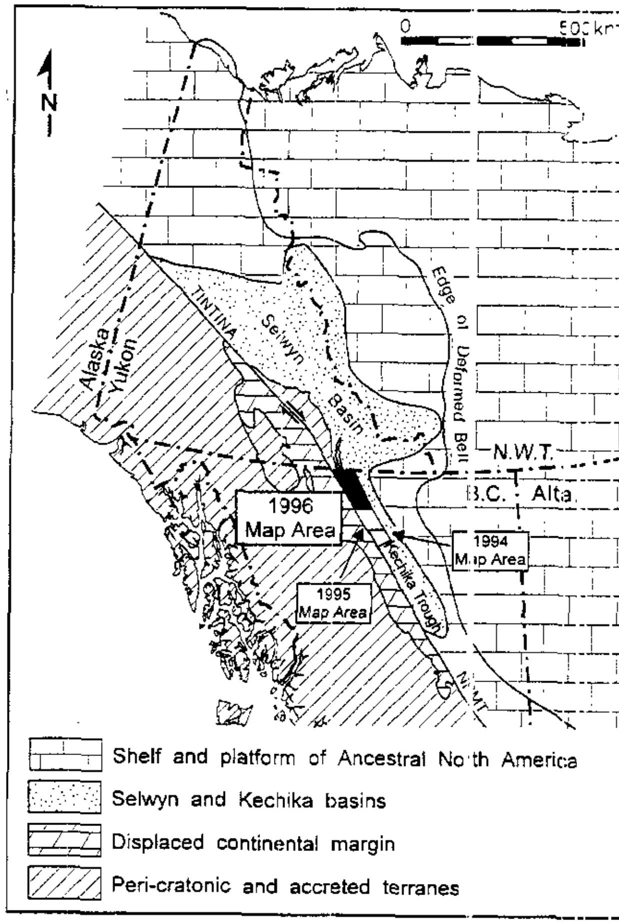

Figure 2: Simplified map of the northern part of the Canadian Cordillera showing the shelf to off-shelf boundary during Ordovician to Silurian time (modified from Cecile and Norford, 1991). NRMT - Northern Rocky Mountain Trench.

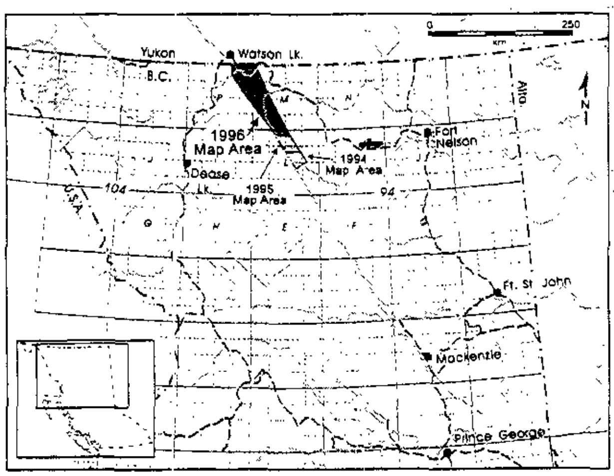

Figure 1: Northeastern British Columbia showing the location of the 1994, 1995 and 1996 map areas.

north as it opens up into the Liard Plain. The eastern limit of mapping roughly follows Netson Creek and the Rabbit River, extends north to Tatisno Mountain, and then northwestwards to the British Columbia - Yukon border.

The sub-alpine peaks around Horneline Creek are part of the Northern Rocky Mountains. These give way northwestward to the rolling hills of the Rabbit Plateau which dominate the southern half of the map area. The northern half falls within the lowlands of the Liard Plain. Rock exposure within the project area is limited to about 1 per cent of the surface area. Scattered exposures can be found along the ridges in the Horneline Creek area. Elsewhere exposures are most readily found along creek valleys and the banks of major drainages. The area east of the Kechika River is old burn, and the dense second-growth forest makes bush travel unusually slow and difficult.

The poor exposure of bedrock within the map area hinders interpretation of the geology. Very few contact relationships were observed between major map units, and no critical stratigraphic sections are exposed. Interpretation relies heavily on a knowledge of the regional stratigraphy and structure gained previously in the better exposed Gataga River and Gataga Mountain areas to the southeast. One significant change to our mapping in the Gataga Mountain area in 1995 (Ferri *et al.*, 1996a, b) is noted here. This arises from recent, preliminary uranium-lead isotopic data which has shown that the volcanics we interpreted as part of the Lower Cambrian Gog Group are in fact Late Proterozoic in age (J. Mortensen, personal communication, 1996), and some 100 Ma older than immediately overlying Cambrian quartzites and carbonates, suggesting the presence of a major unconformity in this area.

Previous work within the project area was carried out by Gabrielse (1962a, b; 1963) who mapped the Kechika (94L), Rabbit River (94M) and McDame (104P) sheets at a 4-mile scale. To the west of the Kechika sheet, Gabrielse (1962c) also mapped the Cry Lake (104I) area at this scale.

The present map area lies along the western margin of the Rocky Mountain subprovince of the Canadian Cordilleran Foreland Belt. The western boundary of the area roughly follows the Northern Rocky Mountain Trench fault, which separates displaced continental margin 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 Fault (Tempelman-Kluit, 1977; Gabrielse, 1985). Only a few traverses were made across the fault into Cassiar rocks.

The Kechika Trough represents a long-lived basin of early to middle Paleozoic age. It connects northward with the Selwyn Basin of the Yukon and Northwest Territories, with which it shares similar stratigraphic and tectonic relationships. The Kechika Trough was delineated through time by 'shale-outs' of shelf and platformal successions. Its stratigraphy is characterized by dark, fine-grained siliciclastics and chert, representing quiet, deeper water deposition. This environment of slow sedimentation in restricted sub-basins, coupled with periodic extensional tectonism was conducive to the formation of sedimentary exhalative mineral deposits at various times within the basin. Upper Devonian rocks of the Earn Group host the most economically important known deposits and are the focus of the present multidisciplinary study. A more detailed description of the regional setting and related references are given in Ferri *et al.* (1995a). A useful regional overview is provided by MacIntyre (1992).

STRATIGRAPHY

Mapping over the course of the summer encountered typical Kechika Trough geology. The stratigraphy that follows is divided into several sections, beginning with layered units familiar from the previous two field seasons and that are of reasonably well known age (Figures 3 and 4). These include: Cambrian siliciclastics, Cambro-Ordovician Kechika Group, Ordovician to Devonian Road River Group and the Devono-Mississippian Earn Group. Also mapped were older and younger units not previously described in this project, namely coarse siliciclastics and carbonates of the Upper Proterozoic Hyland Group, vari-coloured chert of possible Mississippian to Permian age, and Tertiary-Quaternary basalt of the Tuya Formation.

The second section deals with two other informal map units of questionable age and affinity, namely the Aeroplane Lake panel, and the 'Kitza Creek facies'. This section is followed by a brief account of rocks west of the Northern Rocky Mountain Trench. These rocks, assumed to belong to the Cassiar terrane, were not examined in detail and no subdivision was attempted.

There are several types of intrusive rocks in the map area. The most notable are relatively large gabbroic bodies within the Kechika Group in the Gemini Lakes area. Most other intrusions consist of dikes or other small bodies.

A consequence of the large area covered is that most of the layered units show considerable compositional variations, and this should be taken into account in the following descriptions.

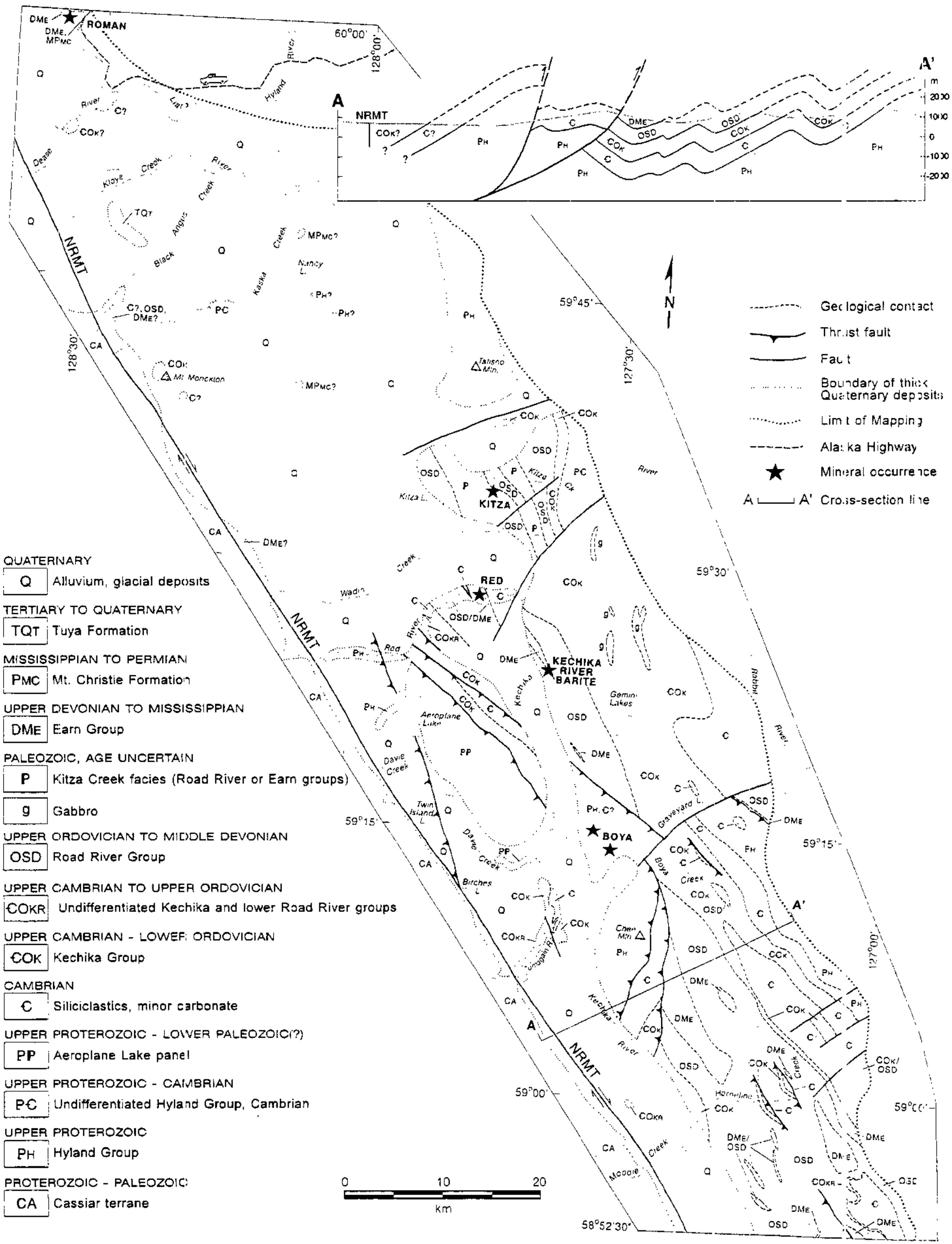

Figure 3: Simplified geologic map of the study area. The southern part of the area, south of Horneline Creek, overlaps with the northern part of the 1995 field area (Ferri *et al.*, 1996a, b). Cross-section A-A' is shown as an inset at the top of the diagram. Please note that this structural section is not at the same scale as shown on the map.

HYLAND GROUP (UPPER PROTEROZOIC)

Sections of grey to brown weathering sandstone and slate with distinctive sequences of fine to coarse, gritty, feldspar-bearing, quartz-rich sandstones and conglomerates have been assigned to the Upper Proterozoic Hyland Group, as defined by Gordey andconglomerates have been assigned to the Upper Proterozoic Hyland Group, as defined by Gordey and Anderson (1993) in the Selwyn Basin. Hyland Group rocks are found along the eastern and western margins of the map area (Figure 3). They were mapped along several creek valleys west of Aeroplane Lake, probably in a thrust panel, and Proterozoic coarse clastics are quite well exposed on the higher peaks and ridges east and northeast of Horneline Creek, at the eastern limit of mapping. The west side of Chee Mountain consists of a large thrust panel of Hyland Group rocks, which probably continues northwards across Boya Creek. Excellent exposures of Hyland Group sandstones and conglomerates occur on the ridges emanating from Tatisno Mountain in the northern part of the map area, and in the Liard Plain to the west, isolated outcrops of clastics are also thought to be Proterozoic.

The Hyland Group, in its type area, has been subdivided into the Yusezyu and Narchilla formations (Gordey and Anderson, 1993). The Yusezyu Formation is dominated by coarse clastics, shale and minor limestone whereas the Narchilla Formation contains thick sections of shale with lesser sandstone. Poor exposure in the present map area does not allow subdivision of the Hyland Group, although lithologies typical of each formation were recognized at some localities.

The Hyland Group on Chee Mountain is dominated by grey to olive green or red brown to maroon, well cleaved slate or phyllite to silty slate. Locally, slate forms sections up to several hundred metres thick. Almost as common as these pelitic rocks are thickly bedded to massive, grey-brown weathering, beige to grey quartz-feldspar sandstone to granule conglomerate, which were found along the top of Chee Mountain and on creeks cutting its western flank. Some quartz grains display an opalescent blue colour, and feldspar constitutes 5 to 15 per cent of the coarser clastics. Sandstone may be quite impure, approaching a wacke locally, with a greenish-grey argillaceous matrix. The immature nature of these coarse clastics is also indicated by poor sorting and sub-angular to sub-rounded nature of clasts.

Slaty or phyllitic rocks are generally interbedded with the coarse siliciclastics, in sections from 0.1 to 20 centimetres thick. Some display ball and pillow or flame structures, and others may contain rip-ups of darker slate or siltstone.

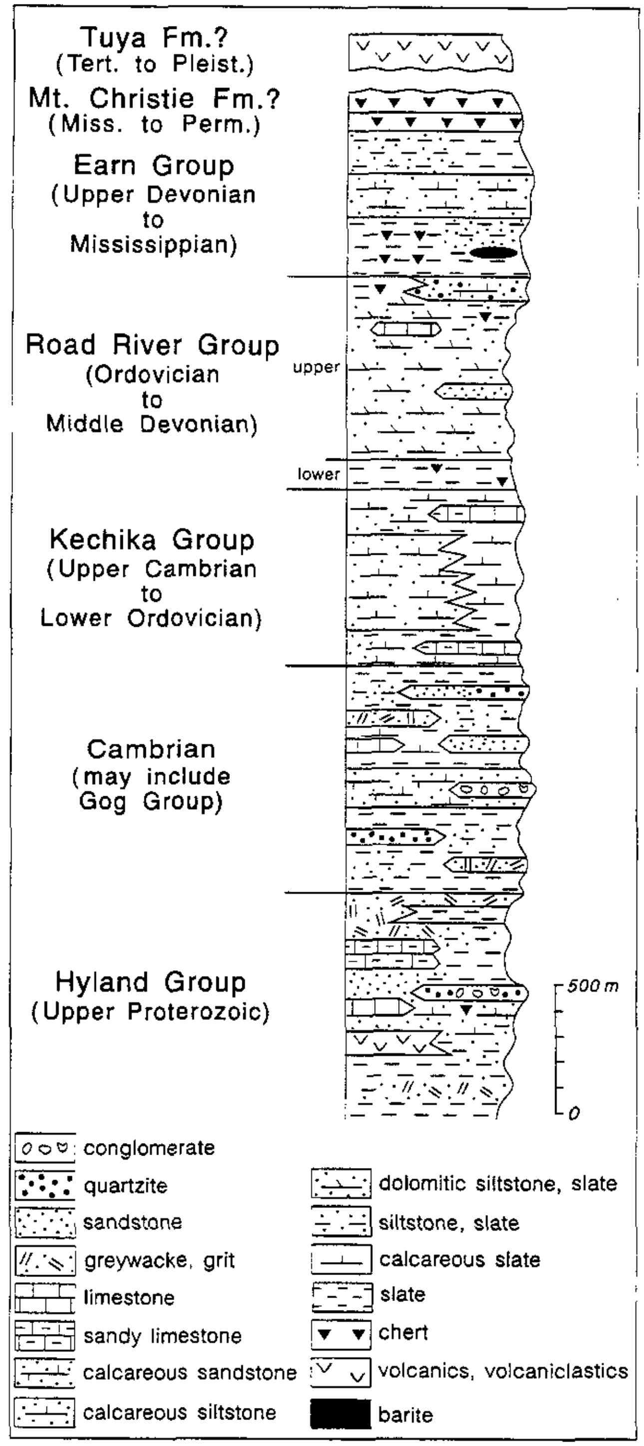

Figure 3: General stratigraphic column based on present work and previous mapping to the southeast in the Kechika Trough (Ferri *et al.*, 1995a, b; 1996a, b). Stratigraphy within each unit is poorly understood; lithology patterns indicate mainly variety and relative proportions of constituent rock types.

Dark grey to brown or orange brown weathering, dark grey finely crystalline massive to platy limestone up to 20 metres thick forms prominent outcrops along the top of Chee Mountain. It is not known if these outcrops represent different horizons or the structural repetition of one section of limestone. The upland immediately northwest of Boya Creek, informally called Boya Hill, is underlain by rocks believed to belong to the Hyland Group, but may include rocks of Cambrian age. Typical grey to orange-weathering, coarse sandstone to granule conglomerate of the Hyland Group occur at the southwest end of Boya Hill. Clasts are predominantly quartz with lesser feldspar and mica. These are associated with several ribs of medium to dark grey, massive to platy, sugary limestone and pale grey to greenish, massive and well cleaved slate. A large gossanous zone composed of iron carbonate and coarse, cream-coloured calcite and dolomite cuts across slate and limestone.

Northeastward, along the main part of Boya Hill, the rocks are variously hornfelsed, hydrothermally altered and mineralized. These are described later in this paper. Grey, massive to thickly bedded, equigranular, medium-grained crystalline limestone or sandy limestone forms the most prominent exposures along the top of the ridge. On the southeast facing slopes, limestone may be thinly interlayered with dark grey slaty siltstone or pale grey chert. These interlayered rocks are associated with brown-weathering, grey to dark grey slate, slaty siltstone to fine quartz sandstone or greywacke, and green to brown volcanic rocks. Volcanic rocks are quite distinct and form a mappable unit several hundred metres thick, which is exposed at several localities. Typically they are buff to orange - brown weathering, green to brown tuff and lapilli tuff. Clasts are composed of feldspar(?) crystals and feldspar porphyry. The rock is very calcareous, suggesting intense alteration; in thin section it is evident that the original clastic components have been pseudomorphed by calcite and quartz. Peatfield (1979a) described agglomerates, flows and intermixed slates and chert in the area. Exposures on the northwest facing slopes of Boya Hill include interlayered laminated to cross-laminated quartz sandstone, siltstone and slaty siltstone; chert; interlayered chert and quartz sandstone or quartzite; and recrystallized limestone.

Overall lithologies on Boya Hill suggest a Precambrian to Cambrian age. The general stratigraphic or structural order was put forward by Peatfield (1979a) is supported by our mapping. It puts the coarser siliciclastic rocks at the base followed by an interlayered limestone, slate and chert package, which also contain the volcanic subunit. Thick to massive limestone and slate lie above and form the top of the section. Sandy limestone at the top of Boya Hill is similar to known Cambrian limestone seen farther south, but interlayered chert and limestone below this is not typical of Cambrian or Precambrian units. However, the associated volcanics bear a strong resemblance to those along Gataga Mountain (Ferri *et al.*, 1996a, b) which have recently been dated as Late Proterozoic (see Introduction, above). It should be noted that volcanism of this nature is widespread throughout the Selwyn and Kechika basins and ranges from Proterozoic to middle Paleozoic in age (Goodfellow *et al.*, 1995).

Photo 1: Thick bedded, feldspar - lithic - quartz conglomerate of the Hyland Group exposed along the ridges leading to Taisno Mountain. These graded, immature, high energy sediments suggest derivation from nearby steep terrain underlain, in part, by igneous and metamorphic lithologies.

Southeast of Graveyard Lake, rocks assigned to the Hyland Group are very similar to those along Chee Mountain except that they lack the distinctive dark grey limestone. They consist mainly of grey argillite or slate, with sections of grey to brownish grey, coarse sandstone to granule or pebble conglomerate with characteristic opalescent blue quartz and chalky white feldspar clasts. Conglomerate clasts are sub-angular to sub-rounded and supported by a finer sandstone matrix. Interlayered with these coarse-grained rocks are massive to cross-laminated white to brownish quartzite, well laminated orange to brown weathering, grey to beige, well cleaved slate and siltstone, and dirty, orange to brown weathering sandstone. The latter contains minor detrital mica and displays flute casts.

Hyland Group rocks along the upper part of the Red River and west of Aeroplane Lake are very similar to those described above. Differences include several intervals of buff to orange weathering, pale grey to cream, very finely crystalline and platy dolomitic limestone up to 10 metres thick.

Perhaps the best exposures of Hyland rocks in the map area can be found along Tatisno Mountain. Interlayered, well cleaved greenish-grey to grey or tan laminated slate to silty slate and fine-grained brown-weathering sandstone to quartzite are predominant. These lithologies are punctuated by massive, tan weathering, beige to white, very coarse sandstone to pebble conglomerate in beds up to 2 metres thick (Photo 1). The clasts are composed of angular to sub-angular quartz (some of which are polycrystalline and with a well developed fabric), white feldspar, grey to dark grey argillite or siltstone, and rare mica. The compositions, angular nature and size of the clasts, together with scouring at the base of many beds indicates that these are immature, high energy deposits most likely derived from an uplifted, steep source terrain dominated by igneous and metamorphic rocks.

Northwest of Tatisno Mountain, several kilometres south and east of Nancy Lake in the Liard Plain, sparse outcrops of coarse sandstone and conglomerate are tentatively assigned to the Hyland Group. They consist of grey to tan weathering, grey to cream, massive to thickly bedded, greywacke to conglomerate or breccia. The granule to pebble sized conglomerate clasts are supported by a coarse to very coarse-grained sandstone to wacke. Clasts are rounded to angular and composed of distinctive green chert, tan to grey or black chert or siliceous argillite, maroon argillite, quartz (locally blue), feldspar and tuffaceous granules.

CAMBRIAN

Slate, siltstone, quartz sandstone to quartzite, conglomerate and minor limestone belong to an unnamed sequence of probable Cambrian age. They occur in the far southeastern corner of the map area, along the eastern and western margins, and as fault slices along the Red River. No fossils were recovered from these rocks. Their age is based on similarities to units immediately to the southeast of the present map area which contain archaeocyathid-bearing limestone at their base, and a paucity of feldspar clasts in the siliciclastics which helps to distinguish this unit from otherwise similar lithologies in the Hyland Group. Also, a distinctive conglomerate northeast of Graveyard Lake is equated with a comparable coarse conglomerate on Brownie Mountain in the Gataga River area that has been correlated with the early Middle Cambrian 'Roosevelt facies' in the Rocky Mountains to the east (Ferri *et al.*, 1995a, 1996a).

Southeast of Graveyard Lake, the Cambrian is characterized by well cleaved, thinly interlayered brown to rusty weathering, laminated to banded or mottled, pale to dark grey micaceous slate, siltstone and grey to maroon very fine sandstone to quartzite. Sandstone and quartzite make up to 30 per cent of the section and beds can reach several metres in thickness. Isolated outcrops of grey weathering, pale to medium grey, fine to medium crystalline, massive to platy limestone in the southeastern part of the map area are grouped with the Cambrian succession as they are found along strike with siliciclastics of this package.

On the south and east sides of Chee Mountain there is a package of rocks which resembles the upper Road River Group, but is correlated with the Cambrian because of its coarser, more siliceous component. It consists predominantly of thinly to thickly interlayered, laminar, orange to brown weathering, greenish grey, dolomitic to calcareous siltstone and grey to black slate to shale. Siltstone is locally bioturbated, and can form up to 70 per cent of the section. In addition, orange to brown weathering, grey to dark grey, thick bedded micaceous sandstone forms sections up to 10 metres thick. Clasts are very fine to fine grained, and composed of quartz and minor dark grey argillite. Sandstone typically shows laminar bedding, and locally it displays low angle or ripple cross laminations and load casts. Slate locally becomes cherty and can be interlayered with calcareous slate or phyllite.

West of the Kechika River, rocks assigned to the Cambrian comprise interlayered dark grey to bluish grey argillite, cherty argillite, slate to phyllite and pale grey, laminated micaceous quartz sandstone. These rocks contain thick sections of massive to thickly bedded grey calcareous quartz sandstone with distinctive rip ups of dark grey argillite. Other clasts consist of well rounded, vitreous quartz, chert, siltstone and limestone or calcite.

Northeast of Graveyard Lake, a broad, poorly exposed region is underlain by sandstone, siltstone, conglomerate and slate, believed to be Cambrian in age. These rocks are characterized by massive to thickly bedded, white or grey to maroon or brown calcareous sandstone or wacke to conglomerate, locally approaching 10 metres in thickness. Sand grains are dominated by spherical, vitreous quartz with lesser dark grey chert, argillite, carbonate and rare feldspar. Conglomerate clasts are typically granule to pebble in size, although locally they approach 30 centimetres (Photo 2). It is this conglomerate that is tentatively correlated with the Roosevelt facies. Clast composition is diverse, with vari-coloured quartzite (white, red to maroon, grey to dark grey), grey limestone (some of which is oolitic), orange-weathering limestone, white to black chert, sandy limestone, grey siltstone and greenish grey sandstone. Quartzite clasts tend to be quite rounded but many range to sub-angular. Clasts are supported by a calcareous quartz sandstone matrix which can approach a sandy limestone in places. These coarser clastics are associated with cream to buff-weathering, blue-grey limestone, red-banded cherty siltstone, olive green chert and cherty argillite and grey slate.

Photo 2: Granule to boulder conglomerate of possible Middle Cambrian age found northeast of Graveyard Lake. Clasts are dominated by well rounded quartzite and chert with lesser argillite and carbonate. These rocks have been tentatively correlated with the Roosevelt facies of the Rocky Mountains; however, the association of other lithologies that may be part of the Kechika or Road River groups suggests they may be younger. See text for details.

Also in this area, thinly interlayered pale to medium grey, laminated and cross-laminated, fine calcareous siltstone to silty limestone and medium to dark grey silty slate may be found near outcrops of the sandstone and conglomerate. These rocks superficially resemble the Kechika Group. Outcrops of orange-weathering, dolomitic siltstone, possibly belonging to the Road River Group, were also noted. These occurrences could represent outliers of younger units, or they may simply be lithological variations within the Cambrian.

The age of the conglomerate and sandstone is debatable. Despite the similarities with the Middle Cambrian Roosevelt facies mentioned above, the association of other rocks more typical of the Kechika and Road River groups suggests that they could be younger than Cambrian. However, these groups do not contain such coarse siliciclastics anywhere in the northern Kechika Trough, and so presently a Cambrian age is favoured. Interpretation of relationships between the various lithologies in this area is hampered by the paucity of exposure.

KECHIKA GROUP (UPPER CAMBRIAN TO LOWER ORDOVICIAN)

Although poorly exposed, the Kechika Group is quite extensive in the map area and displays a degree of thickness and lithologic variations not seen in the other rock packages. It is less than 50 metres thick in the southern part of the map area, where it is difficult to distinguish from dark slates of the lower Road River Group. It quickly thickens to the northwest consisting of thinly to thickly interbedded calcareous slate and limestone or silty limestone.

On lower Horneline Creek, Kechika rocks consist primarily of thinly interlayered grey to dark grey slate, calcareous slate and limestone. Limestone can be discontinuous and display thin planar or rare cross laminations. It can form a large proportion of the section, with beds up to 1 metre thick. These rocks can be traced northward toward Chee Mountain where the slates have a characteristic silvery lustre. Southeast of Graveyard Lake, the Kechika Group comprises thinly interlayered, shiny pale to dark grey slate, calcareous slate and pale to medium grey, fine to very fine grained limestone. Limestone may be well laminated and silty, and locally bedding surfaces have mud cracks and worm burrows. Interbedding of slate and limestone varies from thin rhythmic tabular beds to discontinuous lenses, or on a larger scale, consists of alternating thicker sections of non-calcareous slate and platy grey limestone.

Northwest of Graveyard Lake, the Kechika Group occupies a large area which extends northwards to the Kechika River. The Kechika is unusual in this area, characterized by being more siliceous and more dolomitic. The rocks consist of thinly interlayered grey to orange weathering, pale to medium grey silty slate, calcareous slate, and calcareous siltstone to fine sandstone, all of which may be finely laminated to cross-laminated. Mica flakes are sometimes visibly on some bedding surfaces. These rocks locally grade into silty limestone or dolostone. North of Gemini Lakes, grey to beige weathering, dark grey, platy micritic limestone to argillaceous limestone occurs in sections up to 10 metres thick. This limestone can be dolomitic, contain thin slate partings and display a spaced cleavage in the more argillaceous parts.

This siliceous, planar to cross-laminated limestone and dolostone of the Kechika Group is not typical of the unit within the project area, although regional correlatives in the Selwyn Basin display similar features (Gordey and Anderson, 1993; Cecile, 1982). The transition to this more siliceous Kechika lithology occurs rather abruptly across the Graveyard Lake valley. This northeast trending valley may follow a long lived basinal element later utilized during contractional or strike - slip deformation.

No fossils were found from the Kechika Group within the 1996 map area. Graptolite and conodont collections made during the 1994 and 1995 field seasons, together with regional studies within the Kechika and Selwyn basins, indicate a Late Cambrian to Early Ordovician age (Ferri *et al.*, 1995a, b; 1996a, b).

ROAD RIVER GROUP (MIDDLE ORDOVICIAN TO MIDDLE DEVONIAN)

The Road River Group is widespread in the centre of the southern half of the map area. These rocks can be traced from the northern termination of the 1995 map area northward to Chee Mountain where they disappear below the thrusts carrying Cambrian and Proterozoic rocks. Road River rocks reappear north of Boya Hill and also crop in the lower Red River and Kitza Creek areas. No Road River Group was found farther north in the Liard Plain.

The Road River Group is divided into two informal subunits, although these cannot be separated on the map, as was possible in the 1994 and 1995 map areas. There is an unnamed lower sequence of black shale, siliceous shale, chert and minor limestone, known as the Duo Lake Formation in the Selwyn Basin (Gordey and Anderson, 1993; Cecile, 1982), and an upper sequence of distinctive buff-orange weathering, bioturbated dolomitic siltstone,

Photo 3: Orange - weathering, dolomitic and bioturbated siltstone of the upper Road River Group. This unit is informally referred to as the 'Silurian Siltstone' unit in the map area. It is one of the more uniform and distinct lithologies, and a helpful stratigraphic marker.

informally referred to in this project as the 'Silurian Siltstone'. Road River exposures are dominated by the Silurian Siltstone unit due to its relatively resistant nature.

No macro-fossils were found by us in the Road River Group, although Middle Ordovician graptolites have been recovered in the past from slates in the Kitza Creek area (Miller and Harrison, 1981a). Fossils collected during the previous two field seasons, together with regional work, suggests a Middle Ordovician to Middle Devonian age range for the group (Ferri *et al.*, 1995a, 1996a). The lower Road River Group was previously believed to be Middle to Late Ordovician in the Gataga map area, but conodonts recently recovered from lower Road River rocks in the Terminus Mountain area suggest an Early Silurian age for its upper limit (M.J. Orchard, personal communication, 1996). These conodonts were associated with barite mineralization and are very similar to those found within the Active Member of the Howard's Pass area (M.J. Orchard, personal communication, 1996). The Silurian Siltstone is broadly Silurian to Middle Devonian in age.

Lower Road River Group

The lower Road River Group is poorly represented in the map area due to its recessive nature. It was recognized at the southern end of the map area, along Horneline Creek and possibly along the Red River. This subunit closely resembles the Earn Group and it should be cautioned that sections mapped as Earn Group could in fact be part of the lower Road River Group, and *vice versa*. The difficulty in confirming their identity arises from the lack of fossils and the usually poor stratigraphic control. In isolated, small exposures, the lower Road River Group can also be confused with the Kechika Group, and since mapping in 1994 and 1995 revealed that the lower Road River can be very thin, it was appropriate in many places to combine it with the Kechika Group. This practice has been extended into the present map area, such as in the extreme southeast, in the Turnagain River, and in parts of the Red River valley.

Lower Road River rocks are characterized by dark grey to bluish grey carbonaceous black shale, siliceous shale to argillite, siltstone, cherty siltstone to chert and grey to bluish grey limestone. Bedding can be up to 30 centimetres thick. Interlayered cherty argillite and chert with lenticular bodies of limestone are locally developed. On Horneline Creek, lower Road River rocks are composed of sooty black slate with interbeds of black argillite, and pale grey slate to silty slate. A bluish-grey weathering colour with yellow oxide staining is typical of slates and argillites, a feature shared by the Earn Group and which contributes to their potential confusion.

Silurian Siltstone

Compositionally, this is the most uniform unit within the map area. It consists of orange to brown weathering, grey to greenish grey, wispy, bioturbated siltstone to dolomitic siltstone, argillite and slate (Photo 3). It is thinly to thickly bedded. Stratification is difficult to discern in more massive beds due to the bioturbation, but is quite laminar in undisturbed sections and can display cross-stratification. Siltstone may contain recessive beds of grey to dark grey argillite to silty argillite which is gradational with siltstone. Minor lithologies include grey limestone, grey to grey-brown banded chert and fine to very fine-grained, grey to dark grey quartz sandstone to quartzite. On the east side of the Kechika River, just south of the junction with the Red River, the top of this unit contains several metres of massive, grey, calcareous quartz sandstone with well rounded, spherical quartz grains.

Photo 4: Looking southeast at spectacular fold developed within calcareous facies of the Earn Group along the south side of a creek flowing westward into the Kechika River, just south of the confluence with the Red River. Field of view approximately 5 metres across.

EARN GROUP (MIDDLE DEVONIAN TO MISSISSIPPIAN)

For the most part, the Earn Group is exposed in synclines within the Road River Group in the southern part of the map area. Other sections are believed to occur along the Red River and along the east side of the Kechika River, northwest of Graveyard Lake. The Earn Group is characterized by thinly to thickly bedded, carbonaceous, blue grey to dark grey or black argillite, cherty argillite, siltstone and slate. These rocks have a characteristic yellowish stain on weathered surfaces. Bedding is planar to wavy, and is generally accompanied by slaty cleavage except in chert, siltstone and some argillites.

On the east side of the Kechika River, just south of the junction with the Red River, typical Earn Group lithologies are notably calcareous and associated with thinly to thickly bedded, buff-weathering, grey to sooty black, fetid argillaceous limestone. This platy to blocky limestone may have gradational contacts and be found as individual beds or in sections several metres thick. It forms a spectacular fold at the mouth of one of the creeks in this area (Photo 4). These calcareous rocks are atypical of the Earn Group in the map area, if not regionally (Gordey, 1991). They are very similar to sooty argillite and calcareous argillite to argillaceous limestone of uncertain age found in the Kitza Creek area (see section on 'Kitza Creek facies') suggesting that the latter are part of the Earn Group. Alternatively if the Kitza Creek rocks prove to be older, it suggests that the Kechika River rocks are also older and have been structurally emplaced against the adjacent Road River Group.

No macro-fossils were collected from the Earn Group in the present map area. Fossil collections made elsewhere within the Kechika Trough indicate a late Middle Devonian to Early Mississippian age (Ferri *et al.*, 1995a, 1996a; MacIntyre, 1992).

MOUNT CHRISTIE FORMATION (?) (MISSISSIPPIAN TO PERMIAN)

Approximately 5 kilometres south of the Liard River, some 5 metres of grey to buff weathering, pale grey to dark grey and mottled, moderately to thickly bedded chert is found along the top of a small knoll. Bedding is planar to wavy and has extensive limonitic staining. Pale grey chert is also found along the top of Mount Earle. Thinly and well bedded, pale salmon and green chert with pale green argillite partings also occurs stratigraphically above the Earn Group at the Roman showing along the Liard River (Photo 5; see Economic Geology section).

No significant sections of pale coloured chert have been encountered within the Earn Group or older stratigraphy anywhere else in this mapping project, suggesting that these rocks are a different, younger unit. Thick sections of post-Earn Group chert have been

Photo 5: Thinly, well bedded pale salmon and green chert stratigraphically above the Earn Group. This section is found near the Roman showing, situated along the Liard River west of Lower Post. These cherts have been tentatively assigned to the Mount Christie Formation; they strongly resemble Mississippian to Permian cherts that overlie the Earn Group within the Cassiar terrane.

described in the Selwyn Basin and belong to the upper part of the Mississippian to Permian Mount Christie Formation (Gordey and Anderson, 1993). Farther east, within the Rocky Mountains, chert of similar age belongs to the Permian Fantasque Formation (Bamber *et al.*, 1991). Pale red and green chert of broadly Mississippian to Permian age has been described from the Cassiar Mountains (Nelson and Bradford, 1993) and may be a western equivalent of the Liard River cherts.

These sporadically exposed, pale coloured cherts in the northern part of the map area are tentatively assigned to the Mount Christie Formation, in accordance with established Selwyn Basin nomenclature.

TUYA FORMATION (?) (TERTIARY TO QUATERNARY)

Massive to fragmental, fresh-looking basalt occurs on several hill tops between Black Angus and Kloye creeks, approximately 10 kilometres southwest of the Liard River. These rocks consist of grey weathering, dark grey-brown to dark green, aphanitic or plagioclase-olivine phyric basalt. Basalt fragments can be vesicular, angular to sub-rounded and up to 30 centimetres in size; small pockets of black volcanic glass were also noted. The tuffaceous matrix displays a yellow to tan colour locally, indicating some alteration. It is not known if these volcanics are sub-aerial or sub-marine.

Pleistocene or Tertiary basalt has been described from the McDame (Gabrielse, 1963) and Jennings River (Gabrielse, 1969) map areas. The volcanics form prominent flat-topped volcanic cones in the Jennings River area and are grouped within the Tuya Formation (Gabrielse, 1969). The basaltic deposits in the present map area are similar to descriptions of Tuya Formation volcanics to the west and are grouped with them.

Layered Rocks of Uncertain age

'AEROPLANE LAKE PANEL' (UPPER PROTEROZOIC AND/OR LOWER PALEOZOIC?)

Low grade metamorphic rocks on the highland east of Aeroplane Lake and extending down through the lower parts of Davie Creek and towards the Turnagain River are of unknown affinity. Compositionally, certain sections bear a strong resemblance to the Kechika Group, and others to clastics and carbonates of Cambrian and Proterozoic age, respectively. In some places these lithologies occur along strike or intermixed with each other, precluding their simple assignment. Their stratigraphic placement is further complicated by the metamorphic recrystallization in certain areas which has masked primary features, and by the presence of a second phase of deformation generally not seen elsewhere in the map area. The stronger metamorphism and deformation in this package suggest it may at one time have been at a greater depth than surrounding rocks, and was later uplifted along a deep-rooted fault or thrust. This interpretation would imply that these rocks could be relatively old, perhaps a lower part of the Hyland Group. It is difficult to be more specific about the stratigraphic affinities of the Aeroplane Lake panel because of the limited outcrop available. The panel has been divided into three packages (not differentiated in Figure 3): 1) Calcareous phyllite and schist; 2) Siliceous schist and quartz sandstone; 3) Limestone, phyllite and sandstone.

Calcareous phyllite and schist

Along the Kechika River and on the lower part of Davie Creek are crenulated, finely laminated to banded calcareous phyllites and graphitic phyllites which locally approach schists in texture. Phyllite and schist can be thinly interlayered with silty limestone which are locally recrystallized to marble. These higher grade, crenulated rocks continue northwestward into the ridge east of Aeroplane Lake along which are also found lower grade, thinly interlayered slate, calcareous slate and grey limestone very similar to the Kechika Group. Directly east of Aeroplane Lake, these calcareous rocks pass along strike into grey to greenish-grey phyllites, interlayered with sandy phyllites or thin laminae of quartz sandstone.

Siliceous schist and Quartz Sandstone

Dark grey to grey crenulated phyllite to schist crops out along the lower part of Davie Creek, and on the Kechika River opposite the junction of the Turnagain River. These rocks are found immediately along strike with brown-grey to blue-grey weathering, silvery-grey slate and phyllite, interlayered with micaceous quartz sandstone, wacke and siltstone. Siltstone can be graphitic and is found with dark grey platy limestone. Sections on Davie Creek texturally approach a schist and contain small porphyroblasts of biotite and a carbonate mineral (ankerite?).

East of Aeroplane Lake, siliciclastics consist of interlayered dark grey to grey graphitic banded crenulated slate, calcareous slate, siltstone and greenish grey, micaceous quartz sandstone. Sections up to 10 metres thick of beige to brown weathering dark grey, finely crystalline, platy to massive limestone with thin phyllite partings occur within the siliciclastics. However, overall this package is much less calcareous than the first one described above.

Limestone, phyllite and sandstone

Limestone is the dominant rock type in this package of the Aeroplane Lake panel. It crops out along the southern crest of the ridge east of Aeroplane Lake, in sections up to 15 metres thick. It is coarsely recrystallized to marble, strongly mottled, and contains small phlogopite crystals. Minor pelitic horizons are composed of crenulated muscovite-chlorite schist and greenish-grey calc-silicate. These rocks can be traced into areas of less metamorphosed grey to dark grey, massive to platy limestone with thin phyllite partings. Well layered platy limestone is commonly highly deformed, displaying several phases of deformation including an early layer-parallel fabric with associated small intrafolial folds, and a later series of upright folds. Sections of bluish dark grey micaceous quartz - feldspar sandstone to granule conglomerate is found associated with these calcareous rocks.

'KITZA CREEK FACIES' (LOWER OR MIDDLE PALEOZOIC)

Around Kitza Creek, there are mappable areas of Silurian Siltstone of the Road River Group, and also substantial areas of dark grey to black, carbonaceous calcareous siltstone, silty limestone, siltstone, argillite, slate and chert. The stratigraphic position of the latter group of rocks is not clear because no fossil control is yet available, and contact relations with the Road River have not been determined. Basically, it is not known if this lithological assemblage, which we have called the Kitza Creek facies, is older or younger than, or equivalent to the Road River Group. The slates and argillites resemble those of the Earn Group, but the associated abundant calcareous material is not typical of the Earn regionally. However, east of the Kechika River, similar lithologies apparently sit stratigraphically above the Silurian Siltstone and so have been assigned to the Earn Group despite their calcareous nature.

As an alternative, the Kitza Creek facies also have some properties compatible with rocks of broadly Ordovician to Silurian age of the lower Road River Group, although nowhere in the project area is this unit particularly calcareous. However, in the Paul River area of the southern Kechika Trough, Gabrielse (1981) mapped lower Road River Group rocks that consist of dark grey to black calcareous shale, slate and siltstone succeeded by interbedded platy silty slate, shale and conspicuous limestone beds, a description that fits rocks of the Kitza Creek facies.

A third possibility is that the Kitza Creek facies is a distinct unit intermediate between the Road River and Earn, equivalent to an Early to Middle Devonian clastic and carbonate sequence documented in the southern Kechika Trough (MacIntyre, 1992). Fossil control is needed to resolve these possibilities.

Kitza Creek rocks are characterized by dark grey to black, carbonaceous siltstone to silty argillite and shaly slate. All of these can be calcareous to varying degrees and be interlayered with thinly to thickly bedded buff, pale to medium grey weathering, dark grey to black, silty to argillaceous fetid limestone. Limestone is platy to blocky and poorly cleaved, and in some sections is quite thick, forming prominent topographic ribs. Associated with these lithologies are thin layers of grey-weathering, calcareous quartz sandstone to sandy limestone and pale grey calcareous tuff. The sandstones consist of rounded quartz grains, and argillite and carbonate clasts. Sandstone horizons can be quite massive and several metres thick. Limestone is also found with thinly laminated, orange to brown weathering, grey dolomitic siltstone. Calcareous and siliciclastic rocks locally are interbedded with medium bedded, dark bluish grey to black chert. These rocks are associated, in one locality, with debris flows composed of angular chert clasts and

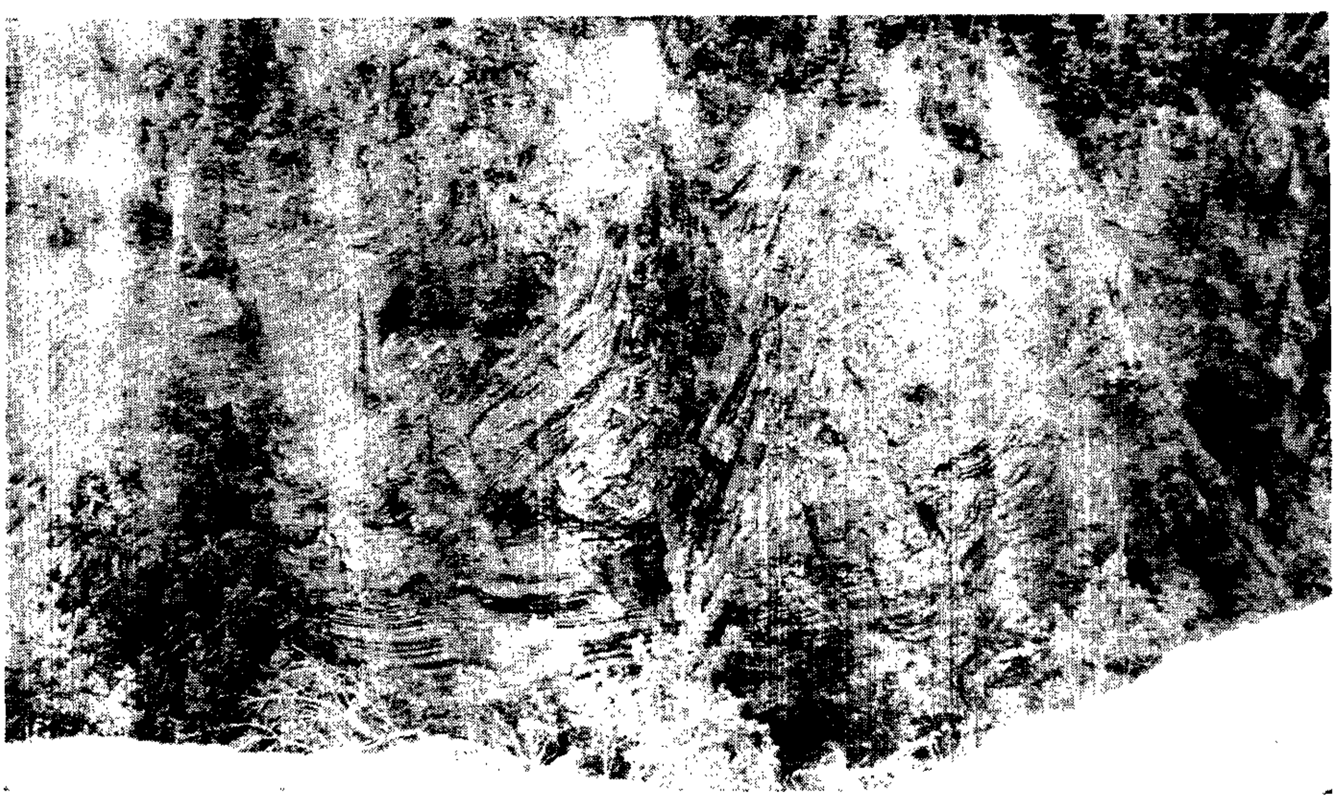

Photo 6: Looking south at a section of highly contorted rocks along the lower part of Horneline Creek. This rock face was inaccessible but the overall appearance is similar to that of Kitza Creek rocks seen elsewhere.

limestone intraclasts up to cobble size. Elevated barium concentrations occur in argillaceous limestone at one locality on Kitza Creek.

Rocks similar to the Kitza Creek facies are present along the Red River and along the lower parts of Horneline Creek (Photos 6, 7 and 8). Contact relationships with surrounding units in both localities are obscured or faulted. On the Red River, calcareous argillites and limestones (Photo 7), as found around Kitza Creek, are associated with rusty weathering, dark grey to black carbonaceous slate or argillite with interbedded thin laminae or wispy layers of tan to buff weathering dolomitic siltstone. These dolomitic horizons give the rock a characteristic striped appearance (Photo 8). Siltstone layers are from 0.1 to 10 centimetres thick and comprise up to 50 per cent of the rock. The dark grey to black argillite and slate in these sections resembles those of the Earn Group, yet the dolomitic siltstone horizons are more characteristic of the Silurian Siltstone. This suggests these rocks may be part of the upper unit of the lower Road River Group, transitional with the Silurian Siltstone unit.

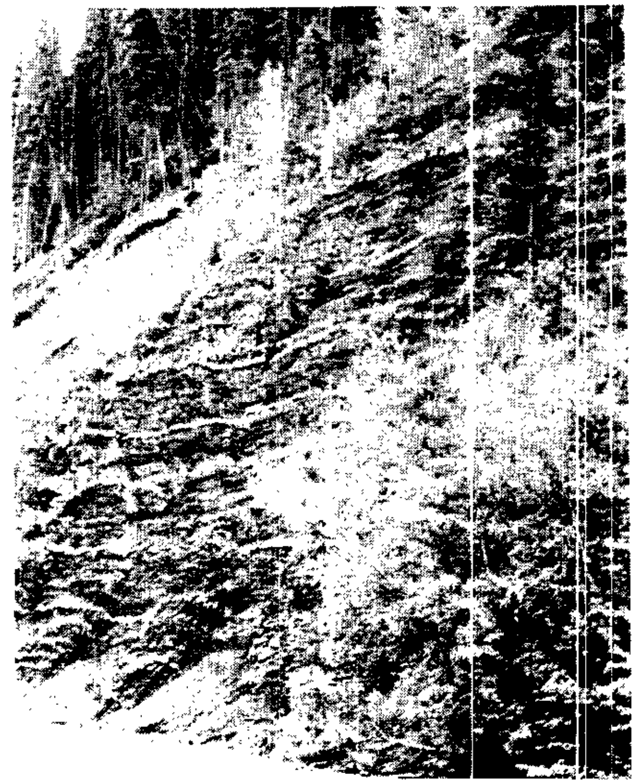

Photo 7: Dark grey to black calcareous argillite and argillite interlayered with white weathering, thin to thickly bedded argillaceous limestone exposed along the north bank of the lower Red River.

Cassiar Terrane

A few traverses were made across the Northern Rocky Mountain Trench. West of Mount Monckton[i] , strong shearing in grey laminated phyllite is believed to

Photo 8: Folded, interlayered dark grey argillite and tan to buff weathering siltstone to dolomitic siltstone, along the south bank of the lower Red River. These rocks are also characterized by a conspicuous banding, as shown here.

reflect deformation in the fault zone. Immediately to the west, presumably in the Cassiar terrane, rocks are quite variable and range from quartz-feldspar bearing sandstones of Late Proterozoic age to siltstone of possibly Siluro-Devonian age. Medium grey, moderately to thickly bedded quartz sandstone with rare feldspar clasts and phyllitic partings are most likely Late Proterozoic and thus belong to the Ingenika Group. The affinities of the other rocks encountered are more problematic due to the paucity of available data. These include: grey to yellow or orange weathering, grey to green, massive to finely laminated dolomitic siltstone, cherty siltstone and chert; yellow to orange, grey, faintly laminated silty limestone to calcareous siltstone; and grey, coarse-grained calcareous quartz sandstone to quartzite and grey slate. These lithologies may belong to the Road River, Kechika and Atan groups, respectively.

Intrusive Rocks

Several intrusive rock types have been found in the map area. Gabbro, hosted by the Kechika Group, forms the only bodies of mappable size; the rest consist of small stocks or dikes.

GABBRO

Northeast of Gemini Lakes, gabbro is interpreted to form several elongate bodies within rocks of the Kechika Group. Intrusive relationships were seen in only a few localities, and in one it appears that the gabbro forms a sill - like body. Gabrielse (1962a) described dikes and sills of gabbro in rocks of Proterozoic and Early Paleozoic age, and has suggested that they are no younger than Kechika age as they are never found intruding younger rocks (H. Gabrielse, personal communication, 1996). Our observations support this.

Gabbro is orange-brown weathering, speckled green and white, non-foliated, equigranular and medium to coarse grained. Plagioclase is grey to pinkish and comprise between 40 to 50 per cent of the rock. The remainder is dark green pyroxene, hornblende and biotite.

BOYA HILL INTRUSIVES

Tungsten-molybdenum skarn mineralization on Boya Hill is related to dikes, sills and small stocks of medium grained quartz-biotite-feldspar porphyry and quartz porphyry (Peatfield, 1979a). The largest stocks are some 100 metres in diameter (Peatfield, 1979a), and all are altered. The age of these intrusions is believed to be 100 ± 3 Ma (late Early Cretaceous) based on whole rock potassium - argon systematics from surrounding hornfelsed sediments (T.G. Schroeter, personal communication, 1980). These intrusive rocks were not examined in detail during our mapping and the following descriptions are taken from Peatfield (1979a).

Quartz-biotite-feldspar porphyry is of quartz monzonite or granodiorite composition. The unaltered rock has abundant potassium feldspar in the groundmass. Quartz porphyry is leucocratic and only weakly porphyritic such that it locally appears aplitic. The groundmass typically contains abundant potassium feldspar and some localities contain sparse potassium feldspar and biotite phenocrysts. Also present in this area are thin dikes of quartz-feldspar ± biotite porphyry with a dark purplish groundmass.

OTHER INTRUSIONS

Several feldspar and quartz-feldspar porphyry dikes were found within the low grade metamorphic rocks of the Aeroplane Lake panel, and also in the footwall of this thrust panel. The groundmass of these dikes can be medium bluish grey and weakly calcareous. Set in this are pink to orange-buff feldspar and brown biotite phenocrysts. These bodies are up to several metres across, and where observed have chilled margins and cut the fabric of the host rocks. Their age is unknown but they may be related to the Boya Hill intrusions, 10 kilometres to the southeast, in which case they would be Early Cretaceous.

Rocks underlying Mount Monckton are strongly hornfelsed, indicating the proximity of a large intrusive body. Several outcrops of intrusive rock were found in the area, which is along the extension of the Northern Rocky Mountain Trench fault zone, and their undeformed condition suggests they are younger than the fault, making them no older than latest Cretaceous or Early Tertiary.

Several kilometres west of Mount Monckton is a small body of speckled grey, medium grained granite or granodiorite with subhedral quartz phenocrysts up to 2 millimetres in diameter. Fracture surfaces are coated with magnetite or hematite. Another intrusion, of pale yellow, altered quartz porphyry was found a few kilometres southeast of Mount Monckton.

STRUCTURE

The overall structural style is one of northwest-trending folds and thrust faults similar to that mapped to the southeast in the Kechika Trough (Ferri *et al.* 1995a, b; 1996a, b), although folding may be more gentle in this area, and the map pattern appears to be less affected by the thrust repetition typical of the Rocky Mountains. This impression may be largely the result of the sporadic exposure. The poor control governing most of the geological contacts prevents distinguishing between a stratigraphic or tectonic relationship between map units,

Photo 9: Looking northwest at steep, northeast-verging folds in calcareous siltstone and argillaceous limestone of the Kitza Creek facies, Wadin Creek.

and the apparent absence of even a thick map unit could be accounted for simply by non-exposure, and not necessarily by an unconformity or structural omission. As a result, a fairly conservative interpretation has been applied to the map and cross-section. The structure is characterized by open to moderate, upright to northeast-verging folding (Figure 3; Photos 4, 8 and 9), but there may be considerably more thrust faulting involved, and thickness variations, than has been assumed.

The most obvious major thrust is that on the east side of Chee Mountain, where Cambrian quartzites and slates overlie Earn Group rocks. West of the Cambrian rocks, on the west side of Chee Mountain, are Proterozoic grits and limestone of the Hyland Group which we think are separated from the Cambrian by another northeast-verging thrust fault. The two thrusts may merge to the north, just south of the Boya Creek valley. This Proterozoic thrust panel probably continues northwards across Boya Creek to Boya Hill. Another significant thrust carrying Proterozoic rocks passes through Aeroplane Lake in the Rocky Mountain Trench. Its northward extension, across the Red River, is obscure due to the absence of outcrop. Elsewhere in the map area, a few, relatively minor thrust faults are inferred to explain the juxtaposition of Cambrian rocks against the Road River Group or Earn Group.

Major fold axes and homoclines trend consistently northwest. Stereograms of bedding indicate that most dips are fairly gentle to moderate throughout the area. dip directions are highly variable, but there is a bias towards the southwest. Overturned beds were noted in several localities, but no major overturned folds were recognized. Isolated, lenticular outcrop areas of black slates and argillites within Road River Group in the southern quarter of the map area may represent Earn Group in the cores of minor, doubly-plunging synclines. It is also possible that some are, in fact, lower Road River Group in which case the folds would be anticlines. A larger, poorly exposed syncline of Earn Group is present in the footwall of the Chee Mountain thrust, extending south to Horneline Creek.

The dominant cleavage is generally parallel or subparallel to bedding. Stereograms reveal that cleavage is somewhat steeper with a more consistently northwest-striking and southwest-dipping attitude than bedding. Crenulation cleavage is rare, and is best developed in the metamorphic rocks of the Aeroplane Lake panel. This cleavage generally strikes north-northwest to north-northeast, and dips gently to steeply east. Crenulated phyllites and schists in the Aeroplane Lake panel are associated with polydeformed carbonate (see section on Aeroplane Lake panel). Limestone contains a strong, layer parallel fabric with associated tight folds and these are overprinted by broader, upright fold structures. The significance of this earlier deformation is uncertain.

The Northern Rocky Mountain Trench is a broad, well defined valley as far north as the Red River, beyond which it opens out into the Liard Plain. The dextral Northern Rocky Mountain Trench fault probably forms a wide fault zone in the valley. The fault itself has been tentatively positioned along the western border of this inferred fault zone, close to the basal slopes of the Cassiar Mountains (H. Gabrielse, personal communication, 1996), rather than in the centre of the Trench. The fault zone may be exposed in the Turnagain River valley where highly disrupted blue-black calcareous and non-calcareous slates and argillites are visible in scattered outcrops along the river banks for several kilometres. Farther north, in the Liard Plain, the position of the Northern Rocky Mountain Trench Fault is virtually unconstrained and is very tentative.

A number of steep, northeast-trending, dip-slip or oblique-slip faults are present in the map area. Those in the southeast, east of Horneline Creek, affect Proterozoic and Cambrian units, and the Kechika Group. They account for the minor offsets in their geological contacts across transverse valleys. Faults along the Graveyard Lake-Boya Creek valley, the northern stretch of the Kechika River, and south of Tatisno Mountain, are more significant in that the geology changes substantially across them. The 'block' between Graveyard Lake and the Kechika River is characterized by a facies of the Kechika Group possibly reflecting shallower water conditions (see

Stratigraphy, under Kechika Group). It is speculated that the faults bounding it might represent older basement structures which were reactivated during orogeny; originally they formed the sides of a localized, perhaps more shallow water depositional entity along the miogeoclinal margin where this shallower water Kechika facies formed. Northeast-trending structures in the paleocontinental margin basement are believed to have exerted significant control on lower Paleozoic stratigraphy and facies changes along the margin (Cecile *et al.*, 1997), particularly in this region near the transition between the Kechika Trough and the Selwyn Basin.

ECONOMIC GEOLOGY

Regionally, sedimentary exhalative deposits are by far the most economically significant mineral occurrences within the Kechika and Selwyn basins. Massive sulphides occur at various stratigraphic horizons within these basins: in the Cambro-Ordovician (Anvil district), the Early Silurian (Howard's Pass area) and the Late Devonian (Tom, Jason, Driftpile Creek, Cirque). Several occurrences of barite mineralization were examined in the present map area, including some new ones. Previously documented porphyry molybdenum and related tungsten skarn mineralization, and sulphide bearing quartz-carbonate veins are also present.

Sedimentary Exhalative Deposits

KECHIKA RIVER BARITE

A significant Earn-hosted barite-pyrite stratiform deposit was discovered during mapping in 1996. It is one of the few occurrences of this type known within the map area. It is situated along a creek valley approximately 9 kilometres northwest of Gemini Lakes and one kilometre upstream from the creek's junction with the Kechika River (Figure 3).

The bedded barite sequence is at least 4 metres thick, and its base is not exposed. The entire outcrop weathers a bright orange colour due to oxidation of iron sulphides. Individual barite beds are from 1 to 10 centimetres thick and make up approximately 30 per cent of the sequence (Photo 10). A pale coloured, well cleaved rock of unknown composition is interlayered with the barite. It may be either altered slate or possibly fine-grained felsic tuff. Barite is fine to medium-grained and contains fine pyrite laminations or tiny orange spots which may be the product of weathered sulphides. Locally, pyrite is also finely disseminated within the layers of the pale coloured rock. The barite sequence is overlain by medium to dark grey slate with flattened pyrite concretions, horizons of barite nodules and finely laminated pyrite.

Photo 10: Bedded barite at the Kechika River Barite showing. Hammer handle for scale. Fine to medium-grained barite contains fine pyrite laminations.

KITZA CREEK AREA

Another new but apparently minor occurrence was found on Kitza Creek, approximately 2 kilometres east of Kitza Lake (Figure 3). The host rocks consist of blocky to platy, medium to dark grey or black, fine to medium grained limy siltstone to silty limestone of the Kitza Creek facies. There are also thin, pale buff-grey calcareous sandstone beds within the section. These rocks are probably either part of the Earn Group or the lower Road River Group (see section in Stratigraphy, above). No barite was noted, but the calcareous rocks feel slightly heavy, and analysis reveals they are slightly anomalous in barium. The relevant mineral may be witherite rather than barite. The general area around Kitza Creek has been explored in the past (Miller and Harrison, 1981a) resulting in the discovery of numerous sulphide-bearing veins (see below).

Photo 11: Skarn mineralization at the lower contact of Proterozoic (?) marble, at the West Hill showing of the Boya prospect, on Boya Hill. The gossanous mineralization, 1 to 2 metres thick, below the marble consists of massive pyrrhotite, with diopside and quartz, lesser garnet and a trace amount of chalcopyrite.

ROMAN

Sulphide mineralization of possible stratiform nature is present at the Roman showing (MINFILE occurrence 104P 072), situated approximately 9 kilometres northwest of Lower Post on the Alaska Highway (Figure 3). This mineralization is associated with numerous sulphide-rich veins that are described below. The main showing occurs along the south bank of the Liard River just 1 kilometre south of the British Columbia - Yukon border. A smaller barite showing, related to this occurrence, occurs along the south bank of the Liard River some 8 kilometres to the northwest of the main showing. The Roman occurrence was first staked in the early 1960s and worked on intermittently until the late 1980s (Cukor, 1981; Rainsford, 1984 and Mark, 1988).

The main showing was not visited by the authors; the following account is taken from Mark (1988) and Rainsford (1984). The showing is hosted by black graphitic slate and thin to moderately laminated dark grey silty limestone of the Earn Group. Carbonaceous sandstone to quartzite occurs above the sulphide bearing horizon. Several concordant to discordant sphalerite and galena bands, up to 20 centimetres thick, can be traced for 10 metres before they disappear under the Liard River. Fine pyrite laminations and barite lenses are described from a related site across the Yukon border. Reported assays of the sulphide horizons at the main showing are 22.6 per cent zinc, 46.3 per cent lead and 23 grams per tonne silver (Mark, 1988). The contact zone between carbonaceous slates and quartzites exhibits a pervasive muscovite-sericite alteration and bleaching, and there are numerous quartz veins cutting the silicified zone. Patches of galena, sphalerite and tetrahedrite are found within the silicified zone. Rainsford (1984) suggests these features are part of a sedimentary exhalative feeder system, although our observations of the vein system on the north side of the river suggest that it is much younger, and related to regional folding (see below). This does not rule out the possibility that some of these veins may indeed represent a syn-sedimentary feeder system.

On the opposite side of the river, rocks very similar to those at the main showing are overlain by well bedded and thinly interlayered pale salmon and green chert with thin pale green argillite partings. This unit is very similar to a chert unit of Mississippian to Permian age which overlies the Earn Group in the Cassiar Mountains (Nelson and Bradford, 1993). A small exposure of orange-weathering, carbonate-altered feldspar porphyry occurs immediately east of the main showing. East of this is dark grey to orange-weathering, finely planar to cross-laminated micaceous sandstone and argillite. The sandstone is bioturbated with bedding-parallel worm burrows. The exact age of these rocks is unknown. Their dip is the same as the section at the main showing, suggesting that they lie stratigraphically above it. This would make them younger than Permian, if the correlation of the cherts with those in the Cassiar Mountains is correct, and possibly Triassic. Unfortunately contact relationships between these two packages are covered, allowing the possibility that the coarser clastics represent a thrust panel of older rocks, perhaps of Cambrian or Silurian age.

Porphyry/Skarn

The Boya prospect (MINFILE occurrences 094M 016 and 021) is situated on Boya Hill, approximately 10 kilometres southwest of Graveyard Lake (Figure 3). It was discovered in the late 1970s by Texas Gulf Canada Ltd. during a regional exploration program that targeted sedimentary exhalative deposits in the northern Kechika Trough. It was initially staked as a tungsten skarn; subsequent exploration indicated molybdenum potential (Peatfield *et al.*, 1978). Encouraging initial results led to an intensified exploration program, further ground acquisition and approximately 3950 metres of diamond drilling in 16 holes (Peatfield, 1979a, b, c; 1980a, b; 1981a, b). Low grades and structural complexities, particularly the truncation of mineralization at depth by a thrust fault, led to abandonment of the property.

Mineralization is concentrated at two localities. At the 'Main Face' showing (MINFILE 094M 021), contact metamorphism, patchy skarnification, and pyrite, chlorite and carbonate-sericite alteration are present near the quartz-biotite-feldspar porphyries were they intrude the Proterozoic host rocks. A distinctive, finely banded or mottled quartz-diopside calc-silicate rock, probably derived from calcareous slate or siltstone, is locally mineralized with pyrrhotite, chalcopyrite and scheelite. Samples assayed up to 0.11 per cent copper and 0.15 per cent oxide of tungsten (Peatfield *et al.,* 1978). Garnetiferous skarn in marble locally contains disseminated or semi-massive pyrrhotite, with lesser chalcopyrite, molybdenite and scheelite. The most significant mineralization is hosted by quartz stockworks and fracture-filling veins in the intrusions and altered metasediments and comprises thin streaks of molybdenite and minor scheelite. Traces of galena, sphalerite, bismuthinite, chalcopyrite and arsenopyrite were also reported in quartz veins.

At the other main locality, the 'West Hill' showing (MINFILE 094M 016), approximately 3.5 kilometres to the northeast, similar porphyritic bodies have intruded massive limestone, and interbedded slate, siltstone and quartz sandstone. Thermal aureoles around these intrusions are marked by hornfelsing and alteration. This is manifested as bands or zones of pyrrhotite-diopside-garnet-quartz and calc-silicate skarn around carbonate contacts (Photo 11). The skarn locally contains metre-scale lenses of massive pyrrhotite, with minor chalcopyrite and traces of very fine scheelite. As at the Main Face, values of copper and tungsten are low. Some areas of skarn contain more significant amounts of molybdenite. Minor amounts of arsenopyrite, sphalerite, galena and bismuthinite were found in the drill core (Peatfield, 1979c).

Veins

Low grade sulphide vein mineralization occurs in the Kitza Creek area and along the Red River. Host rocks in both areas belong, in part, to the 'Kitza Creek facies'. At the Roman showing along the Liard River, galena and sphalerite-bearing veins are hosted by the Earn Group.

RED RIVER

Vein mineralization along the Red River (the "Red" MINFILE occurrence 094M 020) was first reported in the early 1980s by St. Joseph Exploration, which later became Sulpetro Minerals Ltd. (Miller and Harrison, 1981b, c). Preliminary work along the Red River indicated low grades; this, and the generally poor exposure discouraged further exploration. Mineralization occurs approximately 5 kilometres upstream from the junction with the Kechika River (Figure 3). There are three main localities of vein mineralization. The western showing is a 3-metre long quartz breccia zone with sphalerite, galena and pyrite. Smithsonite bearing quartz - calcite veins were also noted during our mapping in this area. Approximately 500 metres to the east is an outcrop containing quartz veins with minor chalcopyrite and pyrite. Both occurrences are hosted by rocks of uncertain affinity and could be either part of the Road River or Earn groups. These rocks also share similarities with lithologies described as the 'Kitza Creek facies' (see section above). Another 500 metres to the east a vuggy, irregular quartz vein with low grades of galena and sphalerite is found within rocks of Cambrian age.

KITZA CREEK

Mineralization in the Kitza Creek area (the "Kitza" MINFILE occurrence 094M 018) was discovered by Sulpetro Minerals Ltd. in the early 1980s as part of a larger regional program along the entire Kechika Trough (Miller and Harrison, 1981a). The veins occur in Kitza Creek facies rocks along a belt 8 kilometres long by 3 kilometres wide, centred roughly 3 kilometres east of Kitza Lake (Figure 3). Several dozen veins are known, containing one or more of tetrahedrite, honey-brown sphalerite, barite, quartz, calcite and rare galena. These veins are described as being restricted to calcareous mudstones (Miller and Harrison, 1981a). Smithsonite was reported as matrix in some fault zones and pale green fluorite was found in a few veins (Miller and Harrison, 1981a). The rocks in the area carry elevated metal levels, and Miller and Harrison (1981a) speculated that the veining may be related to de-watering of the host rocks. The low grade of the veins, together with the limited exposure, led to abandonment of the property after a few years of preliminary exploration.

ROMAN

Mineralization of sedimentary exhalative origin at the Roman showing was described above. Sulphide-bearing veins at the property are, in part, interpreted to be much younger and probably related to regional tectonism, although (Rainsford, 1984) has suggested some may be part of a feeder system to sedimentary exhalative mineralization. The history of vein mineralization is complex and is related to at least three phases of deformation. The Earn Group host rocks contain lenses of pyrite along cleavage planes of the first phase of deformation (D_1). This cleavage is pervasive and related to northeast-verging folding and thrusting in the Northern

Rocky Mountains. These lenses are kinked (F_2) by northeast-trending folds, and pyrite is also concentrated in hinge areas of F_2 kinks. These zones show strong carbonate and silicate alteration and associated bleaching. Related to this are thick quartz-calcite-ankerite-tetrahedrite veins which cut the foliation. These veins are deformed by late, north-trending kinks (F_3); related fractures in the altered lithologies are coated with sphalerite, galena, marcasite and pyrite. The thick quartz-carbonate veins also cut the salmon and green chert unit (Mount Christie Formation?) that overlies the Earn Group.

A silica-carbonate altered felsic intrusion immediately east of the Roman vein mineralization may be genetically linked to these veins. The metals may have originated within this felsic body or may have been remobilized from elsewhere in the stratigraphy, possibly from sedimentary exhalative mineralization.

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[i] Mount Monckton is incorrectly labeled on the 1:250 000 scale map (104P) and Map 1110A (Gabrielse, 1963). The correct location is the 3881' peak, approximately 20 kilometres east of the indicated location on 104P.

LAST SEEN HEADING SOUTH: EXTENSIONS OF THE YUKON-TANANA TERRANE INTO NORTHERN BRITISH COLUMBIA

by JoAnne Nelson

Keywords: Yukon-Tanana Terrane, Big Salmon Complex, Dorsey Terrane, Volcanogenic Massive Sulphides, Devono-Mississippian

INTRODUCTION

Kudz Ze Kayah (KZK) and Wolverine are volcanogenic massive sulphide deposits hosted by Early Mississippian meta-rhyolites, marine metasedimentary rocks and intermediate to mafic metatuffs of the Yukon Tanana Terrane in the Simpson Range, southern Yukon (Figure 1). This project aims to pinpoint, within central northern B.C., stratigraphy favorable to the formation of Early Mississippian volcanogenic massive sulphide deposits similar to Kudz Ze Kayah and Wolverine, and also Devono-Mississippian sedex environments in basinal stratigraphy west of the Cassiar batholith.

In the Simpson Range, the Yukon-Tanana Terrane forms a large klippe cut off to the southwest by the Tintina Fault. Figure 2 illustrates the history of the terrane and the elements that make up its distinctive character, based on geology by Mortensen and Jilson (1985). Besides the crucial Early Mississippian rocks that host the volcanogenic massive sulphide deposits, the Yukon Tanana Terrane is characterised by pre-Mississippian continentally-derived siliciclastic metasediments, Early Mississippian intrusions that are coeval and probably cogenetic with the volcanic stratigraphy, Pennsylvanian and Permian limestone, Permian volcanic and plutonic rocks, and cross-cutting Early Jurassic plutons. This capsule geologic history provides a "thumbprint" of the terrane that can be used to help identify its correlatives.

The closest "look-alikes" to the Yukon-Tanana Terrane in north-central B.C. are the Dorsey Terrane, the Teslin Tectonic Zone (called the Big Salmon Complex in the Jennings River Map Area), and the Rapid River Tectonite in the Sylvester Allochthon (Figures 1, 2, 3). Although modern geologic map coverage in these areas is rudimentary at present, they all are known to bear sufficient similarities to the Yukon Tanana Terrane to warrant investigation for Early Mississippian volcanogenic environments. For the 1996 field season, targets were picked within these terranes, with consideration of added encouraging indicators, such as rhyolites or known exhalative mineralization (Figure 3). The specific targets and the rationales for their selection are as follows (listed in order of mapping):

1. **COT claims, along Cottonwood River, 104O/8**
Known sedex mineralization, in rocks described as Earn Group (Cathro 1985; Gal and Nicholson 1992)

2. **Dorsey Terrane near Blue Light claims, 104O/9 and 10**
Quartz-sericite schist and Early Mississippian limestone encountered during 1986 field visit by the author

3. **Dorsey assemblage near McNaughton Creek (104O/15)**
Possible stratigraphic equivalent of Target 2.

4. **Big Salmon Complex, Hazel Ridge, 104O/15**
Piedmontite schist (R. Stevens, personal communication); perhaps a metamorphosed Mn-rich exhalite?

5. **Nizi claims near Nizi Creek in the Rapid River tectonite, 104P/14-15**
Felsic volcanics reported to host epithermal veins (Bond 1993) and by E&I Regional Geologist Paul Wodjak (personal communication 1994)

6. **Southern Rapid River Tectonite near Cry Lake, 104P/15**
Felsic metavolcanic float reported by H. Gabrielse, G.S.C. (personal communication 1996)

RESULTS

Mapping of meta-rhyolite at two of the targets, #2 in the Dorsey Terrane and #4 in the Big Salmon Complex, shows that these two tectonic units are likely to contain appropriate stratigraphy to host KZK/Wolverine-type VMS deposits.

In target area #2, pyritic quartz-sericite schist (meta-rhyolite tuff) forms two tabular bodies within metamorphosed mafic to intermediate tuff, interbedded with limestone from which one Early Mississippian conodont age was obtained in 1986 (see Table 1). On Hazel Ridge (target #4), quartz-sericite schist occurs in transitional contact with piedmontite-hematite-bearing meta-chert. This meta-rhyolite/meta-iron formation couplet is identical to the stratigraphic setting of the Wolverine deposit. At target #1, extensive outcrops of siliceous black argillite strongly resemble the Earn

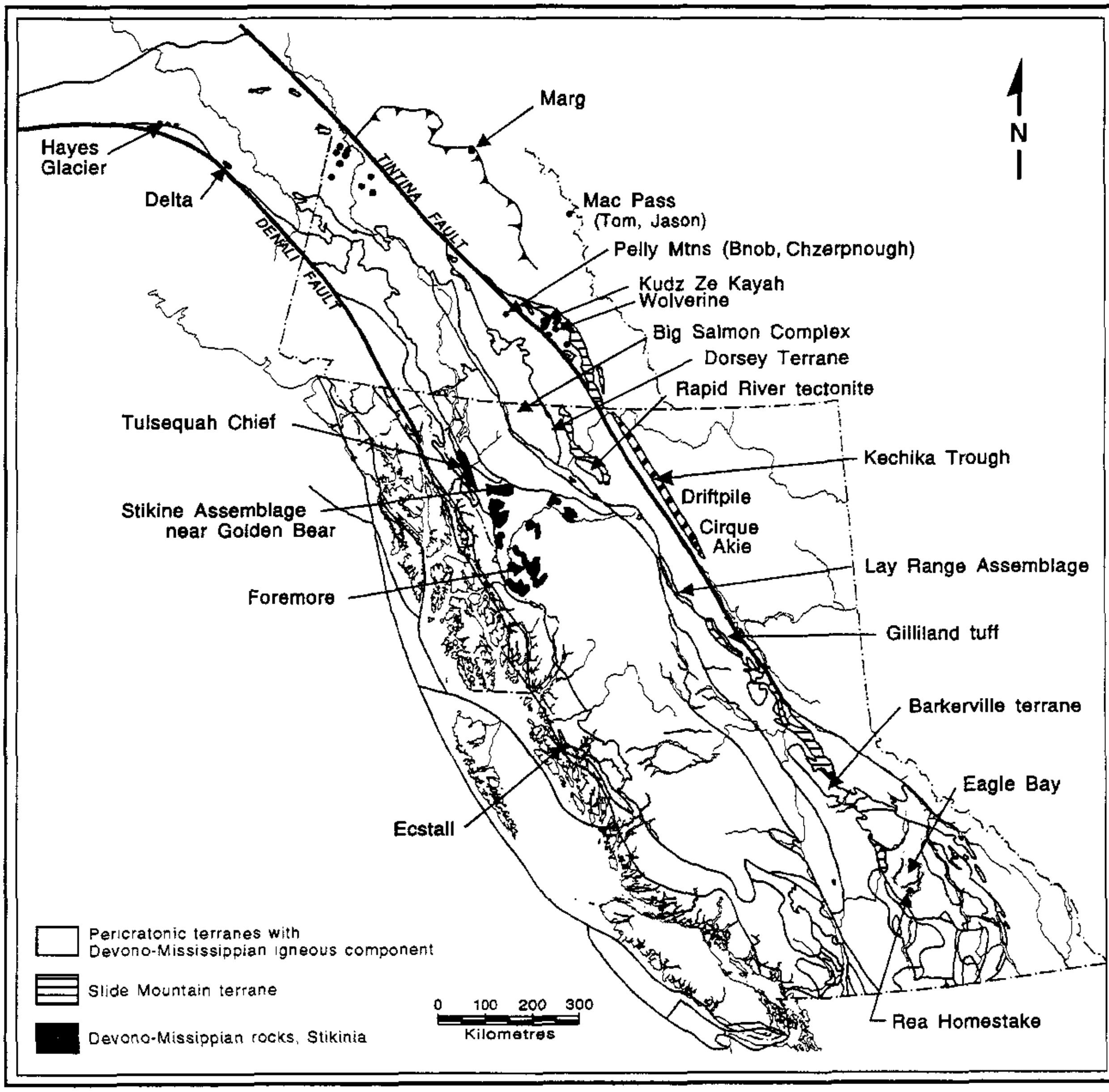

Figure 1. Map of the Canadian Cordillera showing pericratonic and continental margin assemblages known to host syngenetic volcanogenic and sedimentary exhalative massive sulphide deposits of Late Devonian to Early Mississippian age. The shaded areas include both North American marginal and more allochthonous terranes: both are prospective for Devono-Mississippian deposits. The Stikine Assemblage of Stikinia is included because it hosts Tulsequah Chief, a late Mississippian volcanogenic massive sulphide, and because there is evidence for indirect linkages between it and pericratonic terranes to the west.

Group in the Kechika Trough, as suggested by earlier workers (Cathro, 1985; Nicholson and Gal, 1992). Widespread wispy pyrite laminae, baritic chert, elevated barium contents in lithogeochemical samples, and disseminated sphalerite and galena in the argillites suggest a sedimentary exhalative environment.

At the other targets, no evidence of appropriate Early Mississippian volcanic environments was found, although observations were made that contribute to our understanding of the relationships of the Yukon Tanana Terrane with other tectonic elements of the Cordillera.

The local geology of each of the targets is described below, in order of mapping.

TARGET 1

The area east of the Cottonwood River and north of the the headwaters of the Blue River is underlain by metamorphosed, highly deformed black argillite with limestone and pyritic chert (exhalite?) interbeds. Previous work on the property outlined geochemical anomalies in Pb, Zn, and Ba, and disseminated sulphides in black argillite (Gal and Nicholson, 1992; Cathro, 1985). Field observations this season confirmed

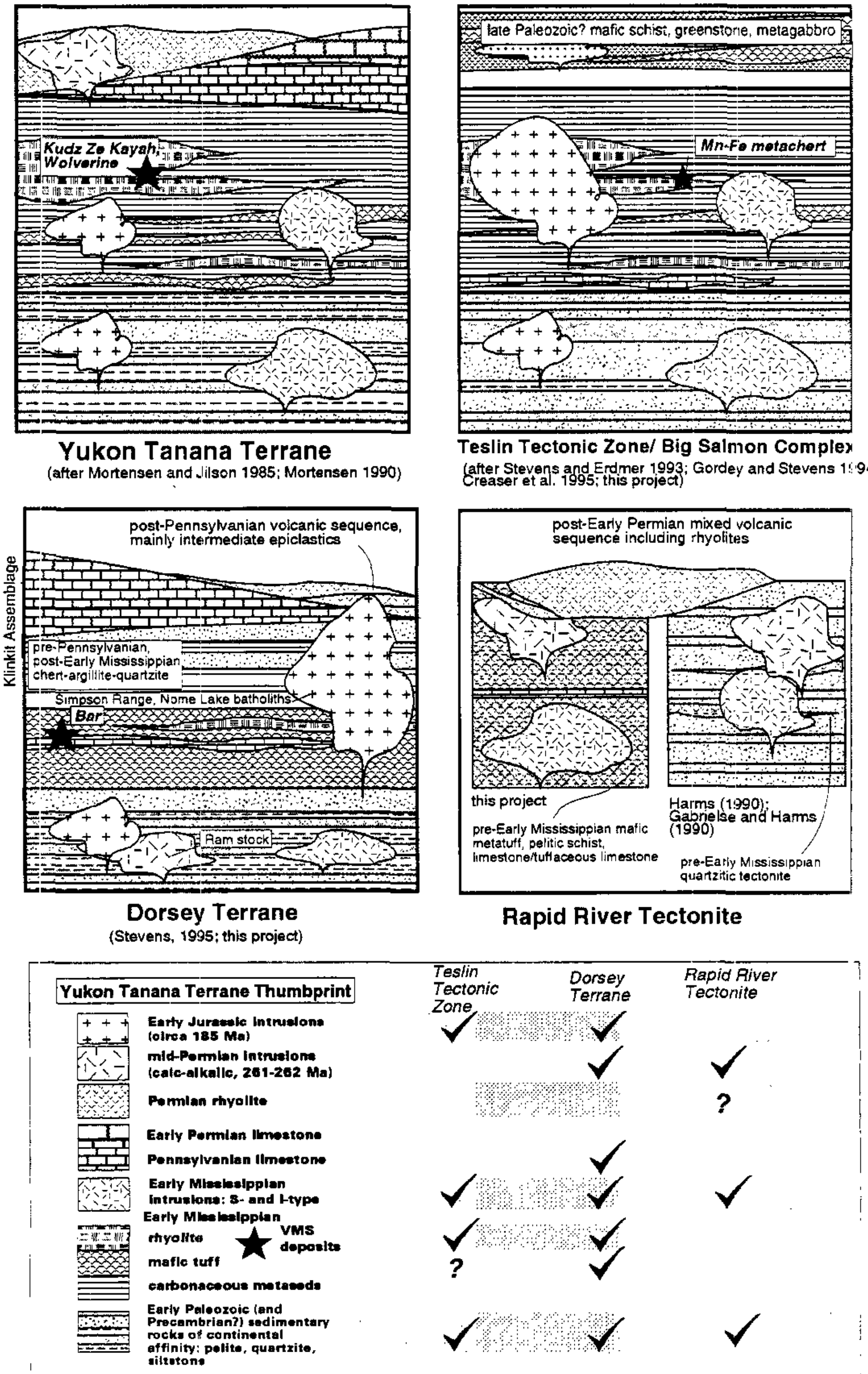

Figure 2. The lithotectonic "thumbprint" of the Yukon Tanana Terrane, as it appears in the Simpson Range and Klondike area. The presence of shared elements, in particular Early Mississippian igneous rocks, qualifies other terranes as possible equivalents. Some of these, the Big Salmon Complex, the Dorsey Terrane and the Rapid River Tectonite, are discussed in the text.

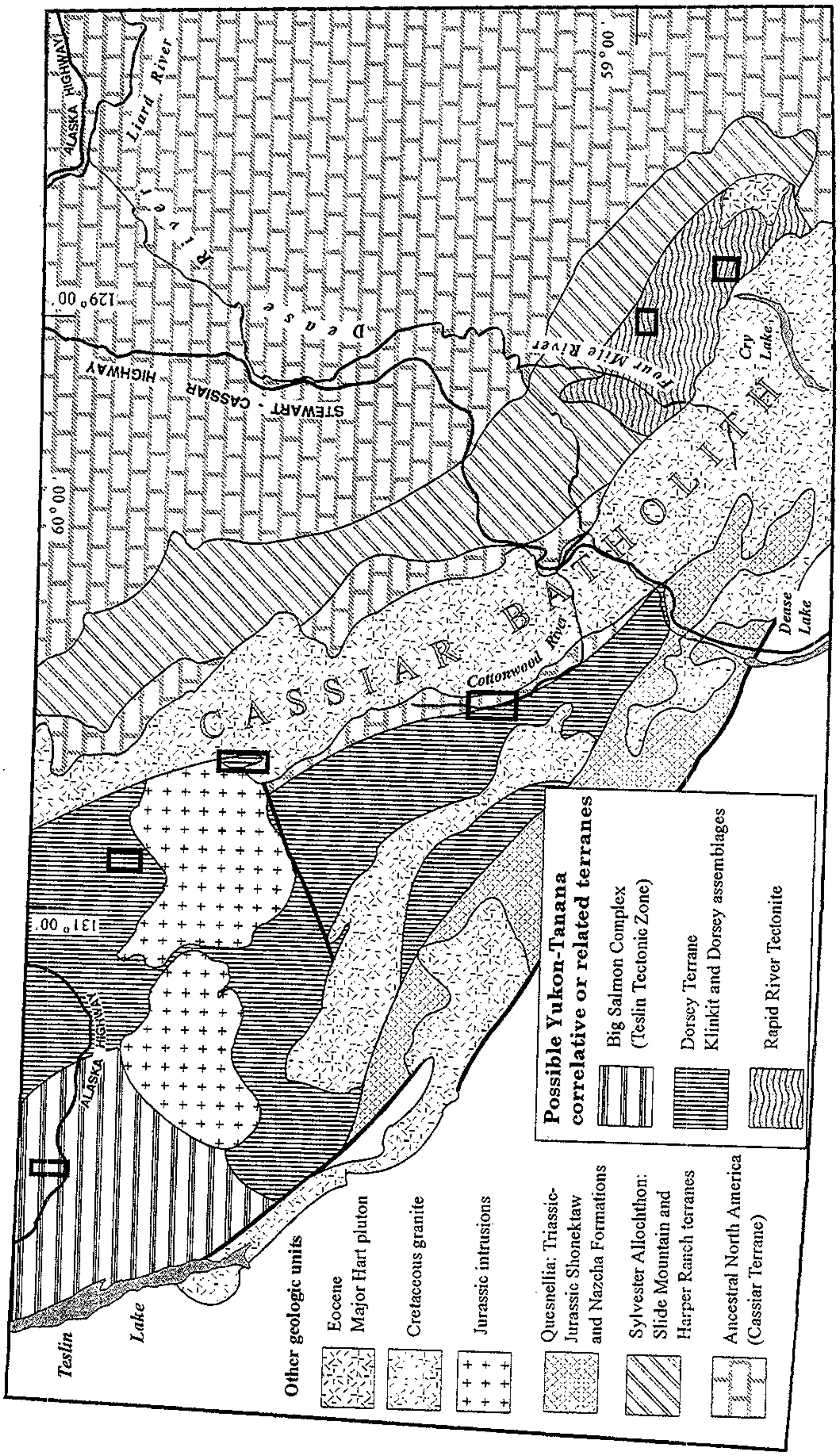

Figure 3. Pericratonic and adjacent terranes of northern British Columbia, with 1996 targets shown.

Table 1. Conodont identification by M.J. Orchard, Geological Survey of Canada

Conodont sample from Dorsey assemblage near Little Rancheria River

Field Number: 86-JN-28-6-1
GSC Number: C-117562
UTM: 417200E, 6611600N
Rock unit: limestone with thin green tuffaceous laminae; overlies green tuffaceous chert
Conodont taxa:
"?*Hindeodella*" *segaformis* Bischoff (1)
CAI: 5
Age: Early Carboniferous ?late Tournaisian

the strong resemblance between these rocks and the siliceous black argillites of the Earn Group. In general they are at a somewhat higher metamorphic grade than the Earn Group, and they show several phases of intense minor folding. At the main, Dakota showing on the property, laminated chert contains pyrite and barite. In thin section, coarse barite grains intergrow with a mosaic of quartz grains that have recrystallized from the original siliceous mud. Six limestone samples were collected for conodont dating through Suzanne Paradis and Steve Irwin of the Geological Survey of Canada, as part of an ongoing cooperative study of Devono-Mississippian sedex deposits. One sample of galena from a cross-cutting early sphalerite-banded quartz vein, folded by F2(?) deformation, has been submitted for Pb-Pb analysis in order to compare it to Cassiar Terrane and Kechika Trough sedex occurrences.

TARGET 2

South of the Little Rancheria River, the structurally lowest exposures of the Dorsey Terrane are cut off by the Cassiar Batholith. They consist primarily of metamorphosed, strongly deformed mafic to intermediate tuff, volcanic flows and/or high level intrusions, limestone, chert and two prominent bands of pyritic quartz-sericite schist (Figure 4). An Early Mississippian (Tournaisian) age was obtained in a conodont sample collected from the limestone in 1986 (Table 1). The quartz-sericite schist bands average 5 metres thick and are continuous for more than a kilometre along strike (Figure 4). They appear to be metatuffs, and grade into chert with sericite partings. In thin section they are seen to contain broken crystals of plagioclase and quartz in a highly foliated, fine grained matrix of quartz and sericite.

These meta-rhyolite tuffs represent a more distal volcanic environment than that at Wolverine and Kudz Ze Kayah, where coarsely porphyritic sills and spherulitic flows are present; however their presence is encouraging in that stratigraphically equivalent but more proximal felsic volcanic environments may occur along strike in the lower levels of the Dorsey Terrane. In order to check the Early Mississippian age suggested by the conodont sample, a sample was collected from the meta-rhyolite for uranium-lead dating.

TARGET 3

This area near McNaughton Creek (Figure 5) is underlain by strata from the upper part of the Dorsey Terrane, structurally and possibly stratigraphically higher than the possible Yukon-Tanana equivalents within it, which are described at target #2 (see above). A tripartite stratigraphy, repeated by thrust faults, includes a lower unit of weakly deformed chert, argillite and quartz (-feldspar) sandstone; a middle limestone of probable early to middle Pennsylvanian age by correlation with limestones mapped by Stevens (1995) along the Yukon border; and an upper unit of intermediate lapilli and crystal-lithic tuff. These rocks in general correlate with the upper part of the Dorsey Terrane near the Seagull Batholith (middle and upper units of Stevens, 1995), informally referred to as the Klinkit Assemblage (R. Stevens and T. Harms, personal communication, 1996). The stratigraphic succession is strikingly similar to that described by Ferri (in press) in the Lay Range Assemblage type section. The Klinkit Assemblage is intruded regionally by Early Jurassic plutons (Gabrielse, 1969) and locally by acicular hornblende porphyry dikes that are texturally identical to Early Jurassic intrusions in central Quesnellia near Nation Lakes (Nelson and Bellefontaine, 1996). Tekla Harms, who is also studying the Dorsey Terrane under a Lithoprobe grant, is planning to chemically analyse and date samples of the dikes to test this correlation. Conodont samples were collected from the limestone to aid in comparing it to limestone in the Lay Range.

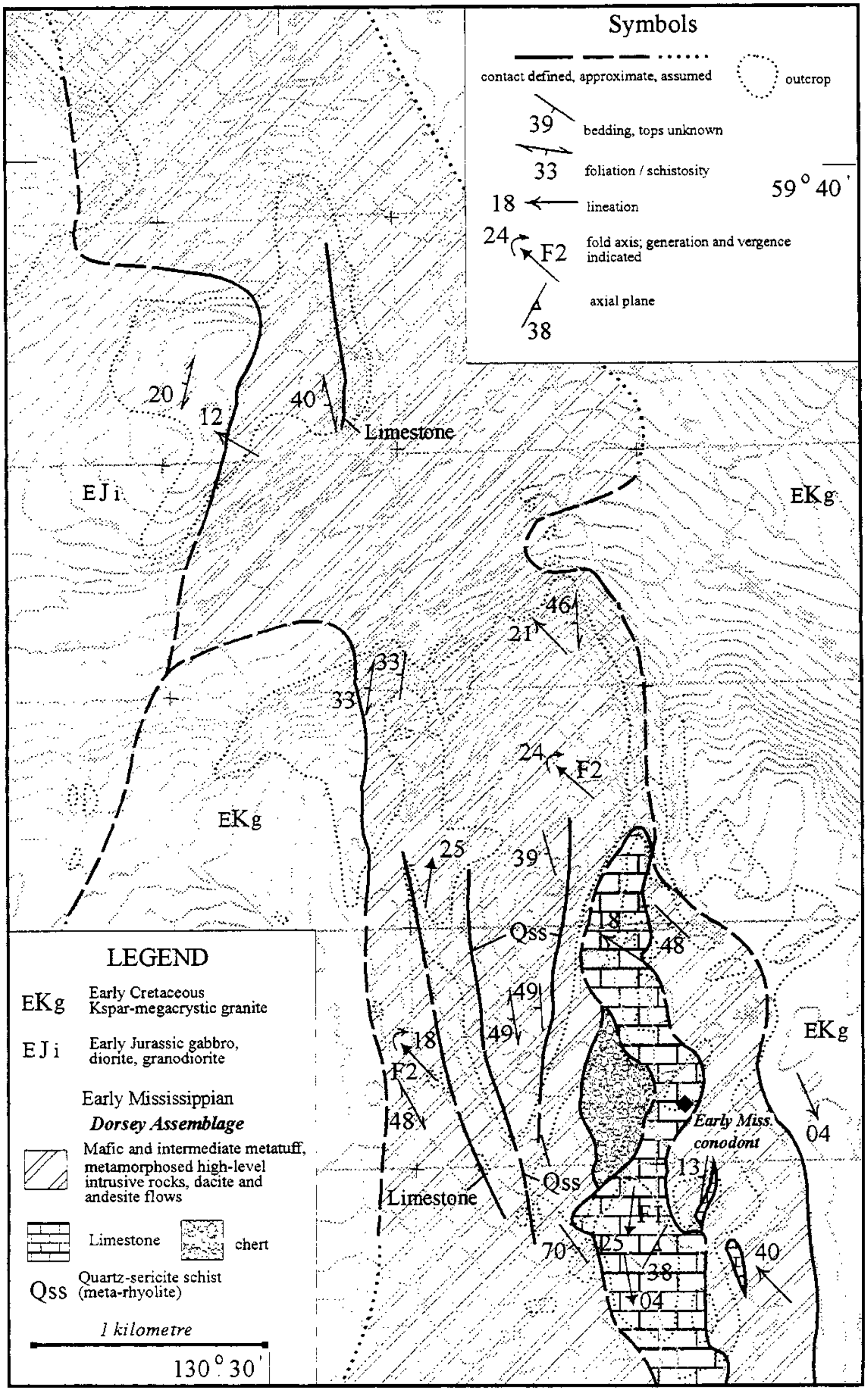

Figure 4. 1:25,000 geologic map of Target 2, near the Little Rancheria River.

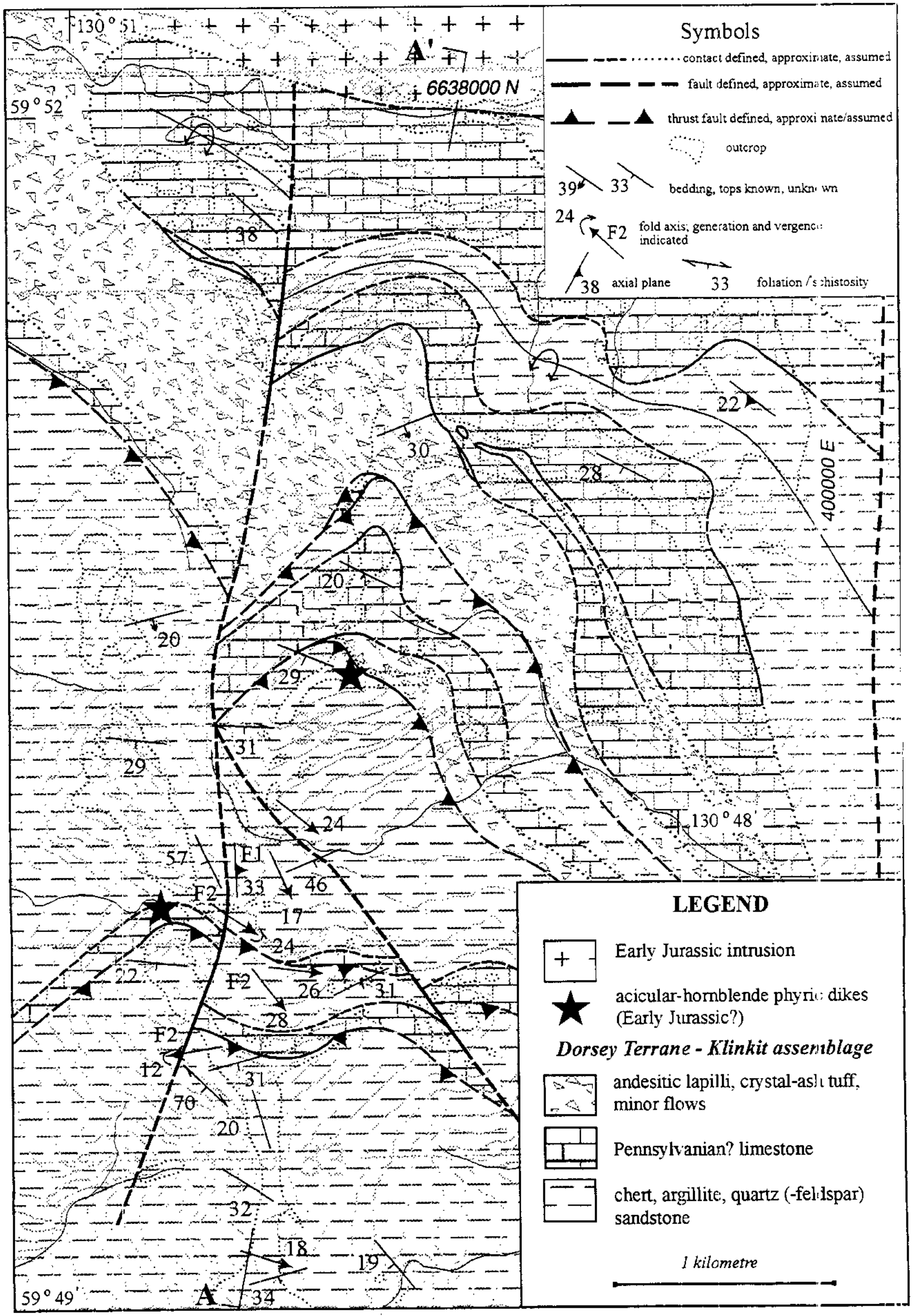

Figure 5. 1:25,000 geologic map of target #3, near McNaughton Creek

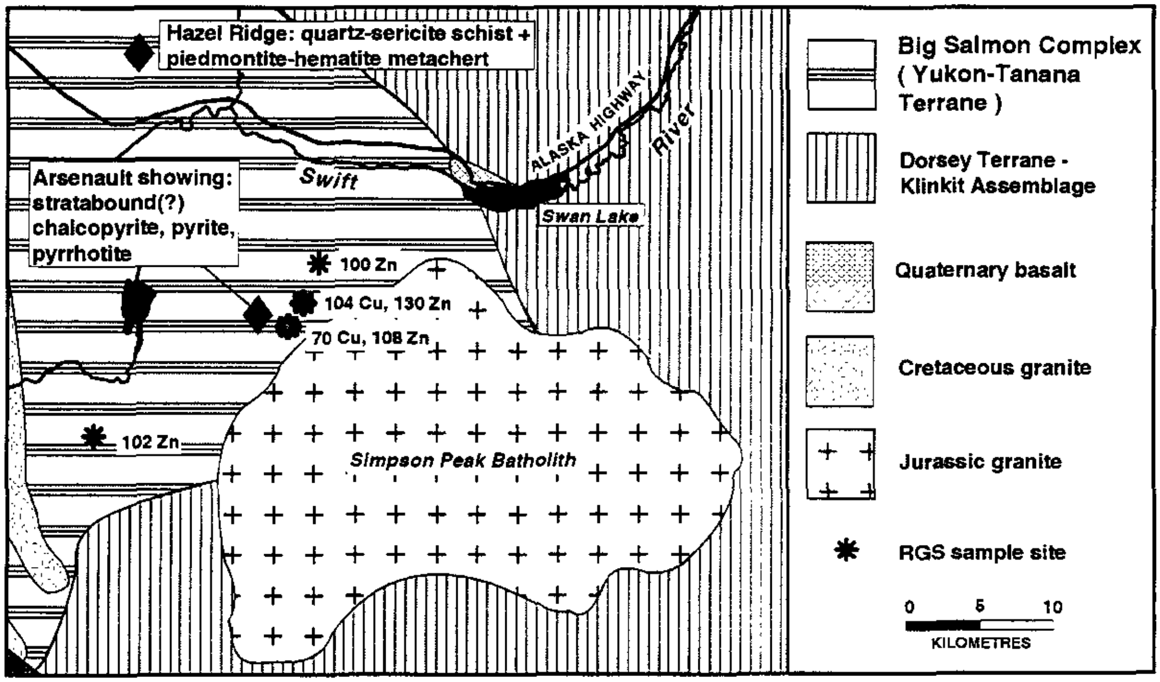

Figure 6. Regional map of the Big Salmon Complex in northwestern Jennings River map area (104O). The geochemical anomalies are from the Regional Geochemical Survey, Geological Survey of Canada Open File 561.

TARGET 4.

A single traverse on Hazel Ridge encountered the most favorable stratigraphy for hosting Kudz Ze Kayah/Wolverine type deposits of the entire project: an enclave of meta-rhyolite and banded bright red piedmontite and grey hematitic meta-chert, surrounded by intermediate to felsic metaplutonic rock. These rocks are located on the southernmost and highest point on the ridge, next to a geodetic survey marker. The meta-rhyolite is a white, glossy, coarse grained quartz-muscovite schist. It grades into piedmontite-hematite meta-chert over several metres, with the disappearance of muscovite and intensification of color from pale rose pink to deep carmine. The meta-chert is a medium grained quartzite with pronounced piedmontite and/or hematite layers and laminae. Yellow magnesian garnet accompanies the piedmontite.

At Wolverine, the massive sulphide horizon lies above quartz-sericite schist and below a chert iron formation. Although the iron at Wolverine is in magnetite and that on Hazel Ridge is in hematite, the stratigraphic similarity is very close. The Hazel Ridge rocks lie within the Big Salmon Complex of Gabrielse (1969), an assemblage of metavolcanic, meta-sedimentary and metaplutonic rocks that lies east of Teslin Lake in the Atlin (104N) and Jennings River (104O) map areas (Figure 3). To the north, the Big Salmon Complex strikes into the Teslin Tectonic Zone (usage of Creaser *et al.*, 1995; also referred to as Kootenay Terrane by Stevens and Erdmer, 1993; Gordey and Stevens, 1994), which forms the eastern margin of the Yukon-Tanana Terrane against the Cassiar Terrane, truncated to the north by the Tintina Fault (Figure 1). Restoration of 450 kilometres of strike slip motion on the Tintina places the Teslin Tectonic Zone directly on strike with the Simpson Range volcanogenic massive sulphide district of the southern Yukon.

The Arsenault base metal showing (104O-011), located 15 kilometres south-southeast of Hazel Ridge (Figure 6) is described in part as a stratabound chalcopyrite-pyrite-pyrrhotite occurrence, remobilized into fold hinges (Phendler, 1982). A number of stream sediment copper and copper-zinc RGS anomalies are associated with it (Geological Survey of Canada, 1978). Except for local mapping in assessment reports, the Big Salmon Complex has never been geologically analysed and subdivided. The presence within it of rock units strongly similar to those associated with volcanogenic massive sulphides in the Simpson Range, and of possible stratabound sulphide mineralization, make it a highly prospective target.

TARGET 5

The rocks that host epithermal vein mineralization on the Nizi property, located south of the headwaters of Nizi Creek (Figure 3) are a varied sequence of volcanics that range from hornblende phyric andesites through plagioclase phyric dacites to white, pyritic rhyolite. Although previously included within the Rapid River Tectonite (Gabrielse, 1994), they are undeformed and only weakly metamorphosed. Dikes related to them cut a coarse grained plutonic body, which is though to be of Early Permian age, based on its resemblance to the Early Permian Nizi Creek Pluton that outcrops southwest of Nizi Creek (H. Gabrielse, personal communication, 1996). The plutonic rocks in turn contain rafts of garnet amphibolite, which form part of the Rapid River Tectonite. Equivalent amphibolite along strike to the southeast in map area 104I/15 has returned an Early Mississippian K-Ar hornblende age (Gabrielse, 1994). Field relationships suggest that the volcanic rocks on the Nizi property are post-Early Mississippian and probably post-Early Permian, much too young to be equivalent to the Simpson Range meta-rhyolites. A sample for uranium-lead dating has been collected from the Nizi rhyolite. Results will be published in a more detailed geological report on the property in 1997 (McMillan and Nelson, in preparation).

TARGET 6

No felsic metavolcanic material was seen in this area, located east of Cry Lake near the western margin of the Rapid River Tectonite (Figure 3). Assemblages there include metaplutonic amphibolite, basalt metatuff with interbedded limestone, metapelite, meta-chert and possibly granite conglomerate. All are highly deformed and metamorphosed, with metamorphic grades ranging from upper greenschist to garnet amphibolite facies. The sequence is imbricated by thrust faults marked by ultramafic slivers. It is cut by megacrystic granite sills, which are themselves highly deformed, as well as a large body of metagabbro. The mafic nature of this sequence is in sharp contrast to the "siliceous tectonites" described by Harms and Gabrielse (1990) on the ridge immediately south of the Dease River. Clearly the Rapid River Tectonite is a complex entity. Our limited field examination did not locate any meta-rhyolites likely to be of Early Mississippian age within it; however they may exist in other areas.

IMPLICATIONS FOR MINERAL EXPLORATION

Metamorphosed rhyolites of probable Early Mississippian age were found in two of the terranes examined in this reconnaissance project. Meta-rhyolite accompanied by metamorphosed iron formation occurs on within the Big Salmon Complex, which is equivalent to the Teslin Tectonic Zone, the southern strike equivalent of the Yukon Tanana Terrane in the Simpson Range northeast of the Tintina Fault. These rocks, like the meta-rhyolites near Kudz Ze Kayah (D. Murphy, personal communication, 1996), are intruded by now highly deformed intermediate to felsic plutonic rocks of probable Early Mississippian age. The strong similarity of the geology on Hazel Ridge to the host rocks of the Kudz Ze Kayah and Wolverine deposits suggests that this largely unknown and long-neglected terrane deserves exploration attention.

The presence of Early Mississippian meta-rhyolite tuffs was also confirmed at target #2, in a mixed metavolcanic-marble sequence near the structural base of the Dorsey Terrane. This assemblage potentially extends along the eastern edge of the Dorsey Terrane, tens of kilometres south, where helicopter reconnaissance shows that terrane resting on black argillite of possible Earn Group affinity in the mountains west of the Cottonwood River (Figure 7). In part of that belt, west of the headwaters of the Cottonwood River, strong multielement stream sediment anomalies from the RGS survey (Figure 7; data from Geological Survey of Canada, 1978) led to claim staking and follow-up geochemical work and prospecting (Smith and Gillan, 1980). No source for the anomalies was discovered, but strong northwest-trending soil anomalies were defined. Near target #1, 10 kilometres south of the anomalous area, the basal part of the Dorsey Terrane is very complex, but contains, among many other structurally slivered rock types, nearly mylonitized felsic intrusions. A sample of one of these was collected for uranium-lead dating, to ascertain whether it is coeval with the Early Mississippian(?) rhyolite at target #2.

The base of the Dorsey Terrane crosses the Yukon border near 131° west longitude (Figure 3). North of the Yukon border, the Dorsey Terrane is well exposed near the Seagull Batholith, where Stevens (1995) characterized its basal unit as consisting mainly of metamorphosed siliciclastic rocks intruded by highly deformed plutonic bodies (possibly Early Mississippian, personal communication, 1996). R. Stevens and T.Harms (personal communication, 1996) refer to this unit as the Dorsey Assemblage. These rocks are directly overlain by weakly metamorphosed strata of the Klinkit Assemblage. The Early Mississippian volcanic rocks appear to be missing. They may reappear farther north in the southeast Teslin map area, where the Bar stratabound Pb-Zn-Ag-barite occurrence is hosted by a succession of shale, chert, chert sandstone and minor volcanics that overlies Mississippian limestone (K. Dawson *in* Gordey, 1992).

IMPLICATIONS FOR TERRANE CORRELATIONS

The sequence observed on Hazel Ridge is close enough in character to Early Mississippian units in the Simpson Range to support the idea that this characteristic and definitive component of the Yukon Tanana Terrane extends southward across a restored Tintina fault into the Big Salmon Complex of far northern British Columbia. Locally, the nature of the structural contact of the Big Salmon Complex with the Dorsey Terrane is not known, but in Teslin map area north of the Yukon border these rocks, referred to as Kootenay Terrane by Gordey and Stevens (1995), rest above unmetamorphosed late Paleozoic sedimentary and volcanic strata that are on strike with the upper part of the Dorsey Terrane near the Seagull batholith.

The upper part of the Dorsey Terrane, the Klinkit assemblage, consists of a structurally repeated tripartite

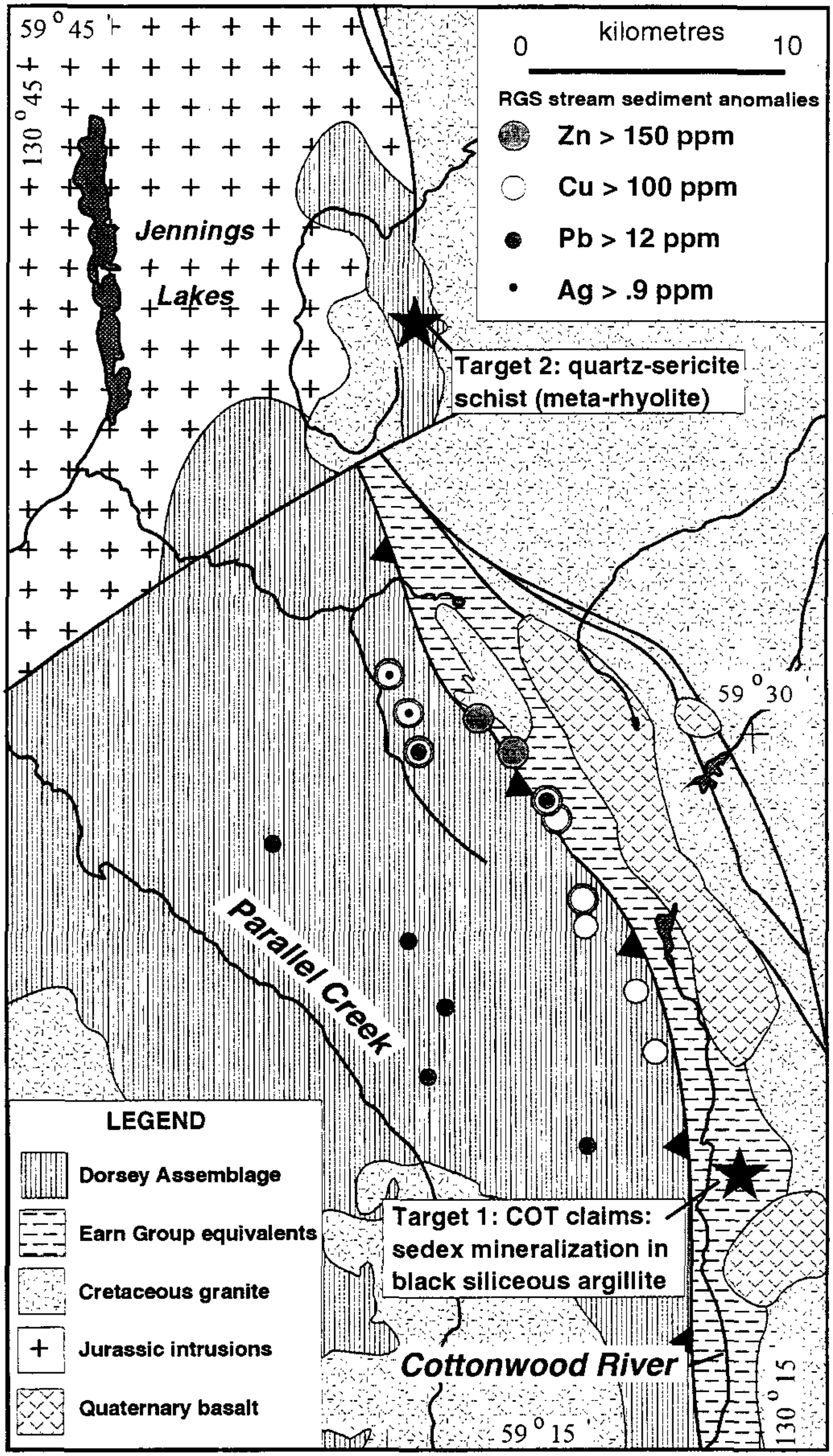

Figure 7. Regional map of the lower Dorsey Terrane, showing the location of Targets #1 and #2.

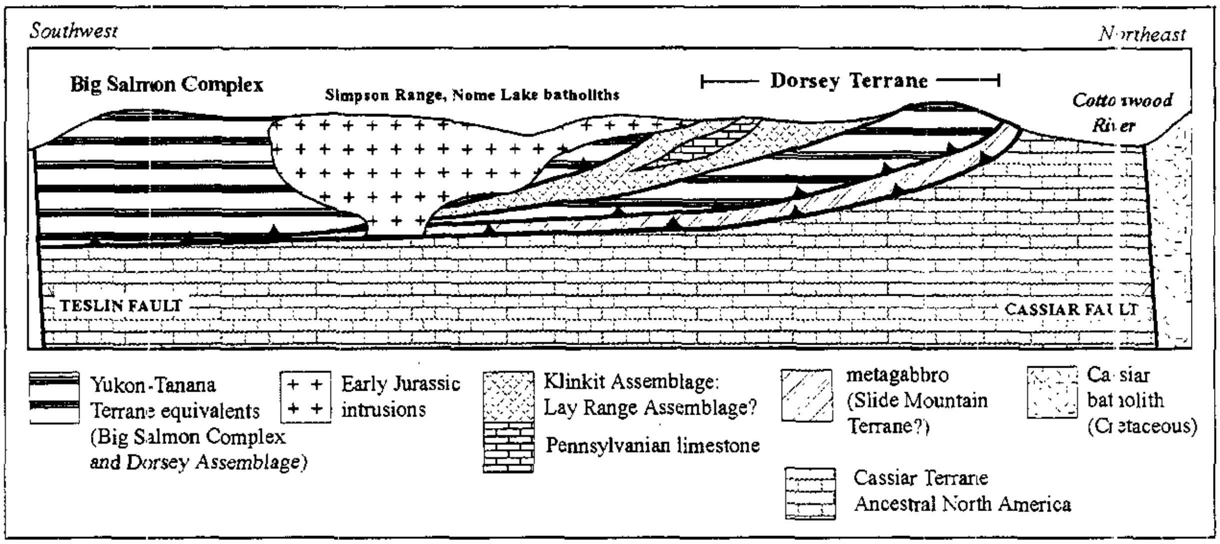

Figure 8. Cartoon cross section of the Big Salmon Complex and Dorsey Terrane in the Jennings River map area.

stratigraphic sequence that bears strong resemblance to to the Lay Range Assemblage in its type area. This sequence is intruded by Early Jurassic plutons and by dikes that are texturally identical to extrusive lithologies in the Triassic-Jurassic Takla Group. Thus the upper part of the Dorsey Terrane may be equivalent o Quesnellia. Its structural (and possibly stratigraphic) underpinnings, the Dorsey assemblage, include Early Mississippian limestones interbedded with mafic to felsic metatuffs at target #2 as well as metamorphosed siliciclastic sedimentary rocks. The Dorsey assemblage is a possible Yukon-Tanana analogue. West of the Cottonwood River near target #1, it rests on a gently west-dipping structural contact above a body of highly foliated layered metagabbro and quartz gabbro, which in turn lies structurally above black meta-argillites that are considered to be possible Earn Group equivalents.

Figure 8 summarizes these structural relationships. Because the contact between the Big Salmon Complex and the Dorsey Terrane is cross-cut by an Early Jurassic batholith, it is depicted as a pre-Jurassic thrust fault. The age of displacement on the fault that separates the Dorsey Terrane from the Cassiar Terrane is less well constrained and may be somewhat younger, since in the Jennings River area, at least, it marks an eastern limit to the suite of Early Jurassic intrusions. This cross section shows an Early Mesozoic Quesnel arc constructed on an imbricated basement of Yukon-Tanana and Lay Range Assemblage. Internal relationships in the Dorsey Terrane can be interpreted to indicate that the Yukon Tanana Terrane formed basement to the Lay Range Assemblage. This would imply that the late Paleozoic and Quesnellia arcs draped across some part of an older pericratonic crustal block characterised by Early Mississippian arc-type volcanism and, at least locally, groups of syngenetic massive sulphide deposits.

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POTENTIAL FOR KUTCHO CREEK VOLCANOGENIC MASSIVE SULPHIDE MINERALIZATION IN THE NORTHERN CACHE CREEK TERRANE: A PROGRESS REPORT

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KEYWORDS: mineral potential, volcanogenic massive sulphide, Cache Creek Terrane, French Range Formation, Teslin Formation, Kutcho Formation, blueschist, mineral exploration, geochemistry

INTRODUCTION

New geochronologic and geochemical data from the volcanic Kutcho Formation enclosing the Kutcho Creek volcanogenic massive sulphide deposit, call for a reevaluation of the age and tectonic affiliation of these rocks. This dominantly bimodal volcanic succession was previously considered part of a calc-alkaline arc complex of Upper Triassic age (Rb-Sr 210 ±10 Ma; Thorstad and Gabrielse, 1986). More recently, Childe and Thompson (1995) obtained U-Pb zircon age dates from rhyolite at the deposit which are Late Permian (*circa* 249 Ma); approaching the Permian age (275 ±15 Ma) originally reported by Panteleyev and Pearson (1977). Barrett *et al.* (in press) reported major oxide and rare earth element analyses from a select suite of Kutcho Formation rocks showing them to have tholeiitic affinities, indicative of a rifted intra-oceanic setting, probably in a forearc environment.

Potential Kutcho Formation correlatives to the south include the Sitlika Assemblage near Takla Lake (Schiarizza and Payie, 1997), which may originally have formed in a belt contiguous with the Kutcho Formation prior to dextral offset and crustal shortening on major faults (Gabrielse, 1990). Both Kutcho and Sitlika rocks sit within the oceanic Cache Creek Terrane (Wheeler *et al.*, 1991), yet contain felsic volcanic rocks. In fact, coeval and lithologically identical rocks occur within the Cache Creek Terrane far to the south, near Ashcroft (Childe *et al.*, 1997; Figure 1 inset).

Correlations with strata of the Cache Creek terrane north of the Kutcho area had not been made despite the fact that more than half of the area underlain by Cache Creek terrane rocks occurs in the large, pie-shaped, crustal block thatextends northwest from its apex at Kutcho Creek (here called the northern Cache Creek Terrane). Permian volcanic strata are known within northern Cache Creek Terrane, where they have been mapped as the French Range Formation by Monger (1969, 1975) and Gabrielse (1994). Moreover, Monger (1969) notes a quartz-bearing lapilli tuff in the French Range, which, like the silicic Kutcho Formation, is unexpected within the Cache Creek oceanic assemblage. Since silicic volcanic rocks exist in the northern Cache Creek terrane, it is possibile that coexisting volcanogenic

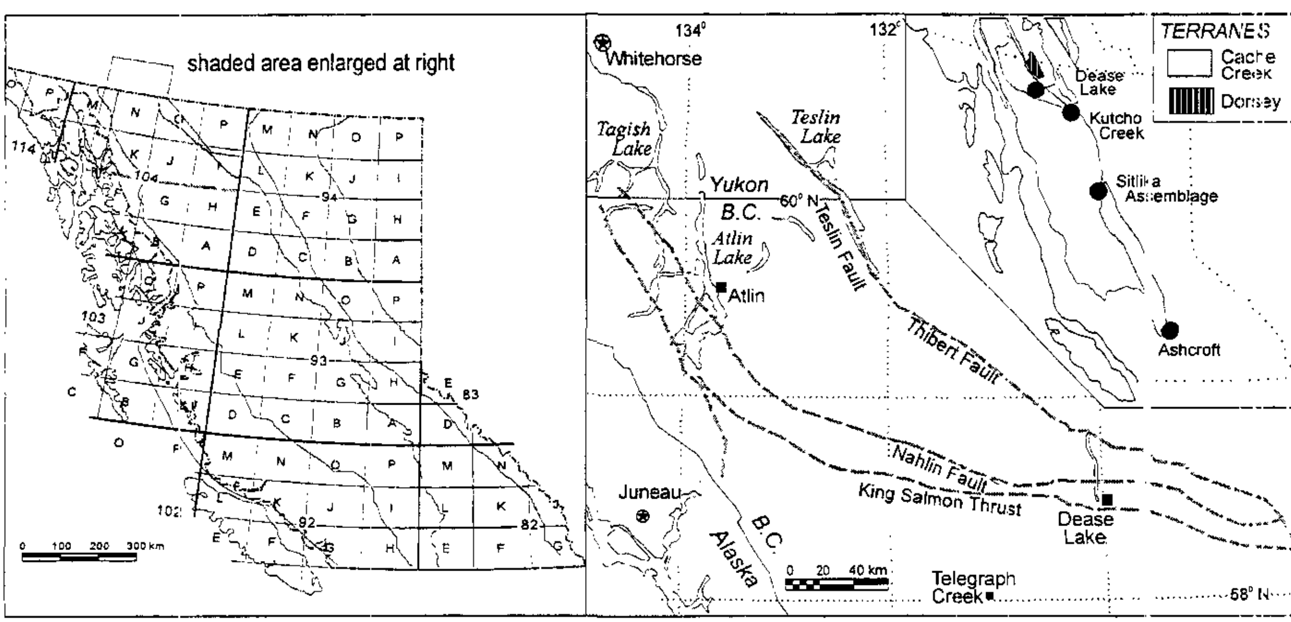

Figure 1. NTS and physiographic location of, and major structural elements bounding, the Northern Cache Creek terrane. The inset shows the distribution Cache Creek Terrane rocks and locations of potentially correlative Late Permian felsic volcanic strata.

massive sulphide (VMS) deposits also occur.

Lack of exploration for Kutcho-style VMS deposits in northern Cache Creek Terrane (especially the eastern belt) results from a combination of factors, not the least of which is the lack of recognition of silicic volcanic rocks in this region. Another factor is relatively subdued topography, and therefore, poor exposure. Poor exposure leads to muted and spatially restricted geochemical responses. In fact, the entire Dease Lake sheet (104J) lacks regional geochemical survey coverage because its subdued topography makes it a less appropriate survey candidate than adjacent, more mountainous areas. Without the benefit of geochemical dispersion, notoriously small (but rich) VMS deposits are difficult targets, especially in the expanse of Northern Cache Creek terrane which, except near Atlin or Dease Lake, is largely inaccessible. As well, prior to 1996, much of northern Cache Creek Terrane was covered by the Kawdy-Level Mountain Protected Area Study area, which was drastically reduced in size in 1996 (Figure 2, inset). Given these factors, a reconnaissance field program was undertaken in 1996. Known as the French Range project, its principal objective is to evaluate the potential for VMS deposits in northern Cache Creek Terrane. During the course of field studies the presence of quartz-bearing tuffs was confirmed, and previously unreported ignimbritic rhyodacite tuff was discovered in the French Range. Preliminary stratigraphic, structural, lithogeochemical and paleontologic data are presented here.

"STRATIGRAPHY"

Current knowledge of French Range Formation and Teslin Formation stratigraphy stems primarily from the work of Monger (1969, 1975) who named them while investigating Paleozoic successions throughout northern Cache Creek Terrane. Monger showed that these rocks, mainly confined to a belt along the terrane's northeastern margin, display a relatively coherent internal stratigraphy, and a restricted age range of Early to Late Permian. They appear to sit structurally and, in some cases, stratigraphically above hemipelagites of the Kedahda Formation, which contains fossils as old as Early Carboniferous. Interpretation and nomenclature is coplicated by depositional interfingering and enclosure of one formation by another, and subsequent. An eloquent discussion of these problems is presented by Monger (1975).

Investigations during the 1996 field season focused briefly on five localities between Dease Lake and the Yukon border (Figure 2). Observations presented here augment those of Monger (1969, 1975) who presents more comprehensive descriptions.

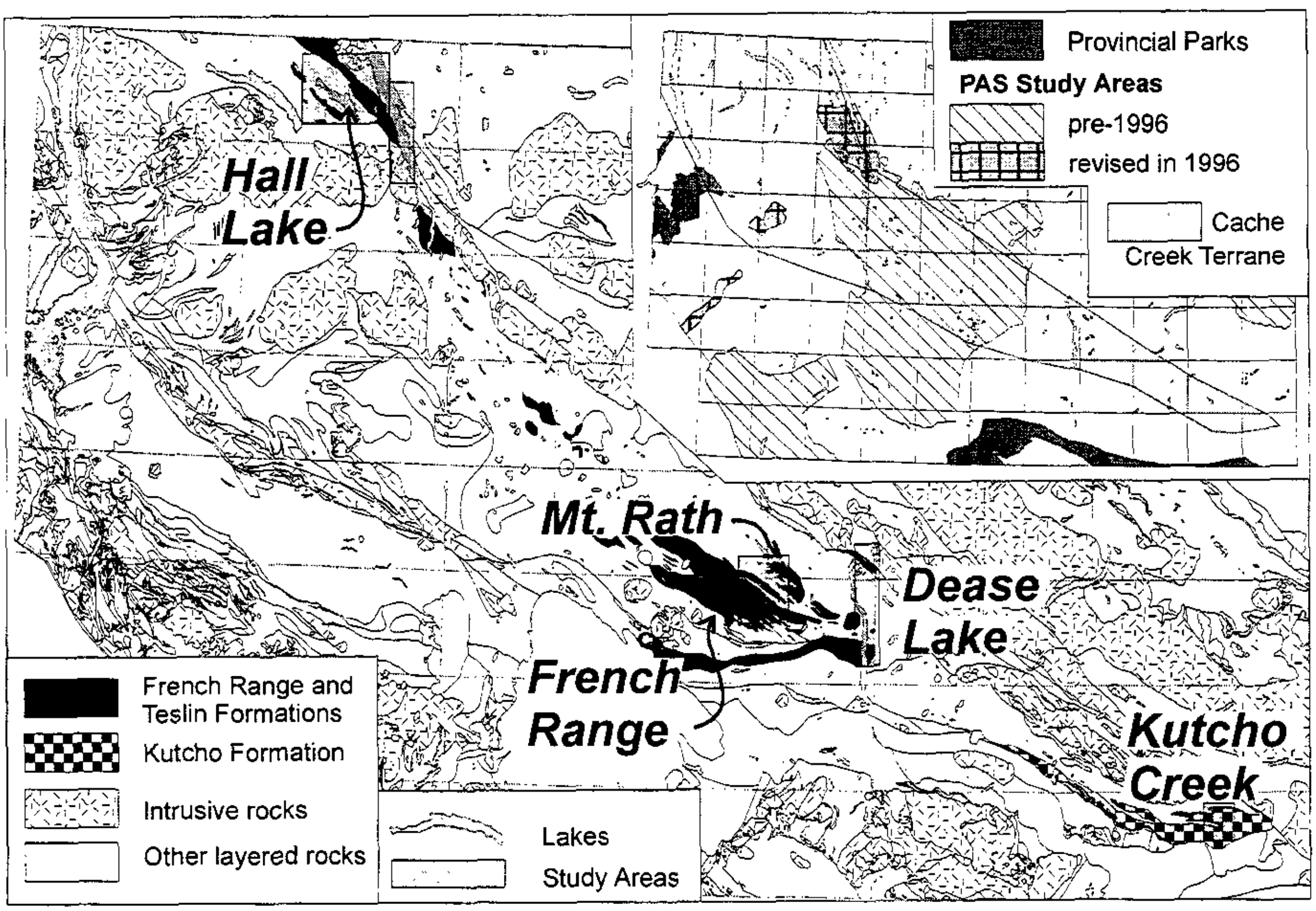

Figure 2. Distribution of the French Range and Kutcho Formations in northern Cache Creek Terrane (modified from Mihalynuk *et al.*, 1996; terrane limits are shown shaded in inset), and study areas visited as part of the French Range Project. Parks and Protected Area Strategy study areas are also shown in the inset.

Teslin Lake

Teslin Lake is occupied by the Teslin Fault (Figure 1) which juxtaposes the Cache Creek and Dorsey terranes (e.g. Wheeler *et al.*, 1991). Cache Creek Terrane rocks, which are well exposed only along the northern stretches of the western shoreline, are dominated by folded and weakly foliated ribbon chert. Argillite partings in the chert may coarsen to fine greywacke, although no coarse greywacke interbeds were observed. Massive greywacke layers 5 m or more thick, and intraformational argillite rip-up clast conglomerate (Photo 1), form cliffs along the lake at, and north of, an irregular bird's foot shaped peninsula. Close examination of the wacke section shows that it is cut by low angle faults, possibly thrusts, in at least two places.

The contact between ribbon chert and the massive wacke sections is not exposed near the lakeshore. Greywacke content rapidly increases eastward in the Teslin Lake section. Perhaps the section is comprised of a series of thrust panels separated by cryptic faults, and represents an originally more gradational facies change that has been subsequently telescoped.

Hall Lake

Stratigraphic successions at Hall Lake are dominated by two major lithologic divisions. The structurally and stratigraphically lower division consists of folded and weakly foliated argillite and chert. The upper, mainly non-foliated division, consists of volcano-sedimentary strata belonging to the French Range and Teslin Formations.

Argillite is typically black and rust weathering. At one locality, tuffaceous fragments are conspicuous. A weak phyllitic texture is common, especially in argillite which occurs as 0.5 to 8 cm thick beds that alternate with 2 to 12 cm thick beds of chert. Chert is tan, grey and black and locally weathers white. It is generally recrystallized and displays a bedding-normal fracture pattern spaced at 2 cm or greater. In zones of high strain, chert layers become rodded and/or transposed.

The French Range Formation at Hall Lake consists of massive basalt, basalt breccia and trachyandesite tuff with interfingering, fossiliferous and massive Teslin Formation limestone. Basalt is typically structureless, aphyric, black to dark green and blocky weathering. Rare bulbous weathering surfaces may be pillows. Distinct pillow breccia occurs at one locality east of northern Hall Lake. Hyaloclastite and layers of varitextured lapilli and ash all appear to be water lain. Nowhere are subaerial pyroclastic deposits clearly evident. Most tuffaceous deposits appear to be basaltic, however, tuff interbedded with limestone on the highest knolls east of Hall Lake, have a trachytic composition (Figure 3, Tables 1 and 2).

Limestone is typically tan to white with angular weathered surfaces resulting from closely-spaced orthogonal fractures. It is invariably recrystallized and, in places, is dolomitized. Less abundant is fossiliferous limestone which is white to dark grey, poorly bedded and commonly fetid. Ripple cross-stratification in crinoidal grainstone occurs rarely. Fossils consist mainly of fusulinids and crinoids. Fusulinid packstone horizons up to 10 cm or more thick, occur at scattered localities.

Contacts between chert and limestone are generally poorly exposed. However, northeast of Hall Lake scoriaceous limestone appears to sit directly on ribbon chert. A fabric is developed at the contact, but it is interpreted to be the result of strain partitioning during post-depositional deformation. At some localities, chert and limestone are interbedded. Such beds tend to be 2-15 cm thick and irregular (Photo 2). At one locality, however, an isolated, 30 cm thick, continuous, parallel-sided chert bed occurs within limestone.

Contacts between limestone and volcanics are clearly gradational. This is especially well displayed with tuffaceous rocks where across one or two metres the lithology changes from coarse ash lapilli tuff to lapilli in a calcareous matrix to carbonate debris in a tuffaceous matrix (Photo 3), to massive carbonate.

Contacts between ribbon chert and volcanic rocks were not observed in the Hall Lake area. The presence of tuffaceous material in cherty argillite, however suggests that chert deposition and volcanism were in part synchronous.

Dease Lake

Strata near Dease Lake are dominated by the same stratigraphic elements as at Hall Lake. Typically, the structurally lowest and most deformed are units are hemipelagites of the Kedahda Formation. At the highest structural levels the French Range Formation volcanic strata and Teslin Formation carbonates are least deformed.

Photo 1. Angular argillite rip-up clasts within coarse, quartzose wacke on west side of Teslin Lake.

TABLE 1. MAJOR OXIDE ANALYSES

Sample Description	Field No.	NTS map	UTM E	UTM N	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	MnO	Cr_2O_3	Ba ppm	LOI	Total
Hall Lake basalt -PP	MMI96-06-09	104N/16	645650	6635350	45.30	3.98	13.45	14.41	5.78	8.83	3.05	0.86	0.43	0.19	0.01	190	2.47	98.78
Hall Lake basalt -PP	MMI96-07-06b	104N/15	636550	6632450	48.47	1.07	15.08	9.51	7.39	8.89	3.15	1.61	0.38	0.16	0.03	1082	2.86	98.71
Hall Lake tuff -PP	MMI96-05-04	104N/16	641600	6639350	53.18	1.39	17.75	9.84	3.02	2.87	3.52	3.12	0.92	0.06	0.01	1390	3.81	99.63
Hall Lake tuff -PP	MMI96-07-04	104N/15	636800	6633750	49.44	2.34	18.74	15.09	2.26	1.53	2.44	2.34	0.31	0.02	0.08	1022	4.58	99.30
French Rg. basalt -PP	MMI96-08-03	104J/16	417700	6514600	50.46	0.91	14.78	9.93	6.80	6.98	3.56	1.27	0.14	0.13	0.04	223	4.02	99.04
French Rg. basalt -PP	MMI96-17-03	104J/09W	418525	6503450	47.45	1.65	14.92	12.51	6.26	5.93	2.45	2.59	0.26	0.13	0.02	154	4.36	98.55
French Rg. tuff -PP	MMI96-09-04	104J/9W	416250	6508400	59.39	1.04	14.18	12.23	0.58	1.33	5.94	1.50	0.31	0.10	0.01	666	0.96	97.66
French Rg. rhyodacite -BS	MMI96-09-02	104J/9W	416950	6508150	64.83	0.97	13.22	7.89	1.16	0.88	4.56	3.23	0.20	0.12	0.01	921	1.56	98.74
Kutcho Ck. basalt -GS	MMI96-15-12	104I/01	534300	6449650	50.43	0.77	15.25	9.92	7.54	7.56	2.62	0.26	0.10	0.18	0.04	88	3.89	98.57
Hall Lake gabbro -PP	MMI96-07-06a	104N/15	636550	6632450	46.94	3.74	17.44	11.98	2.40	5.12	4.60	1.75	1.25	0.15	0.01	556	4.19	99.64
Dease Lk. pyroxenite	MMI96-12-05a	104J/09E	441050	6598900	43.24	2.19	12.67	19.15	8.74	6.29	2.52	0.15	0.23	0.11	0.01	94	4.14	99.45

Samples prepared at BC Geological Survey Branch Laboratory using steel mill grinding; Fe and Cr contamination is known to occur.

Samples anaylzed at Cominco Laboratory by fused disc X-ray fluorescence. Results reported as Wt. % except Ba which is ppm.

Sample abbreviations refer to metamorphic grade: PP = prehnite-pumpellyite, BS = blueschist, GS = greenschist.

Mapsheets with 104N designation are Zone 8; 104I and 104J are Zone 9.

TABLE 2. TRACE ELEMENT ANALYSES BY INDUCTIVELY COUPLED PLASMA MASS SPECTROSCOPY

Field No.	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	^{160}Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Th
MMI96-06-09	32.9	278	46.17	174	31.01	68.2	8.56	36.3	8.39	2.70	8.32	1.15	6.66	1.217	3.27	0.430	2.5	0.385	6.3	1.75	3.18
MMI96-07-06b	18.0	116	7.47	1051	28.40	60.2	7.43	30.1	5.69	1.64	4.75	0.63	3.54	0.691	1.91	0.258	1.7	0.235	2.5	0.18	6.50
MMI96-05-04	24.2	640	127.60	1307	90.16	191.0	21.20	78.7	13.53	3.73	9.69	1.25	5.99	0.951	2.24	0.265	1.4	0.195	13.0	6.42	10.09
MMI96-07-04	8.6	242	58.49	932	25.12	42.5	4.67	16.7	3.35	1.56	2.84	0.42	2.42	0.417	1.16	0.166	1.2	0.163	4.8	1.81	3.92
MMI96-08-03	27.3	118	9.14	183	7.28	16.7	2.27	10.3	3.10	1.09	4.21	0.69	4.97	1.043	3.28	0.457	3.2	0.461	2.8	0.24	0.84
MMI96-08-03R	27.1	112	9.16	178	7.34	16.7	2.25	10.1	3.15	1.15	4.16	0.74	4.82	1.050	3.21	0.471	3.2	0.461	2.7	0.41	0.85
MMI96-17-03	26.8	113	8.13	116	7.87	19.4	2.82	13.6	4.08	1.47	4.88	0.77	4.96	1.014	2.91	0.429	2.7	0.393	2.6	0.32	0.55
MMI96-09-04	49.9	447	72.62	545	55.77	119.3	14.51	59.7	12.85	5.22	11.54	1.75	10.09	1.926	5.49	0.763	4.9	0.738	9.4	3.66	6.29
MMI96-09-02	87.0	845	111.63	765	76.78	165.5	20.22	80.0	18.66	4.76	17.78	2.76	16.85	3.356	9.55	1.363	8.5	1.262	17.5	5.71	9.57
MMI96-09-06	95.5	957	144.27	954	105.20	218.3	25.52	96.1	19.82	4.17	18.56	2.86	17.69	3.648	10.13	1.443	9.5	1.409	20.2	7.37	15.43
MMI96-15-12	15.2	42	0.63	51	1.81	5.6	0.95	5.1	1.84	0.60	2.14	0.37	2.56	0.560	1.76	0.256	1.6	0.252	1.1	0.04	0.16
MMI96-12-05a	45.7	156	9.18	62	11.26	31.2	4.48	21.7	6.77	2.11	9.06	1.40	8.47	1.777	5.00	0.687	4.2	0.701	3.9	0.31	0.68
MMI96-07-06a	51.3	384	90.06	498	59.02	129.6	16.44	67.5	14.05	4.42	13.38	1.89	10.86	2.021	5.33	0.717	4.0	0.636	8.6	3.45	5.53
detection limit:	0.9	3	0.09	4	0.03	0.3	0.01	0.1	0.09	0.02	0.05	0.02	0.05	0.005	0.03	0.008	0.1	0.006	0.3	0.03	0.07

Analyses performed at Memorial University of Newfoundland. Analytical method is peroxide fusion-ICPMS. Detection limit method is mean blank + 3σ blank.

Sample MMI96-08-03R is a duplicate analysis.

Sample MMI96-09-06 is a "rhyodacite" from the French Range; oxide values are not reported because of a low total (91.19). For other sample description information refer to Table 1.

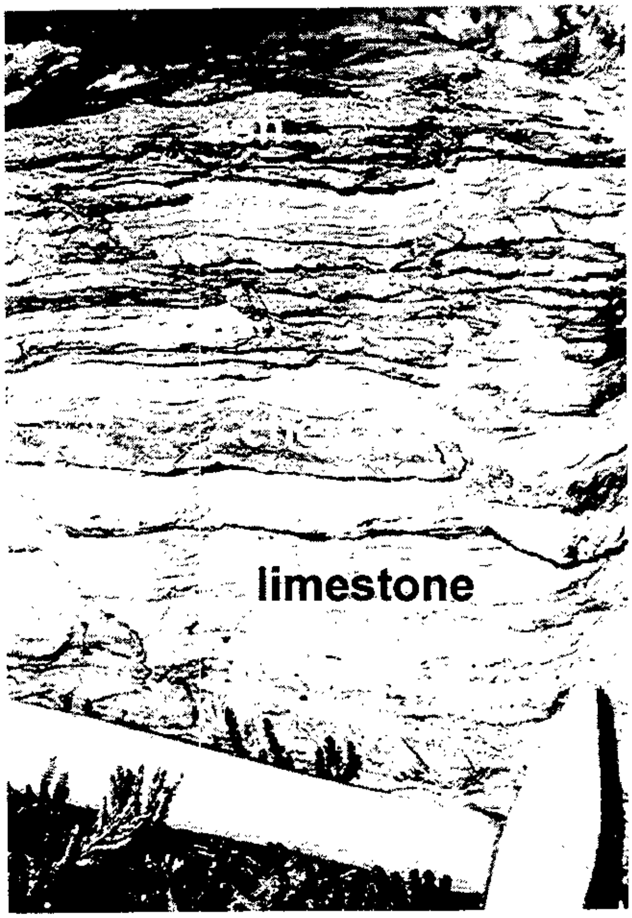

Photo 2. Parallel chert and ash beds in limestone on west flank of Mount Rath, French Range.

Photo 3. Carbonate debris deposit with tuffaceous matrix.

Kedahda Formation rocks along the shores of Dease Lake are strongly foliated phyllites and, in places, weakly developed schists. Protoliths were dominantly graphitic and silty argillite. Kedahda Formation in the French Range is more chert-rich and, locally, is not foliated. For example, ribbon chert on the north flank of Mount Rath is highly folded, but is neither foliated nor strongly recrystallized and thus preserves a good radiolarian fauna (Table 3).

Volcanic strata are dominated by basalt tuff, massive fine-grained flows and pillowed flows. Most units are between 1 and 15m thick; although some basalt accumulations probably reach a few hundred metres in thickness. Basalt flow rocks contain sparse amygdales of calcite, chlorite, and locally, stilpnomelane. Some pillow basalt flows display interpillow sediments which weather recessively (Photo 4). Flows are interlayered with green to maroon, basalt to trachyandesite lapilli tuff. The basalt

TABLE 3. RADIOLARIANS FROM NORTHERN CACHE CREEK TERRANE

Sample No.	UTM E	UTM N	Radiolarian Genus/Species	Age
96FC-5-1			Latentifistula sp.	
			Quadriremis sp.	
			?Entactinia sp.	
				Paleozoic, probably Permian
96FC-15-2			Follicucullus scholasticus Ormiston and Babcock morphotype I Ishiga	
			Follicucullus scholasticus Ormiston and Babcock morphotype II Ishiga	
			Follicucullus sp. cf. ventricosus Ormiston and Babcock	
			Pseudoalbaillella sp.	
				Guadalupian

tuff is mint green, locally with up to 20% coarse bladed feldspar and highly vesicular clasts (Photo 5). It may envelope sparse, but conspicuous ferrugenous chert layers. Rare red ribbon chert layers (some contain radiolarians) occur within the mafic successions. Weakly crenulated argillaceous partings in the chert may be blue as a result of abundant fine-grained, blue amphibole, such as occurs on the ridge west of Slate Creek. Trachyandesite tuffs generally display a weak to moderate foliation and commonly grade into limestone or comprise the matrix of carbonate debris flow deposits. Some tuff appears reworked and displays vague ripple cross stratification, and therefore, is tuffite.

Silicic tuffs in the headwaters of western Slate Creek contain embayed quartz phenocrysts and display an eutaxitic texture (Photo 6). Unfortunately, alteration and blueschist metamorphism have destroyed any relict pumice outlines that may once have been present. Therefore it is not possible to demonstrate that the banded and flattened nature of volcanic clasts is due to welding and not due to compaction alone. Major and trace earth

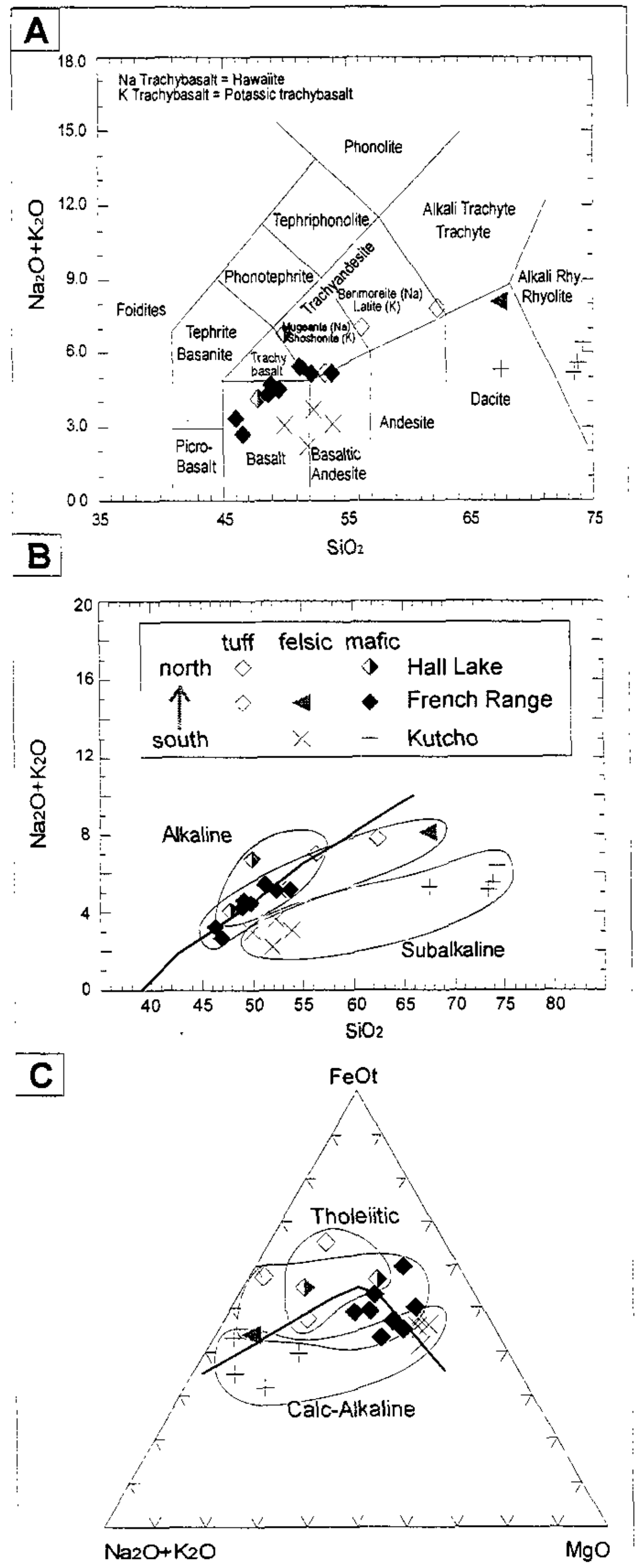

Figure 3. (a) Samples collected and analyzed as part of this study are classified by the method of LeMaitre (1984). Kutcho Formation: felsic crosses and mafic x's, Hall Lake volcanics: basalt = half filled diamond and tuff = open diamond, and French Range volcanics basalt = solid diamonds and rhyodacite = left-pointing triangles. Felsic volcanic samples from the French Range fall within the dacite field, near the rhyolite boundary and are herein classed as rhyodacite (see text for discussion). Major oxide volcanic classification diagrams (following the method of Irvine and Barager, 1971) show distribution of (b) Alkalis versus silica separating alkaline from subalkaline rocks, and (c) alkalis - FeOt and MgO to resolve subalkaline rocks into tholeiitic and calc-alkaline series. See text for a discussion on possible sources of error.

Photo 4. Pillow basalt in the French Range. Interpillow sediments have weathered recessively.

Photo 5. Monomict, coarsely bladed feldspar porphyry lapilli tuff and breccia.

element analyses of two samples indicate that they are of rhyodacitic composition (see "Lithogeochem-istry" below).

Teslin Formation limestone varies from white, buff or pink and generally poorly-bedded, to black and well-bedded. The bed thickness is variable, but is generally 3 to 15 cm in well-bedded varieties. Limestone may be interbedded with black or red chert and green or maroon ash tuff.

Contacts between many units are undoubtedly modified by faults; however, there is clear evidence for gradational contacts between the three major lithologic divisions (Kedahda Formation chert, French Range Formation basalt and tuff and Teslin Formation limestone). The contact between the combined French Range and Teslin Formations and Kedahdah Formation may in part be a regionally significant, low to moderate-angle fault. Evidence for this is based on the high strain zones observed at the top of the Kedahda Formation at several localities south of Mount Rath and at one locality along Highway 37, east of Dease Lake (see "Deformation and Metamorphism" below).

BIOGEOCHRONOLOGY

At the time of writing only 2 of 30 samples containing radiolarians, radiolarian ghosts or radiolarian-like artifacts have been processed to yield preliminary age data. One of these samples is from near Hall Lake, the other is from the French Range.

A small isolated outcrop of light green-weathering chert southwest of Hall Lake was collected for radiolarian extraction. Preliminary identification of radiolarians etched from the sample indicate a probable Permian age (96FC-5-1, Table 1). This poorly bedded chert occurs within a section of interbedded limestone and volcaniclastic debris. The age is consistent with Permian fusulinid identifications from the adjacent limestone reported by Monger (1975).

A sample of well-bedded, strongly folded grey ribbon chert on the north flank of Mount Rath contains abundant radiolaria readily visible in hand sample. Chert and argillite form beds 2-20 cm thick (mainly 5-15 cm). Folds are generally open with gently dipping axial surfaces and hinge lines that plunge shallowly southeast and northwest. Contacts were not observed, but outcrops both down slope and up slope are limestone. Limestone of the upper outcrop grades upwards into tuff. Well preserved radiolaria, identifiable to morphotype level, indicate a Guadalupian age (lower Late Permian). Limestone in a homotaxial section 5 km southwest of Mount Rath contains Permian (probably earliest Guadalupian) Fusilinids and is in contact with underlying

Photo 6. Eutaxitic texture is displayed by rhyodacite in the French Range.

chert and overlying agglomerate of the basal French Range Formation (Monger, 1969). These basal French Range Formation strata grade upwards into tuffs, including rhyodacite (see "Discussion").

DEFORMATION AND METAMORPHISM

Deformation is generally less intense in the Hall Lake than in the Dease Lake area. Regional metamorphic grade

Photo 7. (a) south verging folds in Kedahda Formation east of Dease Lake. (b) photomicrograph showing crenulations common in Kedahda Formation phyllite. (c) transposed bedding in a more highly strained phyllitic schist east of northern Dease Lake. Long dimensions of photomicrographs is approximately 4 mm.

is prehnite-pumpellyite facies at Hall Lake, but varies from prehnite-pumpellyite to lower greenschist and blueschist near Dease Lake.

Folds at Hall Lake are upright with steep limbs and nearly vertical axial surfaces. A foliation fabric is developed in tuffaceous units and the argillaceous partings of ribbon chert locally become phyllitic. Basalt flows and massive to thick-bedded limestone display little or no fabric.

Hemipelagic sediments along Dease Lake are strongly deformed by mainly south-verging, inclined folds with wavelengths of metres to hundreds of metres. Parasitic folds are ubiquitous at scales ranging from millimetres to decimetres (Photos 7a, b, c). In good road and canyon exposures, macroscopic folds alone have resulted in shortening of this rock package to less than a third of its original length. The same fold styles are visible in the French Range although phyllitic partings are not so common and shortening is probably much less. On the northwest flank of Mount Rath a series of south-verging folds cascade down the dip slope (Photo 8).

Contractional faults are difficult to identify. One candidate is a strongly foliated zone exposed along Highway 87 between Kedahda Formation and overlying French Range Formation. It contains lenses of limestone and basalt in a sheared cherty argillite matrix with a moderately north-dipping fabric. Similar relationships are displayed south of Mount Rath in the French Range. A strong mylonitic flaser fabric is developed in chert just below the contact with French Range Formation volcanics. These high strain zones might be part of regional, low angle faults that place panels of French Range and Teslin Formation rocks atop Kedahda Formation and are later folded and faulted. Alternatively, they could be due strain partitioning around the relatively competent French Range volcanic succession. The possibility of a regional reverse fault that places blueschist grade rocks atop the Kedahda Formation is intriguing and warrants further investigation.

Everywhere the primary foliation (including blueschist minerals) has been subjected to one or more successive phases of folding. However, in no case did we

Photo 8. South verging cascading folds on the northwest flank of Mount Rath.

identify a pervasive metamorphic fabric developed during the later fold event(s). Late folding is probably related to emplacement of the Cache Creek Terrane during Aalenian-Bajocian times (early Middle Jurassic; Mihalynuk *et al.*, 1995). Blueschist metamorphism may be Late Triassic as elsewhere in the Cache Creek Terrane (e.g. Paterson and Harakel, 1974). Efforts to date the metamorphic mineralogy using $^{40}Ar/^{39}Ar$ techniques are currently underway.

LITHOGEOCHEMISTRY

Volcanic rocks displaying no obvious evidence of alteration, secondary veins or amygdales are rare within the northern Cache Creek Terrane. Nevertheless, five

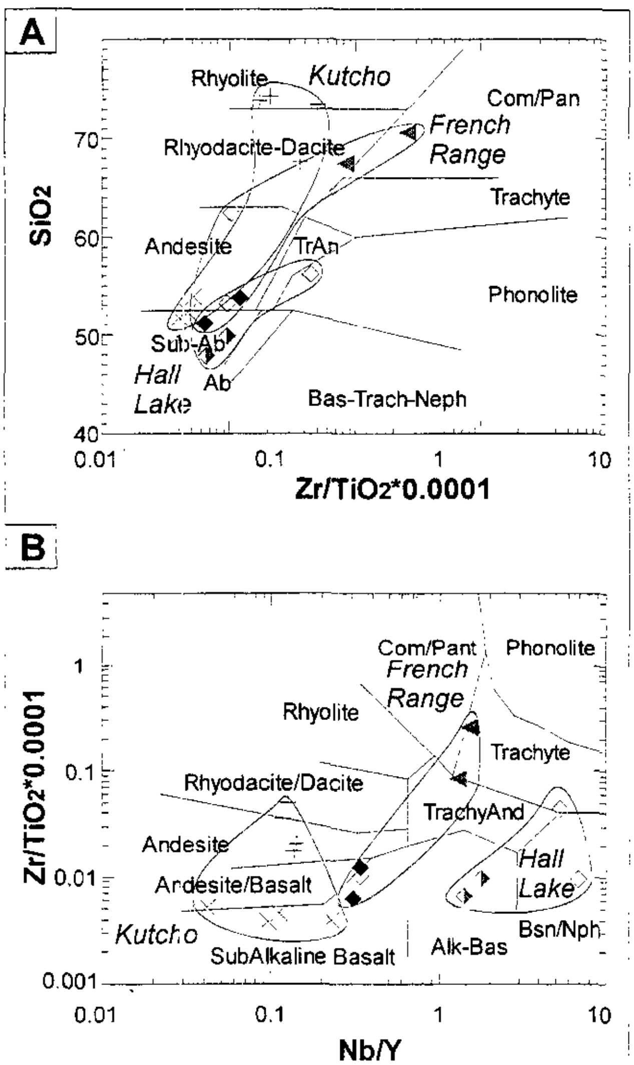

Figure 4. Volcanic rock classification diagram of Winchester and Floyd (1977) based upon the abundances of relatively immobile elements. A clear separation of Hall Lake (alkaline basalt) and French Range (subalkaline basalt) samples is evident. See Figure 3 for symbols. Abbreviations: Com = comendite, Pan = pantellerite, Bsn = basanite, Nph = nephelinite

apparently fresh, very fine-grained basalt units without veins or inclusions were selected for chemical analysis; the analytical data are shown in Tables 1 and 2. Tuffaceous rocks are by nature more heterolithic and may be affected by eruptive or depositional processes that modify their chemistry. Despite this, five of the least altered tuffaceous samples were also selected for analysis. Analytical results from a gabbro near Hall Lake (MMI96-07-06a) and a pyroxenite along northern Dease Lake (MMI96-12-05a) are also tabulated (Tables 1 and 2), but are not discussed here.

The five basalt samples include two of blueschist grade basaltic andesite/mugearite pillows from the French Range and two of massive, prehnite-pumpellyite grade basalt/mugearite from near Hall Lake (Figure 3a, b). For comparison, one sample of lower greenschist grade foliated, basaltic andesite of the Kutcho Formation was analyzed. The Kutcho sample is from an outcrop that displays possible relict pillows.

Three of the tuff samples are trachyandesite. One is from the French Range and two are from near Hall Lake. They all contain plagioclase phenocrysts, and are maroon or green and moderately foliated. The other two silicic tuffs are from the French Range. They are dacite or rhyolite depending on the scheme used to classify them (i.e. Le Maitre (Figure 3a) versus, Cox *et al.*, 1979 -not shown), and are herein refered to as rhyodacite. No volcanic rocks this silicic are known from the Hall Lake area.

Rhyodacite analyzed during this study is compared with published data from Kutcho Formation rhyolite of Barrett *et al.* (in press). Basalts analyzed as part of this study are compared with previously published major oxide data for basalts near Hall Lake and the French Ranges (Monger, 1975) and with data for rocks near the Kutcho deposit (Barrett *et al.*, in press).

Late Permian volcanic strata at Kutcho Creek, and Hall Lake mark the south to north spatial limits of the samples studied. French Range samples are not only geographically located between those at Kutcho Creek and Hall Lake, they also display geochemical characters that consistently plot between those of the other two sample suites.

Major and Trace Elements

Rock classifications based upon the abundance of major oxides, especially mobile alkali and alkali earth species in old, altered volcanic terrains, are error prone due to the susceptibility of alkalis to alteration and metamorphism (cf. Smith and Smith, 1976). Normalized major oxide data from French Range Formation basalts and tuffs are plotted on alkalis-silica (Figure 3b) and alkalis-FeOt-MgO (AFM, Figure 3c) diagrams following the method of Irvine and Barager (1971). Figure 3b shows that Hall Lake and Kutcho Formation fall separately into dominantly alkaline and subalkaline fields. French Range samples tend to be subalkaline, but plot between and overlap the other suites.

On the AFM diagram (Figure 3c) French Range compositions straddle the boundary between the tholeiitic and calc-alkaline fields. This could be due to shifting of the basalt analyses towards the alkalis axis as a result of sodium metasomatism, common in a submarine environment. However, there is no correlation between alkali depletion and hydration. Indeed, the analysis with the lowest H_2O (0.6%, MV66-159; Monger, 1975) plots closer to the alkalis axis than other samples with nearly equivalent SiO_2. The uniformly subalkaline Kutcho Formation volcanics also straddle the field boundary. In this case the basalts are tholeiitic and felsic rocks tend toward calc-alkaline. As in Figure 3a, geochemical character changes consistently from Kutcho volcanics in the south to Hall Lake volcanics (plotted in Figure 3c for reference) in the north, in this case Fe increases northward.

To mitigate the effects of alteration, some classification schemes consider only elements that are relatively immobile, especially high field strength trace elements. Figure 4 shows two such plots: Zr/TiO_2 versus Nb/Y or SiO_2 (Winchester and Floyd, 1977). Sample suite classifications based on these plots confirm volcanic classifications based on major oxides. Again, the sample suites display a geochemical variation that is consistent with their geographic distribution. Nb/Y ratios are particularly useful in distinguishing between the alkaline Hall Lake, subalkaline Kutcho and intervening French Range Formation suites, which are completely separated on Figure 4b.

In some instances, trace element distribution can be used to provide clues as to the tectonic setting in which the sample was formed. Ti, Zr, Ta, Th, Nb and Y are especially powerful descriminants in this regard. Figure 5a shows tectonic descrimination of basalts based upon the Ti-Zr-Y ternary plot (Pearce and Cann, 1973). Hall Lake samples fall in the within-plate basalt field while Kutcho Creek basalts are clearly low potassium tholeiites. French Range samples plot in an intermediary position displaying calc-alkaline and within plate characteristics. A clearer picture is presented by Figure 5b which shows the logarithmic distribution of Zr/Y versus Zr (Pearce and Norry, 1979) for the most common basalt-forming environments. Kutcho Creek samples clearly display island arc basalt characteristics while Hall Lake samples display a strong within-plate signature. French Range samples plot between with a slight within-plate signature.

Ti-Zr fractionation trends can aid in establishing magma parentage of evolving melt compositions from various lava settings (Figure 5c). A rigorous application of this technique is not only beyond the scope of the paper, it is probably not possible due to the fragmental preservation and structural complexity of the Kutcho Formation as well as widespread alteration of phenocryst phases. Nevertheless, useful comparisons can be made

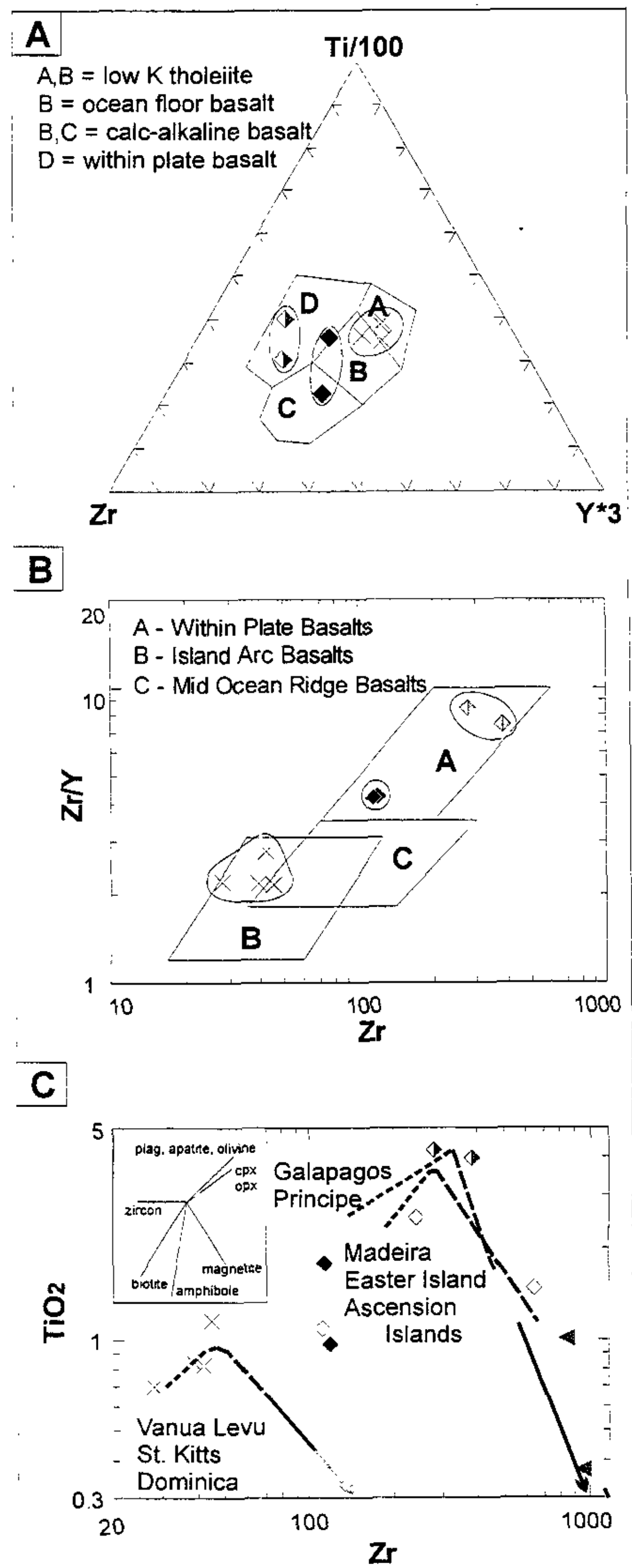

Figure 5. (a) Discrimination diagram showing low-K tholeiitic character of Kutcho basalt, within-plate character Hall Lake basalt and mixed character of Dease Lake basalts (method of Pearce and Cann, 1973). (b) Descrimination diagram showing island arc affiliation of Kutcho basalts, strong within plate affiliation of Hall Lake basalt, and transitional character of Dease Lake basalt (method of Pearce and Norry, 1979). (c) TiO_2 and Zr content of Kutcho Formation samples are consistent with model fractionation curves for volcanic series in arc settings while those of the French Range Formation are follow trends from lava series in within plate settings (model fractionation curves from Pearce, 1982). See Figure 3 for symbols.

with fractionation trends of unaltered rocks in known plate settings (e.g. Pearce, 1982). Kutcho Formation lavas mimic the fractionation trend of volcanic arc lava series like those of Vanua Levu, St. Kitts and Dominica. Hall Lake and French Range samples plot near within-plate volcanic series fractionation trends like those of Galapagos-Principe (upper curve) or Easter Island-Madeira-Ascention Islands (lower curve). The difference in arc versus within-plate fractionation trends is due mainly to early fractionation of magnetite in arc settings. Negative slopes on the felsic ends of all the fractionation trend lines is consistent with the lack of reported biotite or hornblende in both Kutcho Creek and French Range volcanics.

Rare Earth Elements and Spidergrams

Interpretations drawn from rare earth element (REE) data echo those of the trace elements. REEs from a single sample of Kutcho basalt (x's, Figure 6a) display a Mid-ocean ridge basalt (MORB) signature, with overall depletion relative to N-MORB (Sun and McDonough, 1989 normalizing factors) and slight overall negative slope. In contrast, Hall Lake basalts (half solid diamonds) show a strong negative slope; a within-plate setting is suggested. French Range samples (solid diamonds) appear transitional with respect to the other two suites, possibly representing a hybrid source area. A weak negative Eu anomaly in the lower French Range curve may indicate minor plagioclase fractionation.

A comparison of felsic volcanics from Kutcho Creek (crosses) and the French Range (sideways triangles) is shown in Figure 6b. Plagioclase fractionation is indicated by a negative Eu anomaly in both suites. Otherwise Kutcho rhyolite shows weak enrichment. French Range samples show very strong LREE enrichment and an

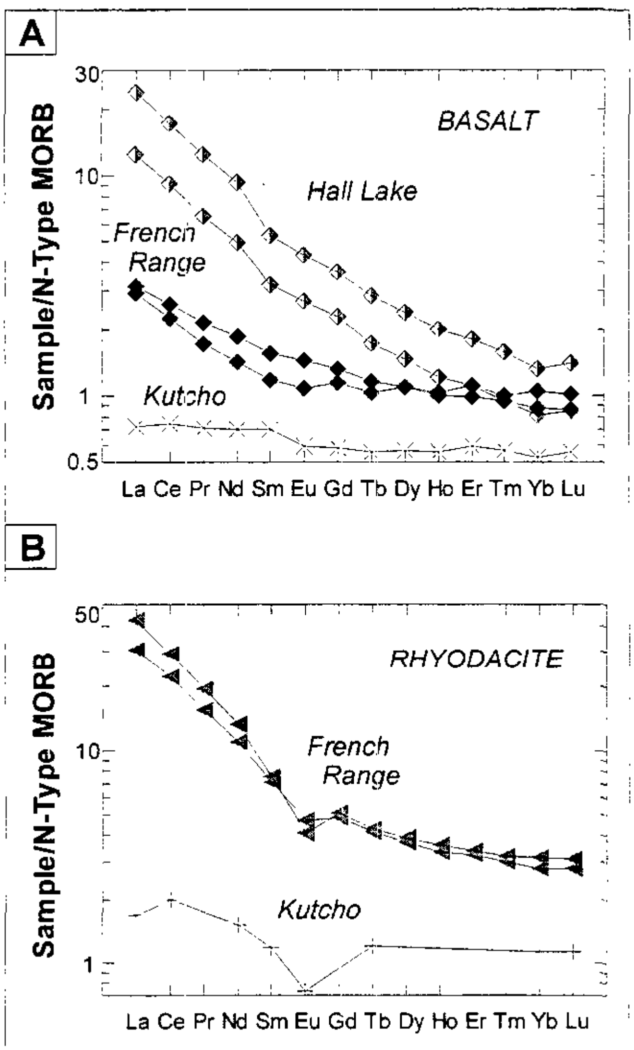

Figure 6. Rare earth element plots comparing (a) basalts from Kutcho Creek (x's), French Range (closed diamonds) and Hall Lake (half closed diamonds), and (b) rhyolite from Kutcho Creek (crosses; T. Barrett sample number 95-298) and the French Range (sideways triangles). Normalizing factors are those of Sun and McDonough (1989).

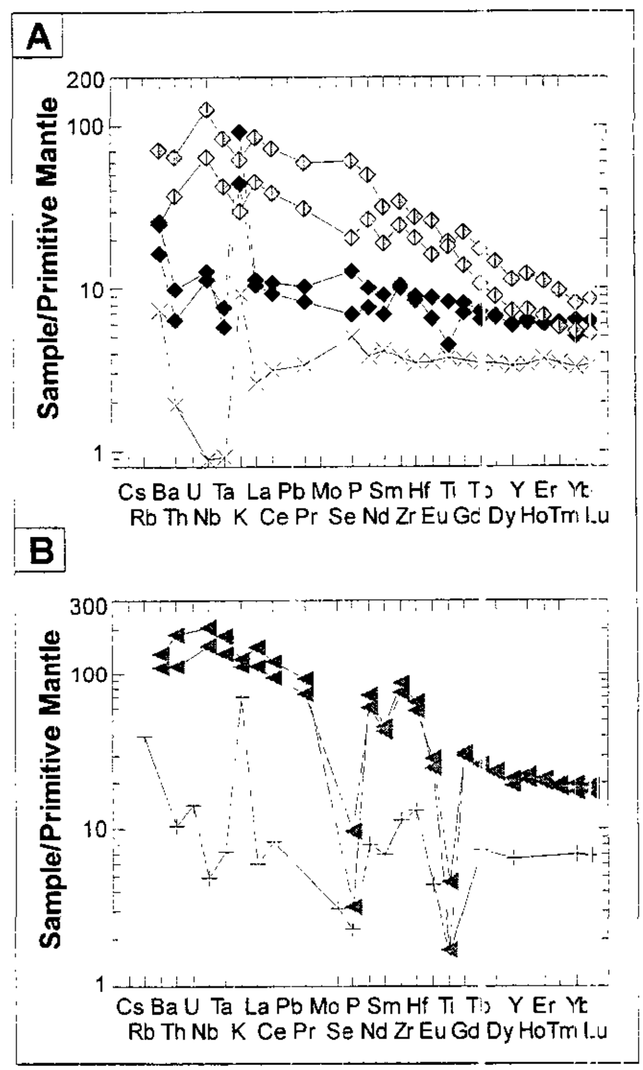

Figure 7. Spider diagrams which compare (a) basalts from Kutcho Creek (x's), French Range (closed diamonds) and Hall Lake (half closed diamonds), and (b) rhyolite from Kutcho Creek (crosses) and the French Range (sideways triangles). Sericitization of the Kutcho Creek rhyolite causes elevation of K (T. Barrett sample number 95-298). Normalizing factors are those of Sun and McDonough, 1989).

overall negative slope, similar to the Hall Lake basalt

A more complete story is shown in the spidergrams of Figure 7. Kutcho basalt chemistry display classic indications of subduction zone influence: a negative Nb-Ta anomaly and enrichment of large ion lithophile elements like Th, Ba and K relative to Ta. In contrast, Hall Lake samples display enrichment in Th, Ba, Ta and Nb, indicative of a within-plate setting. Once again, French Range samples display transitional characteristics, but with a arc-like trough showing Th, Nb and Ta depletion relative to LILs, Ba and K. All basalts display small amounts of enrichment and depletion of Ti and P relative to neighbouring elements, probably reflecting Fe-Ti oxide and apatite fractionation.

Nb-Ta depletion and LIL enrichment is also shown by the Kutcho rhyolite sample (Figure 7b; T. Barrett, data in press, sample 298). French Range rhyolite displays a within-plate signature (contrast with the French Range basalt in Figure 6a). Both samples suites display strong relative depletion of P and Ti.

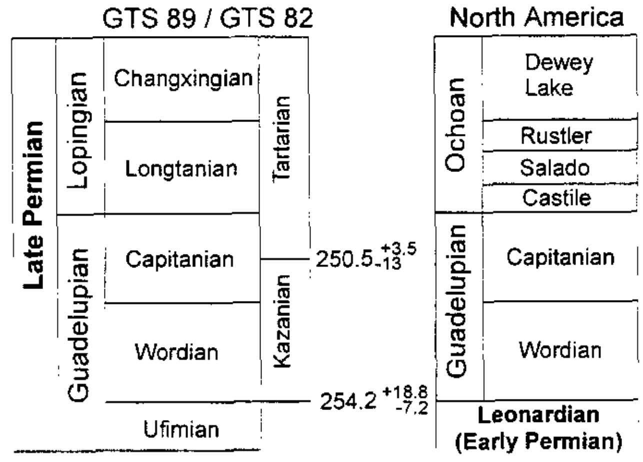

Figure 8. Late Permian stages and estimated absolute age limits with errors (data from Global Time Scale 1989 (GTS 89), Harland *et al.*, 1990 and Global Time Scale 1982 (GTS 82), Harland *et al.*, 1982.).

DISCUSSION

Rhyodacite in the French Range was clearly deposited as part of the stratigraphic succession less than a few hundred metres above Late Permian limestone containing fusulinids of probable Earliest Guadalupian age (Monger, 1969; fossil locality C-75293). A discontinuously exposed section above the rhyodacite includes an approximately 0.5 km thick limestone layer with Tethyan fusulinids of probable Late Guadalupian age (*Yabeina* sp.; fossil locality C-75291; Monger, 1969), the hallmark fossil of the Cache Creek Terrane.

Absolute age limits for the Guadalupian are uncertain due to extensive revisions to Late Permian nomenclature. Some revisions are reflected in Harland *et al.* (1990) and are shown in Figure 8. The Guadalupian sub-epoch includes, from oldest to youngest, the Ufimian, Wordian and Capitanian. Classical use of "Guadalupian" in North America, however, does not include rocks as old as Ufimian. Absolute age limits are interpolated by Harland *et al.* only for the old Kazanian and Tartarian stages of the Late Permian. The Kazanian stage extends from basal Wordian to mid-Capitanian, the lower two thirds of the Guadalupian stage as defined in North America. Interpolated absolute age limits for the Kazanian stage are $254.2\ ^{-18.8}/_{-7.2}$ to $250.5\ ^{+3.5}/_{-13}$ Ma. Asymmetrical errors are calculated as the difference between the maximum or minimum chronogram age (Harland *et al.* 1990, Table 5.4) and the interpolated age (Harland *et al.* 1990, Table 5.8.5). Thusly defined, "Guadalupian" rocks have a permissive age range from less than 237.5 Ma to a maximum of 273 Ma, which brackets the 249 Ma U-Pb age determination from the Kutcho Formation reported by Childe and Thompson (1995; and the circa 242 Ma age for felsic rocks near Ashcroft reported by Childe *et al.*, this volume).

French Range rhyodacite may be Early to Late Guadalupian in age and, therefore, coeval with Childe and Thompson's U-Pb determination. An Isotopic age determination from the rhyolite is required to tighten this possible age linkage. U-Pb isotopic analyses of zircons extracted from the French Range rhyodacite are currently underway at the University of British Columbia Geochronology Laboratory.

Correlation of the French Range Formation with the Kutcho Formation carries several important implications. French Range Formation volcanics are intercalated with hemipelagites, presumably part of the oceanic crustal succession. A correlative Kutcho Formation would probably have displayed similar original contact relationships with Cache Creek Terrane crustal rocks. If this is true, they apparently record the first pulse of subduction-related volcanism in an oceanic setting. Although it is not possible to draw regional conclusions from the small geochemical data set presented here, the consistent northward geochemical change from arc to within plate character is intriguing. It may represent the fossilized limit of a Late Permian subduction zone. If correlation can be extended to Late Permian felsic volcanics that are associated with the Cache Creek Terrane along its entire length (Figure 2, inset), and if their distribution is represenative of their original minimum extent, it may be possible to reconstruct belt of nearly synchronous volcanism at least 1250 km long. Infant intraoceanic arc volcanism in the Southwest Pacific (Izu-Bonin-Mariana) occurred nearly synchronously in the Middle Eocene in a zone 300 km wide by several thousands of kilometres long. Such volcanism is characterized by very depleted boninitic and arc tholeiitic lavas (Bloomer *et al.*, 1995). Deposition of the Permian felsic volcanic suite in an incipient arc setting (or forearc as suggested by Barrett *et al.* (in press) for the arc thoeiites at Kutcho Creek) is significant since the attached forearc oceanic crust has a relatively high potential for preservation as ophiolite (e.g. Bloomer *et al.*, 1995) and might help to explain the preservation of ophiolitic rocks in the Cache Creek terrane. A Late Permian intra-oceanic arc that extended well into the paleo-Pacific Ocean basin, may have helped to deliver Tethyan fauna to the North American realm - a journey that is otherwise geodynamically difficult to accomplish between the Late Permian (age of Tethyan fusulinids; Monger, 1969, 1975) and the Late Triassic (age of blueschists emplacement in Cache Creek Terrane near Pinchi Lake; Paterson and Harakel, 1974).

CONCLUSIONS

Recognition of rhyodacite within the French Range Formation calls for a significant upgrading of estimated potential for volcanogenic massive sulphide deposits in the vastness of the northern oceanic Cache Creek Terrane. Significant reduction in the size of the Kawdy Level Mountain Protected Area Strategy study area during 1996 (11000 km^2 to 490 km^2 now known as the Teslin River Wetlands; Figure 2 inset) once again opens the French Range, and most other strata of probable Late Permian age in northern Cache Creek Terrane, to mineral exploration.

Late Permian basalts in northern Cache Creek Terrane display a south to north variation in character from tholeiitic arc of the Kutcho Formation near Kutcho Creek to within plate in the French Range Formation at Hall Lake. Kutcho Formation volcanic rocks share the same lithologic and geochemical characteristics with Sitlika assemblage and coeval rocks at the southern end of the Cache Creek Terrane in the Ashcroft area. If these disparate volcanic assemblages are truly correlative, they could be remnants of a juvenile intraoceanic arc-forearc complex thousands of kilometres long - a possible bridge between Tethyan and North American realms in the Late Permian.

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AGE OF THE WILLISON BAY PLUTON AND OVERLYING SEDIMENTS: IMPLICATIONS FOR THE CARNIAN STAGE BOUNDARY

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KEYWORDS: geochronology, paleontology, Triassic, Carnian, Norian, Willison Bay pluton, Skagway, Bennett, regional geology

INTRODUCTION

A nonconformity between the granodioritic Willison Bay pluton and Triassic sediment is well exposed near the south end of Atlin Lake, northwestern British Columbia (NTS 104M/8; Figures 1 and 2). Earliest comprehensive mapping in the region (Christie, 1957) recognized this nonconformity and attributed a possible pre-Permian age to the Willison Bay Pluton on the basis of overlying sediments that contain clasts of the pluton, which in turn are capped by a limestone layer, believed at the time to be of Permian age. Bultman (1979) considered the limestone to be Upper Triassic (Norian or Carnian) in age based upon several fossil collections identified by John Wells (Cornell University) and himself. He correlated the limestone with the Sinwa Formation along southwest structural trend in the Tulsequah area. Subsequent mapping in the Atlin Lake (Mihalynuk *et al.*, 1990, 1996) and Tulsequah regions (Mihalynuk *et al.*, 1994, 1995, 1996) confirmed this correlation and led to the recognition of Carnian fossils within strata between Sinwa Formation and the eroded top of the Willison Bay pluton (Figures 2 and 3).

Bultman obtained K-Ar age determinations on hornblende from two samples of the Willison Bay pluton which gave 180 ±3 and 222 ±5 Ma (recalculated from 175 ±3 and 215 ±5 Ma, using revised decay constants of Steiger and Jäger, 1977). Argon loss during alteration of hornblende in the less fresh sample, probably accounts for the younger age. The older age is consistent with Norian fossils in the overlying strata based on the Norian age limits of Harland *et al.* (1990, 223.4 to 209.5; Figure 3), but is too young to be overlain by Carnian strata, unless the error limits for Carnian stage boundaries are considered ($235^{+7.5}/_{-12}$ to $223.4^{+4}/_{-3}$ Ma; Harland *et al.* 1990, Table 5.4). New data presented here provides better control on the age of the pluton.

Absolute ages for Late Triassic stage boundaries are relatively unconstrained. They are interpolated from bracketing data sets, and as such, have large uncertainties. Imprecise Upper Triassic stage boundaries have been a source of confusion for mineral explorationists working in rocks from this important metallogenic time frame. Conflicting isotopic and biochronologic age determinations are recognized from geological investigations of the Guichon Creek Batholith (McMillan,

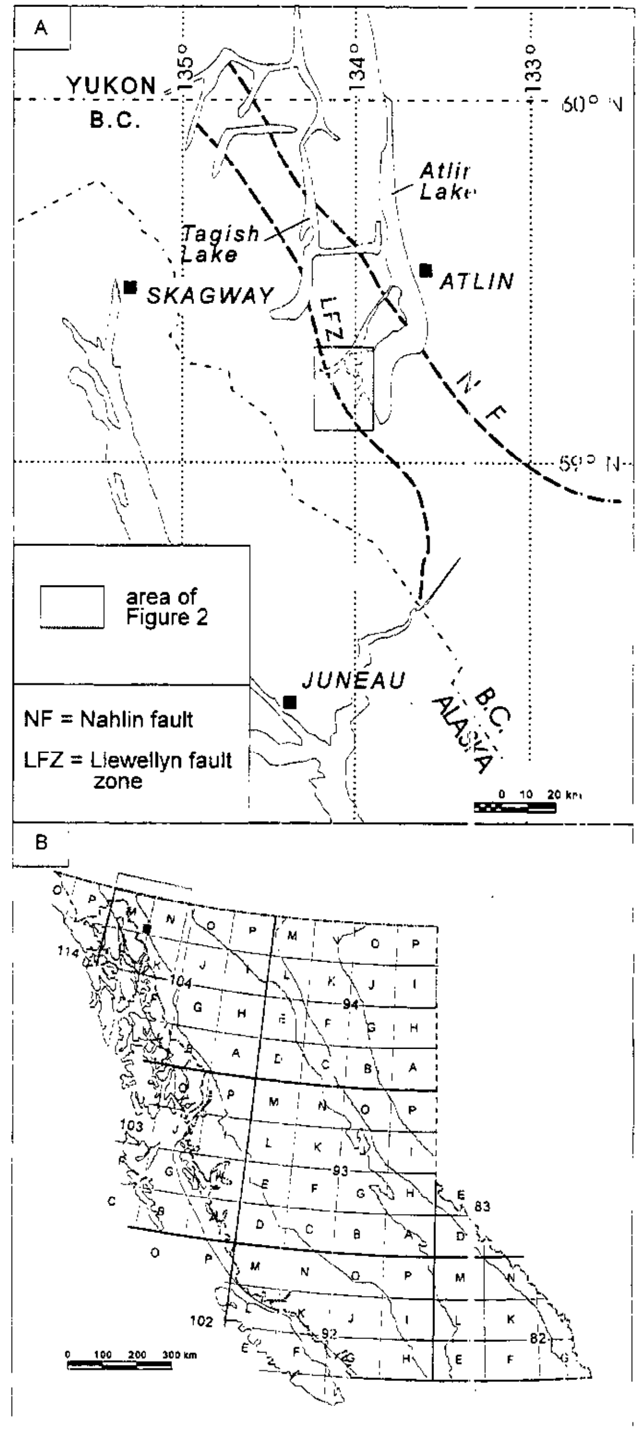

Figure 1. Location of the study area, southern Atlin Lake.

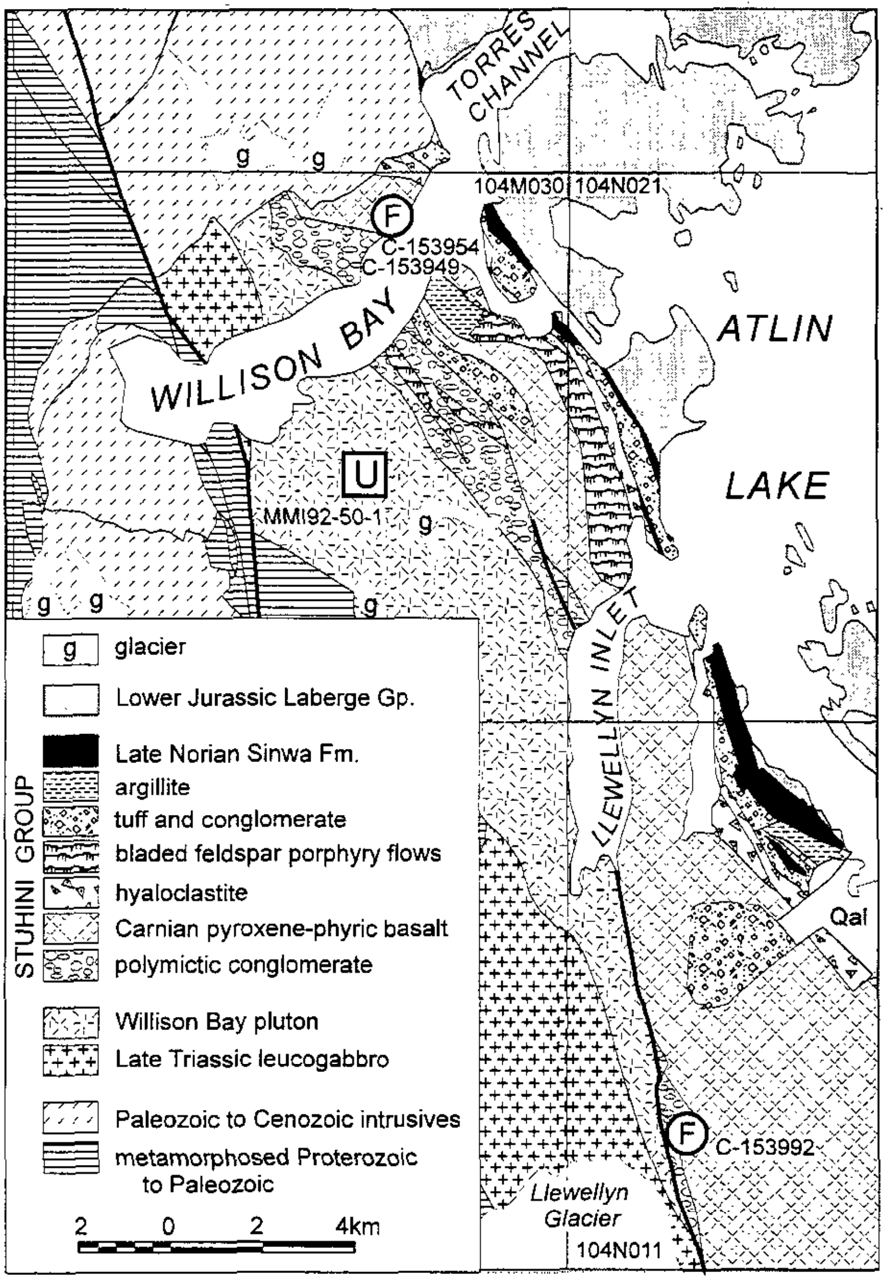

Figure 2. Generalized geology of area around Willison Bay (from Mihalynuk *et al.*, 1996) and location of fossil localities and U-Pb geochron sample site.

1976); Lost Horse intrusions of Copper Mountain (Preto, 1979); and plutons of the Missezula Lake area (Preto, 1972). Thus, it is important to establish precise age determinations for all Upper Triassic magmatic rocks with corresponding biostratigraphic age control, such as is the case for the Willison Bay pluton.

WILLISON BAY PLUTON SETTING

The Willison Bay pluton covers about 42 km^2 and extends from north of Willison Bay to the terminus of the Llewellyn Glacier (Figure 2). Resistant blocky outcrops typical of the pluton (Photo 1) weather grey to tan and are white, pink or tan on fresh surfaces. Some joint surfaces are coated with epidote and chlorite. A weak to moderate foliation may be displayed. Potassium feldspar megacrysts up to 5 centimetres long (normally 2.5 cm, 10%) may be weakly perthitic and commonly contain concentric zones of plagioclase and hornblende inclusions. Fresh, prismatic hornblende comprises up to 4% (3 mm), altered biotite to 3% ($\leq$2 mm), and fine to medium-grained titanite 2% of the rock. Locally, all major mineral phases are phenocrystic. At such localities K-feldspar megacrysts (10 to 15%) occur together with 4 mm tabular plagioclase phenocrysts (up to 60%), and grey quartz eyes (15%) in an aphanitic grey to pink groundmass. Modal mineralogy and X-ray fluorescence

Photo 1. Massive non-porphyritic phase of the Willison Bay pluton at the U-Pb age date sample site. Norm Graham for scale.

Photo 2. (a) View to the north of the Willison pluton's faulted eastern contact at the terminus of the Llewellyn Glacier. Conglomerate is visible at the far eastern foreground. (b) Close-up of the exposed faulted contact at Llewellyn Inlet. Craig Hart of the Yukon Geoscience Office for scale.

analysis of major oxides indicate that the pluton is a metaluminous calcic granite (Figure 4).

Western and southeastern contacts of the pluton are bounded by the Llewellyn Fault (Photo 2), a long-lived, high-angle crustal scale dip-slip fault, and a subsidiary, coalescing fault to the east. Southwestern pluton contacts are intrusive into greenstone of the Boundary Ranges Metamorphic Suite and foliated, polyphase leucogabbro that is probably comagmatic (Werner, 1978 unpublished; Wilton, 1971; Mihalynuk *et al.*, 1996 and unpublished). The pluton also intrudes leucogabbro on its northwestern margin. At its northern extremity, the Willison Bay Pluton is cut by the post-kinematic Cathedral Pluton of probable Late Cretaceous age. Contacts on the northwestern margin of the Willison Bay pluton are nonconformable with local, minor, syn-(?) and post-depositional fault disruption. A sample for U-Pb age determination was collected from central Willison Pluton where it crops out on the alpine plateau south of Willison Bay (NTS 104M/1, UTM 553200E 6567000N, Zone 8V; Photo 1).

U-Pb age determination

Six zircon fractions from sample MM92-50-1 have been analyzed. Complete U-Pb analytical procedures employed at the UBC Geochronology are reported in Mortensen *et al.* (1995). Raw data are presented in Table 1, and the analyses are plotted on a concordia diagram in Figure 5. Five of the six samples lie on or near concordia along a chord which passes through zero and has an upper intercept age of 216 ±4 Ma. The sixth fraction, which consisted of unabraided fine non-magnetic zircons, appears to have lost lead. None of the fractions appear to contain significant amounts of inherited zircon, although fractions B and C may contain minor xenocrystic zircon. The linear array formed by fractions A, B and C suggests some degree of lead loss.

A best age estimate for this rock is 215.6 ±4 Ma, as defined by the correlated errors regression (Ludwig, 1980) that is forced through zero and all fractions. Support of this age is given by the mean $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages for the two concordant fractions F and G

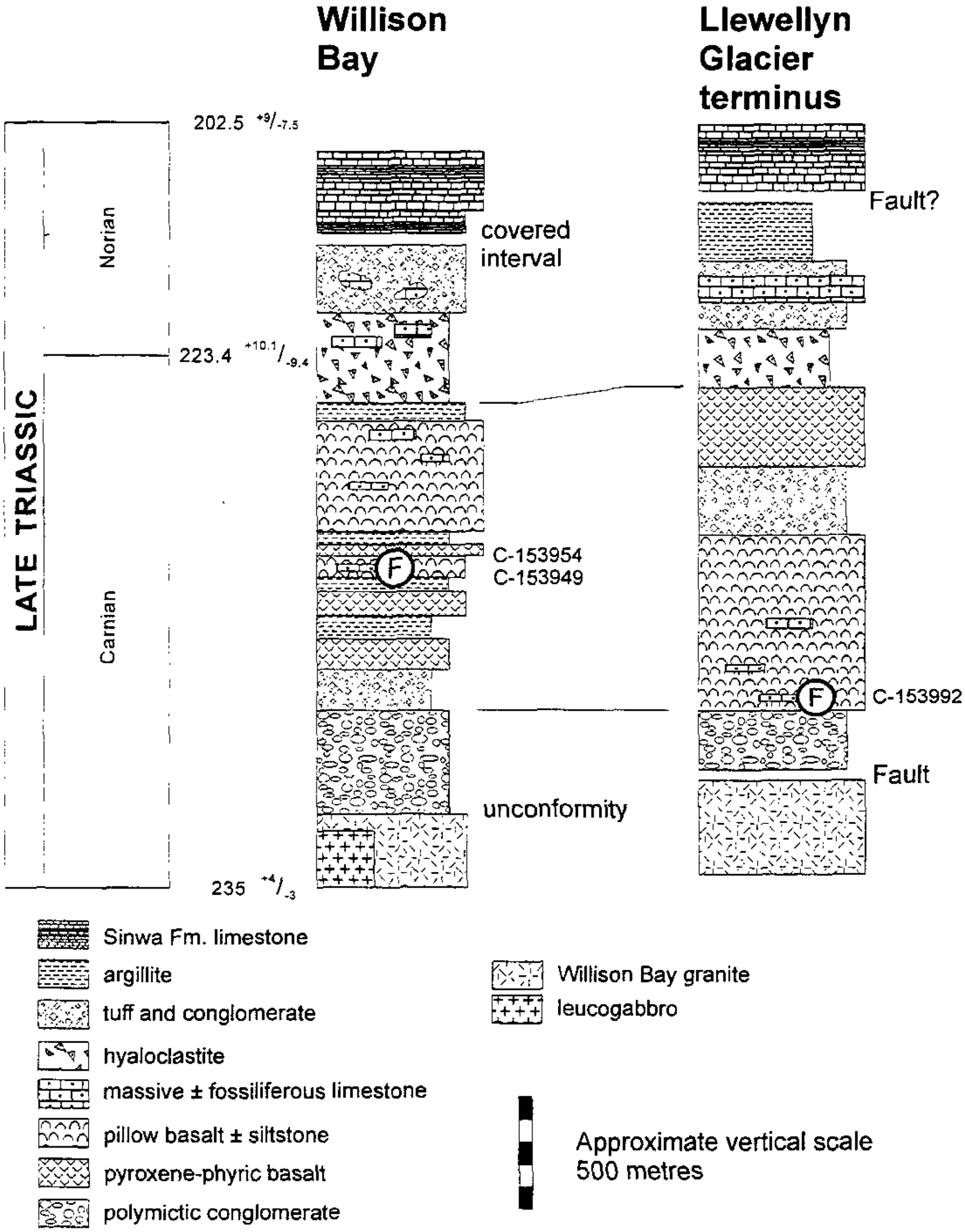

Figure 3. Stratigraphy of the Willison Bay area, location of the Willison Bay pluton chronostratigraphic tie point, and locations of micro and macrofossil faunas. Geologic time scale is that of Harland *et al.* (1990).

CARNIAN-NORIAN VOLCANO-SEDIMENTARY SUCCESSION

Volcano-sedimentary units that lie atop the Willison Bay pluton are described in Bultman (1979) and Mihalynuk and Mountjoy (1990). Readers interested in more comprehensive information about the Willison Bay section may wish to refer to these reports. Only selected parts of the succession are detailed here. A section from near the Llewellyn Glacier terminus is described here for the first time.

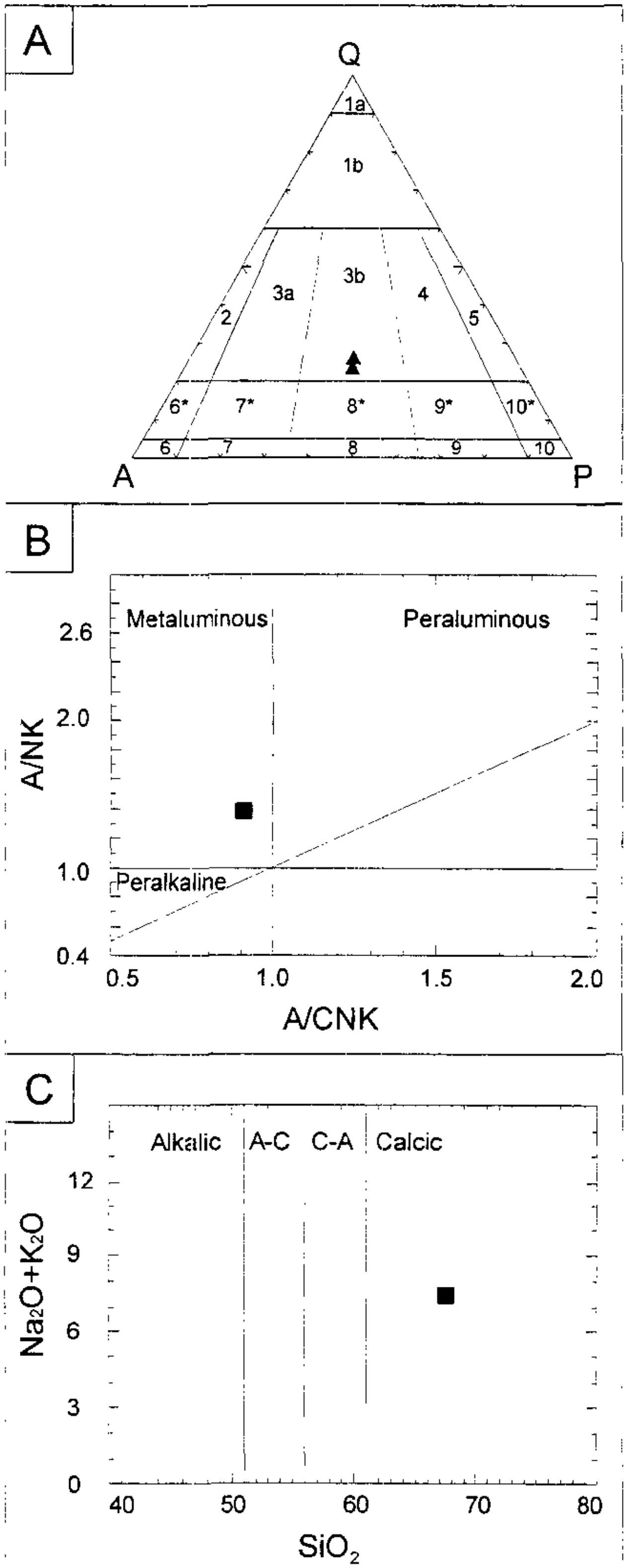

Figure 4. (a) Modal mineralogy plot of the Willison Bay Pluton where Q = quartz, A= alkali feldspar and P = plagioclase. (b) Granite classification diagram of Maniar and Piccoli (1989) shows the ratio of A/(N+K) versus A/(C+N+K) where A= Al_2O_3, C=CaO, N=Na_2O, K=K_2O. (c) Granite classification diagram of Peacock (1931) showing the ration of SiO_2 versus K_2O and Na_2O. Data are from X-ray fluorescence analysis of sample MMI89-2-2.

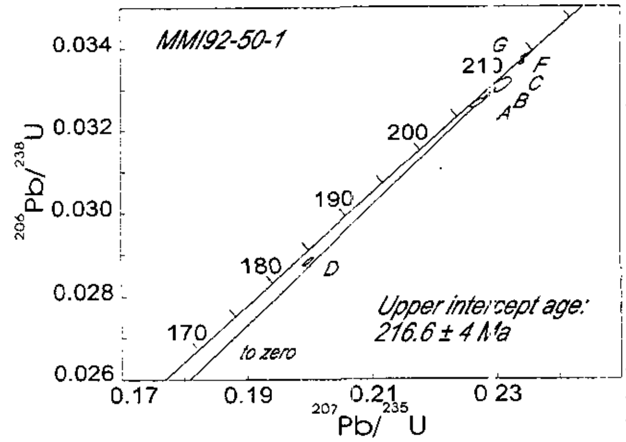

Figure 5. Concordia diagram for Willison Bay pluton sample number MMI92-50-1. Six fractions are plotted. Data is summarized in Table 1.

Willison Bay

One of the most complete and best exposed sections of Stuhini Group strata is exposed along the shores of Willison Bay. Between 2.5 (north shore) and 3 km (south shore) of strata are preserved above the Willison Bay pluton. Clast populations exhibit a 'reverse stratigraphy' recording exhumation of the Stuhini arc. Volcanic derived clasts dominate the lower conglomerates (Photo 3), plutonic clasts and finally metamorphic clasts gain importance in higher conglomerates. Where conglomerate directly overlies the Willison Bay pluton it is locally comprised of only pluton clasts. This makes it difficult to determine the exact contact location. Moving outwards from *bona fide* igneous textures in the pluton, feldspars become turbid and grain boundaries indistinct. At about 2m, vague boulder outlines (up to 1m diameter) with K-feldspar phenocrysts truncated at boulder margins, are apparent in what otherwise appears to be an intrusive rock. A few metres farther upsection, bedding with hydrodynamic sorting of mineral granules is apparent, and rare quartzite cobbles are present. Farther up section, intermediate volcanic clasts become an important, locally dominant, component. Some volcanic clasts are recycled volcanic conglomerate, all are apparently derived from the exhumed Stuhini arc as probable source rocks can be mapped to the north. Metamorphic clasts become more important upward, and at about 450m from the base, pyritic, siliceous phyllite chips dominate a 5-20m thick layer. Fine-grained clastic layers become more prominent and are punctuated by maroon and green tuffite (Photo 4). Increasingly sparse pluton clasts and common layers of pyroxene crystal-rich clastics mark a transition from arc erosion to another constructional phase. Sheets of pyroxene-phyric basalt (2-20m thick) punctuate deposition of calcareous siltstone and argillite (1-3m thick). About 350m above the first basalt flows (~1100m above the base) are flows comprised of large pillows (2m diameter) with interpillow micrite (Photo 5). These sit

TABLE 1. U-PB ANALYTICAL DATA FOR WILLISON BAY PLUTON SAMPLE MMI92-50-1.

Fraction[1,2]		Wt. mg	U^{3} ppm	Pb^{3} ppm	$^{206}Pb^{4}/^{204}Pb$	Pb^{5} pg	^{208}Pb %[6]	Isotopic Ratio (± %1σ) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Apparent Age (Ma, ±2σ) $^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
A	+a	0.709	420	14	3193	185	8.2	0.03265 (0.18)	0.227 (0.24)	0.05042 (0.14)	207.1 (0.7)	214.6 (6.4)
B	-b+c	0.491	485	16	10571	45	8.7	0.03286 (0.22)	0.229 (0.22)	0.05054 (0.05)	208.4 (0.9)	220 (2.2)
C	-c+d	0.170	552	18	4176	46	9.3	0.03308 (0.27)	0.2308 (0.36)	0.05061 (0.25)	209.8 (1.1)	223.2 (12)
D	-d na	0.278	795	23	3280	122	9.4	0.02884 (0.19)	0.1998 (0.22)	0.05025 (0.08)	183.3 (0.7)	206.4 (3.8)
F	+b	0.182	408	14	2831	55	8.7	0.03362 (0.07)	0.2341 (0.09)	0.05051 (0.06)	213.1 (0.3)	218.7 (2.7)
G	+b tips	0.208	402	13	5027	35	8.3	0.03376 (0.10)	0.2346 (0.13)	0.05039 (0.08)	214.1 (0.4)	213.1 (3.6)

Notes: Analyses by J.E. Gabites, in the Geochronology Laboratory, Department of Earth and Ocean Sciences, U.B.C.
IUGS conventional decay constants (Steiger and Jäger, 1977) are: $^{238}U\lambda=1.55125x10^{-10}a^{-1}$, $^{235}U\lambda=9.8485x10^{-10}a^{-1}$, $^{238}U/^{235}U=137.88$ atom ratio.

1. Column one gives the label used in the Figure.
2. Zircon fractions are labelled according to magnetic susceptibility and size. NM = non-magnetic at given amperes on magnetic separator. Side slope is given in degrees. All fractions are NM2A/1°, abraded except where indicated (na). Size fractions are: a 149, b 104, c 74, d 44µm. The - indicates zircons are smaller than, + larger than the stated size.
3. U and Pb concentrations in mineral are corrected for blank U and Pb. Isotopic composition of Pb blank is 206:207:208:204 = 17.299:15.22:35.673:1.00, based on ongoing analyses of total procedural blanks of 37 ± 1 pg (Pb) and 6 ± 0.5 pg (U) during the time of this study.
4. Initial common Pb is assumed to be Stacey and Kramers (1975) model Pb at the $^{207}Pb/^{206}Pb$ age for each fraction.
5. Radiogenic Pb.
6. Total Common Pb in analysis.
7. Errors are % 1σ except $^{207}Pb/^{206}Pb$ age errors which are 2 σ in Ma.

above a scoured bed of *Halobia*-bearing siltstone-argillite. The interpillow micrite contains Carnian conodonts (see below).

Approximately 700m of basalt flows and interflow sediments overly the Carnian fossil locality and are in abrupt contact with a distinctive, 200m thick, continuous belt of bright green, poorly lithified hyaloclastite breccia. These coarse pyroxene-phyric rocks display a sheared contact with overlying cherty, tuffaceous argillite and succeeding planar-bedded, quartz-rich, volcanic conglomerate and coarse lithic sandstone. Near the mouth of Willison Bay the volcanic conglomerate is structurally overlain by Sinwa Fm. carbonate, but the contact is intruded by The Cathedral pluton. On the south shore carbonate clasts within the conglomerate are common, suggesting a depositional tie with the overlying carbonate, but the contact is not exposed. Similar nebulous contact relations between Sinwa Formation and underlying volcanic conglomerate exist farther south along Atlin Lake.

Llewellyn Glacier terminus

Near the terminus of the Llewellyn Glacier, the Willison Bay pluton is in fault contact with up to 260m of basal conglomerate. Like the section north of Willison Bay, the lower part of the basal conglomerate is dominated by clasts derived form the pluton. Contained within the conglomerate are layers of red ash tuff, disrupted argillite and oncolitic carbonate. Metamorphic clasts are abundant at the top of the conglomerate, where it is overlain by pyroxene-feldspar crystal tuff and pyroxene-porphyry flows and flow breccia. Overlying, dark green, pillow basalt flows are porphyritic with medium to coarse-grained, crowded pyroxene (25%) and medium to fine-grained, tabular plagioclase (20%;). Laminated micrite at pillow intersections contains Carnian conodonts (Table 2). An approximate 800m thickness of flows is exposed in semi-continuous outcrop. A covered interval separates them from presumably overlying maroon lapilli tuff comprised mainly of fine plagioclase porphyry.

Fossil age dates

Siliceous argillite and fine siltstone containing *Halobia* (NWI89-4-3c and MMI89-4-3c; Table 2) are directly overlain by pillow basalt with interpillow micrite containing Carnian conodonts (MMI89-4-3; Table 2; Photo 5). *Halobia* are not sufficiently well preserved to permit identification to the species level. Thus, an age no more precise than Late Triassic can be assigned.

Photo 3. Polymictic conglomerate derived in part from the Willison Bay pluton. Farther down section this conglomerate is composed entirely of pluton-derived clasts.

Conodonts were extracted from samples of interpillow micrite from the Willison Bay and Llewellyn Glacier terminus areas. They occur 1000m and 300m respectively, above the main conglomerate unit (MMI89-4-3 and MMI91-29-2-3, Table 2; Figures 1, 2). Both samples contain Metapolygnathus identifiable only to the genus level; nevertheless, a Carnian age can be assigned.

Photo 4. Tuffaceous interbeds within the basal conglomerate indicates the onset of an arc constructional phase. Note white granitoid boulders at right.

DISCUSSION

New age data from the Willison Pluton and overlying strata indicate that the present age assigned to the Carnian-Norian stage boundary is too old. Revision is in order if the following conditions are true: (1) the estimated isotopic age is an accurate reflection of the true age of the pluton, and (2) there are no cryptic thrust faults between plutonic conglomerate and fossil-bearing strata.

Condition 1 appears satisfied since the U-Pb age reported here (216.6 ±4Ma) is the most precise age determination from this body to date, is concordant with an earlier K-Ar age determination (222 ±5 Ma; Bultman, 1979), and is concordant with a U-Pb date from the Tally Ho leucogabbro along the Llewellyn fault in the Yukon (213.6 ±0.6 Ma; Hart, 1995). Tally Ho leucogabbro is correlated with the leucogabbro at Willison Bay which, based upon textural evidence, is believed to be a coeval precursor intrusive pulse of the Willison Bay pluton.

Condition 2 also appears to be satisfied. Although the section contains a mapped fault, it is a high angle fault which does not repeat stratigraphy. Preservation of an original stratigraphic succession without repetition is supported by: (1) lack of any near bedding parallel

TABLE 2. CARNIAN-NORIAN FOSSIL COLLECTIONS FROM THE WILLISON BAY AND NEARBY CORRELATIVE STRATA.

Field No.	GSC No.	UTM E Zone 8	UTM N	Fossil Genus and Species	Determined Age
Norian Conodonts					
87JR-45-5	C-153920	52375	6625350	Epigondolella ex gr. bidentata Mosher	Late Norian
Carnian Conodonts					
MMI89-4-3	C-153954	553500	6572000	Metapolygnathus sp.	Carnian
MMI91-29-3-2	C-153992	559450	6555800	Metapolygnathus sp.	Carnian
Carnian Macrofossils					
NWI89-4-3c	C-153949	553500	6572000	*Halobia* sp.	Upper Triassic
MMI89-4-3c	C-153962	553500	6572550	*Halobia* sp.	Upper Triassic

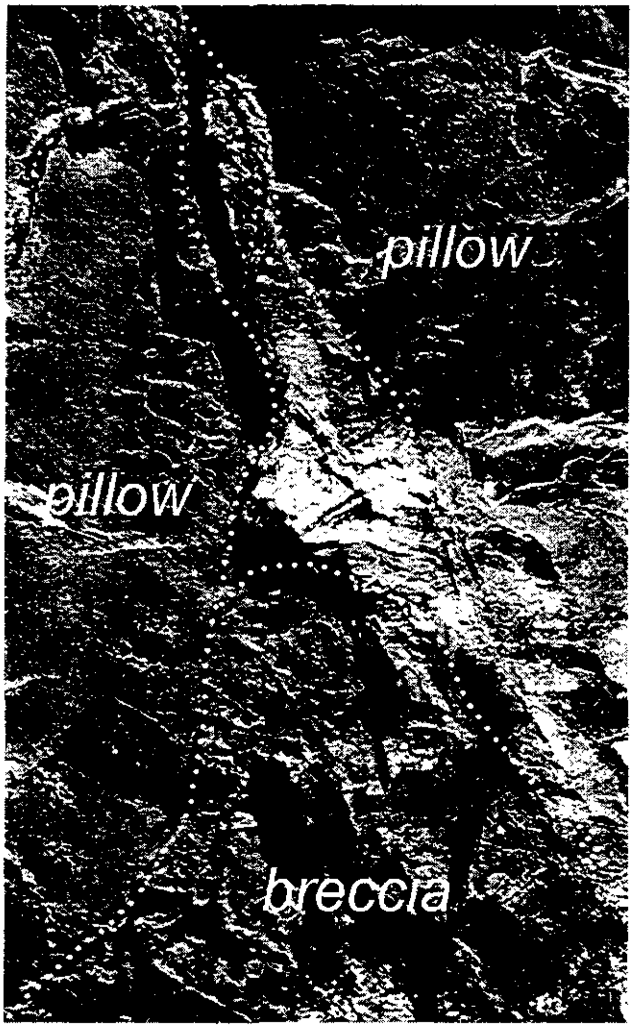

Photo 5. Pillow basalt with interpillow micrite containing Carnian conodonts sits atop a scoured set of silty argillite beds containing Halobia.

foliated zones, (2) upsection decrease in abundance of igneous clasts derived from the Willison Bay pluton, (3) upsection increase in pyroxene crystal tuff component of sediments upon approaching pyroxene basalt flow units.

Exposed sections indicate that at least 1 km of strata was deposited atop the eroded Willison Bay pluton prior to deposition of strata containing Carnian fossils. Hence, the Carnian fossils must be younger than 216.6 ±4 Ma. The Carnian-Norian boundary set by Harland *et al.*, at 223.4 $^{+4}/_{-3}$ Ma, is concordant with the new U-Pb date, but only at the very limit of combined errors. A downward revision of the Carnian-Norian boundary by a minimum of 2.8 Ma is required to agree with the maximum age indicated by the U-Pb date (220.6 Ma). This still assumes that no time elapsed while the Willison Bay pluton was intruded, cooled, exhumed, eroded and buried by 1 km of sediment. The youngest exposed granitoid pluton known on Earth has a solidification age of 2.2 ±0.3 Ma and was probably exposed in middle Pleistocene time (Harayama, 1992). If Willison pluton exhumation was equally quick, and if immediately following exhumation, the overlying sediments were instantaneously deposited, the Carnian fossil site would have a minimum absolute age of about 214.4Ma.

A more precise Late Triassic time scale for the British Columbian Cordillera will be of benefit to mineral explorationists, regional mappers and researchers with interest in this important metallogenic epoch. Ongoing revision of the Late Triassic time scale will also complement the work of J. Pálfy (e.g. Pálfy, 1996) which focuses on revision of the Jurassic Time Scale.

ACKNOWLEDGMENTS

Moira Smith, Keith Mountjoy and Craig Hart provided valuable field observations. Vic Preto collected the finest *Halobia* specimens. Norm Graham not only performed the duties of a tireless and talented helicopter pilot, but also crushed geochron samples *con mucho gusto*.

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THE PALEOZOIC MASSIVE SULPHIDE PROJECT:

AN INVESTIGATION OF YUKON-TANANA CORRELATIVES IN BRITISH COLUMBIA

JoAnne Nelson, Steve Sibbick, Trygve Höy, Peter Bobrowsky, and Michael Cathro

INTRODUCTION

Cominco's 1994 announcement of the discovery of significant stratiform sulphide mineralization in the ABM zone, later called the Kudz Ze Kayah project, generated a strong swell of staking and exploration in the Finlayson Lake area of the southern Yukon. One result was Westmin's optioning of claims held by Atna Resources Ltd., near Wolverine Lake 20 kilometres southeast of Kudz Ze Kayah. In 1995 Westmin announced several ore-grade sulphide drill intersections at Wolverine. These dual successes have spurred Yukon exploration to an all-time high in 1996, in terms of both expenditures and claims staked (J. Hunt, personal communication, 1996).

Kudz Ze Kayah and Wolverine lie within the Yukon Tanana Terrane. The volcanogenic massive sulphide orebodies are hosted by meta-morphosed sequences of Early Mississippian rhyolite, argillite, mafic tuff and coeval, probably cogenetic plutons. The Yukon Tanana Terrane is not confined to Yukon. In Alaska it extends into the Alaska Range, where it hosts the VMS deposits of the Delta and Bonnifield districts. In British Columbia, Yukon Tanana extensions and correlatives include the Nisling Terrane in the Coast Mountains, which hosts the Ecstall deposit and which may be related to the Stikine Assemblage around the Tulsequah Chief deposit; pericratonic terranes of far northern B.C.; and the Kootenay Terrane, which hosts Late Devonian(?) VMS deposits in the Eagle Bay Assemblage north of Kamloops (Nelson, this volume, Figure 1).

This multidisciplinary project was undertaken by the Geological Survey Branch to emphasise the exploration opportunities afforded by these large tracts of promising but underexplored pericratonic terranes in British Columbia. The various component studies are designed to fill gaps in the present state of knowledge about parts of these terranes, particularily in the style and distribution of known mineral deposits, and offer new ideas about how additional discoveries might be made.

The Yukon Tanana correlative terranes in the far north are poorly known, with little geologic mapping since initial 1:250,000 coverage by the Geological Survey of Canada in the early 1960's. They are also underexplored: prior to the 1994-95 discoveries, the Yukon Tanana Terrane was not considered to be highly prospective ground. Therefore, the northern bedrock project aimed at reconnaissance mapping of target areas scattered through these terranes, in order to locate Devono-Mississippian volcano-sedimentary units that might host VMS deposits. This project is conducted by JoAnne Nelson.

In contrast, the Eagle Bay Assemblage in the southern part of the Kootenay Terrane is well-mapped and has been extensively explored by traditional methods. It is likely that new discoveries will be in drift covered or forested areas. The current focus there is on establishing geochemical dispersal signatures for known deposits via detailed till geochemistry surveys and biogeochemical orientation studies of selected examples of the region's key mineral deposit types, and on providing regional hydrogeochemical (stream water chemistry) data. Peter Bobrowsky and Steve Sibbick are responsible for this work.

The Kootenay Terrane as a whole, because of its easy accessibility, might be assumed to be well explored; but the discovery of a sulphide boulder train near Barkerville by Barker Minerals in 1994 (Ace property) emphasised that new grassroots finds are still possible. In a third contribution to this project, Trygve Höy is documenting the highly varied stratigraphic settings of syngenetic minera-lization in the Kootenay Terrane. More than the Yukon Tanana, the Kootenay Terrane shows a prolonged history of continent margin extension and related hydrothermal systems, from Cambrian to Mississippian. These offer alternative models for exploration that should be pursued along with the currently popular Devono-Mississippian scenario.

RESULTS

NORTHERN BRITISH COLUMBIA RECONAISSANCE

With restoration of 450 kilometres of dextral displacement on the Tintina fault, the rocks of the Finlayson Lake area are on strike with the Teslin Tectonic Zone, which extends south into the Jennings River map area of northern British Columbia. Its equivalents there are the Big Salmon Complex (Gabrielse, 1969) and the lower part of the Dorsey Terrane, which forms a belt a few kilometres west of the Cassiar batholith. A third possible Yukon-Tanana correlative in northern B.C. is the Rapid River Tectonite in the Sylvester Allochthon, an assemblage of highly deformed rocks intruded by Early Mississippian plutons (Gabrielse and Harms, 1989). This year's brief reconnaissance of these three terranes yielded metamorphosed felsic volcanic rocks analogous to the stratigraphy hosting Kudz Ze Kayah and Wolverine at two separate localities, one in the Big Salmon Complex and one in the lower part of the Dorsey Terrane (Nelson, this volume). At the first locality, piedmontite-hematite meta-chert interbedded with the metarhyolite is similar to the hanging wall iron formation at Wolverine.

METALLOGENY OF THE KOOTENAY TERRANE, SOUTHERN AND CENTRAL BRITISH COLUMBIA

The Kootenay Terrane comprises intensely deformed, variably metamorphosed clastic sediments, subordinate volcanics and limestones ranging in age from Proterozoic to Triassic. Major rock packages in the Kootenay terrane include the Lower Paleozoic Lardeau Group, the Eagle Bay Assemblage, eastern assemblages of the Late Paleozoic Milford Group, and equivalent rocks in the highly metamorphosed Shuswap complex to the west. The Barkerville and Cariboo terranes farther north are similar pericratonic terranes. Reconnaissance work this past summer focused on the variety of massive sulphide deposits in these terranes, including SEDEX deposits in dominantly Cambrian successions and VMS deposits in both Middle Cambrian and Devonian volcanic rocks.

Massive Pb-Zn deposits occur in basal Eagle Bay rocks of the Kootenay terrane on Adams Plateau and in possibly correlative Cambrian successions in marginal North American rocks. Large, highly deformed and metamorphosed Pb-Zn deposits, some with Broken Hill-type characteristics, also occur within paragneisses of the Shuswap Complex. One of these, Cottonbelt, is currently being explored by Canquest Resources, Inc. Volcanogenic massive sulphide deposits in the Index Formation, the basal unit of the Lardeau Group, record hydrothermal activity during Lower Paleozoic regional extension. The Goldstream deposit has closed recently; however, Rain continues to be actively explored as does the Ace prospect in the Barkerville Terrane near Likely.

Late Devonian arc volcanics in the Eagle Bay assemblage contain a number of polymetallic VMS deposits, including Rea and Homestake. Work this past summer concentrated, in part, on a disseminated copper sulphide deposit, Harper Creek, located near Vavenby (Höy, this volume). Reconnaissance work in the Barkerville terrane recognized possibly similar volcanic arc stratigraphy, associated with Late Devonian intrusive rocks, enhancing the exploration potential for massive sulphide deposits here as well.

EAGLE BAY HYDROGEOCHEMICAL SURVEY AND ORIENTATION STUDIES

The Eagle Bay Assemblage of the Kootenay Terrane is a 40 by 80 kilometre belt located between Shuswap Lake and Clearwater in south-central B.C. The area is well known for its volcanogenic massive sulphide deposits. Small, high-grade deposits such as Homestake (Kamad) have been explored and mined since the early part of the century. Exploration activity boomed from the mid-1960's to the late 1980's, fueled by the discoveries of Harper Creek, Chu Chua, Rea and Samatosum in 1966, 1978, 1983, and 1986 respectively. Despite the demonstrated high mineral potential, exploration has waned in recent years: since 1991 very few significant drilling programs have been conducted and numerous claims have lapsed. Numerous prospects and deposits are currently available for option.

The Eagle Bay Assemblage shares a similar geologic and tectonic history with the Yukon Tanana Terrane. Both terranes embrace a moderately to strongly deformed and metamorphosed package of sedimentary and volcanic rocks deposited in a rifted continent-margin setting from Cambrian up to Late Devonian time, with a superimposed Devono-Mississippian magmatic arc. Common elements include Devono-Mississippian mafic to felsic metavolcanics and associated Kuroko-type polymetallic deposits and large areas of associated quartz-sericite-pyrite alteration; and plutons that are coeval and probably cogenetic with this magmatic event. Adjacent late Paleozoic oceanic terranes - the Anvil Assemblage in southern Yukon and the Fennell Group in southern B.C. - contain Cyprus-type massive sulphide copper deposits. The newly disovered Ice prospect of Expatriate Resources Ltd. in the Anvil Range is similar in setting and metal content to the Chu Chua deposit in the Fennell Group.

The Adams Lake- Clearwater area has moderate terrain, excellent infrastructure and access, and a very good database of geological and exploration information (Schiarizza and Preto, 1987). The completion of a Land and Resource Management Plan for the area in 1995 means that the land use situation is relatively stable, with no new alienation issues likely.

Exploration in the area has been hampered by the obscuring effects of metamorphism and deformation and the relatively small size of the target deposits in the region. The presence of carbonaceous interbeds in many of the prospective rock units makes the interpretation of electromagnetic geophysical data problematic. Extensive overburden cover is probably the most significant obstacle to mineral exploration. In future, geochemical exploration techniques will play a key role in new mineral discoveries.

Two exploration geochemistry programs were conducted as part of the Eagle Bay project (Sibbick *et al.*, 1997). These included a regional hydrogeochemical (stream water chemistry) survey and a detailed soil and biogeochemical orientation study of selected examples of the region's key mineral deposit types. The goals of the Eagle Bay Exploration Geochemistry program are to:

- Produce regional stream water geochemistry maps of major and minor elements.
- Determine critical geochemical exploration parameters for massive sulphide mineralization in overburden covered areas.

Details of this survey are reported in Sibbick *et al.* (1997). The hydrogeochemical survey involved the collection of stream waters from primary and secondary drainages and the in-field measurement of the field parameters pH, redox potential, conductivity and temperature. Filtered and acidified water samples were analysed by ICP-MS for approximately 70 elements; sulphate was also determined on unfiltered sample splits. Results are currently being compiled for release in early 1997.

EAGLE BAY SURFICIAL GEOLOGY AND TILL GEOCHEMISTRY SURVEY

Quaternary geologic mapping and till geochemistry surveying was initiated and completed in 1996 by the B.C. Geological Survey Branch with assistance from the Department of Earth Sciences, Simon Fraser University. The study area, located northeast of Kamloops includes most of NTS 82M/4 (Adams Plateau) and 82M/5 (North Barriere Lake), or approximately 2000 square kilometres of rugged, drift-covered terrain, overlying economically interesting Devono-Mississippian rocks of the Eagle Bay Assemblage. Work centred on two related components which rely on the use of drift covered terrain exploration methods:

Surficial mapping at a scale of 1:50 000 including airphoto interpretation and upwards of 50% polygon checking for ground truthing and sampling of basal till deposits as part of a reconnaissance level till geochemistry exploration project for analysis of major and minor elements by ICP and INA.

Surficial mapping completed on both sheets resulted in the identification of several types of deposits, which in order of abundance included basal till, ablation till, colluviated till, colluvium, glaciofluvial, fluvial, glaciolacustrine and organic sediments. Terrain geology maps have been published for the two map sheets (*cf.* Dixon-Warren *et al.* 1997b, Leboe *et al.* 1997). A total of 660 field stations were used to verify air photo interpretations. Details of the surficial mapping efforts are given in Dixon-Warren *et al.* (1997a). Samples collected as part of the survey were only obtained from deposits representative of the first four types. A total of 525 samples were collected and analyzed. Details regarding the till geochemistry component are presented in Bobrowsky *et al.* (1997).

Results of this work indicate that although the area was glaciated more than once, exposed sediments overlying bedrock are products of the final glaciation during the Late Wisconsinan.

Glacial ice which covered this area originated in the northwest and expanded south and southeastward towards the USA border between 22 000 and 11 000 years ago. This simple ice flow history is ideal for drift exploration purposes, as is the fact that overburden cover in the area is minimal, rarely exceeding a few tens of metres and commonly being less than a few metres thick. Coupled with the observation that most sediments are basal till in origin, the reliance on the surficial maps and till geochemistry survey maps thus provides a very good opportunity for further exploration activity directed toward buried mineralization.

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SUB-BASIN RECOGNITION IN THE PURCELL ANTICLINORIUM

By Andrew Legun

KEYWORDS: Aldridge Formation, Sullivan Deposit, Moyie sills, synsedimentary faults, marker laminites, Fringe marker, stratigraphic isopachs

INTRODUCTION

This study traces the stratigraphy above and below the Sullivan deposit. Thickness trends are assessed within a regional context. The presence of marker laminites within the Middle Aldridge facilitates such a study. Cominco has identified more than twenty marker zones, some of great lateral extent (Heubschmann, 1973). Hagen (1981) used the markers to evaluate sedimentation patterns between time lines. He concluded, "It should be possible to assess the role of syndepositional faulting in the evolution of the basin and in ore formation." The present study pursues this theme. It considers the stratigraphic interval from the Fringe marker to the footwall quartzite below the deposit. The area of study extends from the Kimberley area to Moyie Lake (Figure 1).

THE SULLIVAN DEPOSIT

The Aldridge Formation hosts the Sullivan deposit, a large stratified lens of iron-lead-zinc sulphides. The lens rests on intraformational conglomerate which in turn overlies a tourmalinite pipe consisting of breccia, altered strata and veinlet sulphides.

The orebody is up to 100 metres thick and about 2000 metres in diameter. The orebody consists of massive sulphides that grade vertically and laterally into interbedded sulphides and clastic rock. The sulphides comprise pyrrhotite, sphalerite, galena and pyrite in bands, which are very finely laminated over distances of two kilometres. Synsedimentary features include delicate monomineralic bands, clasts of pyrrhotite indenting sediment laminae, and soft sediment slumps of sulfide rich sediment (Hamilton *et al.*. 1982; Ransom 1989, see photo 15)

The Sullivan deposit formed as a result of discharge of metal-bearing hydrothermal fluids to the seafloor through a vent system. The well-bedded eastern ore formed as a result of precipitation from a convecting brine cell developed over the vent (Höy *et al.*, 1990).

The deposit grades laterally into a fine grained sequence of rocks, the Sullivan facies, located at the top of the Lower Aldridge Formation and lying directly under coarser sediments of the Middle Aldridge.

Regionally the Sullivan facies has elevated values of Pb, Zn, Ag. For this reason there has been extensive drilling to the Sullivan "horizon" in search of other vents.

THE DEPOSIT MODEL

The model for shale-hosted submarine exhalative deposits stresses the importance of sub-basins within a host extensional basin. Subbasins are bounded by faults, and such basins may host ore deposits. The Helena embayment is a second order basin; a re-entrant at the eastern edge of the Aldridge basin in Montana. The Sheep Creek Cu-Co camp is related to the Volcano fault at the edge of the embayment (Himes and Peterson, 1990). Here, dramatic facies changes within the Newland Formation mark the fault.

Winston (1986) notes that it is not easy to discern the faults of the Helena embayment away from the basin edge. Their principal signature within the main basin appears to be dramatic thickness changes and areas of soft sediment deformation.

The Sullivan deposit lies well within the main Aldridge basin (Höy, 1993) within a second order basin. The trace of the Kimberley fault relates to the original bounding fault. The fault parallels offsets in isopachs of overlying Middle Aldridge turbidites (Höy 1993) and is associated with anomalous concentration of tourmalinite and conglomerate (Höy *et al.* 1993). However the Kimberley fault may differ in trend from an original structure. Thickness isopachs as in Figure 2 are a direct means to locate and determine the trend of such a structure. Figure 2 shows the eastern margin of the Sullivan sub-basin defined by a rapid thinning of the Fringe to Sullivan horizon interval.

The Sill Factor

Numerous sills and minor dikes intrude the Aldridge succession. Locally sills may occupy a high proportion of the stratigraphic interval. For example, Turner *et al.*, 1992 estimate the aggregate thickness of gabbro exposed in the Lower Aldridge near Bootleg Mountain is 1000 metres within a sequence 3000 metres thick.

The sediment adjacent to the sills shows features ranging from original bedding, to disturbed areas with fluid escape structures, to homogenized and chemically altered sediments. Höy (1989) concluded that some sills intruded wet unconsolidated sediments at shallow depths.

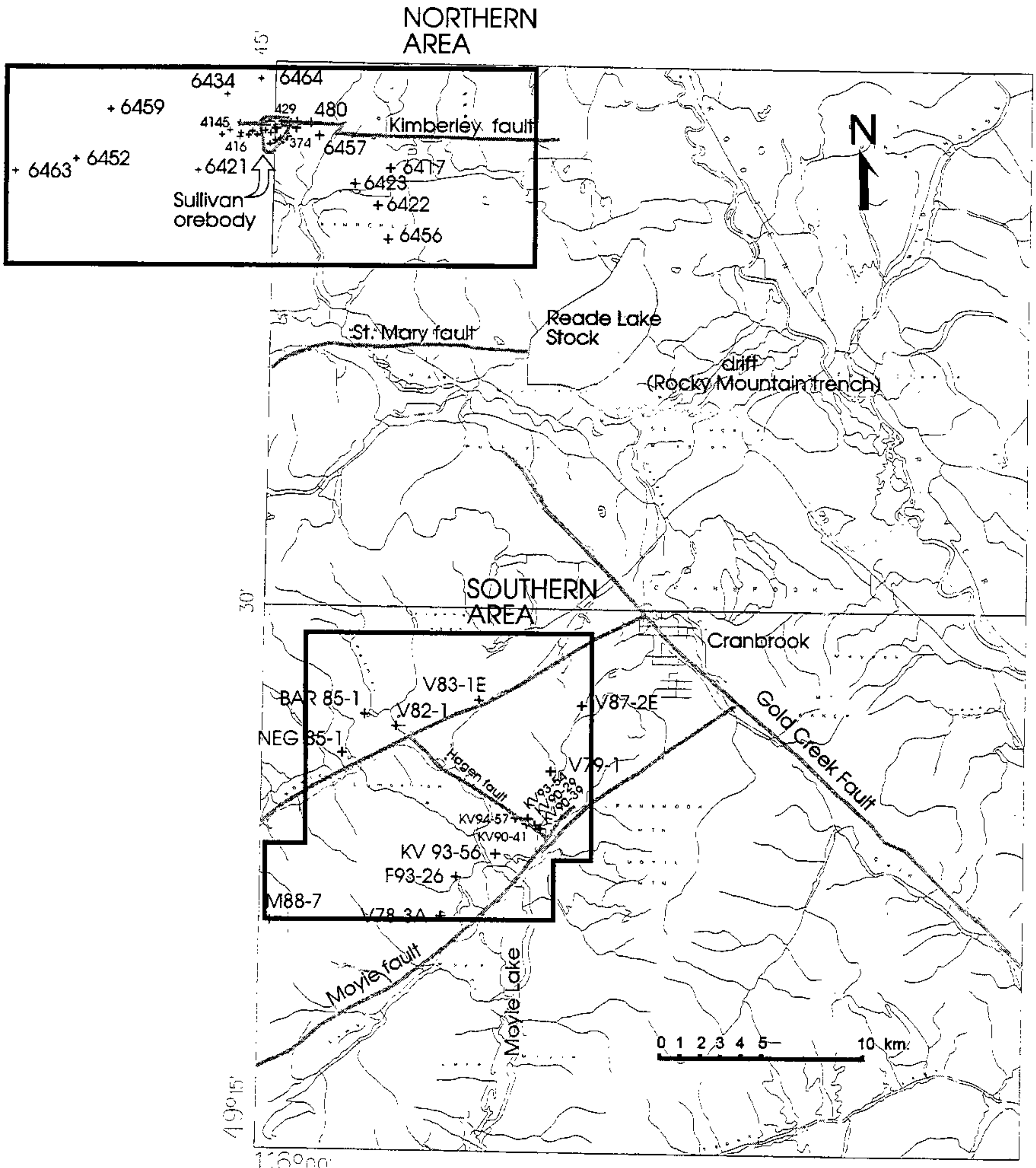

Figure 1. Location of data

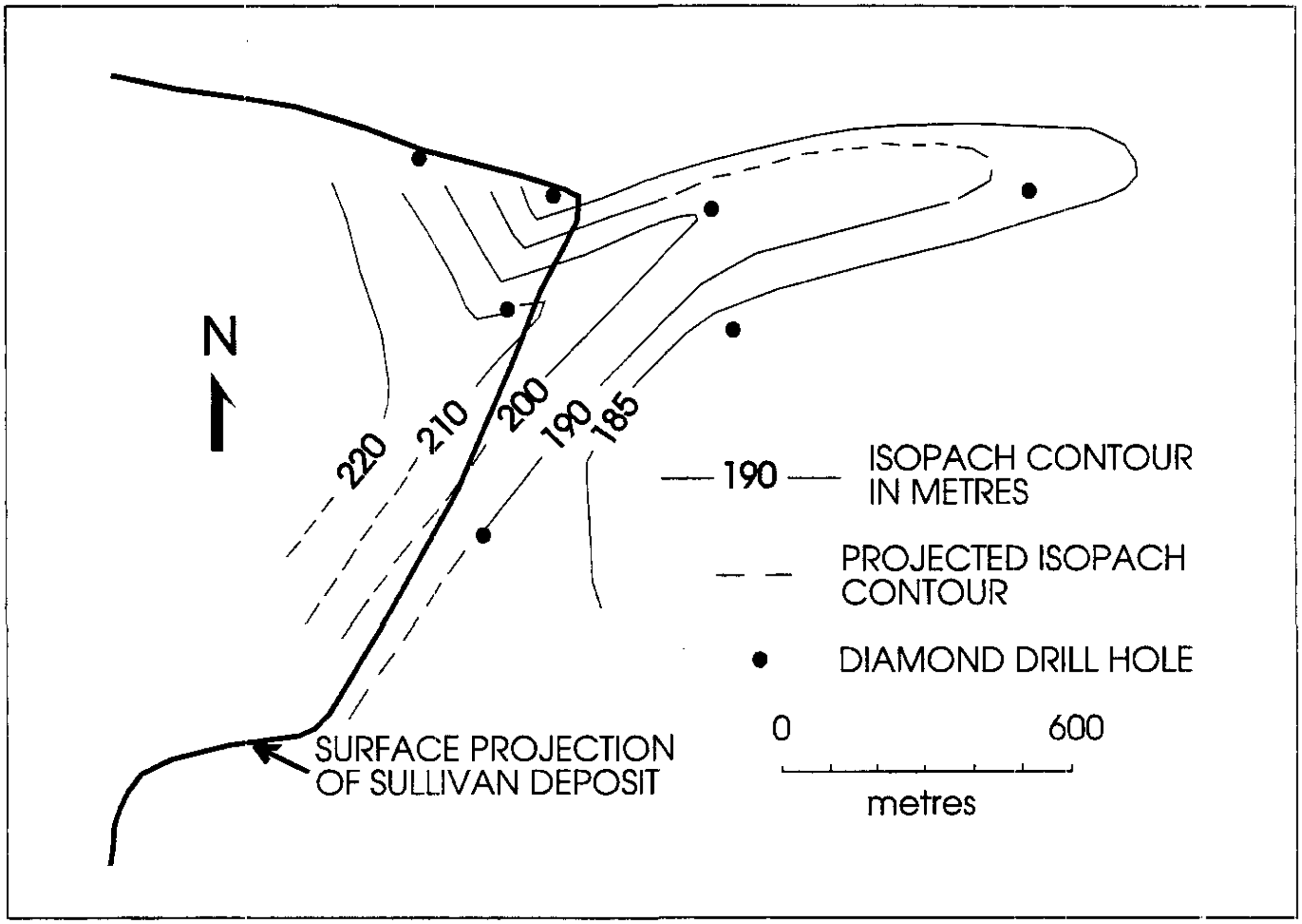

Figure 2. Isopach map of Fringe marker to Sullivan horizon (after Delaney 1983).

These synsedimentary sills are part of the history of subsidence in the Aldridge basin. Höy (personal communication, 1996) suggests they record periods of basin extension, deepening and increased heat flow. Buckley and Sears (1995) give evidence of growth fault development as a result of sill intrusion near Perma, Montana. Such growth faults may be a consequence of differential loading by the dense magma.

The writer sought evidence for changes in the thickness of stratigraphic units at the margins of thick sills where growth faults may occur.

METHODS UTILISED

The writer gathered drill log data from the Vine, Fors, McNeil, Eng, Bar, McNeil, Mt. Mahon properties, as well as Cominco properties extending east and west of the Sullivan mine. The author examined core from the Vine, McNeil and Fors properties, examined a type section at Rabbit Foot Creek with Trygve Höy, and reviewed Cominco exploration reports.

Marker laminite data was collated. The trigonometric formulae found in Ragan (1985) were applied to specific drill hole data. For example holes drilled to intersect the Vine vein were not drilled in a strike-normal direction. The result is an apparent bedding dip in drill core. In these cases, true bedding orientation was sought from geologic maps.

A contouring program - Quikgrid, by W.J. Coulthard (Internet address: w.j.coulthard@ubc.ca) - was used to delineate trends. Due to proprietary interests the data is not complete, ie. marker data is not available.

STRATIGRAPHY

The stratigraphic subdivisions utilised in this study are as follows (Figure 3):

In the Lower Aldridge- Footwall quartzite, Upper Siltstone and Sullivan facies;

In the Middle Aldridge- U quartzite and Fringe marker.

Lower Aldridge

The Lower Aldridge is dominated by rusty wacke which is interbedded with siltstone and quartz wacke.

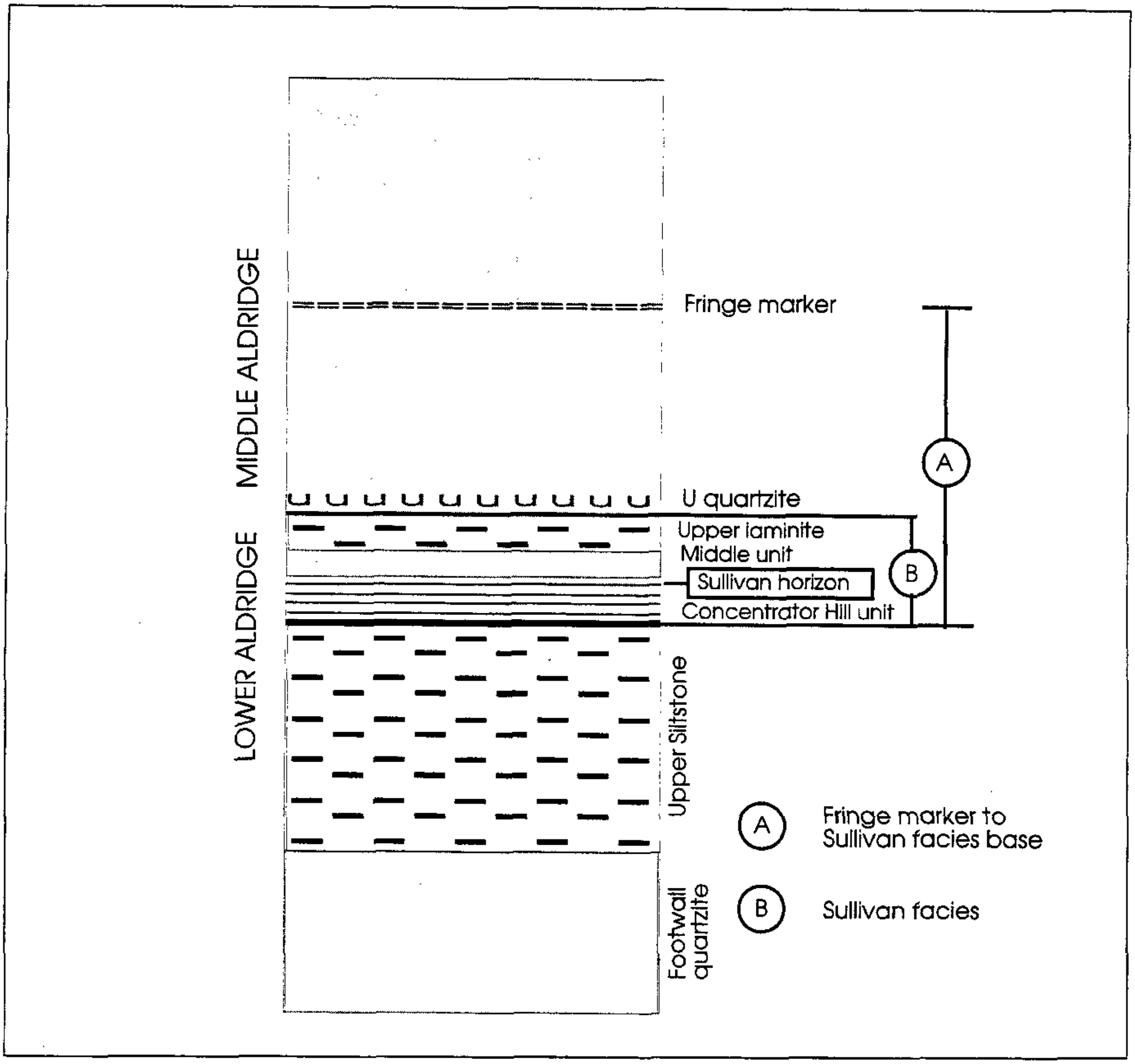

Figure 3. Stratigraphic subdivisions utilised to assess thickness trends in the study area. Not to scale.

The footwall quartzite is similar to the Middle Aldridge, consisting of quartz wacke with thin mudstone tops. Thin quartz laminae separated by pyrrhotite-biotite microlaminae form markers of local extent.

The Upper Siltstone consists of interbedded siltstones and fine grained wacke, subwacke with an occasional quartz wacke bed. The top of the Upper Siltstone is characterised by slates at the footwall of the Sullivan deposit

The Sullivan facies at the top of the Lower Aldridge consists of laminated to non laminated argillite, mudstone, siltstone and wacke. The wacke may be graded. Flat, parallel laminations of pyrrhotite are common. Intervals of slumped sediment are often seen in core as sets of intersecting laminae. The upper contact may be sharp or grade into the U quartzite. In the area of the deposit, the Sullivan facies includes thick turbidite beds, locally derived from slumping, and sulphide bands, intimately associated with argillite.

Middle Aldridge

Beds of quartz wacke and wacke interbedded with siltstone and argillite dominate the Middle Aldridge. Locally the thicker quartz wacke layers have flute or load casts at their bases. The occasional unit is crossbedded, very thick bedded or lenticular. The quartz wackes commonly grade into wacke in the top few centimetres.

The U quartzite is the lowest quartz wacke.

MARKER LAMINITES

Marker beds in the Middle Aldridge are a few centimetres to tens of metres thick and consist of even, parallel, dark and light grey bands of fine-grained sediment from 0.1 to 1.0 cm thick. Each varve-like sequence of light and dark laminae is distinctive for each marker laminite.

The dark laminae are finely micro-laminated but the light bands are massive. The boundaries of the dark and most light laminae are somewhat diffuse but the occasional light laminae has a sharp base.

Petrographically, the dark bands have greater carbonaceous content. Quartz, feldspar, muscovite and biotite grains, about 0.3 mm in diameter, comprise both types of bands.

Marker laminite intervals include non-laminated beds which may comprise the greater proportion of the marker interval. Cominco has shown that these non-laminated beds are distal turbidites. If these beds are subtracted out the marker laminite interval thickens or thins proportionately from place to place. As Huebschmann noted "Over tens of miles, each individual light and dark band varies in thickness proportionally to adjacent bands so that the same sequence remains equally expanded or decreased."

Marker intervals have been matched laminae to laminae for distances to 300 km. These laminae clearly represent time lines that extend across the basin. Occasionally laminae are missing. Fragments of marker laminae are found in turbidite beds, suggesting they were deposited but subsequently eroded by turbidite flow.

The Fringe marker consists of approximately 10 cm of laminated sediment. It is the first significant marker in the Middle Aldridge occuring about 200 metres above the Lower Aldridge contact. The Hiawatha marker, over a metre thick, lies about 250 metres above the Fringe.

Sedimentary Environment

Sedimentary structures indicate that most of the Aldridge Formation represents deposits from turbidity flows. Cominco utilises a submarine fan model to classify the turbidite facies (Delaney, 1983). Aldridge sediments lie on proximal, medial or distal parts of the submarine fan. The lower Aldridge shows characteristics of more distal turbidites while the middle Aldridge is dominated by a mid fan facies. The finer, often laminated mica rich mudstones and argillites of the Aldridge probably represent hemipelagic mud deposited from suspension between pulses of turbidites.

The origin of the marker laminites is uncertain but the carbon content of the dark laminae suggests a biochemical control on sedimentation. Heubschmann (1973) and Turner *et al.* (1992) suggest the light laminae have an eolian component while Cressman (1989) thought suspension of fines contributed by rivers was an adequate explanation of their origin.

THICKNESS TRENDS

The distribution of drill holes studied is shown in Figure 1. Drill holes west of the Sullivan mine are not shown but are listed in the stratigraphic table.

Drill holes are concentrated in two areas, the Kimberley area in the north and the Vine, Neg, Bar, McNeil property area in the south. The intervening area exposes stratigraphy that is either older or much younger. The southern area is also displaced westward based on the known movement of the St. Mary fault.

Trends in the northern and southern areas are described separately.

Sullivan Horizon

In the Sullivan mine area thickness in exploration reports are given in relation to the Sullivan horizon. The Sullivan horizon appears to be the top of the D sulfide band or base of I quartzite on Cominco's ideal geologic column, (Hamilton *et al.*, 1982 and Figure 3). The position of the datum is surmised from notes of Delaney (1983) and the 1977 exploration report of Cominco. Sullivan horizon has also been used on occasion to refer to the entire stratigraphic interval of the Sullivan facies (Hagen and Ransom, 1986). As defined here the Sullivan horizon is a specific stratigraphic position within the Sullivan facies. As a datum the Sullivan horizon is useful only in the immediate area of the deposit where the sulphide sheet or the equivalent CHH is present. For thickness trends reported here, references to the Sullivan horizon are recalculated or approximated to the base of the Sullivan facies (Figure 3).

Fringe marker to base of Sullivan facies

NORTHERN AREA

Delaney (1983) isopached the Fringe marker to "Sullivan horizon" on the eastern edge of the orebody (Figure 2). The interval varies from 180 to 220 metres. Delaney stated "although this database is somewhat limited it illustrates that above the eastern fringe of the Sullivan there is an abrupt thickening of sediment which follows an arcuate trend coincidental with the margin of the orebody. To the northeast, sediment thickness' taper to define a narrow, eastward shallowing trough. These relationships illustrate that ...... immediately after (sulphide) emplacement, there was a steep sided depression."

The thickness of the sulphide sheet (a to d bands of the Sullivan deposit) needs to be added to calculate a total isopach for the Fringe to Sullivan base interval in the area

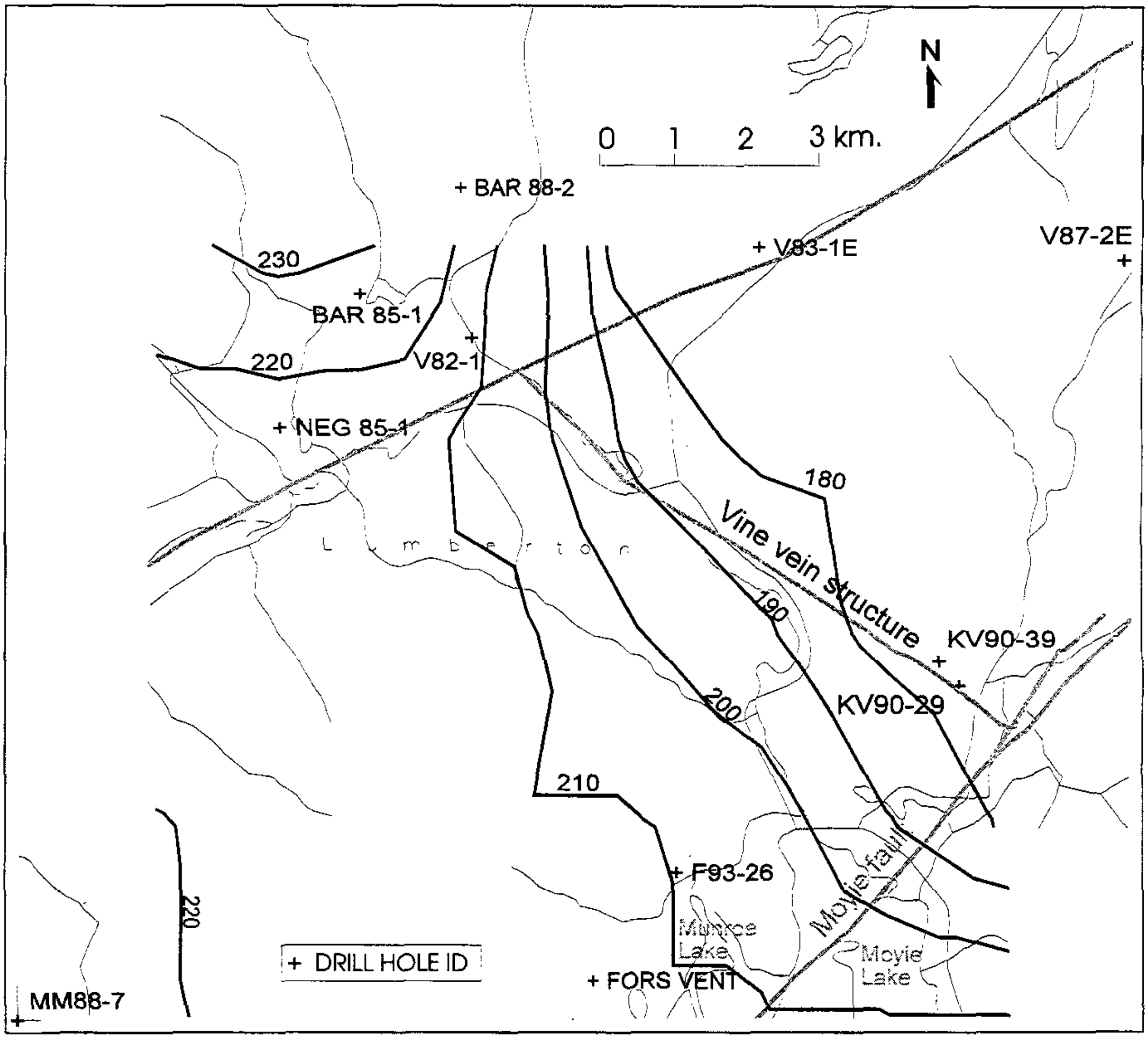

Figure 4. Contour plot of Fringe marker to Sullivan base thickness, southern area. Contour interval is 10 metres.

of the orebody. Outside the ore limit of the deposit, this thickness is insignificant, ranging from 0.5 to 1.5 metres. However, within the eastern part of the orebody the sulphide sheet is reported to vary from 11 to 36 metres thickness (Hamilton *et al.*, 1982). This suggests the interval is 231 to 256 metres thick (220+36 metres). This may increase to over 270 metres in the western part where average thickness of the sulphide sheet is 50 metres. This suggests a considerable down-drop at the very start of sulphide deposition.

Only a few data points are available outside the deposit. Southeast of the deposit thicknesses are about 155 metres. To the north the Fringe to Sullivan interval is not recorded in DDH# 6464, which intersected the faulted northern portion of the orebody. The Fringe to Sullivan base interval is approximately 164 metres northwest of the deposit. This is based on restoring the site of DDH# 6434 to its original location, immediately northwest of the orebody. The restoration is based on the 3.5 kilometres of horizontal component of movement on the Kimberley fault. This amount of movement is based on the relationship of the gabbro and granophyre to the sub-basin facies in DDH# 6464. The relationship of the intruding gabbro to bedded sulphides matches that known only in the northwest part of the mine (Ransom 1989).

Data from the Matthew Creek area farther to the west is unavailable.

Unfortunately the stratigraphic interval of interest is eroded in the area of the North Star trend. Along this trend a sedimentary graben is postulated in lower Aldridge time (Turner *et al.*, in preparation).

SOUTH (FIG. 4)

Within a perimeter defined by DDH's #V83-1E, V87-2E, KV90-39, KV93-54 the Fringe to Sullivan base interval occupies a narrow range from 170 to 178 metres. To the southwest the interval is 201 to 238 metres (DDH's #F93-26, V82-1, Neg85-1, Bar85-1). Further to the southwest the interval is approximately 221 metres on the McNeil property (MM 88-7). Though data is sparse an inflection in the thickness trend is suggested in the Vine-Fors area.

This area is characterised by the westward appearance and thickening of sills in the Lower Aldridge, (Cook and Van der Welden; 1995). One sill, over 250 metres thick, is exposed immediately SW of Fors and is traceable westward (Fig. 2 in Britton and Pighin, 1995). The sill is intersected just below the Sullivan unit in DDH# V-78-A some 400 metres southwest of Fors. However the sill was not intersected in two holes to the appropriate depth at the Fors prospect. The sill must cut up or down section, or terminate in this area. The sill is not recognised in drill core on the Vine property to the east but gabbro of unknown thickness is present at a lower stratigraphic interval (ibid).

At Fors there is evidence of a dewatering pipe associated with hydrothermal activity (Britton and Pighin, 1995). The pipe contains up to pebble size clasts of sandstone and siltstone. The writer noted an abundance of bluish grey (hydrothermally altered) mudstone clasts in Fors core (DDH #F93-26). Klewchuk *et al.* (1983) report that several fragmentals, stacked in vertical sequence, extend northwest from the Fors along a minor fault. Banting (1989) describes one of the fragmentals as a conglomerate comprising elongate shaly fragments in an argillaceous matrix. A stratabound "homogenised" quartz wacke is thickest near this fault. The Fors dewatering vent may thus be related to an early northwest trending zone of weakness. The zone of weakness may in turn be related to differential subsidence along a northwest trend.

Lithologically, the Fringe to Sullivan interval is sporadically calcareous; the carbonate distribution is irregular from hole to hole.

Sullivan unit (sub-basin facies)

NORTHERN AREA

A threefold lithologic subdivision is recognised in the Sullivan facies east of the Sullivan deposit (1985 Sullivan Exploration Annual Report). The basal unit is known as the Concentrator Hill horizon (CHH). The middle unit consists of turbidites that are described as beds of quartz wacke, sandy wacke and calcareous wacke. The upper unit is described as the "upper laminite" but includes graded beds of siltstone. It extends to the base of the U quartzite.

The Sullivan facies is about 15 metres thick near Concentrator Hill, 5.5 kilometres southeast of Sullivan and thickens northwest toward the orebody. At the orebody it varies from about 50 to over 100 metres thick.

The CHH correlates with the pyrrhotite fringe of the orebody. The base of the CHH is equivalent to the footwall slates (Paul Ransom personal communication, 1995). The equivalent top is uncertain. According to Ransom, markers in CHH are split in the ore-bearing sequence and the top of CHH may be as high as the HU ore. The CHH has a geochemical signature that is similar to the waste bands of the A to D ore interval (Ransom, 1988). The CHH can be considered, at a minimum, to be the equivalent of the main stratabound ore at Sullivan (bands A to E). The top of this interval is the Sullivan "horizon" previously mentioned. The CHH thus thickens from a few metres at Concentrator Hill to as much as 36 metres at the ore zone in the eastern part of the orebody (Hamilton *et al.*, 1982).

A comparison of drillhole logs (1977 Cominco Exploration report) suggests the CHH thins dramatically southwest of the orebody (DDH# 6421) and may not be present in the Matthew Creek area to the west. Here the middle unit is not developed either, and the Sullivan facies may be represented by the "upper laminite" alone. CHH is present north and west of the Kimberley fault (DDH# 6464) where 30 cm of sulphides were intersected. Interestingly, the thickness of the Sullivan unit (U-quartzite to Sullivan base) is recorded as 100 metres by Ransom (1988). This suggests that the basin continues northward though it is lacking in sulphides. The Sullivan facies immediately to the northwest of the orebody (in DDH# 6434) is much reduced in thickness.

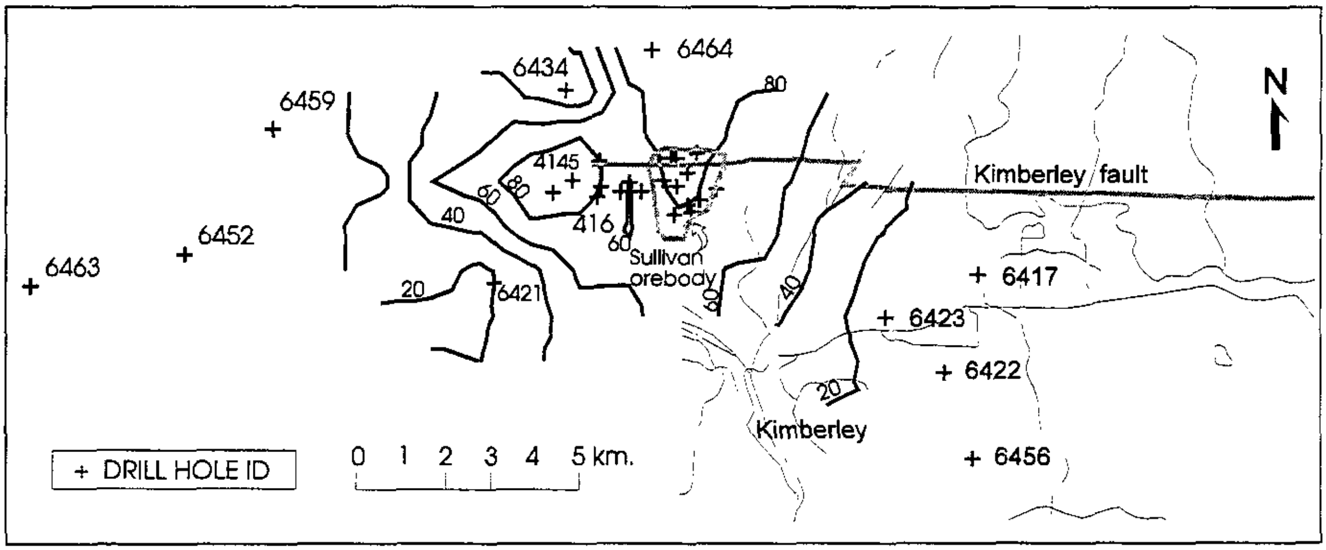

Figure 5. Contour plot of Sullivan facies, northern area. Contour interval is 20 metres. Data compiled from assessment reports, cross sections and sulphide isopachs. Data is incomplete immediately east of the orebody.

There is data from immediately west of the orebody. from a stratigraphic drill plan titled Exploration Drilling Surface Holes. The plan indicates thickening of the interval U quartzite to Sullivan horizon. The writer has simply used a ruler to measure the interval and incorporated it into the database utilised for a contour plot. It is assumed that the thickness of the CHH or sulphide sheet is negligible in this area.

In the area of the mine, orebody cross-sections (eg. latitude 11600 north in Hamilton, 1982) indicate 60 metres between the U quartzite and the top of the sulphide sheet. Sulphide isopachs are added to this 60 metres to estimate the thickness of the Sullivan unit in the central region of the deposit where the U quartzite is not shown (ibid). The result of the compilation is shown in Figure 5. It suggests a second depression west of Sullivan bordered by thinned strata to the north (relocated hole # 6434). These areas of thickening correspond to a north-widening zone of stratabound and cross-cutting breccias and conglomerates along the North Star corridor. Interestingly fragmentals were not intersected in hole# 6434.

SOUTHERN AREA

The trend surface map (Fig. 6) shows variations in the thickness of the Sullivan facies. In the Fors area, the Sullivan facies is obscured by alteration at the contact with a sill. Hence the thicknesses of 7.6 metres at F93-26 and V78-3A are tentative. There are two areas of greater sediment accumulation named here basins area 1 and 2. They are separated by an arch of thinned strata.

Basin area 1

In this area, the Sullivan facies ranges from 11.8 to 21 metres in thickness.

In the area of the Vine vein the Sullivan facies is 11.8 to 16.4 metres thick and consists of laminated and microlaminated silty argillite and argillite. Rock geochemical plots suggest an anomalous interval , 1 to 2 metres thick, is present a few metres above the base of the Sullivan facies in the Vine vein area.

Höy and Pighin (1995) note that the Sullivan facies is thicker to the west and east. In DDH# V79-1, 19.4 metres is present, characterised by a pyrrhotite laminated zone with a slump feature at its base and subwacke interbeds at the top. To the southwest, in KV93-56, the facies is interpreted to be 21 metres thick.

The thinner values over the Vine structure suggested to Höy and Pighin that a seafloor high existed in this area flanked by shallow basins. The regional contour plot supports this. They also suggests a depression parallel to the Moyie fault based on 50 metres of fragmentals at the Sullivan "horizon" in the Munroe Lake area. Additional details of this data would assist in defining trends in basin area 1 and help relate them to geochemical trends.

Basin area 2

Basin area 2 has few data points but the Sullivan unit has a wide range of interpreted thicknesses (17.6 to 47 m.). Some thickening is expected toward the basin axis, but the thickness in hole Bar 85-1 seems anomalous.

In hole V-82-1 the Sullivan facies interval consists of 17.6 metres of massive to laminated wacke with evidence of slumping at the top. In Neg N85-1 it consists of 24.3

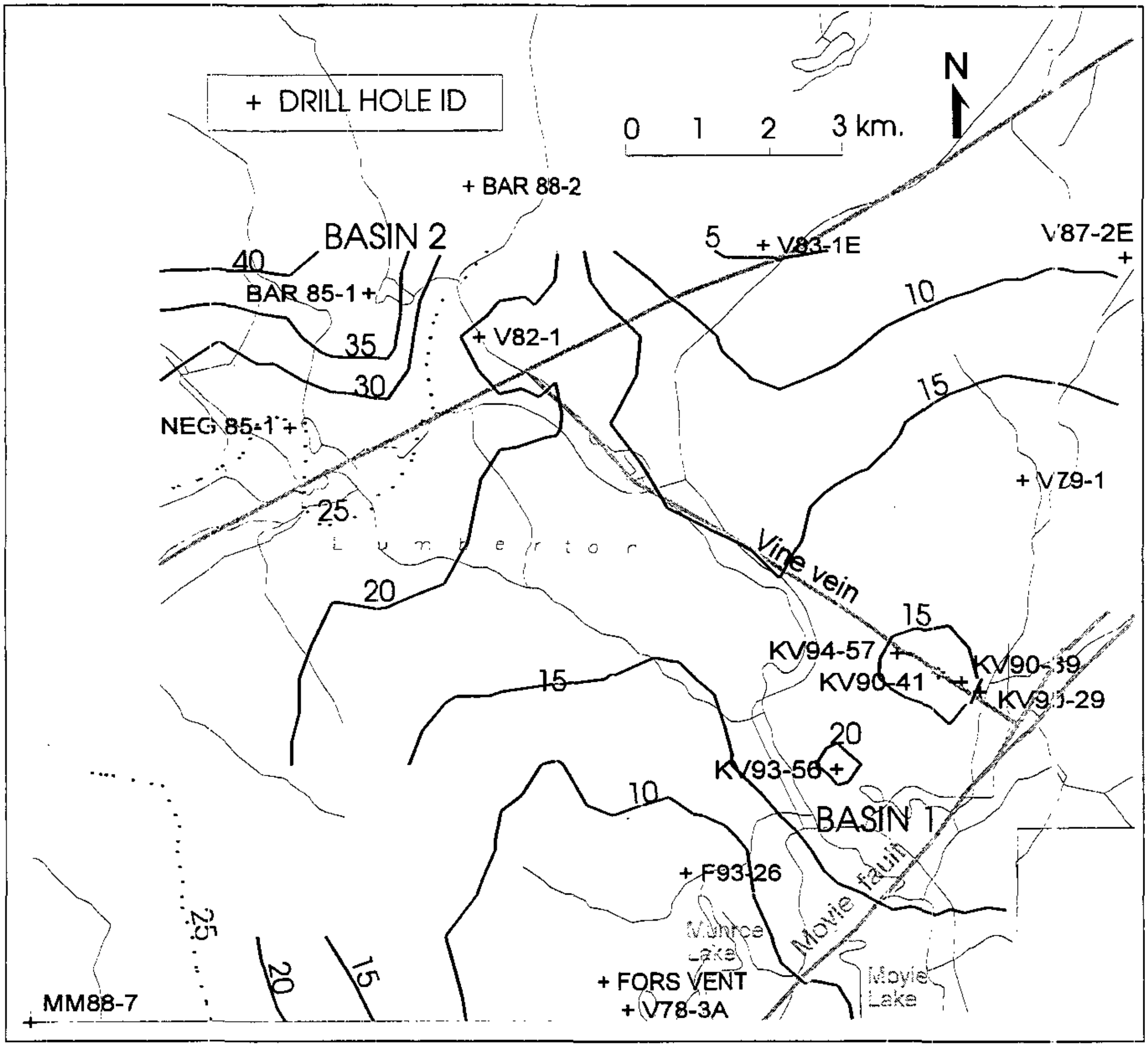

Figure 6. Contour plot of Sullivan facies thickness, southern area. Contour interval is 5 metres.

metres of wacke that is thin to medium bedded, flat lying and very finely laminated throughout with pyrrhotite.

In McNeil drillhole# MM 88-7 the Sullivan facies is thick (about 25.3 metres). Massive altered siltstone grades into pyrrhotite laminated silty argillite. This is overlain by an interval of interbedded matrix-supported fragmental and laminated sediment. In the interbeds, clasts are rounded and indistinct, some have pyrrhotite rims and internal laminations (slump unit). Overlying siltstone is abruptly overlain by quartzite.

In hole Bar 85-1, 42.6 metres of Sullivan facies rocks with thin interbeds of intraformational conglomerate are underlain by 20 metres of conglomerate consisting of subangular to rounded clasts of mudstone(blue-grey), siltstone and sulphides in a matrix of siltstone and fine sandstone. The percentage of clasts decreases upward. Laminations (to 0.5 cm) of pyrrhotite are common on the top of the conglomerate (CHH equivalent?). The conglomeratic interval is probably a product of sediment extrusion, given the rounded nature of the locally derived clasts.

UPPER SILTSTONE

The Upper Siltstone is a distal turbidite facies lying between more proximal turbidites represented by the Footwall quartzite and the Middle Aldridge. The Sullivan facies, though treated as a separate sequence is essentially a period of low sedimentation at the very end of distal turbidite (i.e. Upper Siltstone) deposition in this part of the Aldridge basin.

In the north, data is lacking regarding westward changes in the thickness of the Upper Siltstone unit. The Upper Siltstone appears to be thick below the Sullivan orebody (drillhole# 6793) but thinner just to the east in drillhole #6423 (195 versus 168 metres). More data would be required from the area west of the orebody to define thickness trends.

In the south in the Vine and Neg area, the Upper Siltstone facies appears to be more calcareous in the east (drillhole V-83-1e, V-87-2e) and siliceous in the west (Neg 85-1). The proportion of quartz wacke to wacke increases toward the west. The unit is thinner than it is in the vicinity of Sullivan mine.

On the Vine property, the facies consists of purple-grey (biotitic) to brownish siltstone and minor fine grained feldspathic arenite. It is weakly calcareous and predominantly thin to medium bedded.

On the McNeil property, the siltstone facies is often silicified. Two intervals of maroon quartzite are present in drillhole MM 88-7.

The Upper Siltstone facies thus becomes more quartzitic to the south and west. This probably indicates a lateral facies change from wacke to quartz wacke. Further to the southwest quartz-rich sediments of a major turbidite fan are present (Rampart facies, see Brown and Stinson, 1995).

FORS-VINE EXPLORATION PLAY

The isopach trend for the Fringe to Sullivan interval in Fig. 4 suggests a northwest trend. Along this trend to the north a sill is present near the stratigraphic position of the Hiawatha marker. This sill is crosscutting and varies from 160 to over 200 metres in thickness. Its base is 490 metres above middle Aldridge contact in drillhole Neg 85-1 and 400 metres above the contact in Bar 85-1. In Bar 88-2 the top of the same sill is intersected about 90 metres below the middle Aldridge. It appears to be downcutting to the southeast and it is not found in drillhole V82-1 which penetrated 97 metres of Lower Aldridge. The relationship of this sill to the one at Fors is not known as they are in different fault blocks. However both show a change in geometry possibly related to exploitation of early fault structures. Both are on the general trend of thickening of the Fringe to Sullivan base interval.

Leask (1988) noted stratigraphic thickening in Bar 88-2 relative to Bar 85-1 based on a marker above Hiawatha time. There is considerable hydrothermal carbonate alteration in Bar 88-2. Carbonate and tourmaline alteration extends above the Hiawatha marker. Edmunds (in Leask, 1988) thought the drillhole was close to a boron source. Further work was not done in the area because the Sullivan horizon is too deep. However, the area is prospective for a Fors type vent at a higher stratigraphic position.

CONCLUSIONS AND SUMMARY

Sedex deposits occur in structural sub-basins within a host extensional basin. Abrupt facies changes and thickness changes define structural boundaries of sub-basins. When a sub-basin develops away from the edge of the main basin large scale depositional processes such as axial turbidite fans mask recognition of the sub-basin. In this regard thickness isopachs become relevant in defining the margins of second order basins.

In the study area variations in the thickness of the Fringe marker to Sullivan base interval suggest differential subsidence and original structural boundaries. The best example of this is the linear depression that extends east from the Sullivan deposit (Delaney 1983).

This study suggests there is differential subsidence outside the Sullivan deposit, albeit of a gentler gradient. For example, differential subsidence is indicated southwest of the Vine vein toward the Fors property. The Fors vent is also along a linear trend of fluidisation that is parallel to the thickness isopachs. A similar vent may be present in the Vine and Bar area to the northwest along this trend.

More data is required to authenticate isopach trends, and to relate these to sill intrusion.

Isopachs of the Sullivan facies suggest a basin extension north of the mine and another basin to the west. The northern extension corresponds to the discovered northern fringe of the orebody across the Kimberley fault. The western area corresponds to the north star trend.

In the southern part of the study area, the Sullivan facies appears to be thick near Bar 85-1.

The equivalent of the CHH (Concentrator Hill Horizon) may be present near the southern end of the Vine vein. Some potential for a thickened Sullivan facies exists toward the Moyie fault.

ACKNOWLEDGEMENTS

The author wishes to thank Trygve Höy for suggesting the study and Bill McMillan for his support. Various exploration personnel, including Doug Anderson, Paul Ransom of Cominco, Dave Pighin of Consolidated Ramrod Gold Corporation, and Mike Bapty of Bapty Research freely gave of their time. The manuscript benefitted from review and editing comments by Bill McMillan, Derek Brown, Trygve Höy and Neil Church.

TABLE 1. STRATIGRAPHIC DATA

Note values for locations Sulliso 1 -10 reconstructed from sulphide isopach data. Values for holes 976, 4145, 5487, 5451, 423, 4142, 416 obtained from cross-sections.

DRILL HOLE ID	UTM ZONE	UTM NORTH	UTM EAST	FRINGE	SUL_TOP	SUL_BASE	SUL_THIC	FRINGE-SUL_BASE
6464	11	5510100.00	567700.00	0.0	0.0	0.0	100.0	0.0
6434	11	5509250.00	566050.00	0.0	0.0	0.0	18.1	170.0
6459	11	5508600.00	563810.00	0.0	594.4	607.7	13.0	0.0
SULLISO1	11	5508140.00	572280.00	0.0	0.0	0.0	90.0	0.0
429	11	5508060.00	572500.00	0.0	0.0	0.0	0.0	202.0
478	11	5508000.00	573100.00	0.0	0.0	0.0	0.0	199.0
480	11	5508000.00	573740.00	0.0	0.0	0.0	0.0	187.0
3303	11	5508000.00	572740.00	0.0	0.0	0.0	0.0	183.0
SULLISO2	11	5508000.00	571660.00	0.0	0.0	0.0	72.0	0.0
SULLISO3	11	5508000.00	571740.00	0.0	0.0	0.0	90.0	0.0
420	11	5507920.00	570240.00	0.0	0.0	0.0	98.0	0.0
6414/468	11	5507780.00	572700.00	0.0	0.0	0.0	0.0	210.0
3660	11	5507680.00	573070.00	0.0	0.0	0.0	0.0	183.0
976	11	5507520.00	570860.00	0.0	0.0	0.0	61.0	0.0
SULLISO4	11	5507500.00	571500.00	0.0	0.0	0.0	72.0	0.0
4145	11	5507500.00	569700.00	0.0	0.0	0.0	98.0	0.0
SULLISO5	11	5507420.00	571700.00	0.0	0.0	0.0	90.0	0.0
5487	11	5507420.00	570360.00	0.0	0.0	0.0	73.0	0.0
6457	11	5507350.00	574200.00	0.0	276.9	0.0	0.0	0.0
SULLISO6	11	5507340.00	572660.00	0.0	0.0	0.0	72.0	0.0
5451	11	5507320.00	571000.00	0.0	0.0	0.0	37.0	0.0
374	11	5507300.00	572620.00	0.0	0.0	0.0	0.0	190.0
423	11	5507280.00	570680.00	0.0	0.0	0.0	61.0	0.0
4142	11	5507260.00	569320.00	0.0	0.0	0.0	104.0	0.0
416	11	5507240.00	570260.00	0.0	0.0	0.0	61.0	0.0
SULLISO7	11	5507140.00	572260.00	0.0	0.0	0.0	90.0	0.0
SULLISO8	11	5507000.00	572040.00	0.0	0.0	0.0	90.0	0.0
SULLISO9	11	5506840.00	571720.00	0.0	0.0	0.0	72.0	0.0
SULLISO10	11	5506840.00	572040.00	0.0	0.0	0.0	72.0	0.0
6452	11	5506020.00	562100.00	0.0	146.4	161.7	15.0	0.0
6417	11	5505800.00	577650.00	0.0	0.0	0.0	14.0	154.1
6421	11	5505450.00	568100.00	0.0	0.0	0.0	15.3	185.3
6463	11	5505400.00	559050.00	0.0	275.4	283.8	8.2	0.0
6423	11	5504900.00	575950.00	0.0	73.3	86.4	12.5	0.0
6422	11	5503850.00	577100.00	397.3	540.3	557.5	17.3	155.7
6456	11	5502150.00	577650.00	409.0	531.3	546.6	15.4	0.0
V83-1E	11	5478600.00	582750.00	0.0	1116.7	1121.4	4.7	169.7
V87-2E	11	5478550.00	587650.00	737.5	906.5	916.3	9.5	175.9
BAR 85-1	11	5477800.00	577400.00	0.0	1435.0	1482.0	42.6	237.6
V-82-1	11	5477200.00	578900.00	0.0	855.9	873.5	17.3	201.3
NEG-85-1	11	5475800.00	576350.00	741.0	933.8	958.5	24.3	214.2
V-79-1	11	5475150.00	586350.00	0.0	458.0	474.0	16.0	0.0
KV 94-57	11	5472680.00	584720.00	0.0	391.0	408.0	14.6	0.0
KV 93-54	11	5472650.00	585300.00	233.6	405.7	420.3	14.0	177.6
KV 90-41	11	5472400.00	585300.00	0.0	0.0	0.0	11.8	0.0
KV 90-39	11	5472300.00	585600.00	184.2	362.0	378.2	16.3	171.0
KV 90-29	11	5472200.00	585900.00	0.0	0.0	0.0	16.4	0.0
KV 93-56	11	5470841.00	583783.00	0.0	1075.7	1100.0	21.0	0.0
F93-26	11	5469550.00	581850.00	463.3	669.6	677.2	7.5	210.7
V 78-3A	11	5467500.00	581150.00	0.0	191.0	198.7	7.5	0.0
MM 88-7	11	5467100.00	573050.00	612.6	810.0	835.7	25.3	220.6
MM 84-1	11	5439500.00	574050.00	0.0	385.9	402.3	0.0	164.0
E 90-3	11	5437400.00	566550.00	75.9	249.0	256.0	6.8	174.0

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HARPER CREEK: A VOLCANOGENIC SULPHIDE DEPOSIT WITHIN THE EAGLE BAY ASSEMBLAGE, KOOTENAY TERRANE, SOUTHERN BRITISH COLUMBIA (82M/12)

Trygve Höy

KEYWORDS: Volcanogenic disseminated sulphide deposit, volcanogenic massive sulphide deposit, Devonian, Kootenay Terrane.

INTRODUCTION

Harper Creek is a volcanogenic sulphide deposit within highly deformed Late Devonian metavolcanic rocks of the Eagle Bay Assemblage (Figure 1). As well as disseminated chalcopyrite, it includes a number of massive to semimassive magnetite-sulphide or sulphide layers.

The deposit is located near the headwaters of Harper Creek, 10 km southwest of Vavenby and approximately 100 kilometres north of Kamloops in south-central British Columbia. The area is in heavily wooded mountainous terrain within the Shuswap Highlands, at elevations ranging from approximately 1400 to 1700 metres (Plates 1 and 2). Overburden in the immediate deposit area is extensive and exposures are mainly restricted to trenches and logging or exploration road cuts. A large part of the deposit area has been recently logged.

Access to the property is provided by the Lost Creek road south from Vavenby, then the Jones Creek (11.1 km) and Barriere Lake (2 km) logging roads.

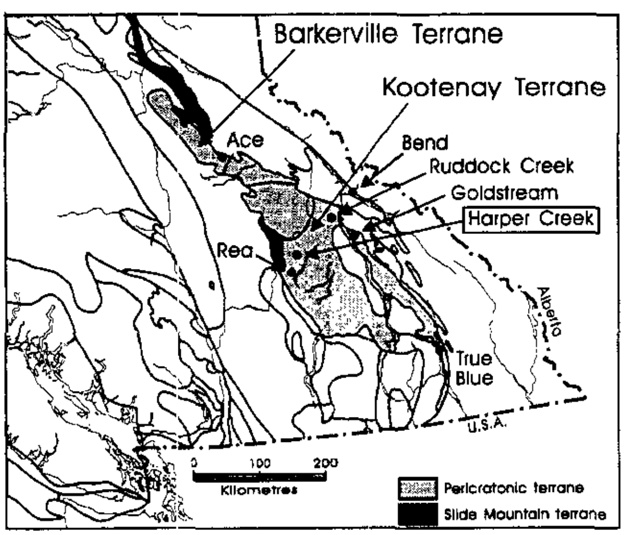


Figure 1: Terrane map showing location of selected massive sulphide deposits in the Kootenay terrane, southern British Columbia.

This paper is part of a regional study of massive sulphide deposits and mineral potential of the Kootenay Terrane of southern British Columbia and the correlative Yukon-Tanana Terrane in the northern part of the province and Yukon Territory. It summarizes four days of detailed trench and road mapping in late September, 1996; results of exploration drilling, just commenced, are not included.

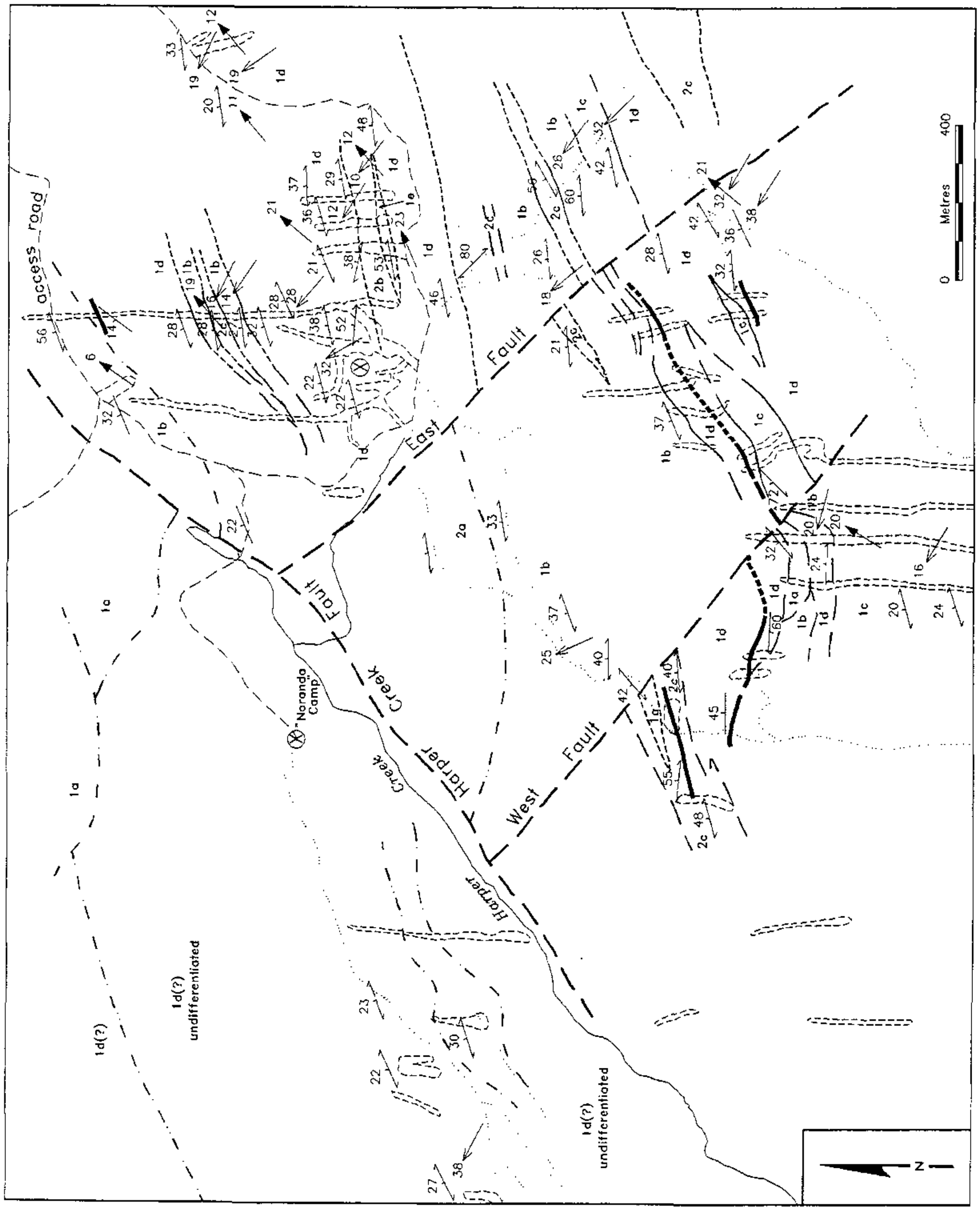
EXPLORATION HISTORY

Noranda Exploration Company Ltd. staked the Sue and Goof claims in 1966 as a result of a reconnaissance geochemical survey, followed immediately by staking of the Hail claims to the east and south by Quebec Cartier Mining Company. Exploration of the two properties was carried out independently until 1970, followed by a joint venture under Noranda's supervision. This exploration included soil geochemistry, geophysical surveys, trenching, geological mapping, and more than 25 800 m of diamond drilling in 163 drill holes. Two adjacent mineralized zones were defined, the East Zone on Quebec Cartier property and the West Zone on the Noranda property (Figure 2) with combined reserves of 85.5 m tonnes containing 0.388 percent copper (Kraft, 1974).

Based in part on recognition of volcanogenic massive sulphide potential and precious metal content, Aurun Mines Ltd. acquired the Hail claims in 1986 and continued trenching, geological mapping and sampling. Phillips Barratt Kaiser Engineering Ltd., in a pre-feasibility study, calculated total "mineable reserves of 65.3 million tonnes grading 0.36 percent copper, 0.040 g/tonne gold and 2.2 g/tonne silver". The Noranda and Quebec Cartier properties, collectively referred to as the Harper Creek deposit, have been inactive until work this past fall by American Comstock Explorations Ltd. of Vancouver.

Initial work proposed by American Comstock includes a UTEM geophysical survey, base line environmental studies, metallurgical studies and diamond drilling. Diamond drilling commenced in late September, 1996 to determine the northeastern extent and grade of mineralization.

Figure 2: Geological map of the Harper Creek deposit.



REGIONAL GEOLOGY

The Eagle Bay Assemblage is within the Kootenay terrane, a succession of variably metamorphosed and deformed clastic sediments, subordinate volcanics and limestones that range in age from Proterozoic to Triassic. Lower Paleozoic rocks of the terrane appear to be in stratigraphic contact with North American rocks (Fyles and Eastwood, 1962; Colpron and Price, 1992; 1995). Mafic volcanic rocks of the Slide Mountain terrane occur as fault-bounded slices along the western edge of the Kootenay terrane; they are interpreted to record remnants of a Mississippian-Permian marginal basin or ocean (Nelson, 1993). To the west are dominantly volcanic arc rocks of the Quesnell terrane.

The Eagle Bay Assemblage comprises Lower Cambrian to Mississippian metasedimentary and metavolcanic rocks that are intruded by Late Devonian orthogneiss (Schiarizza and Preto, 1987). Okulitch (1977) correlated the assemblage with the Lardeau Group of the Kootenay arc, essentially confirmed by discovery of archeocyathid fossils just northwest of Vavenby within the Lower Cambrian Tshinakin limestone (Schiarizza and Preto, *op.cit.*); Struik (1986) correlated the Eagle Bay with rocks of the Barkerville terrane in the Cariboo Mountains.

Paleozoic rocks of the Eagle Bay assemblage are contained within four west directed thrust slices that collectively contain a succession of Cambrian (and possibly Late Proterozoic) quartzites, grits and quartz mica schists (Units EBH and EBQ), mafic metavolcanic rocks and limestone (EBG), and overlying schistose sandstones and grits (EBS) with minor calcareous and mafic volcanic units. These are overlain by a "...Devono-Mississippian succession of mafic to intermediate metavolcanic rocks (Units EBA and EBF) intercalated with and overlain by dark grey phyllite, sandstone and grit (EBP)" (Schiarizza and Preto, 1987). Unit EBA hosts many of the sulphide occurrences in the Eagle Bay assemblage, including the Harper Creek deposit (Schiarizza, 1986a; 1986b; Schiarizza and Preto, *op. cit.*).

Unit EBA comprises dominantly light grey to pale green sericite-quartz phyllite, less chlorite phyllite and up to 10 percent metasedimentary intervals of dark grey phyllite, siltstone and limestone. In the Vavenby area, it thins to the east, from several hundred to several tens of metres. Just south of the Harper Creek deposit, Unit EBA is structurally underlain by greenstones, chloritic phyllites, quartzitic units and orthogneiss of EBG, and north of the deposit, by dominantly metasedimentary rocks of EBP (Schiarizza, 1986a; Schiarizza and Preto, *op. cit.*).

LEGEND

Contact (after Belik, 1973)	-·-·-·-·-	Early foliation; schistosity	20
Geological Contact	——, — —, ·······	Bedding	14
Fault (inferred)	— — — — —	L1 (mineral) lineation	→
Trench		L2 crenulation lineation	→
Exposure			
Sulphide – magnetite lens	——, — —, ·······	Road, 4-wheel drive	- - - - - - - -
		cat trail	··········

Devonian – Eagle Bay Formation (Eba)

Sulphide layers

- 3b massive magnetite, pyrite, pyrrhotite, chalcopyrite
- 3a massive to semimassive pyrite, minor chalcopyrite

Metasedimentary units (minor metavolcanic)

- 2c carbonaceous phyllite, calcareous phyllite, minor dolomite, grey limestone
- 2b grey, pale green or tan sericite phyllite, quartzitic phyllite
- 2a quartzite, sericitic quarzite; minor sericitic and chloritic phyllite

Metavolcanic units (minor metasedimentary)

- 1e quartz–eye phyllite, schist; quartz–sericite phyllite
- 1d quartz–sericite phyllite, minor schist; tan to silver grey; minor chloritic phyllite
- 1c sericite phyllite; chlorite–sericite phyllite; minor quartz–sericite phyllite
- 1b chlorite phyllite; chlorite–sericite phyllite; minor quartz–sericite phyllite
- 1a greenstone; foliated, locally fragmental; chlorite phyllite

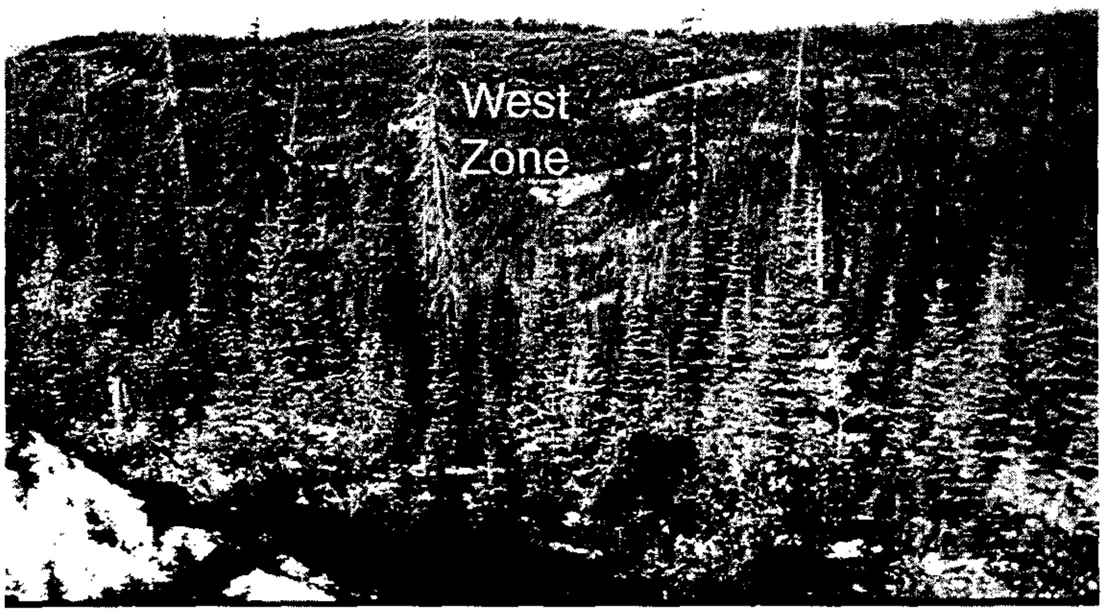


Photo 1: View looking northwest towards the West Zone of the Harper Creek Deposit.

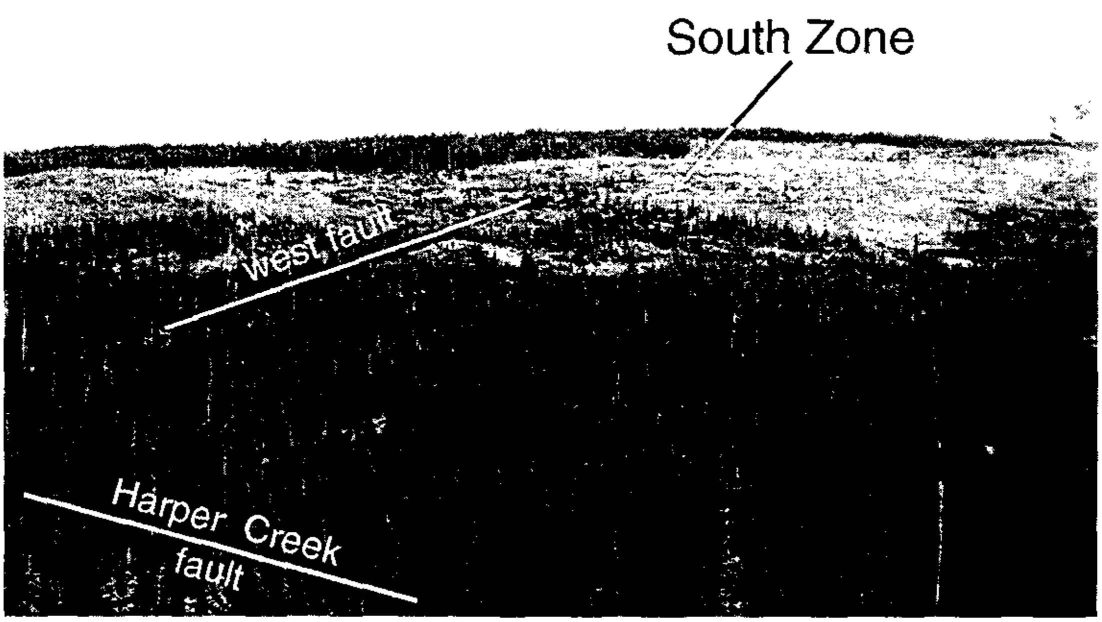


Photo 2: View looking southeast towards the South Zone of the Harper Creek Deposit.

HARPER CREEK DEPOSIT

INTRODUCTION

The geology of the Harper Creek deposit has been studied by Preto (1971) and Belik (1973) and described in a number of company assessment reports (Lammle, 1986; 1987; Phillips Barratt Kaiser Engineering Ltd., 1988) . This report draws considerably from these previous works.

STRATIGRAPHY

The area has undergone intense deformation, with development of a penetrative foliation that largely masks bedding. Units, including the massive sulphide layers, are not repeated and all recognized bedding/cleavage intersections indicate that the north-facing stratigraphic succession is on the upper limb of a tight anticlinal structure that closes to the south. Hence, it is interpreted that the structurally lowest units in the south are also the oldest.

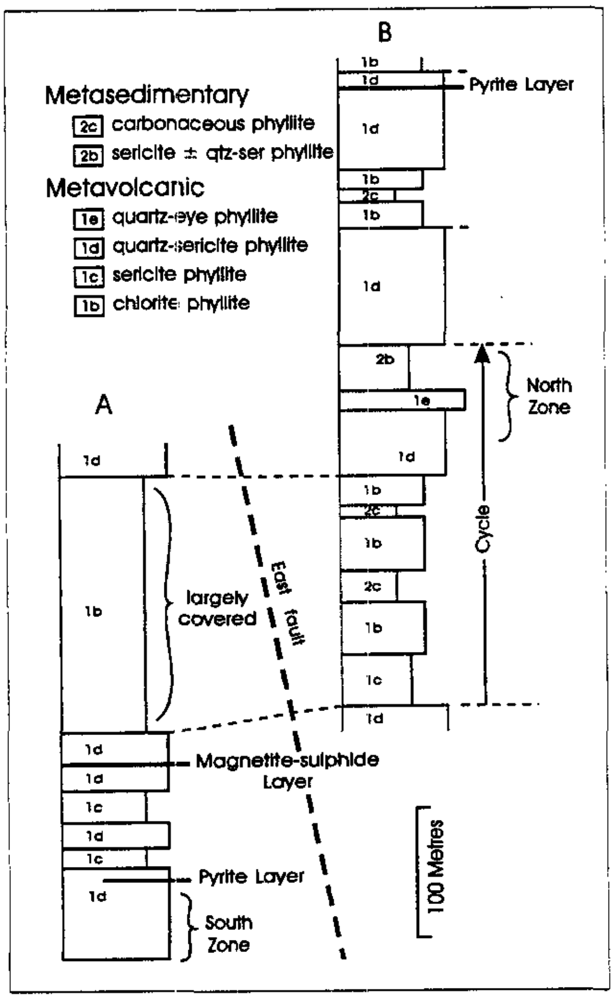


Figure 3. Schematic sections of Unit EBA, Harper Creek: (A) west of the East fault; (B) east of the East fault.

Units are divided into either dominantly metavolcanic or metasedimentary rocks. However, intense alteration, particularly sericite development, as well as the penetrative foliation, commonly makes interpretation of the protolith difficult. Figure 3 shows composite sections in the area, and assumes there are no structural repetitions.

METAVOLCANIC UNITS

Unit 1a is foliated, massive to fragmental greenstone, with less chlorite phyllite, that outcrops in the northern part of the area (Belik, 1973) It is medium to dark green, with locally angular to subrounded amphibolite or greenstone fragments up to several centimetres across. The matrix comprises fine-grained, foliated actinolite, clinozoisite, feldspar, chlorite, sphene, carbonate and quartz. Unit 1a is interpreted to be a mafic ash and lapilli tuff (Belik, *op. cit.*).

Unit 1b is dominated by chlorite phyllite, with minor sericite or quartz-sericite phyllite. It occurs throughout the central part of the area (Figure 2) and in thin lenses within quartz-sericite schists of Unit 1d. A number of dark grey, carbonaceous phyllite layers, assumed to be argillaceous intervals, occur within it. The chlorite phyllite consists of foliated chlorite, with variable carbonate, feldspar, quartz, sphene and minor sericite and clinozoisite. Rusty-weathering siderite? typically forms thin discontinuous laminae, and occasionally occurs as disseminated euhedral grains. Disseminated pyrite is common, and intense sericite alteration locally produces soft, pale green coloured exposures. Abundant chlorite and common sphene suggest that the protolith of Unit 1b is a mafic ash tuff.

Unit 1c is a pale green to grey-green sericite phyllite that commonly contains minor amounts of chlorite. It occurs in the southern part of the area, stratigraphically below the magnetite-sulphide layer (Unit 3b). Siderite, as disseminated grains or irregular laminae, is common throughout, and quartz may occur as fine discontinuous segregations. Disseminated and vein sulphides are also locally common, with malachite staining on foliation planes and in cross-fractures. The fine felted nature of the sericite, local abundance of sulphides and variable chlorite and quartz content suggests that sericite of Unit 1c is an alteration mineral related to introduction of potassium. Siderite content, little visible quartz and variable amounts of chlorite suggest that the dominant protolith is a mafic tuff, with perhaps minor intermediate tuffs or sediments. The occurrence of Unit 1c beneath the most prominent sulphide layer further suggests that it may be the highly sheared and foliated remnants of a footwall alteration zone.

Unit 1d is the most abundant and conspicuous unit throughout the map area (Figure 2). It comprises dominantly lustrous, silvery-grey to tan coloured quartz-sericite phyllite, with quartz occurring interstitial to sericite, in thin foliation parallel laminae and as prominent quartz "eyes". Accessory minerals include variable amounts of chlorite, albite and dolomite. Locally it is coarser grained, and is referred to as a quartz-feldspar-sericite schist. It hosts the disseminated chalcopyrite of the northeastern Quebec Cartier showing, and may be the host of two of the sulphide lenses. The protoliths of sericite schists that contain quartz eyes are interpreted to be felsic tuffs. Others, lacking these quartz eyes, may be felsic tuffs or siliceous metasediments.

Unit 1e is a prominent quartz-eye phyllite with abundant elliptical to subrounded quartz eyes up to a centimetre in length. With decreasing size and abundance of quartz eyes it grades into Unit 1d. It may be a more felsic volcanic tuff, with a rhyolitic or dacitic composition.

METASEDIMENTARY UNITS

Quartzites of Unit 2a, interbedded with quartzitic phyllites, occur south and southwest of the Noranda camp. They form white to light green, resistant orthoquartzite, sericite quartzite and albite-sericite quartzite outcrops (Belik, 1973). Belik (*op.cit.*) differentiated a carbonaceous quartzite unit within Unit 2a. Mineralization southwest of the Noranda camp occurs in quartzitic units that have been assigned to 2a, as well as in carbonaceous phyllites and quartz-sericite phyllites. Unit 2a is dominantly a siliceous metasedimentary unit; however, more phyllitic units within it may be felsic to intermediate tuffs.

Unit 2b consists of sericite, quartz-sericite and chlorite-sericite phyllites that appear similar to "intermediate" tuffs of Unit 1c. However, rapid lithological changes in layer stratigraphy, and the common association with carbonaceous phyllites, suggest that they may be metasediments or possibly metamorphosed tuffaceous sediments. They occur interlayered with quartz-eye phyllites stratigraphically above Unit 1e (Figure 2) and as interbeds in units 1b and 1d. These latter occurrences are not differentiated on the map.

Unit 2c includes dark grey to black carbonaceous phyllite, pale grey calcareous phyllite, grey limestone and minor tan dolomite. It occurs as scattered, discontinuous lenses throughout the area, most commonly in chlorite phyllites of Unit 1b. It hosts copper mineralization of the Noranda camp, and a semi-massive pyrite layer, associated with massive dolomite, in a trench on the southern slopes of Harper Creek. Many exposures of Unit 2c contain euhedral phenocrysts of pyrite, locally up to a centimetre across.

DISCUSSION

Stratigraphic sections of Unit EBA in the Harper Creek deposit area are illustrated in Figure 3. Essentially, the succession comprises two sequences of felsic to intermediate tuffs, separated by mafic tuffs and interbedded fine-grained clastic sedimentary units (units 1b and 2c). The massive magnetite-sulphide layer occurs near the top of the stratigraphically lowest felsic unit; the pyritic lens to the northwest (Figure 2), within metasediments that record a hiatus in volcanism prior to onset of deposition of mafic tuffs of Unit 1b.

The overlying succession of mafic tuffs (1b), intermediate to felsic tuffs (1d) and quartz-eye phyllites (1e) may record a volcanic cycle that is capped by metasediments of Unit 2b. Disseminated mineralization near the Quebec Cartier camp occurs at the top of this volcanic succession and in the transition to overlying mixed intermediate and mafic tuffs. The upper pyrite layer in section B (Figure 3) is also near the top of a more felsic volcanic package, overlain by mafic volcanics of Unit 1b.

STRUCTURE

Regional structures of the Vavenby area are described by Schiarizza (1986a). He recognizes two early phases of intense deformation, associated with Jurassic regional metamorphism, and three phases of post-metamorphic folding. The most conspicuous post-metamorphic deformation is east-west trending folds that are probably related to intrusion of the Baldy batholith. North-trending faults, commonly filled by Tertiary dikes, cut east-trending folds and are interpreted to be related to the final phase of deformation (Schiarizza, *op. cit.*)

Two phases of folding are clearly recognized in the Harper Creek deposit area. An intense penetrative foliation (Phase 2 of Schiarizza, 1986a) strikes easterly and dips variably to the north (Figure 2). It generally obliterates bedding or transposes it parallel to foliation. Where bedding/foliation angles are preserved, bedding dips are less steep. This is clearly displayed in the most northern trench (Figure 2) where a sub-horizontal to shallow north-dipping semi-massive pyrite layer is cut

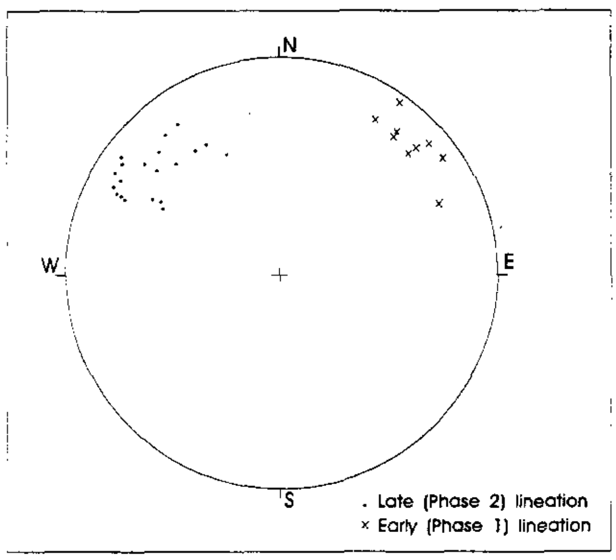


Figure 4. Stereoplot of early mineral lineations and late crenulation cleavage lineations.

Plate 3. Thin pyrite layer from the most northern trench (see Figure 5) showing the angle between layering and more steeply dipping foliation.

by more steeply dipping foliation (Plate 3). These relations define an antiformal closure to the south, with the Harper Creek succession on the upper limb of the antiform, and hence right-way-up. Mineral lineations related to these early folds plunge at low angles to the northeast (Preto, 1971); (Figure 4).

A prominent, steeply dipping to vertical crenulation cleavage trends northwest throughout the area (Figure 4). Macroscopic folds related to these structures were not recognized.

Northeast and northwest-trending late faults are inferred in the deposit area. A northeast- trending fault is mapped by Belik (1973) in the Harper Creek valley (Figure 2). Displacement on this fault is not known as lithologies cannot be correlated readily across it. Schiarizza (1986b) defines a more northerly trending, steeply dipping fault in the Harper Creek valley; maximum inferred west-side up displacement is a few hundred metres.

Two steeply dipping, northwest-trending faults are interpreted to cut the Harper Creek succession south of Harper Creek (Figure 2). Both follow airphoto lineaments, are interpreted to have steep dips, and have west-side up displacements of a few tens of metres. The more western fault appears to offset the massive magnetite-sulphide lens and truncates Unit 2c farther northwest. The eastern fault appears to truncate (or offset?) more quartzitic members of Unit 2a and may truncate the magnetite-sulphide layer (Figure 2).

MINERALIZATION

Mineralization on the Harper Creek prospect includes disseminated sulphides, vein and fracture controlled sulphides and massive to semimassive sulphide and sulphide-magnetite layers (Preto, 1971; Belik, 1973). The disseminated sulphide zones are considered to have the most economic potential (Phillips Barratt Kaiser Engineering Ltd., 1988; M. Sanguinetti, personal communication, 1996). They form discontinuous zones that approximately parallel the trends of bedding and foliation.

DISSEMINATED SULPHIDE ZONES

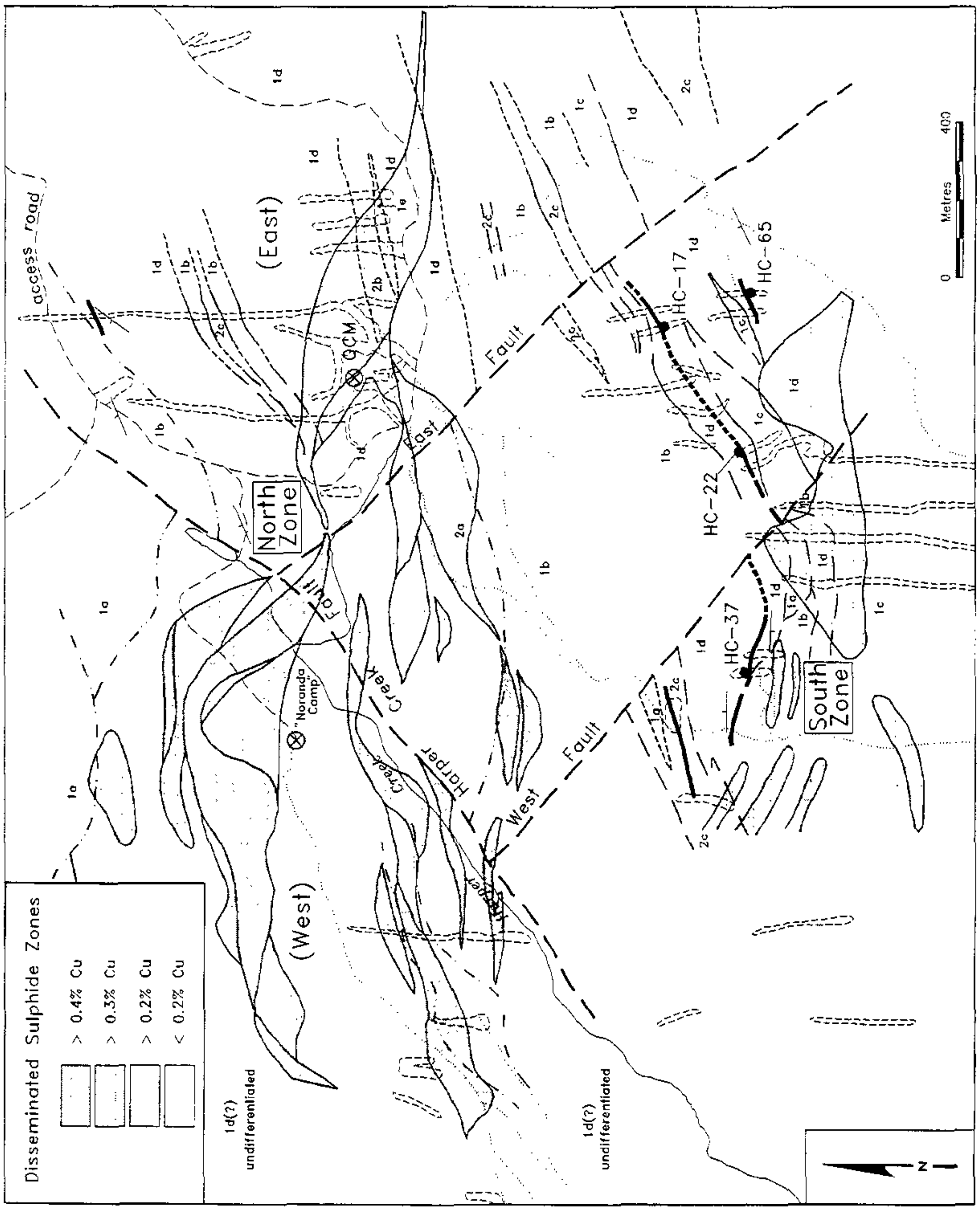
The dominant sulphide minerals in the disseminated sulphide zones are, in decreasing order of abundance, pyrite, pyrrhotite and chalcopyrite. Disseminated pyrite content ranges up to 10 percent; disseminated chalcopyrite is restricted to pyritic zones and generally does not exceed 2 percent (Belik, 1973). Minor disseminated sphalerite and locally, arsenopyrite also occur within the pyritic zones (Preto, 1971; Belik, *op. cit.*). The disseminated sulphides occur as finely dispersed grains on foliation planes. Chalcopyrite also occurs commonly in fine, north-trending hairline fractures, and with quartz and calcite in north trending veins or tension gashes. Pyrite is also found outside the disseminated sulphide zones.

Two large irregular zones of disseminated sulphide mineralization, defined by surface and diamond drill core assays, are recognized. Although the zones trend easterly and dip at a shallow angles to the north, essentially parallel to foliation trends, they clearly crosscut layering. Geological reserves, described below, are from Phillips Barratt Kaiser Engineering Ltd. (1988). The zones are schematically shown on Figure 5. The more northern extends from east of the Quebec Cartier camp, west across Harper Creek to the Noranda camp area. It splays to the west resulting in two higher grade zones separated by less mineralized rock, and as well increases in surface extent and grade to the west (Figure 5). The eastern zone increases in grade and thickness in the subsurface to the north, with grades more comparable to those exposed at surface to the west, supporting a model of west-side up movement on the Harper Creek fault. Copper grades range from less than 0.2 percent to greater than 0.4 percent. Total geological reserves east of Harper Creek are 42.5 million tonnes grading 0.37 percent copper, 0.043 g/t gold and 2.4 g/t silver; reserves west of Harper Creek are 53.5 million tonnes grading 0.42 percent copper, 0.047 g/t gold and 2.6 g/t silver.

The north zone comprises disseminated and fracture controlled chalcopyrite and malachite within dominantly quartz-sericite phyllites. Pyrite is ubiquitous, sericite alteration is locally intense, and silicification in the form of quartz veinlets and "sweats" is common.

The southern zone is less well defined, smaller and generally of lower grade. It comprises disseminated chalcopyrite and malachite within a zone of intense sericite and dolomite alteration, in probable mafic to intermediate tuffs. It is underlain by sericite-altered tuffaceous sediments and overlain by more siliceous tuffs that contain the sulphide layer. The zone is between 100 and 200 metres in width, with calculated geological reserves of of 20.5 million tonnes containing 0.3 percent copper. The south zone appears to be offset by the western northwest trending fault (Figure 5) and increases in grade to the west.

Figure 5: Geological map of the Harper Creek deposit, showing locations of disseminated sulphide zones and sulphide layers (after A. Soregaroli, 1972, unpublished Noranda Explorarations Co. Ltd. report; Phillips Barratt Kaiser Engineering Ltd., 1988).



SULPHIDE-MAGNETITE LAYER (UNIT 3b)

A sulphide-magnetite layer that ranges in thickness from a few tens of centimetres to several metres has been traced intermittently for a strike length of approximately 600 metres. It varies from massive magnetite with dispersed pyrite to dominantly pyrite in a magnetite matrix. Chalcopyrite content ranges up to approximately 4 percent. The sulphides and magnetite locally produce a crude banding in the layer. Copper values grade from 0.9 percent to less than 0.1 percent; lead, zinc and arsenic values are low (Table 1), silver content is generally less than 10 ppm, and maximum gold content in analyzed samples, less than 250 ppb. A magnetite-rich grab sample assayed 0.01 oz Au/ton; (M. Sanguinetti, personal communication, 1996).

Unit 3b is dominantly within quartz-sericite phyllites that may originally have been felsic tuffs. However, it is possible that quartz laminae and veinlets within this unit record silicification associated with sulphide deposition. The layer and siliceous envelope is underlain by intense sericite alteration and disseminated sulphides of the south sulphide zone. Fine-grained, massive to foliated, brown weathering dolomite, locally with abundant quartz, commonly occurs adjacent to the layer.

PYRITIC LAYERS (UNIT 3a)

A number of other thin, discontinuous massive to semimassive sulphide layers occur throughout the area (Figure 2). They are less than a metre thick and can only be traced a few tens of metres, perhaps due to limited surface exposure. They comprise pyrite with minor pyrrhotite, magnetite and chalcopyrite in a chlorite-quartz-sericite gangue. The most southern pyrite layer is a few tens of centimetres thick and can be traced across two trenches. It is within a siliceous quartz-eye sericite schist. A sulphide layer northwest of the sulphide-magnetite layer is within carbonaceous phyllite and grey limestone of Unit 2c. Massive, fine-grained dolomite, cut by quartz veins that carry sphalerite and pyrite, occurs along its margin.

Thin pyritic layers also occur within quartz-eye phyllite in the most northern trench (Plate 3). The pyrite is medium grained within a dark quartzitic matrix.

ALTERATION MINERALOGY

Distinction between alteration minerals associated with sulphide deposition and metamorphic minerals is difficult, particularly as metamorphism has overprinted alteration assemblages. Hydrothermal alteration minerals recognized in the field include intense sericite development, brown-weathering dolomite, calcite and quartz, and possibly chlorite.

TABLE 1. SELECTED ASSAYS OF TWO SULPHIDE LAYERS, HARPER CREEK DEPOSIT (FROM THIS STUDY).

Sample	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	As ppm	Au ppb
HC-17	4746	47	284	3.6	89	288	880	11	232
HC-22	1196	21	43	<.3	55	103	448	2	23
HC-37	1931	58	121	1.3	20	279	131	85	34
HC-65	7678	36	179	10.1	69	248	342	129	73

Sericite, of assumed hydrothermal origin, produces a soft, pale greyish-green rock in which all primary bedding features are obliterated. It contrasts with coarser grained sericite that is abundant in more siliceous units, does not appear to be as texture destructive and is assumed to be of metamorphic origin. Sericite alteration is most intensely developed in the trenches in the south of the map area (Unit 1c, Figure 2); the protolith of this unit is assumed to include mafic tuffs, with minor intermediate tuffs or sediments. Sericite alteration is also common at the south end of trenches near the Quebec Cartier camp. These alteration zones are in the footwall of the most intense sulphide mineralization, beneath both the massive sulphide-magnetite layer and the disseminated sulphide zones. Hence, it is assumed that they reflect potassium metasomatism associated with sulphide deposition.

Dolomite and siderite are common in all chloritic units, commonly producing rusty-weathering outcrops. Carbonate occurs as disseminated grains and in thin, very rusty-weathering laminae within more chloritic phyllites. Total carbonate content varies considerably; within the mineralized zones it is estimated to average 12 percent (Phillips Barratt Kaiser Engineering Ltd., 1988). Dolomite and siderite also occur in thick, cross-cutting massive veins, with quartz, pyrite, chalcopyrite and sphalerite. These are conspicuous in the carbonate and carbonaceous phyllite units (2c) at the southwest end of the map area (Figure 2). Massive, fine-grained dolomite, with quartz, also occurs adjacent to the sulphide-magnetite layer. The foliated nature of much of the dolomite indicates that it is a pre- or synmetamorphic mineral and its association with both disseminated and layered sulphides suggests, at least in part, a hydrothermal origin.

Quartz occurs as discontinuous laminae within sericite phyllites, and in cross-cutting quartz-calcite sulphide veins and tension gashes. These modes of occurrences may reflect silicification or, possibly, remobilization of original silica during metamorphism. Rounded quartz eyes in sericite phyllite are interpreted to be original volcanic quartz.

Chlorite is abundant in many of the units, and generally is interpreted to record metamorphism of a mafic to intermediate volcanic unit. However, dispersed chlorite in siliceous sericitic units that are interpreted to be originally felsic tuffs, may be related to Mg alteration. Commonly, dispersed and veinlet sulphides are associated with chlorite.

SUMMARY AND DISCUSSION

Harper Creek is interpreted to be a volcanogenic sulphide deposit within Late Devonian bimodal calcalkaline volcanics of the Eagle Bay Assemblage. It consists of a number of thin sulphide or sulphide-magnetite layers, as well as several large zones of disseminated chalcopyrite and pyrite that approximately parallel the dominant foliation and layering trends in the upper limb of an overturned anticline. Remobilized sulphides also occur in late hairline fractures, quartz veins and tension gashes.

The southern disseminated sulphide zone is within intensely sericitized tuffaceous sediments in the footwall of the sulphide-magnetite layer. This suggests that it may be part of a widespread footwall alteration zone related to massive sulphide deposition. Its conformable nature may reflect an original semiconformable zone or may possibly reflect transposition of a cross-cutting zone into foliation.

The northern zone of disseminated sulphides is within felsic tuffs that are interpreted to be at the top of a volcanic cycle. It is underlain by mafic chlorite tuffs and overlain by metasedimentary phyllites. Its similarity to the south zone, stratigraphic position and semiconformable nature suggest that it also records continued sulphide deposition during volcanism.

A number of other disseminated sulphide deposits in the Eagle Bay Assemblage are described by Schiarizza and Preto (1987). EBL, located between the northeast ends of North and East Barriere Lakes, comprises disseminated pyrite, pyrrhotite and lesser chalcopyrite in dominantly chlorite schists of Unit EBQ. Lydia, 12 km west of Harper Creek, also consists of disseminated pyrite, pyrrhotite and chalcopyrite in chlorite phyllite, calcareous phyllite and quartzofeldspathic schist of EBQ. Associated semimassive sulphides suggest a further similarity with Harper Creek. Other similar occurrences include VM and VAV (Schiarizza and Preto, 1987). A common feature of all these occurrences is the close spatial association with quartz-feldspar orthogneiss units interpreted to be subvolcanic intrusions. This raises the possibility that these are deformed and metamorphosed porphyry copper deposits (Schiarizza, personal communication, 1996).

However, I suggest that these disseminated sulphide deposits may be similar to large semiconformable alteration zones that have been described beneath some massive sulphide deposits (Morton and Franklin, 1987). These alteration zones can have strike lengths of several kilometres and thicknesses of tens to hundreds of metres. In particular, Mattabi-type massive sulphide deposits can have large, well-defined semiconformable alteration zones, characterized by sericite, quartz, dolomite and sulphides, that may extend up to the ore horizon and merge with more typical alteration pipes (Morton and Franklin, *op.cit.*). The thin sulphide lenses at Harper Creek may record seafloor venting of sulphides while disseminated sulphides and associated alteration were deposited in the footwall.

The term "volcanogenic disseminated sulphide deposit" (VDS) has been applied to the Harper Creek deposit (K. Daughtry, personal communication, 1996). Further work is required to determine if Harper Creek is a new deposit type that is distinct from either a porphyry deposit or the semiconformable alteration zones and associated mineralization recognized in the footwalls of some massive sulphide deposits.

ACKNOWLEDGMENTS

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AGE OF MINERALIZATION, CITY OF PARIS VEINS, GREENWOOD AREA (82E/2E)

By B.N. Church, P.Eng.

KEYWORDS: Geochronology, K/Ar age, City of Paris vein, Lexington property, Greenwood area

INTRODUCTION

This report is an update on the age of the City of Paris vein system on the Lexington property, Greenwood mining camp, south central British Columbia (Figure 1). The Greenwood camp is located at the north end of the Republic graben, one of a number of Tertiary grabens in southern British Columbia and northern Washington State which have associated precious metal vein mineralization. For example, the Knob Hill mine at Republic, Washington, exploits a significant gold-silver deposit associated with Tertiary faulting and related structures (Lasmanis, 1996). Similar occurrences in British Columbia include the Brett and Dusty Mac mines in the Okanagan area, and the Picture Rock and Tam 'O Shanter occurrences near Greenwood (Meyers, 1988; Church, 1973, 1986 and 1996).

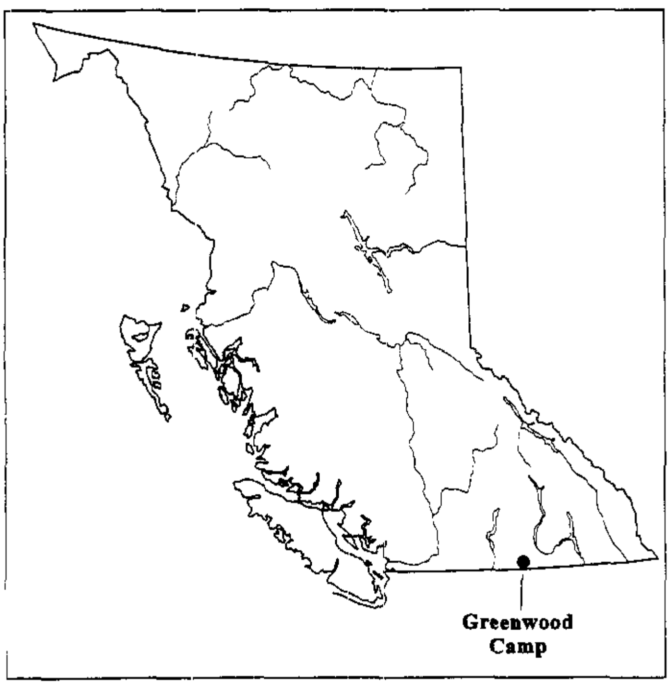

Figure 1. Location Map, Greenwood camp

Exploration on the Lexington property in the Greenwood area first focussed on the gold and silver-bearing quartz veins and stockworks associated with the Lexington quartz porphyry and serpentinite. At the turn of the century, workers at the City of Paris mine developed a system of discontinuous quartz veins extending for about 400 metres along the upper contact of the Lexington intrusion and in the overlying serpentinite. At this time the City of Paris mine yielded 1639 tonnes of ore grading 13.7 grams per tonne gold, 71 grams per tonne silver and 3.12 per cent copper. Porphyry-style mineralization, similar to the nearby Lone Star mine in Washington State, is the subject of ongoing development by Britannia Gold Corporation and Bren-Mar Resources Ltd. (Seraphim *et al.*, 1996).

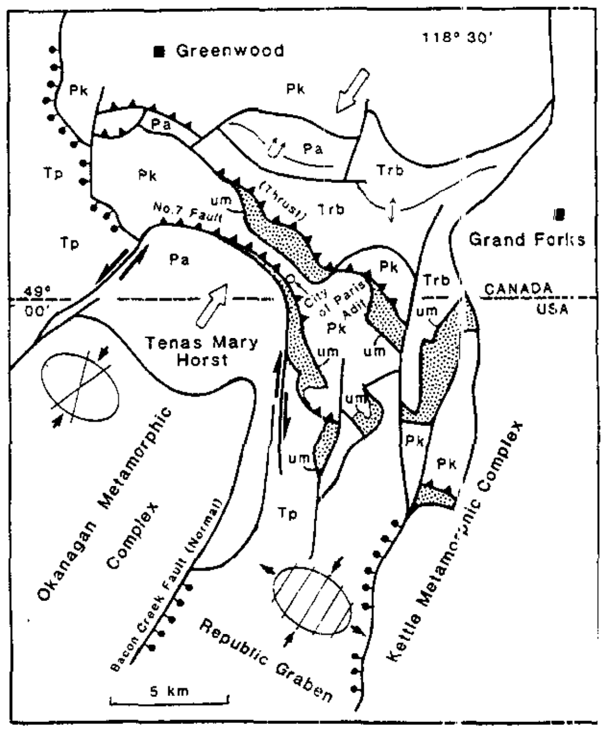

Figure 2. Geology of the Greenwood - Boundary area after Cheney *et al.* (1994), Fyles (1990) and Church (1986), showing interpretation of late Cretaceous-early Tertiary stress fields (ellipsoids); Tp - Penticton Group (Eocene); Trb - Brooklyn Group (Triassic); Pa - Attwood Group (Permian); Pk - Knob Hill Group (Paleozoic); um - ultramafic rocks.

GEOLOGICAL SETTING

The City of Paris vein system is associated with the No. 7 fault zone and a belt of serpentinite that traverses the Lexington property on the Canada - United States border (Little, 1983). The fault zone is an ancient structure believed to be a possible continuation of the Chesaw thrust in Washington State (Cheney *et al.*, 1994).

The serpentinite is a disrupted Paleozoic ophiolite composed primarily of peridotite with zones of talc and listwanite (Fyles, 1990). Because of the ductile nature of these rocks, the belt has become a tectonically active zone and the locus of much shearing, thrusting, igneous intrusion and vein mineralization. The common Mg-Fe carbonate (listwanite) alteration and serpentinization are believed to be related to major thrusting of the ophiolitic rocks during the Jurassic (Monger *et al.*, 1982). In the early Tertiary these thrusts were re-activated by a tectonic compression directed subparallel to the developing northerly elongated graben structures (Church, 1986 page 32). Igneous activity at the same time is believed to be related to numerous vein deposits. Carr et al (1987) interpreted the age of onset of extension (and overlapping compression) in the southern Interior of British Columbia as 58 Ma (early Eocene). The event is linked to interaction between the North American and the subducting Kula - Pacific plate boundaries (Struik, 1992).

Figure 2 proposes an early Tertiary northerly directed stress scheme (ellipsoids and arrows) to explain the apparent lateral movement of the Tenas Mary Horst and corresponding thrusting and tensional structures related to the Republic graben.

The City of Paris mine is on a vein system near the south contact of a major ultramafic lens (Church, 1971). The vein system consists of two locally discontinuous, subparallel veins developed along the margin of a narrow serpentinite appendage flanking the main ultramafic body. The veins trend NW at about 160° and vary in width from 5 metres to mere stringers of ore (Photo 1). The vein system dips 55° degrees northeast and has an exposed strike length of 460 metres. The City of Paris vein, which follows the northeast side of the serpentinite appendage, is the source of much of the mined ore. The Lincoln vein occurs on the south side of the serpentinite appendage. This is explored by the main northwest trending drift on the adit level.

The workings of the City of Paris mine were first described by Brock (1903, p.124A):

"From the northwest drift along the lead, four cross cuts have been run 90 feet. The rock traversed by them is impregnated with and traversed by stringers of quartz and calcite carrying sulphides, which diminish in amount with distance from the main lead. In one cross cut an ore body was encountered running SW, diagonal to the main lead. The ore occurs in chutes. A dark dyke occurs in the mine with ore following it on each side.

"The ore on the northwest drift consists of argentiferous galena, blende, tetrahedrite, chalcopyrite and pyrite, while on the southeast drift the ore is almost massive pyrite and chalcopyrite........."

Some of the best assay results were obtained from the Lincoln shaft and portal area. The metal values are unevenly distributed, running in pay streaks. A grab sample from the vein near the Lincoln shaft assayed 2.1 grams per tonne gold, 182 grams per tonne silver, 1.84 per cent copper, 3.98 per cent lead, 0.12 per cent zinc, 0.073 per cent arsenic, and 0.93 per cent antimony (Church, 1971). The tetrahedrite gave very high assay values (Photo 2).

Photo 1. Quartz veinlets in serpentinite, No.7 Fault Zone, City of Paris mine area

The origin of the vein system is related to reactivation of thrusting at the contact between the Lexington quartz porphyry and hangingwall serpentinite during the development of the Republic graben. The veins clearly existed prior to emplacement of many of the Tertiary dikes, as evidenced by the damming of these dikes adjacent to the veins. However, the veins are also younger than the penetrative deformation that is commonly seen in the surrounding country rocks. An analysis of fuchsite obtained from quartz stringers in listwanite, immediately north of the Lincoln workings, yielded a K/Ar age of 56.7 ±1.0 Ma (see Table 1).

Table 1

Radiometric Date for Fuchsite

Latitude	49° 00.6'
Longitude	118° 36.5'
K%	4.237 ± 0.020
Ar^{40}	9.489 x 10^{-6} cc/gm
% Ar^{40}	90.1
Ma	56.7 ± 1.0

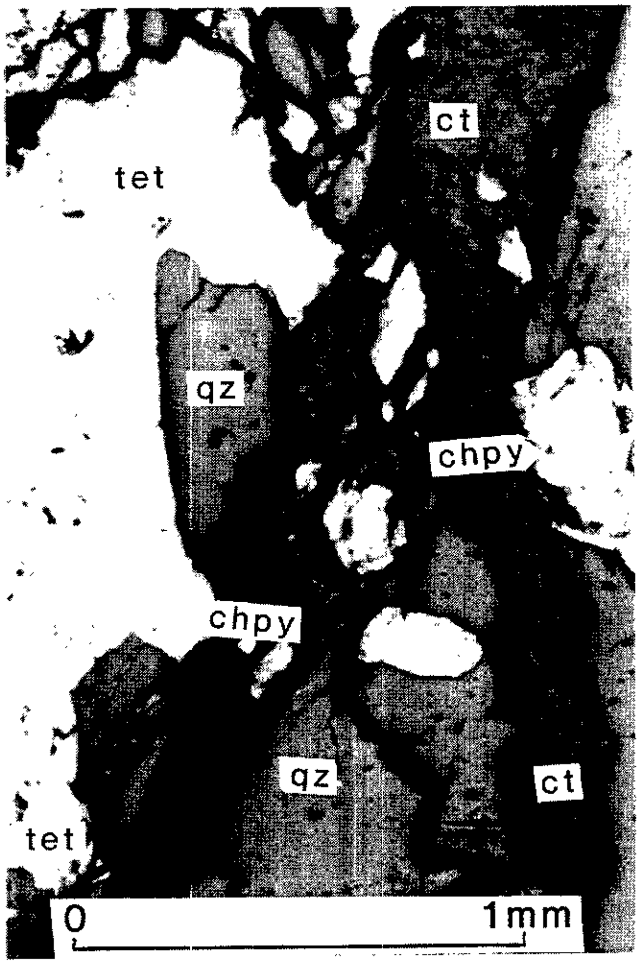

Photo 2. Photomicrograph of Quartz vein ('qz') with islands of chalcopyrite ('chpy' - light grey) in tetrahedrite ('tet' - medium grey) flanked (on right) by calcite gangue ('ct')

DISCUSSION

Theories regarding the genesis of the City of Paris mineralization generally involve faulting and the Lexington intrusion, which was emplaced in the early Jurassic. The serpentinite in the Lexington area was emplaced first, as a ductile body into the northeast dipping No. 7 fault zone. Later, the Lexington magma, in one or several pulses, intruded the same fault zone dividing the serpentine into upper and lower limbs. The Lexington intrusion was emplaced in the early Jurassic, near the time of accretion of Quesnellia to the North American plate; the parental magma was contaminated by, or derived from, early Proterozoic rocks (Church, 1992). This was accompanied by a pulse of copper-gold porphyry type mineralization. Continued movement on the fault zone resulted in penetrative deformation of the serpentinite and the Lexington quartz porphyry that made the contacts between these units locally indistinct. Later movement fractured the margins of the intrusion allowing emplacement of the City of Paris vein system (early Eocene) which was then sheared by still younger movement. Relatively fresh and undeformed dikes, thought to be related to the tensional fissures of the Republic graben, that cross-cut the porphyry mineralization but not the vein system.

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AGE OF A BASALT DIKE, SUSTUT COPPER DEPOSIT (94D/10E)

By B.N. Church (B.C. Geological Survey Branch), J. Dostal (Saint Mary's University, Halifax, N.S.) and V. Gale (Dalhousie University, Halifax, N.S.)

KEYWORDS: Geochronology, K/Ar age, basalt dike, copper mineralization, Sustut deposit.

INTRODUCTION

This report sheds further light on the history of mineralization of the Sustut Copper deposit based on new data on the age and composition of a basaltic dike that cuts the deposit.

The Sustut deposit was described in some detail by Church (1974), Harper (1977) and Wilton (1978). Further information regarding the regional geology of the area around the deposit and Takla Group is provided by Monger and Church (1976) and Gale (1996).

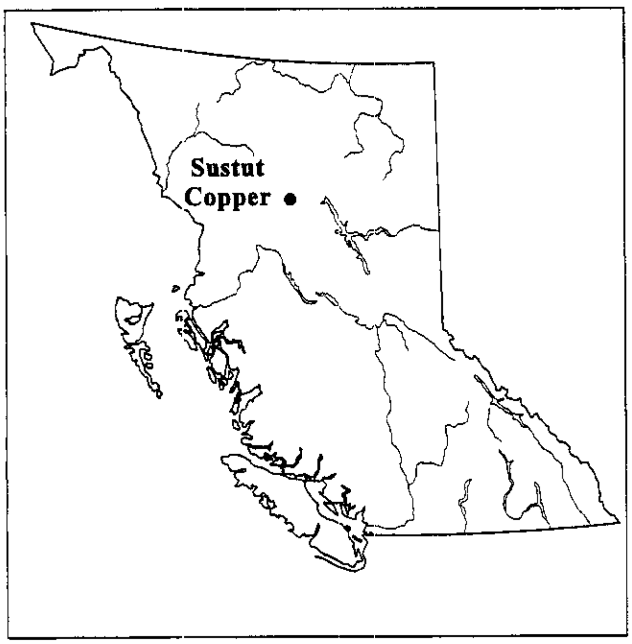

Figure 1. Location map, Sustut copper deposit.

The Sustut Copper deposit is located 130 kilometres north of Smithers B.C. (Fig. 1). It was discovered in 1971 by Falconbridge Ltd. in gently dipping beds of the Takla Group (Upper Triassic). The principal mineral zone is a concordant body of 43.5 million tonnes, grading 0.82 per cent copper, that lies in a transitional middle horizon of the Moosevale Formation between subaqueous and subaerial depositional volcaniclastic facies (Harper 1977). The deposit fits the 'Basaltic Copper' model of Lefebure and Church (1996). The ore body ranges up to 75 metres thick and underlies a 0.9 x 1.8 km northerly elongated area on the south flank of Mount Savage (Lat. 56°36.4', Long. 126°40.3'). The copper minerals, consisting mainly of chalcocite, bornite, chalcopyrite and native copper, are epigenetic and occur with pyrite, epidote, quartz, prehnite and carbonates in tabular structures suparallel to bedding and related to low grade metamorphic and metasomatic reactions (Church, 1974; Wilton, 1978).

THE BASALT DIKE

The only intrusion in vicinity of the Sustut deposit is is a 600 metre long dike that cuts directly across the ore body (Fig. 2). For the most part, the dike is 1.5 metres wide, straight and steeply dipping, at 80° southeast, and remarkably consistent (Photo 1). The largest exposure is a 300 metre long segment that strikes NNE from the East Cirque; the northern extension being lost under felsenmeer blocks towards the North Cliffs. South of the East Cirque, the dike is exposed intermittantly over a distance of about 200 metres. Discontinuities towards the southern extremity of the dike are caused by movement on cross joints and small shears.

The dike is light brown or tan coloured on weathered surfaces and dark grey or blue grey where freshly broken. The rock is characterized by dark augite phenocrysts 2-4 mm in diameter set in a fine grained matrix with numerous feldspar microlites. In thin section the rock is crowded with plagioclase microlites interspersed with solitary, subhedral augite phenocrysts and glomerophenocrysts of augite, plagioclase, intergranular magnetite and chlorite. The feldspar is in the andesine-labradorite composition range.

Chemical analysis shows that the dike is a subalkaline basalt, compositionally intermediate between tholeiitic and calc-alkaline magmatic trends, similar to the Takla volcanic rocks (Gale, 1996). The dike is closest in composition to the plagioclase-rich lava clasts in the Moosevale Formation at Sustut Copper, and the feldspathic Takla lava on the Marmot property, located to the northeast. However, unlike this Takla rock, the dike contains lower K_2O values and a significant amount of normative olivine (Table 1).

MINERALIZATION

The main period of mineralization is believed to be shortly after deposition of the Moosevale Formation (Church, 1974). Accordingly, the hydrothermal solutions which carried the copper and other ions were late stage in the development of Takla volcanism. The solutions flowed through the recently deposited volcanic sandstones and conglomerates between impermeable lahar beds. A minor part of the ore deposit consists of steeply dipping veins that were feeders to the main ore body (Harper, 1977). Some veinlets are younger and hosted by a basaltic dike that cuts the ore body (Wilton, 1978). This late period of mineralization is believed to be related to regional metamorphism that occurred post dike intrusion (early Jurassic or younger).

Table 1
CHEMICAL ANALYSES

	1	2
Oxides Recalculated to 100 percent		
SiO_2	53.20	49.32
TiO_2	0.93	1.29
Al_2O_3	16.97	17.53
Fe_2O_3	4.89	2.84
FeO	4.82	7.84
MnO	0.18	0.18
MgO	6.09	7.27
CaO	7.44	9.63
Na_2O	3.08	3.43
K_2O	2.40	0.67
	100.00	100.00
Oxides as Determined		
LOI	2.00	2.87
P_2O_5	0.37	0.17
SrO	0.08	0.04
BaO	0.03	0.03
Molecular Norms		
Quartz	1.9	-
Orthoclase	14.2	3.9
Albite	27.8	30.7
Anorthite	25.4	30.3
Wollastonite	4.6	6.9
Enstatie + Ferrosilite	19.7	8.5
Forsterite + Fayalite	-	14.9
Illmenite	1.3	1.8
Magnetite	5.1	3.0

1 Takla Lava, (Church, 1994, p. 438)
2 Basaltic Dike, (this study)

Analysis of a whole rock sample from the part of the dike north of the East Cirque yields a late Jurassic K/Ar date of 150 ± 5.0 Ma (see Table 2). Because there are no known late Jurassic volcanic rocks in the area, this date is considered to be the age of regional metamorphism. The true age of the dike is middle Jurassic or earlier - the rock being a likely feeder to nearby Hazelton Group volcanics or related to a late pulse of Takla volcanism.

Table 2
Whole Rock Date

Latitude	56° 36.4'
Longitude	126° 40.3'
K%	0.505 ± 0.012
Ar^{40}	3.061 x 10^{-6} cc/gm
% Ar^{40}	83.6
Ma	150 ± 5

DISCUSSION

The principal manifestation of mineralization at the Sustut Copper deposit is the occurrence of the copper ores as open space fillings (and related replacements) in previously permeable sedimentary rocks of the Moosevale Formation (Wilton, 1978). In the impermeable rocks, such as the massive lava flows and dikes, a similar mineralogy is limited to fillings on joints and shears. During diagenesis, porosity in the sedimentary rocks was sealed and the main phase of mineralization completed.

Copper mineralization took place shorty after deposition of the Moosevale Formation and predated regional metamorphism. The hydrothermal solutions which carried the copper, sulphur and other ions, were late fluids from the last stage of Takla volcanism which flowed through the recently deposited volcniclastics along channelways until impermeable interbeds were reached through which the fluids couldn't flow. Due to stoppage of the flow, cooling and reaction of the metal and sulphur bearing solutions with the red beds, the copper was then precipitated (Wilton, 1978).

The basaltic dike that cuts the ore body is clearly older than the post-Hazelton age for the dike, proposed by Wilton (1978), and the age of regional metamorphism (150 ± 5 Ma, this study). The dike is compositionally similar to the Takla volcanic suite and probably represents a final resurgence of Takla volcanic activity from a sustained magmatic centre under the Sustut Copper deposit - a hot spot source that also contributed to the mineralizing solutions.

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This is to express much appreciation to Gerry Harper of Gamah International Ltd. and Jamie Robertson and Jack Der Weduwen of Falconbridge Ltd. for discussions during a visit to the Sustut Copper prospect during the summer of 1995. Much appreciation is also owing Joe Harakal of the University of British Columbia for K/Ar analyses and to Jim McLeod of Cominco Ltd. for silicate analyses. The author is also much obliged to Mike

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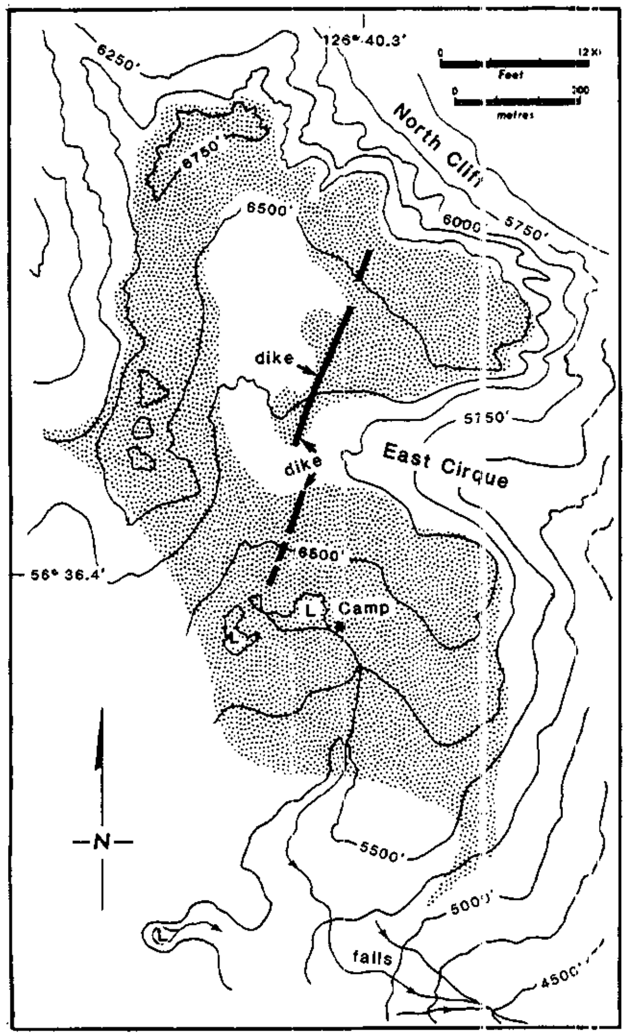

LEGEND

Dike

Topographic contour, interval 250 feet — 5000'

Stream

Lake

Plan view of mineralized area

Figure 2. Geological setting of Sustut Copper deposit

Photo 1. Basaltic dike, view south to the Sustut Copper deposit

U-Pb AGES FOR INTRUSIVE ROCKS AT THE HUCKLEBERRY PORPHYRY COPPER DEPOSIT, TAHTSA LAKE DISTRICT, WHITESAIL LAKE MAP AREA, WEST-CENTRAL BRITISH COLUMBIA (93E/11)

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(MDRU Contribution 085)

KEYWORDS: U-Pb, zircon, Huckleberry deposit, porphyry copper, Bulkley intrusions, Hazelton Group

INTRODUCTION

The Huckleberry porphyry copper deposit is located about 85 km southwest of Houston, in the Tahtsa Lake district of west-central British Columbia (Whitesail Lake map area; 93E) (Figure 1). Previous workers have associated mineralization at the Huckleberry deposit with the intrusion of two small porphyry stocks into Hazelton Group country rocks (Carter, 1974; James, 1976; Jackson and Illerbrun, 1995). In this report we present new U-Pb data and interpreted ages for samples from these intrusions.

This work is one component of a regional U-Pb dating study of mineral deposits in central British Columbia. A more focused mapping, metallogeny and geochronology study continues at the Huckleberry deposit and in the Whiting Creek area to the north (Figure 2). Both of these investigations are being conducted under the auspices of the Magmatic-Hydrothermal Project of the Mineral Deposit Research Unit. The U-Pb ages reported herein were determined at the Geochronology Laboratory of the Department of Earth and Ocean Sciences at the University of British Columbia.

PREVIOUS WORK

The first regional bedrock mapping of the Whitesail Lake map area was conducted in the 1930's (Hedley, 1935). Mapping continued during the 1940's and 1950's, culminating in the publication of a four mile map sheet and an accompanying report by the Geological Survey of Canada (Duffell, 1959).

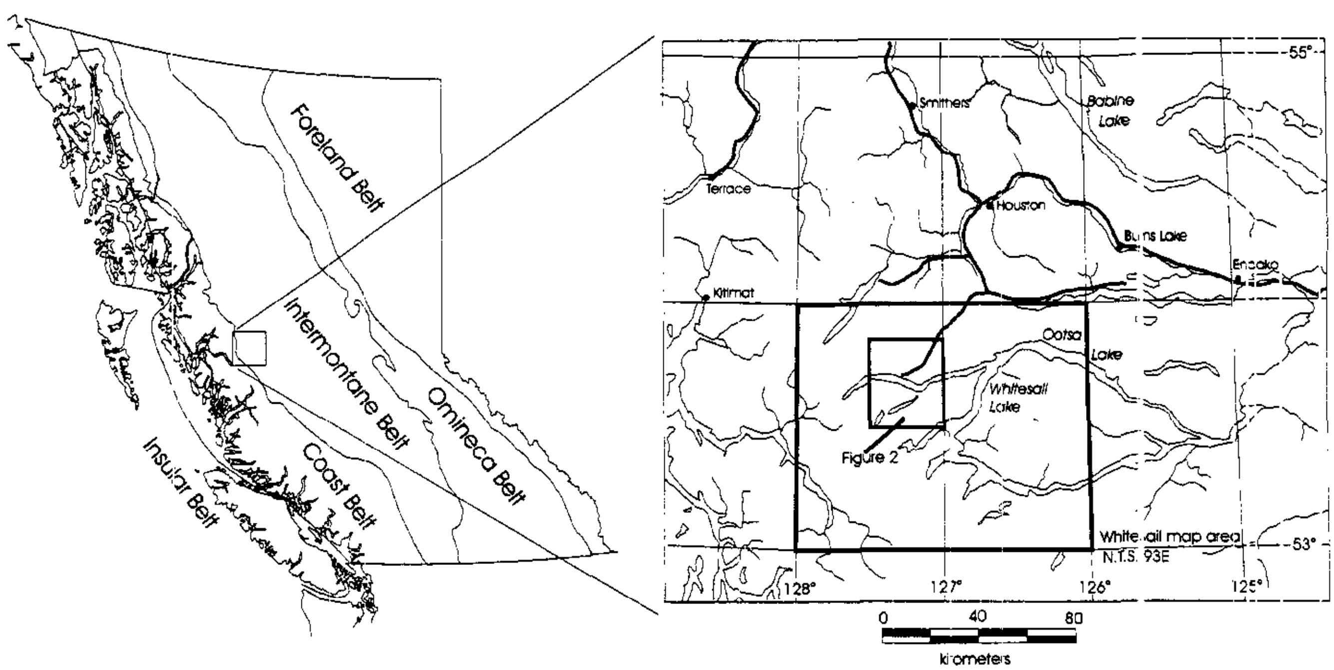

Figure 1. Location map of west-central British Columbia showing the Whitesail Lake map area (NTS 93E) and the area of Figure 2. Inset shows regional position of the Tahtsa Lake area in west-central British Columbia.

A regional stream sediment geochemical survey carried out within the Tahtsa Lake area during the early 1960's by Kennco Explorations (Western) Limited led to the discovery of the Berg and Huckleberry (Main zone) porphyry copper occurrences. These discoveries were responsible for an escalating level of mineral exploration in the area during the 1960's and 1970's, which led to the identification of additional porphyry copper occurrences in the area. Studies focusing on the geology of individual deposits and the district as a whole were conducted by the British Columbia Ministry of Energy, Mines and Petroleum Resources (Sutherland-Brown, 1966,1969; Carter, 1970, 1974; Church, 1971; Carter, 1981; MacIntyre, 1985) and as thesis work (Cawthorn, 1973; MacIntyre, 1974, 1976; Richards, 1974; Panteleyev, 1976). The results of several studies in the area were published in a 1976 volume on porphyry deposits of the Canadian Cordillera (Christopher and Carter, 1976; Carter, 1976; James, 1976). More recent regional mapping in the Whitesail Lake map area was carried out by Woodsworth, (1980) of the Geological Survey of Canada and Diakow and Mihalynuk (1987a;b) of the British Columbia Geological Survey. An up-to-date review of the Huckleberry deposit (Jackson and Illerbrun, 1995) was published in a second volume on porphyry deposits of the Canadian Cordillera.

Detailed geological and geophysical work on the Huckleberry property, conducted by Kennco Explorations, began soon after the initial discovery in 1962 and continued until 1971, when the property was optioned to Granby Mining Company Limited. During the following two years a detailed drilling programme focused on Main zone mineralization, after which activity on the property ceased until 1989. At this time Noranda Exploration Company Limited began work on the east side of the property but subsequently dropped its option. Kennecott Canada optioned the property to New Canamin Resources Limited in 1992. In 1993, during geotechnical drilling by New Canamin Resources for a future tailings pond, the East zone of mineralization was discovered. Drilling programmes carried out by New Canamin Resources during the remainder of the early 1990's focused on the determination of ore reserves in the Main and East mineralized zones. In July of 1995 Princeton Mining Corporation purchased New Canamin Resources. Princeton Mining Corporation currently controls 60 percent of the operating company, Huckleberry Mines, Limited.

GEOLOGY

REGIONAL GEOLOGY

The Tahtsa Lake district lies near the western margin of the Intermontane Belt and within the Stikine accreted terrane (Figure 1). The area is underlain by several unconformity bound volcanic and/or siliciclastic assemblages. In ascending order these are: Lower to Middle Jurassic arc volcanic and clastic sedimentary strata of the Hazelton Group; wackes, fine grained sedimentary rocks and tuffs of the Middle Jurassic Ashman Formation, part of the Bowser Lake Group; Lower Cretaceous, mainly Albian turbiditic sedimentary rocks and subordinate basalt flows of the Skeena Group; and, volcanic and subordinate sedimentary rocks of the Upper Cretaceous Kasalka Group (Figure 2).

These Jurassic and Cretaceous strata in the area have been intruded by numerous small and medium-sized, high-level stocks of the Early to Late Cretaceous Kasalka intrusions, Late Cretaceous Bulkley intrusions, and the Eocene Nanika intrusions (MacIntyre, 1985).

Kasalka intrusions are a group of small intrusive bodies which are commonly areally associated with, and compositionally/texturally similar to Kasalka Group volcanic rocks (MacIntyre, 1985). Fine grained, porphyritic augite-hornblende bearing diorities comprise the majority of these intrusives.

The Bulkley intrusions are defined as mainly small to medium-sized (usually 1-5 km in diameter), high-level, compositionally intermediate, hornblende and/or biotite bearing bodies of Late Cretaceous age, which intrude Lower Jurassic to Lower Cretaceous strata (Carter, 1974, 1976, 1981). They are areally, and likely genetically related to the Huckleberry and other important porphyry copper deposits in the Tahtsa Lake district (Carter, 1974; Christopher and Carter, 1976; James, 1976).

The Bulkley intrusions have been separated into three subtypes by MacIntyre (1985). These are small porphyritic stocks, such as the Main Zone stock at the Huckleberry deposit; relatively large, compositionally zoned, equigranular intrusions, such as the Whiting or Sibola stocks; and late, porphyritc quartz monzonite dyke swarms that cut both of the former types.

Bulkley intrusions are commonly located along, or adjacent to steep north to northwest-trending faults, suggesting that their final emplacement was structurally controlled (Carter, 1976). Local doming of country rock adjacent to some intrusions is indicative of forceful intrusion mechanisms. Contact aureoles generally extend outwards approximately 400-1000 metres from the margins of intrusions.

The Nanika intrusions refer to high-level, compositionally intermediate stocks of Eocene age. They are distinguished from Late Cretaceous intrusions by their greater proportion of primary K-Feldspar. The Berg stock, which is associated with the Berg porphyry copper deposit, is a typical Nanika intrusion.

Rocks of the Tahtsa Lake district have undergone varying degrees of folding and faulting. Hazelton and Skeena Group strata have undergone open to tight folding while Late Cretaceous and younger rocks are only gently warped. Pre-Tertiary rocks are cut by steep, generally north to northwest trending faults.

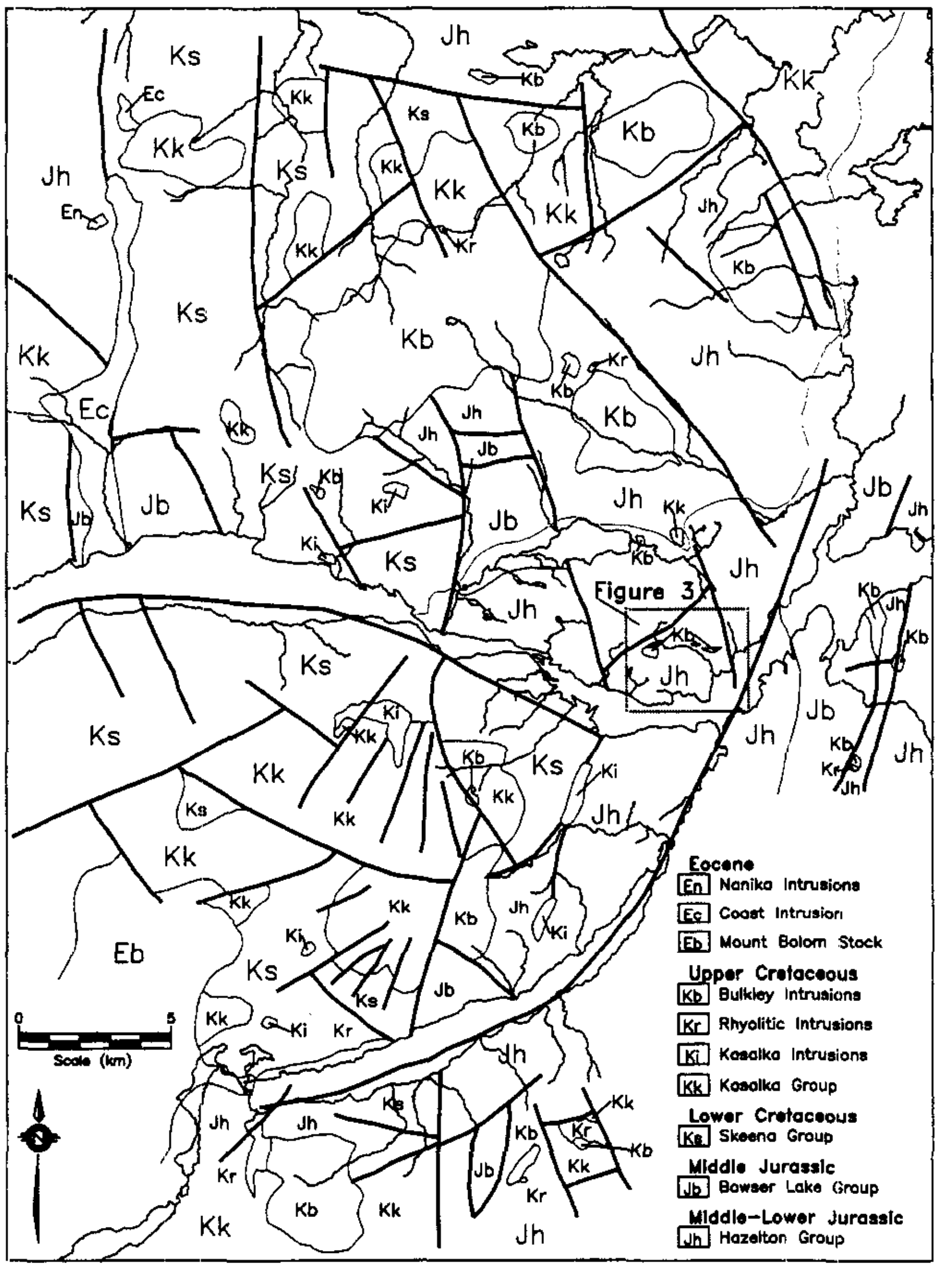

Figure 2. Regional geological map of the Tahtsa Lake District, after MacIntyre (1985).

GEOLOGY AND MINERALIZATION OF THE HUCKLEBERRY DEPOSIT

The Huckleberry deposit is underlain by andesites, dacites and tuffs of the Telkwa Formation of the Hazelton Group. These rocks were intruded by at least two small granodiorite porphyry stocks (the prophyries dated in this study), which metamorphosed adjacent country rock and generated a composite alteration halo of approximately 4 x 2 kilometres in dimension. Two ore zones have been recognized at the Huckleberry deposit (Figure 3). The close spatial relationship of these zones to the Main Zone and East Zone stocks and associated alteration halo/contact aureole led previous workers to propose a model in which mineralization was genetically related to these intrusions (Carter, 1974; James, 1976; Jackson and Illerbrun, 1995). A late Cretaceous age was assigned to the Main Zone stock based on a K-Ar biotite age of 83.1±3.0 Ma (Carter, 1976).

The Main Zone and East Zone stocks are biotite ± hornblende granodiorite porphyries. Recent studies suggest that they both comprise the older phase of a composite body which consists of two phases of granodiorite. Contact relationships between these two phases suggests that they are broadly contempraneous. Phenocryst phases commonly found in the Main Zone and East Zone stocks are plagioclase, biotite and/or hornblende and minor quartz. These phases are set in a fine to medium-grained matrix of quartz and plagioclase (Carter, 1974, 1976; MacIntyre, 1985; Jackson and Illerbrun, 1995). Important accessory phases are magnetite, apatite and zircon. Alteration K-feldspar makes up a small proportion of the matrix and some plagioclase grains have been partly replaced by fine-grained sericite.

Late (post-mineral) lamprophyre and microdiorite dykes cut mineralized zones on the property. One of the latter was sampled for U-Pb dating in this study but no zircon was recovered.

The Main and East mineralized zones are spatially associated with the Main Zone and East Zone stocks, respectively (Figure 3). The Main zone, to the west, lies adjacent to, and follows the margin of the Main Zone stock, and is hosted completely in hornfelsed Hazelton Group volcanic rocks. The East zone is hosted by the East Zone stock and adjacent volcanic rocks. Both ore zones occur within potassic alteration zones, and in both, mineralization occurs primarily within a stockwork of veinlets and fractures which contain or are coated with chalcopyrite, pyrite and subordinate molybdenite and traces of bornite. The intensity of alteration increases towards the stocks and ore zones from chloritic to pyritic to potassic (Jackson and Illerbrun, 1995).

Ore reserves at the Huckleberry deposit have been estimated at 53.7 million tonnes grading 0.445% Cu, 0.013% Mo and 0.06 g/t Au, based on a 0.30% Cu cutoff, for the Main zone, and 108.4 million tonnes grading 0.484% Cu, 0.014% Mo and 0.055 g/t Au at a cut off grade of 0.30% Cu, for the East zone (Jackson and Illerbrun, 1995).

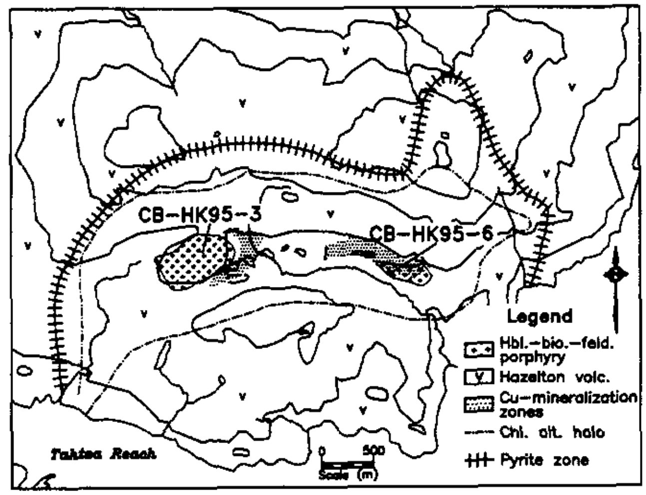

Figure 3. Map of the Huckleberry deposit, after Jackson and Illerbrun (1995).

U-Pb GEOCHRONOLOGY

Three rock samples from the Huckleberry property were collected for U-Pb geochronology during the 1995 field season (Figure 3). These include the Main Zone and East Zone stocks, which intrude, hornfels and are thought to be responsible for mineralization on the property (Carter, 1974; James, 1976; Jackson and Illerbrun, 1995), and a post-mineral cross cutting microdiorite dyke. The Main Zone and East Zone stocks yielded abundant high quality, pale pink, prismatic zircon, whereas no zircon or other minerals that can be used for U-Pb dating were recovered from the dyke.

In the paragraphs below descriptions of the two dated samples are given. This is followed by descriptions of zircon recovered from each sample and the presentation, discussion and interpretation of U-Pb data for each. These data are plotted on concordia diagrams in Figures 4 and 5 and listed in Table 1. Complete U-Pb analytical procedures employed at the UBC Geochronology are reported in Mortensen *et al.* (1995).

MAIN ZONE STOCK: CB-HK95-3

The dated sample of the Main Zone stock is a massive, porphyritic quartz biotite plagioclase intrusive of granodioritic to tonalitic modal composition. The phenocryst phases, plagioclase, biotite and quartz, comprise the majority of the rock (approximately 60 percent). Plagioclase (oligoclase-andesine) phenocrysts are up to 6 mm in length, exhibit oscillitory zoning, have undergone varying degrees of clay-sericite alteration, and make up about 40 percent of the rock. Brown biotite phenocrysts comprise about 10-15% of the rock, are up to 2 millimetres in size, commonly poikiloblastic, containing finer-grained plagioclase, quartz and magnetite, and have been variably altered to chlorite (approximately 10 percent overall). Fresh, anhedral quartz phenocrysts up to 2 millimetres in size make up about 5 percent of the rock. The fine to medium-grained ground mass is made up of approximately equal proportions of plagioclase and quartz (approximately 15-20 percent each) and minor alteration K-feldspar. Accessory phases include magnetite, apatite and zircon.

K-feldspar alteration veinlets about 5 mm in width are cored by pyrite and chalcopyrite. Chalcopyrite and molybdenite coat fracture surfaces.

Abundant, high quality, clear, pale pink, prismatic zircon was recovered from the Main Zone stock. Morphologies vary from stubby prismatic, with aspect ratios of about 1.5:1, to elongate prismatic, with length:width ratios of 5:1.

Three of four analysed zircon fractions (Figure 4, fractions B, C and D) are concordant at approximately 83.5 Ma, and provide the best estimate for the crystallization age of the rock which is 83.5+0.3/-0.4 Ma (Figure 4). Associated errors are derived from the total range of $^{206}Pb/^{238}U$ ages for the three concordant fractions. Fraction A, which consisted of the coarsest grained material analysed, exhibits minor discordance and is interpreted to contain a small component of inherited zircon. No cores were observed in these grains.

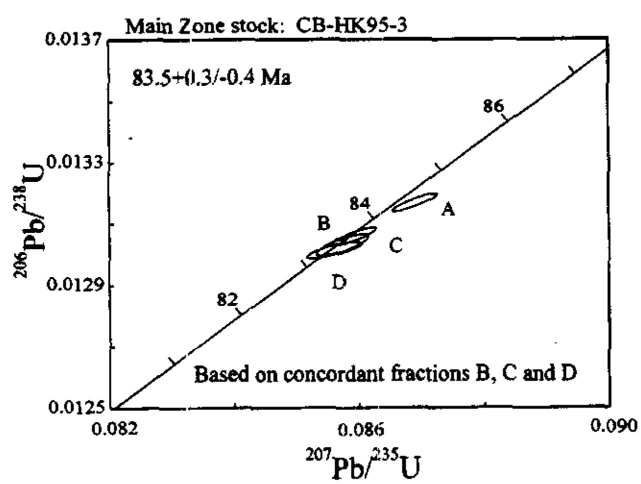

Figure 4. Concordia diagram for the Main Zone stock (CB-HK95-3). Ellipses are plotted at the 2σ level of precision. See text for discussion.

EAST ZONE STOCK: CB-HK95-6

The dated sample of the East Zone stock has been strongly altered and weathered such that little of its primary igneous minerology and textures have been preserved. It consists of plagioclase, K-feldspar, quartz and biotite, with abundant pyrite and chalcopyrite on fracture surfaces and coring veins. Malachite and azurite have also been identified in this sample.

Abundant, high quality, clear, pale pink, prismatic zircon recovered from this sample strongly resemble those from the Main Zone stock described above.

Seven analysed zircon fractions indicate a Late Cretaceous age for the East Zone stock. The best estimate for the crystallization age, 83.5±0.3 Ma, is derived from $^{206}Pb/^{238}U$ ages for concordant and overlapping fractions A and E (Figure 5). Other fractions appear to contain minor inherited zircon and/or to have undergone post-crystallization Pb loss.

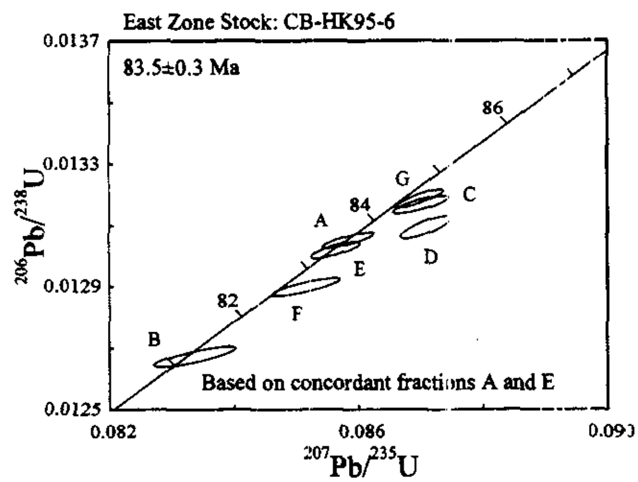

Figure 5. Concordia diagram for the East Zone stock (CB-HK95-6). Ellipses are plotted at the 2σ level of precision. See text for discussion.

DISCUSSION

As presented above, U-Pb zircon ages record the synchronous crystallization and of the Main Zone and East Zone stocks. An overlapping K-Ar biotite cooling age for the Main Zone stock (83.1±3.0 Ma; Christopher and Carter, 1976) indicates a rapid and simple cooling history. This is consistent with the model presented by previous workers in which mineralization, alteration and contact metamorphism at the Huckleberry deposit are related to intrusion of the Main Zone and East Zone stocks (Carter, 1974; James, 1976; Jackson and Illerbrun, 1995). If this model is correct, the U-Pb ages of the Main Zone and East Zone stocks also record the approximate age of mineralization. This may be confirmed by continued sampling and U-Pb dating of post-mineral dykes at the Huckleberry deposit.

TABLE 1. U-Pb ANALYTICAL DATA FOR TWO INTRUSIVE ROCKS FROM THE HUCKLEBERRY DEPOSIT

Fraction[1]	Wt	U^2	Pb^{*3}	$^{206}Pb^4$	Pb^5	$^{208}Pb^6$	Isotopic ratios (1σ,%) [7]			Apparent ages (2σ,Ma) [7]	
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Main Zone Stock: CB-HK95-3											
A cc,N1,p,s	0.424	254	3	4043	22	9.0	0.01317 (0.12)	0.0869 (0.21)	0.04786 (0.11)	84.3 (0.2)	92.5 (5.4)
B cc,N1,p,e	0.245	242	3	2891	17	9.5	0.01303 (0.14)	0.0857 (0.25)	0.04772 (0.15)	83.5 (0.2)	85.6 (7.3)
C c,N1,p,s	0.340	286	4	5481	15	8.9	0.01306 (0.11)	0.0859 (0.21)	0.04772 (0.12)	83.6 (0.2)	85.6 (5.8)
D c,N1,p,e	0.175	266	3	1780	22	10.1	0.01301 (0.11)	0.0856 (0.26)	0.04772 (0.18)	83.3 (0.2)	85.2 (8.7)
East Zone Stock: CB-HK95-6											
A cc,N1,p,s	0.181	264	3	2812	14	9.4	0.01305 (0.10)	0.0858 (0.24)	0.04770 (0.17)	83.6 (0.2)	84.6 (7.9)
B cc,N1,p,s	0.246	311	4	543	113	8.7	0.01267 (0.13)	0.0834 (0.40)	0.04772 (0.30)	81.2 (0.2)	85 (14)
C c,N1,p,s	0.154	305	4	1660	24	10.0	0.01317 (0.11)	0.0870 (0.26)	0.04793 (0.18)	84.3 (0.2)	95.7 (8.5)
D c,N1,p,e	0.120	343	5	3028	11	10.7	0.01309 (0.14)	0.0871 (0.23)	0.04824 (0.14)	83.9 (0.2)	111.0 (6.7)
E c,N1,p,s	0.135	282	4	3000	10	9.7	0.01302 (0.11)	0.0856 (0.24)	0.04770 (0.16)	83.4 (0.2)	84.6 (7.6)
F m,N1,p,s	0.230	294	4	942	60	10.1	0.01290 (0.11)	0.0852 (0.32)	0.04788 (0.24)	82.6 (0.2)	93.5 (11.3)
G f,N1,p,e	0.195	285	4	2967	16	10.8	0.01319 (0.12)	0.0870 (0.22)	0.04784 (0.13)	84.5 (0.2)	91.5 (6.1)

Notes: Analytical techniques are listed in Mortensen *et al.* (1995).

[1] Upper case letter = fraction identifier; All zircon fractions air abraded; Grain size, intermediate dimension: cc = >180μm, c = >180 μm and >134μm. m = <134μm and >104μm, f = <104μm; Magnetic codes:Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1 = nonmagnetic at 1°; Field strength for all fractions = 1.8A; Front slope for all fractions = 20°; Grain character codes: b = broken fragments, e = elongate, eq = equant, p = prismatic, s = stubby, t = tabular, ti = tips.

[2] U blank correction of 1-3pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3] Radiogenic Pb

[4] Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 10pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

[5] Total common Pb in analysis based on blank isotopic composition

[6] Radiogenic Pb

[7] Corrected for blank Pb, U and common Pb. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the $^{207}Pb/^{206}Pb$ age of the fraction.

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U-Pb AGE OF MINERALIZED FELDSPAR PORPHYRY SILLS AT THE LOUISE LAKE Cu-Mo-Au-As DEPOSIT, SMITHERS MAP AREA, WEST-CENTRAL BRITISH COLUMBIA (NTS 93L)

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(MDRU Contribution 086)

KEYWORDS: U-Pb, zircon, Louise Lake deposit, porphyry copper-molybdenum-gold-arsenic, Bulkley intrusions

INTRODUCTION

The Louise Lake porphyry deposit is located about 35 kilometres west of Smithers, in the Hazelton Mountains of west-central British Columbia in Smithers map area 93L/13E (MINFILE 093L 079). Work at the property since its discovery in 1968 has identified a drill indicated resource of about 50,000,000 tonnes containing 0.3 per cent copper and 0.31 grams gold per tonne (Global Mineral and Chemical Limited report, 1995). Cu-Mo-Au-As mineralization at the Louise Lake deposit is related to a swarm of feldspar porphyry sills which intrude Lower Cretaceous sedimentary rocks. In this report we present new U-Pb data and an interpreted crystallization age for a sample of one of these mineralized sills, which constrain the maximum age of mineralization at the Louise Lake deposit. We present a synopsis of the regional setting and local geology of the Louise Lake deposit followed by U-Pb data, an interpreted age and implications of this age. The U-Pb age reported herein was determined at the Geochronology Laboratory of the Department of Earth and Ocean Sciences at the University of British Columbia. The reader is referred to a review of the Louise Lake deposit (Hanson and Klassen, 1995) for information relating to its exploration history and for detailed descriptions of mineralization and alteration.

REGIONAL GEOLOGY

The Louise Lake deposit lies near the western margin of the Intermontane morphogeologic belt, within the Stikine accreted terrane (Wheeler and McFeely, 1991). The deposit is in the western part of the east-west trending Skeena Arch, a regional structural culmination which separates the middle Mesozoic Bowser and Nechako basins (Figure 1). Mesozoic strata underlying the Skeena Arch are divisible into several volcanic and/or siliciclastic assemblages separated by unconformities. In ascending order the units are: Upper Triassic arc volcanics of the Takla Group; Lower to Middle Jurassic arc volcanic and clastic sedimentary strata of the Hazelton Group; wackes, fine grained sedimentary rocks and tuffs of the Middle Jurassic Ashman Formation, part of the Bowser Lake Group; Lower Cretaceous, mainly Albian sedimentary rocks and subordinate basalt flows of the Skeena Group; and, volcanic rocks of the the Upper Cretaceous Brian Boru Formation (Carter and Kirkham, 1969).

Several distinct suites of plutonic rocks also occur in the area. The Early to Middle Jurassic Topley intrusions invade Hazelton Group and older strata (Wheeler and McFeely, 1991; Wanless et al., 1974). Numerous small- and medium-sized, high-level stocks of the Late Cretaceous Bulkley intrusions and the Eocene Nanika intrusions have also been recognized in the region (MacIntyre, 1985). The Coast Plutonic Complex lie directly west of the Louise Lake area in the eastern Coast Belt.

Rocks of the Skeena Arch are variably folded and faulted. Takla, Hazelton and Skeena strata have undergone open to tight folding while Late Cretaceous and younger rocks are only gently warped. The region is cut by steep, generally north to northwest-trending faults.

GEOLOGY OF THE LOUISE LAKE DEPOSIT

The Louise Lake deposit is located near the headwaters of Coal Creek, at an elevation of about 1000 metres (Figure 2). Hazelton Group volcanic and Skeena Group sedimentary rocks, which underlie much of the property, are separated by the east-northeast-trending, steeply dipping Coal Creek lineament. Skeena Group conglomerate, sandstone and argillite, which occur north of the Coal Creek lineament, have been intruded by a swarm of quartz monzoritic feldspar porphyry sills which are altered and mineralized at Louise Lake. Prior to the present study

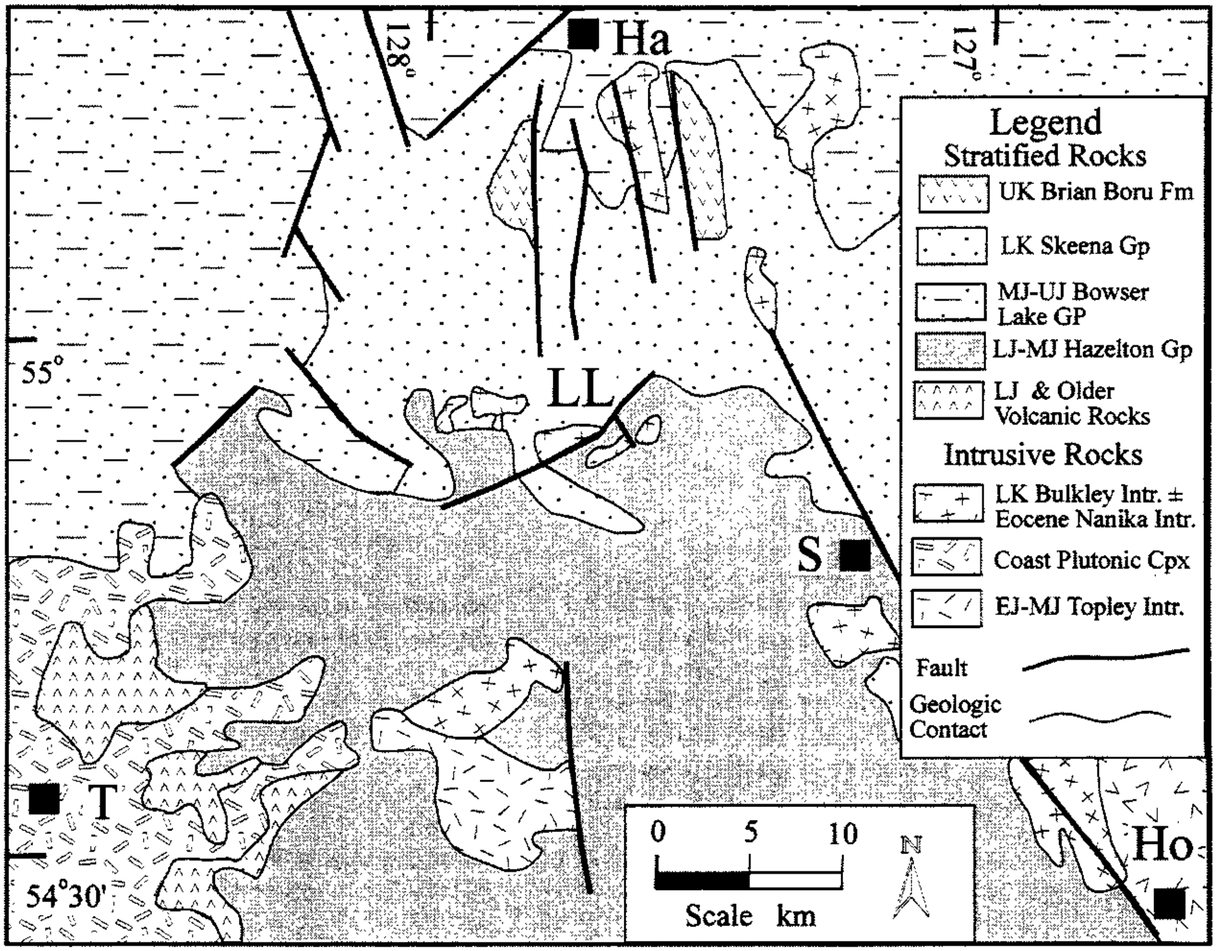

Figure 1. Regional geological map of the western Skeena Arch and vicinity, modified from Hanson and Klassen (1995) and Wheeler and McFeely (1991). Abbreviations: Ha: Hazelton; Ho: Houston; LL: Louise Lake deposit; S: Smithers; T: Terrace.

these sills were undated and were assigned, on the basis of lithology, to the Eocene Nanika intrusions. Postmineral feldspar porphyry dikes cut mineralized sills on the property.

Three distinct alteration zones have been recognized at the Louise Lake deposit. A core zone of strongly silicified and sericitized rocks with intense quartz-pyrite stockworks is mantled by a medial clay and quartz-sericite zone with some quartz-pyrite veining. This is, in turn, surrounded by a peripheral kaolinite zone characterized by modest quartz-pyrite veining. In addition to pyrite, sulfide minerals recognized at the deposit include chalcopyrite and molybdenite, with minor amounts of stibnite, sphalerite, chalcocite, bornite and tennantite; enargite is said to be present in trace amounts (N.C. Carter, personal communication, 1995). Gold appears to be associated with tennantite (Hanson and Klassen, 1995).

U-Pb GEOCHRONOLOGY

New U-Pb zircon data and an interpreted crystallization age for the Louise Lake feldspar porphyry sills are given in this report. Zircons grains were selected for analysis on the basis of their magnetic susceptibility, clarity, colour, grain size and morphology. In general only high quality, crack- and inclusion-free grains were chosen. All fractions were air abraded (Krogh, 1982) to remove about 10-20 volume percent of the outer part of each grain. Complete U-Pb analytical procedures employed at the University of British Columbia Geochronology Laboratory are reported in Mortensen *et al.* (1995). U-Pb data are shown on a concordia diagram on Figure 3 and listed in Table 1.

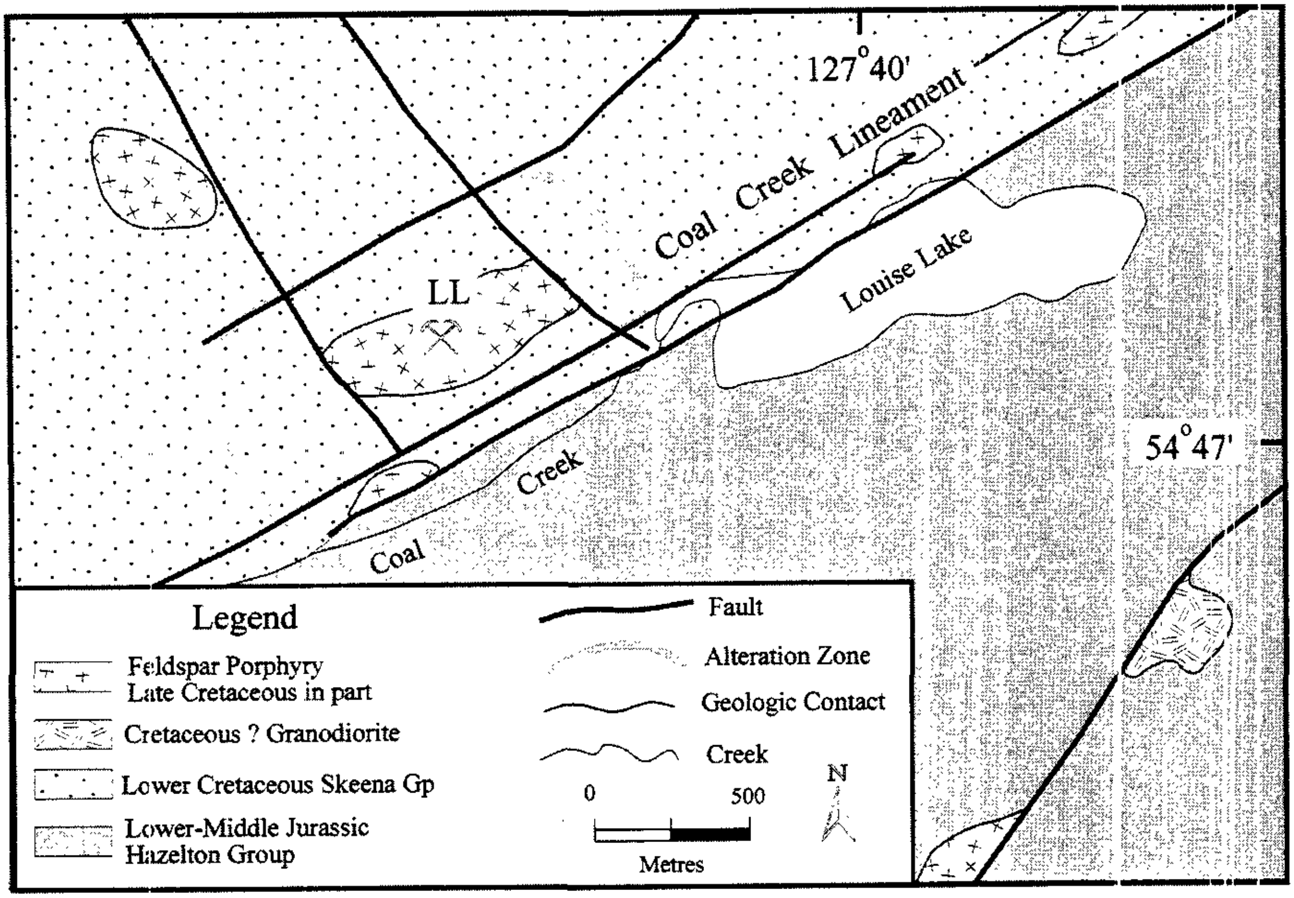

Figure 2. Map of the Louise Lake deposit after Hanson and Klassen (1995). LL denotes location of the Louise Lake deposit.

LOUISE LAKE PORPHYRY SILL: DDH-LL18

A sample of altered and mineralized feldspar porphyry sill was collected for geochronology from drill core during the 1995 field season. The dated sample contained about 15% euhedral to subhedral clay-altered feldspar phenocrysts in a fine-grained matrix of feldspar, sericite, kaolinite and quartz.

This sample yielded abundant, high quality, pale pink, stubby to rarely elongate, prismatic zircon. Three analysed fractions intersect concordia between about 85.5 Ma and 88.0 Ma, and indicate a Late Cretaceous crystallization age. Fraction B has the highest degree of concordance and is thought to provide the best age for this rock, while Fractions A and C appear to have undergone minor Pb loss. An interpreted crystallization age of 87.5 +4.9/-2.0 Ma is based on the $^{206}Pb/^{238}U$ age of fraction B, with conservatively estimated precisions. These errors are derived from the entire overlap of all ellipses with the concordia curve (minimum age) and the weighted $^{207}Pb/^{206}Pb$ age and associated precision of all fractions (maximum age).

A Late Cretaceous crystallization age of 87.5 +4.9/-2.0 Ma for the Louise Lake feldspar porphyry indicates that this intrusive unit is related to the Bulkley intrusions, and not the Nanika intrusions, as previously inferred. This age is several million years older than the reported age range for the Bulkley intrusions, which is based mainly on K-Ar cooling data (Carter, 1974; 1981).

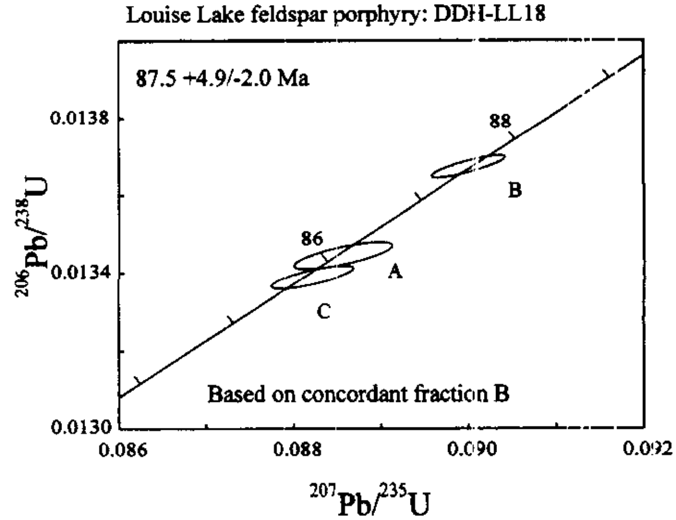

Figure 3. Concordia diagram for the Louise Lake feldspar porphyry (Sample DDH-LL18). Ellipses are plotted at the 2σ level of precision. See text for discussion.

TABLE 1. U-Pb ANALYTICAL DATA FOR THE LOUISE LAKE PORPHYRY

Fraction[1]	Wt	U^2	Pb*[3]	^{206}Pb[4]	Pb[5]	^{208}Pb[6]	Isotopic ratios (1σ,%)[7]			Apparent ages (2σ,Ma)[7]	
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
DDH-LL18: Louise Lake Feldspar Porphyry sill											
A cc,N2,p	0.091	457	6	1414	25	7.2	0.01344(0.13)	0.0886(0.32)	0.04777(0.24)	86.1(0.2)	88.1(11.4)
B c,N2,p	0.125	501	7	2575	21	7.5	0.01367(0.11)	0.0900(0.23)	0.04774(0.15)	87.5(0.2)	86.4(7.3)
C m,N2,p	0.112	541	7	2263	23	7.7	0.01339(0.11)	0.0882(0.27)	0.04778(0.19)	85.7(0.2)	88.4(9.2)

Notes: Analytical techniques are listed in Mortensen *et al.* (1995).

[1] Upper case letter = fraction identifier; All zircon fractions air abraded; Grain size, intermediate dimension: cc=>134μm, c= >134 μm and >104μm, m=<104μm and >74μm, f=<74μm; Magnetic codes:Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1=nonmagnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: b= broken fragments, e=elongate, eq=equant, p=prismatic, s=stubby, t=tabular, ti=tips.

[2] U blank correction of 1-3pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3] Radiogenic Pb

[4] Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 10pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

[5] Total common Pb in analysis based on blank isotopic composition

[6] Radiogenic Pb

[7] Corrected for blank Pb, U and common Pb. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the $^{207}Pb/^{206}Pb$ age of the fraction.

DISCUSSION

Based on the Late Cretaceous U-Pb age determined in this study, the Louise Lake porphyry deposit appears to be associated with the lithologically similar Bulkley intrusions, a plutonic suite responsible for numerous porphyry deposits in west-central British Columbia (Carter, 1974; 1976; 1981; Christopher and Carter, 1976; MacIntyre, 1976; 1985). The crystallization age of 87.5 +4.9/-2.0 Ma for the Louise Lake feldspar porphyry is considered to be a maximum age for alteration and mineralization at the Louise Lake deposit, which is hosted within and adjacent to this intrusion. Although this age does not directly constrain the timing of mineralization, the high-level nature of this intrusion and the associated Louise Lake deposit (Hanson and Klassen, 1995) strongly suggests that it underwent rapid cooling, and that late hydrothermal activity associated with mineralization did not significantly post-date primary igneous cyrstallization.

ACKNOWLEDGMENTS

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GEOLOGY AND MINERAL CHEMISTRY OF TIN-BEARING SKARNS RELATED TO THE SURPRISE LAKE BATHOLITH, ATLIN, NORTHERN BRITISH COLUMBIA.

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KEYWORDS: Economic geology, Atlin, Surprise Lake Batholith, Daybreak, Atlin Magnetite and Silver Diamond skarns, "within-plate" granites, F-rich granites, Sn-W skarns, wrigglite, F-rich garnet and vesuvianite, Cr-bearing garnet.

INTRODUCTION

The Silver Diamond, Atlin Magnetite and Daybreak Sn (W) skarns (B.C. Minfile numbers 104N 069, 126 and 134 respectively) in the Atlin district of northern B.C, are related to the Cretaceous-age Surprise Lake plutonic suite.

This paper describes the geology of these skarns and presents assay results on the mineralization and microprobe analytical chemical data on their garnet, clinopyroxene and vesuvianite assemblages. In addition, major and trace element data of the Surprise Lake Batholith is presented. The Daybreak occurrence, a recent discovery by prospector William Wallis of Atlin, is distinct in containing wrigglite textures in the proximal skarn (Webster *et al.*, 1992). Some of its garnets and vesuvianites contain anomalous quantities of F, Sn, Cl and Cr and the concentration of some of these trace elements is distinctly different in the proximal and distal mineral assemblages.

These three skarns are believed to have a relatively low economic potential, due to their small size and the current poor world market for tin and tungsten. However, because Sn skarns are very rare in B.C., these Atlin occurrences have considerable scientific interest. Moreover, if world markets improve, these occurrences indicate that the margins of the Surprise Lake Batholith, and correlative rocks elsewhere, have an exploration potential for tin, tungsten and fluorite.

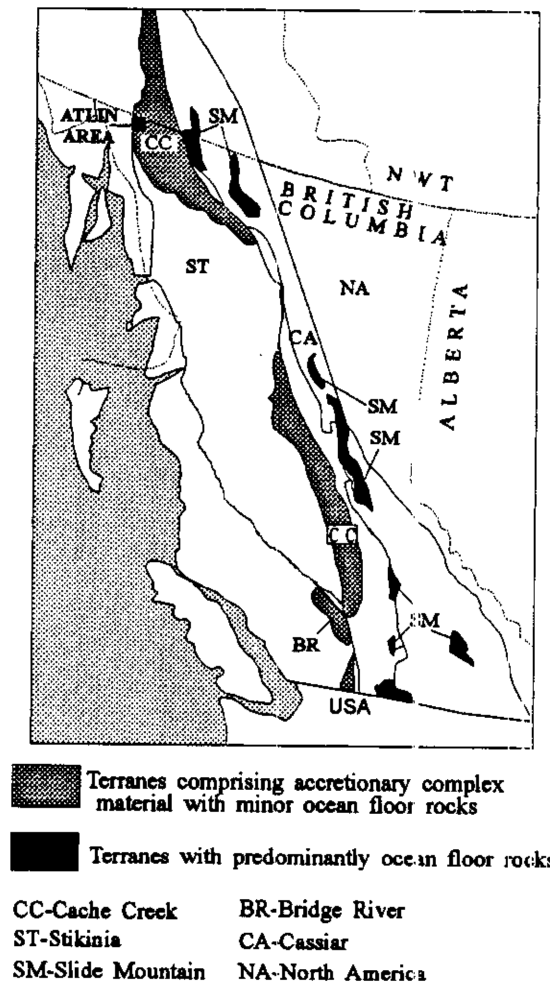

Figure 1. Location of the study area and its relationship to the northern portion of the Cache Creek Terrane in northern B.C. (after Monger, 1977).

REGIONAL GEOLOGY

The skarns described in this paper are situated in north-western British Columbia (Figure 1), approximately 20 kilometres east-northeast of Atlin and a few kilometres north and west of Surprise Lake (Figure 2) The area lies in the Intermontane Belt and is largely underlain by rocks of the allochthonous Cache Creek Terrane (Figure 1). The terrane consists predominantly of accretionary and subduction-related complexes of Mississippean to early Jurassic age (Monger, 1975, 1984; Monger *et al.*, 1982; Cordey *et al.*, 1991; Orchard, 1991). Also present are some ophiolitic ultramafic rocks related to the obduction of oceanic crust (Ash, 1994) and minor reefal limestones that may have formed in an oceanic island or seamount environment (Monger, 1975, 1977; Souther, 1977). The latter represent some of the host rocks for the Silver Diamond, Atlin Magnetite and

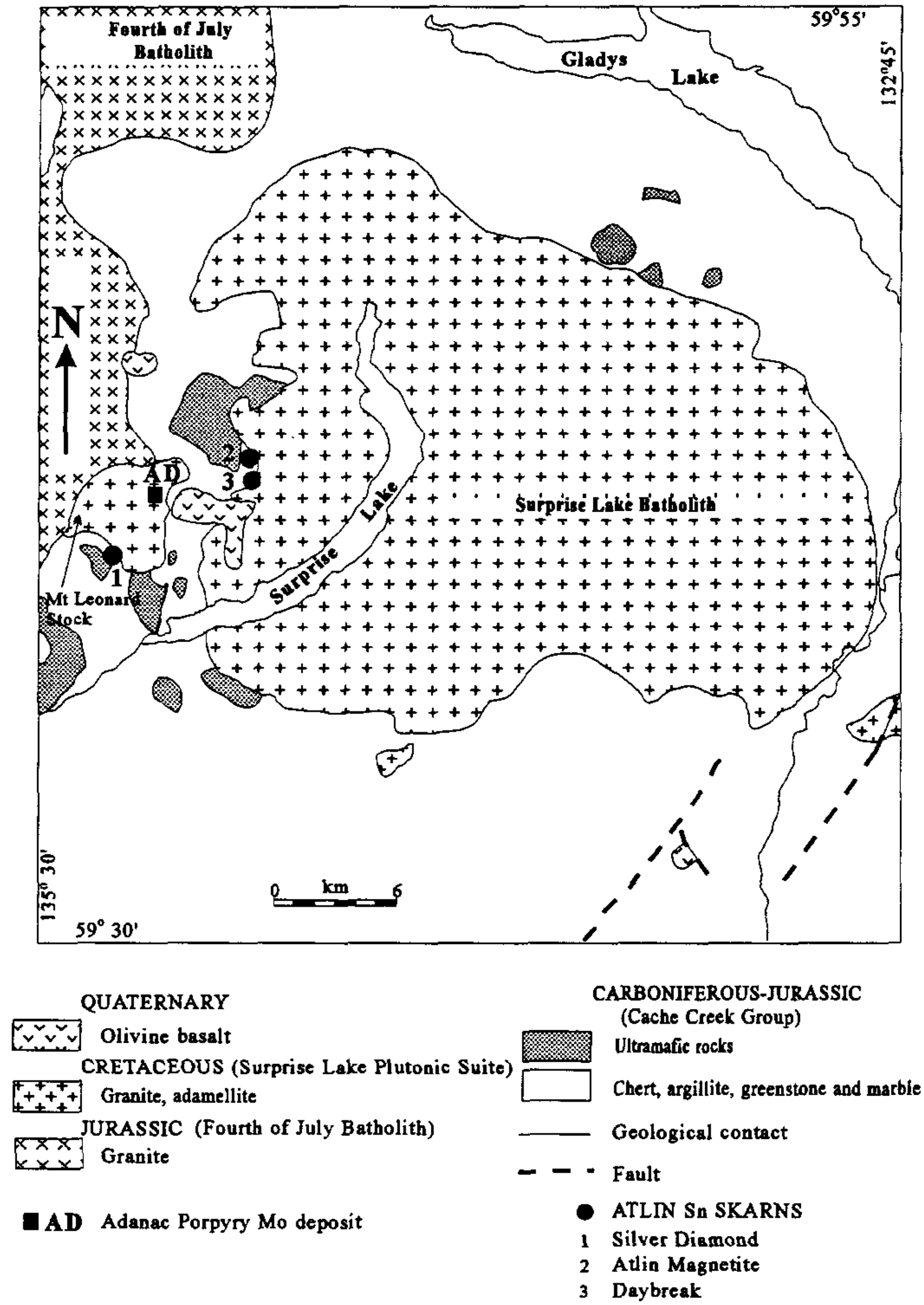

Figure 2. Geology and location of skarns associated with the Surprise Lake plutonic suite near Atlin, northwest B.C. (geology after Aitken, 1959).

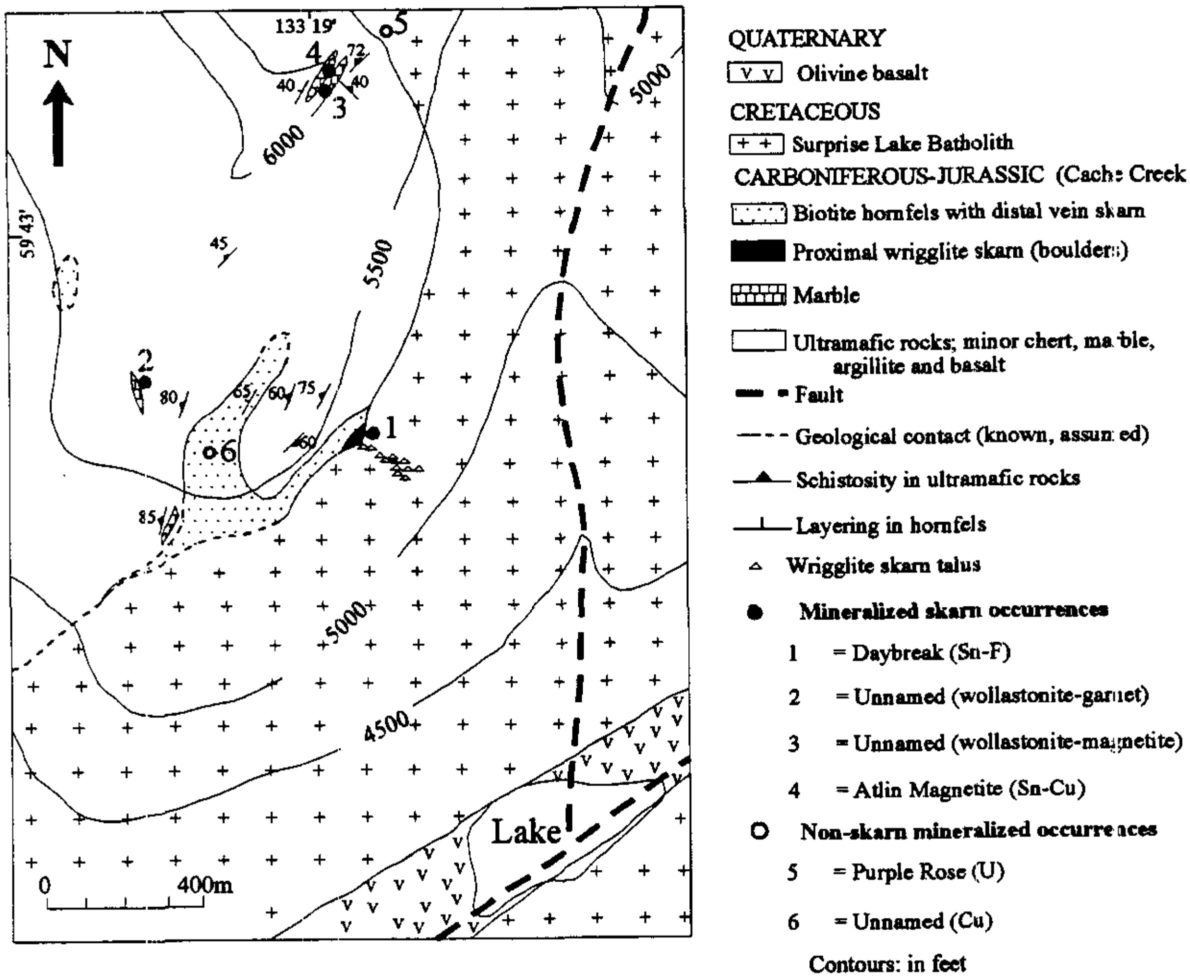

Figure 3. Geology in the vicinity of the Atlin Magnetite and Daybreak skarn occurrences, Surprise lake area (geological mapping by G.E. Ray and C.E. Kilby, 1995).

Daybreak skarns. Typically, the Cache Creek rocks at Atlin have undergone folding with intense brittle deformation and have been metamorphosed to subgreenschist grade (Monger, 1984; Bloodgood *et al.*, 1989a and b).

In the Surprise Lake area, the Cache Creek rocks are intruded by several plutons and smaller stocks. These include multiple phases of the Fourth of July Batholith (Figure 2; Aitken, 1959) which varies in composition from granite to granodiorite to diorite (Bloodgood *et al.*, 1989a and b). U-Pb zircon dating indicate a middle Jurassic age for this suite (Mihalynuk *et al.*, 1992).

A subsequent, regionally developed Cretaceous plutonic episode resulted in a number of major intrusions, including the Surprise Lake Batholith. The batholith forms an oval body approximately 30 kilometres by 20 kilometres in diameter (Figure 2). It has several small satellite bodies, the most westerly of which is the Mount Leonard stock. This stock hosts the Adanac porphyry molybdenum deposit (Figure 2; Christopher *et al.*, 1972; White *et al.*, 1976; Christopher and Pinsent, 1979) which has open pittable reserves of 152 million tonnes grading 0.063 percent molybdenum. The Mount Leonard stock is also associated with the Silver Diamond Sn (W) skarn. It includes coarse granitic and finer grained aplitic phases and, unlike the Surprise Lake Batholith, it locally contains hornblende (Bloodgood *et al.*, 1989a and b).

The much larger Surprise Lake Batholith is associated with a number of Sn-W-F-bearing veins (Bloodgood *et al.*, 1989a and b) as well as several low grade uranium showings (Ballantyne and Littlejohn, 1982) including the Purple Rose occurrence (Figure 3). The batholith is also genetically related to the Atlin Magnetite and Daybreak skarns (Figures 2 and 3). Age dating by various techniques indicates a Late Cretaceous age for the Surprise Lake body; Christopher and Pinsent (1979) report an average biotite K-Ar age of 70.6 Ma whereas U-Pb zircon dating by Mihalynuk *et al.*, (1992) gave an age of 83.8 Ma.

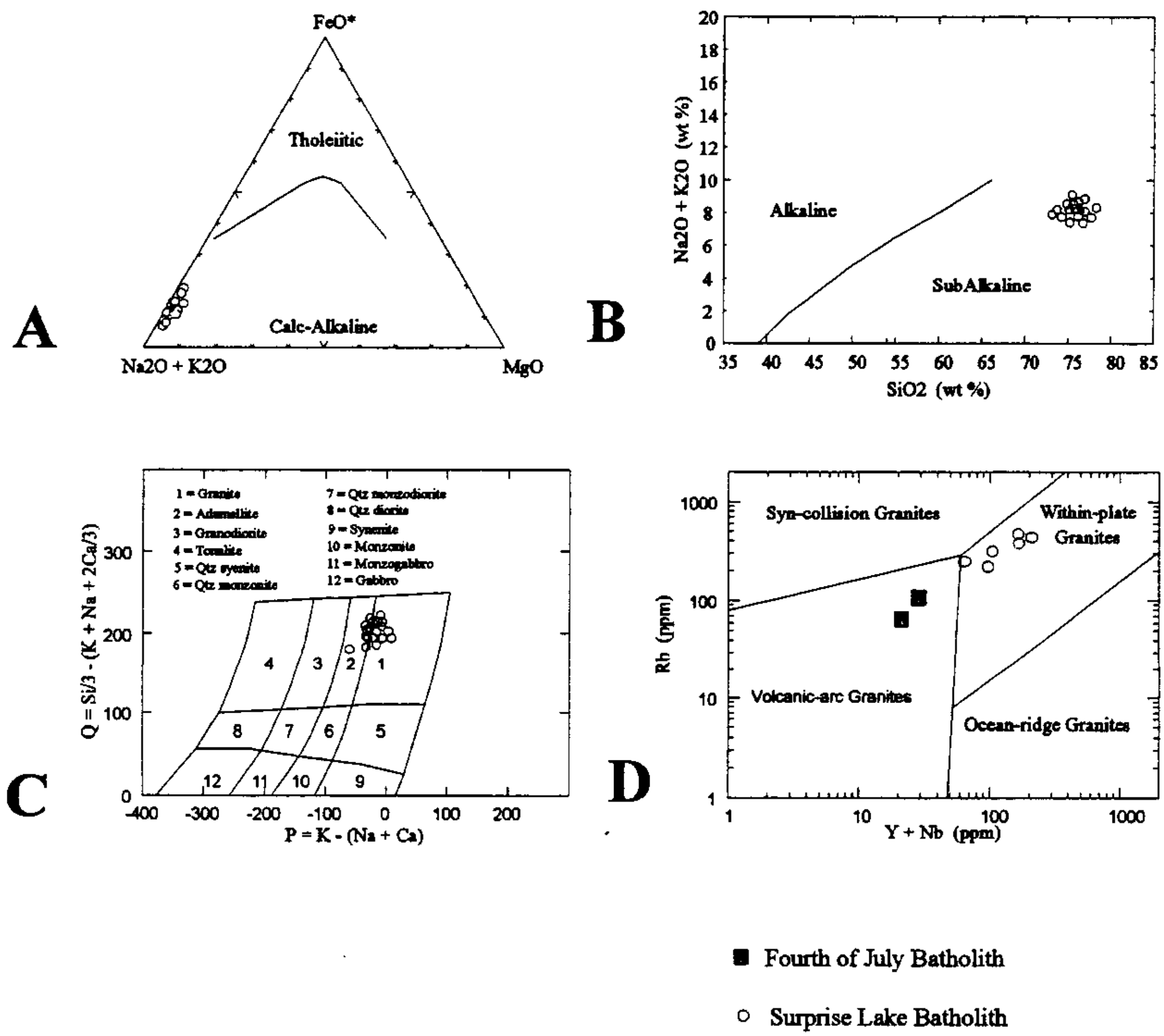

Figure 4. Geochemical plots of the Surprise Lake Batholith samples.
(A) Triangular $Na_2O + K_2O$ - FeO - MgO plot (after Irvine and Baragar, 1971).
(B) Alkali-silica plot (after Irvine and Baragar, 1971).
(C) Q - P plot (after Debon and Le Fort, 1983).
(D) Log Rb versus Log Y+Nb tectonic discrimination plot (after Pearce *et al.*, 1984) illustrating the volcanic arc character of the Fourth of July Batholith (data from Mihalynuk et al., 1992) and the within plate character of the Surprise Lake Batholith (data from Ray and Webster, in press).

The Surprise Lake Batholith largely comprises coarse to very coarse grained equigranular rocks with feldspar crystals up to 2 centimetres in length. It consists of sodic plagioclase, quartz and potassium feldspar with only minor amounts of coarse biotite; dark smoky quartz is a characteristic of the batholith (Bloodgood *et al.*, 1989a). Accessory minerals include zircon, apatite and late sericite and chlorite. Marginal phases of the batholith tend to be more quartz-rich and have a finer grained groundmass.

CHEMISTRY OF THE SURPRISE LAKE BATHOLITH

Major and trace element data of six samples of unaltered, coarse grained rocks collected from the batholith northeast of the Atlin Magnetite skarn are listed in Table 1; this data, together with analyses on another 13 samples presented by White *et al.*, (1976) and Christopher and Pinsent (1979) are used in Figure 4. Plots show that the Surprise Lake Batholith comprises

TABLE 1: Major and trace element chemistry of the Surprise Lake Batholith, Atlin, B.C.

Sample	GR91-145	GR91-146	GR91-147	GR91-148	GR91-165	GR91-166
SiO_2	76.19	76.47	77.00	76.45	75.51	75.58
TiO_2	0.09	0.10	0.11	0.10	0.20	0.06
Al_2O_3	12.45	12.42	12.00	12.39	12.46	13.08
Fe_2O_3*	1.40	1.29	1.52	1.30	2.07	1.19
MnO	0.02	0.01	0.03	0.03	0.05	0.02
MgO	0.03	0.02	0.02	0.02	0.15	0.00
CaO	0.62	0.63	0.54	0.54	0.48	0.37
Na_2O	3.30	3.32	3.24	3.56	3.17	4.01
K_2O	4.47	4.30	4.50	4.55	4.53	4.81
P_2O_5	0.01	0.01	0.01	0.01	0.04	0.01
LOI	0.83	0.95	0.77	0.58	0.84	0.47
Sum	99.41	99.52	99.74	99.53	99.50	99.60
FeO	1.07	0.66	1.04	0.79	1.27	0.66
Fe_2O_3	0.21	0.56	0.36	0.42	0.66	0.46
Fe_2O_3/FeO	0.20	0.84	0.35	0.53	0.52	0.69
K_2O/Na_2O	1.35	1.30	1.39	1.28	1.43	1.20
Ba	153	155	251	333	382	40
Ce	86	99	91	97	86	45
Cr	10	>10	14	>10	>10	>10
Cs	7	6	<5	<5	<5	<5
F	3860	3580	2940	2720	1580	1920
La	41	40	42	40	34	7.5
Nb	34	33	24	19	19	69
Rb	429	396	315	240	250	402
Sc	<5	<5	<5	<5	<5	<5
Sn	25	<15	21	<15	23	<15
Sr	20	19	27	28	45	<5
Th	34	31	34	25	21	33
U	<15	<15	<15	<15	<15	<15
V	<5	<5	<5	<5	<5	<5
Y	126	128	89	87	41	123
Zr	144	146	178	133	177	141

Samples collected by G.E. Ray and I.C.L. Webster, 1991.
Samples are of a coarse-grained, equigranular, biotite-bearing granite
Fe_2O_3* = total iron as Fe_2O_3.
Major elements in percent; trace elements in ppm.
For analytical methods etc. see Ray et al., 1995

calcalkaline, subalkaline rocks of adamellite-granite composition (Figure 4A, 4B and 4C). A trace element tectonic discrimination plot after Pearce *et al.* (1984) indicates that the batholith represents a "within-plate granitoid" in contrast to the older Fourth of July Batholith whose magma source probably had a "volcanic arc" characteristic (Mihalynuk *et al.*, 1992; Figure 4D).

The Surprise Lake Batholith has a markedly different chemistry to the arc-generated plutonic suites related to Fe, Cu, Au and Mo skarns in British Columbia (Ray *et al.*, 1995). On average, it contains less Ca, Fe, Mg, Ba, Cr, Sr, V and more Si, alkalis, Ce, F, La, Nb, Rb, Sn, U and Y than the other suites; this is consistent with it representing a highly differentiated melt derived from continental crust. In much of its overall major and trace element chemistry, the Surprise Lake Batholith closely resembles many of the peraluminous plutons responsible for W skarns in British Columbia (Ray *et al.*, 1995); both suites, for example, are comparatively enriched in Rb and depleted in Sc and Ba (Figure 5). However, the Surprise Lake rocks are distinct in having

TABLE 2A: Assay results of mineralized grab samples from the Silver Diamond skarn, Atlin, B.C.

Sample	GR91-149*	GR91-154A*	GR91-150*	GR91-154*	GR91-155**
Au-ppb	25	29	97	5	55
Ag	169	17	82	15	459
Cu	6600	1400	6200	1400	10200
Pb	1200	62	820	64	10400
Zn	165000	2900	369	2700	20500
Co	6	5	58	5	24
Ni	21	4	48	3	61
Mo	<3	<3	<3	<3	<3
As	37	1	1	1	36
Sb	7	1	16	1	3
Bi	396	32	2400	37	900
Cd	2900	73	14	78	410
Te	6.0	0.7	81.0	0.6	7.0
Se	9.0	<5	<5	<5	13.0
Ba	110	200	<100	330	<100
Cr	25	24	82	32	150
Rb	<30	330	150	350	54
Sn	<300	<300	<300	<300	<400
W	2	4600	3000	4600	5500
F	520	55000	59500	48900	50900

Samples collected by G.E. Ray, I.C.L. Webster and C.E.Kilby, 1991 and 1995.

Analytical methods etc. *see* Ray and Webster, in press.

Analyses in ppm except where stated in ppb

* Pyrrhotite-fluorite samples from Silver Diamond trench.

** Float of mineralized quartz vein, Silver Diamond skarn.

unusually high quantities of F (Figure 6), averaging 2767 ppm F compared to W skarns-related plutons which average less than 400 ppm F (Ray *et al.*, 1995; Ray and Webster, in press).

GEOLOGY AND MINERALOGY OF THE SKARNS

Silver Diamond skarn

The Silver Diamond skarn lies close to the southwest margin of the Mount Leonard stock (Webster *et al.*, 1992; Figure 2) about 4.5 kilometres southwest of Ruby Mountain. Trenches expose mineralized skarn which occurs as pods, veins and irregular lenses of massive to disseminated sulphide, up to 1 metre wide. This mineralization occurs mainly along the contact between a crystalline, massive to thinly layered marble and a unit of greenstone and ultramafic rocks. In parts, the greenstone unit is strongly brecciated and the angular fragments are surrounded and cut by sulphide veinlets. Mineralization consists largely of pyrrhotite and sphalerite with minor chalcopyrite, pyrite, scheelite and fluorite. Locally, the colourless to purple fluorite forms over 50 percent by volume of the rock. It occurs either as large crystalline masses, that are stained with black manganese oxides and intergrown with sericite, or as isolated crystals growing within the massive sulphides.

Assays of mineralized grab samples (Table 2A) indicate that the Silver Diamond skarn contains, in addition to W, Cu, Zn and Pb, anomalous quantities of Ag, Bi, Cd, Te and Se. Float material of vein quartz containing sphalerite and galena also occurs near the skarn. Also, a short distance northeast of the Silver Diamond skarn in what may be a separate occurrence, MINFILE reports some scheelite, cassiterite, molybdenite and tetrahedrite mineralization.

Brown and red coloured garnet is relatively uncommon; it occurs as veinlets cutting the marble and greenstone as well as thin layers that commonly develop

TABLE 2B: Assay results of mineralized grab samples from the Daybreak and Atlin Magnetite skarns, Atlin, B.C.

Sample	GR91-159*	GR95-141*	GR95-142**	GR95-150***	GR95-152***	GR91-140***	GR91-144***
Occurrence	Daybreak	Daybreak	Daybreak	Atlin Magnetite	Atlin Magnetite	Atlin Magnetite	Atlin Magnetite
Au-ppb	19	660	61	201	287	305	646
Ag	1.0	6	19	69	<5	65.0	36.0
Cu	4	13	3463	4362	592	8800	6300
Pb	10	< 5	64	63	28	114	58
Zn	640	556	607	429	1405	539	1300
Co	8	16	92	55	86	56	81
Ni	7	24	187	13	68	23	16
Mo	11	2	< 2	< 2	< 2	<3	<3
As	70	95	12	47	72	87	210
Sb	18	< 5	< 5	< 5	< 5	2	3
Bi	70	917	341	57	64	68	210
Cd	0.4	<0.4	5.1	2.6	8.9	3.6	5.1
Te	0.30	8.4	<0.6	<0.6	<0.6	<0.3	<0.3
Se	<5	2.4	2.4	0.8	0.8	5	<5
Ba	<100	10	193	119	25	<100	<100
Cr	44	< 2	451	19	112	140	70
Rb	<30	<15	<15	55	<15	35	<30
Sn	<200	1754	459	1787	2003	2100	2000
W	550	190	110	89	95	9	39
F	47000	140000	1400	390	350	300	160
Hg ppb	-	15	25	225	30	-	-
U	-	26	13	< 10	< 10	-	-
Nb	-	3	19	< 2	< 2	-	-
Be	-	394	< 1	15	12	-	-
S %	-	0.02	0.02	0.29	0.01	-	-

Samples collected by G.E. Ray, I.C.L. Webster and C.E.Kilby, 1991 and 1995.

Analytical methods etc. see Ray and Webster, in press.

Analyses in ppm except where stated in ppb or percent

* Proximal magnetite-garnet-fluorite-vesuvianite wrigglite skarn, Daybreak.

** Distal garnet-pyroxene-vesuvianite vein skarn cutting hornfels, Daybreak.

*** Magnetite-rich mineralization, Atlin Magnetite.

between marble and green pyroxene-rich skarn. In addition, variable amounts of amphibole, biotite, sericite and very coarse grained clinopyroxene are present in the skarn. The greenstone adjacent to the sulphide-fluorite skarn is bleached, silicified and contains some secondary pyroxene and amphibole. Greenstone adjacent to marble contains remnant patches of a black to dark purple-brown coloured biotite hornfels that have locally been overprinted by skarn alteration. Transition from marble to hornfels is often marked by the following mineral zoning: (1) marble, (2) garnet-rich skarn, (3) pyroxene-rich skarn and (4) hornfels.

In thin section the pyroxene-rich skarn contains very large, well cleaved and tabular crystals of clinopyroxene up to 8 millimetres in length. The moderate to high birefringent pyroxene is intergrown with well twinned sodic plagioclase and is weakly altered to carbonate and sericite. Many pyroxenes are cut by sulphide veinlets and contain small, rounded inclusions of quartz, plagioclase and garnet. Garnet crystals are generally anhedral and seldom exceed 2 millimetres in diameter. They

TABLE 3: Microprobe analyses of pyroxenes from the distal vein skarn, Daybreak occurrence, Atlin, B.C.

	Oxide Weight Percent					
	2	3	4	5	6	18
Na_2O	0.06	0.38	0.23	0.21	0.08	0.20
FeO*	15.03	13.14	13.65	13.51	13.63	14.61
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
SiO_2	51.67	51.38	51.19	51.41	51.85	51.59
CaO	23.80	23.85	24.00	24.20	24.29	24.22
Al_2O_3	0.23	1.21	0.84	0.79	0.16	0.95
TiO_2	0.02	0.11	0.05	0.09	0.00	0.08
MgO	8.40	9.52	9.15	9.37	9.23	8.66
MnO	0.58	0.41	0.36	0.31	0.48	0.39
Total	99.80	100.00	99.48	99.88	99.72	100.69
	Number of ions on the basis of 6 oxygens and 0 OH					
Na	0.00	0.03	0.02	0.02	0.01	0.01
Fe	0.49	0.42	0.44	0.43	0.44	0.47
K	0.00	0.00	0.00	0.00	0.00	0.00
Si	2.00	1.97	1.98	1.98	2.00	1.98
Ca	0.99	0.98	0.99	1.00	1.00	0.99
Al	0.01	0.05	0.04	0.04	0.01	0.04
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.49	0.54	0.53	0.54	0.53	0.49
Mn	0.02	0.01	0.01	0.01	0.02	0.01
Total	3.99	4.01	4.01	4.01	4.00	4.01
Hedenbergite	49.13	43.06	45.03	44.26	44.58	47.98
Diopside	48.95	55.58	53.77	54.72	53.83	50.72
Johannsenite	1.92	1.36	1.20	1.02	1.59	1.31
Fassite	1.07	5.60	3.87	3.61	0.75	4.31

Microprobe analyses by G.E. Ray and S. Cornelius.
FeO* = total iron as FeO

commonly have pale brown margins and dark cores due to abundant opaque inclusions, and are mostly isotropic with very thin, weakly birefringent margins.

Many of the pyroxenes at the Silver Diamond skarn are hedenbergitic and plot as johannsenite-hedenbergite solid solutions (Figure 7). However, a few pyroxenes are diopsidic (Figure 7). Microprobe analyses of garnets from the Silver Diamond indicate they are mostly low-Mn and grossularitic (Figure 7) averaging 82 mole percent grossularite. They are weakly enriched in Sn (up to 0.25 weight percent Sn) but unlike some garnets at the Daybreak skarn, no anomalous Cr or Cl values are recorded and, apart from two crystals containing 0.2 and 0.1 weight percent F respectively, most garnets samples contain no detectable F.

Discrimination plots using garnet-pyroxene composition data as outlined by Einaudi (1982), together with the high pyrrhotite/pyrite ratios of the mineralization suggests that the Silver Diamond formed in a relatively reduced environment.

Atlin Magnetite skarn

The Atlin Magnetite skarn lies approximately 8 kilometres northeast of the Silver Diamond skarn and 1 kilometre north of the Daybreak skarn (Figures 2 and 3) at about 1830 metres (6000 feet) elevation. It is situated approximately 200 metres from the margin of the Surprise Lake Batholith and is hosted mainly by thin, deformed units of marble which are within a thermally

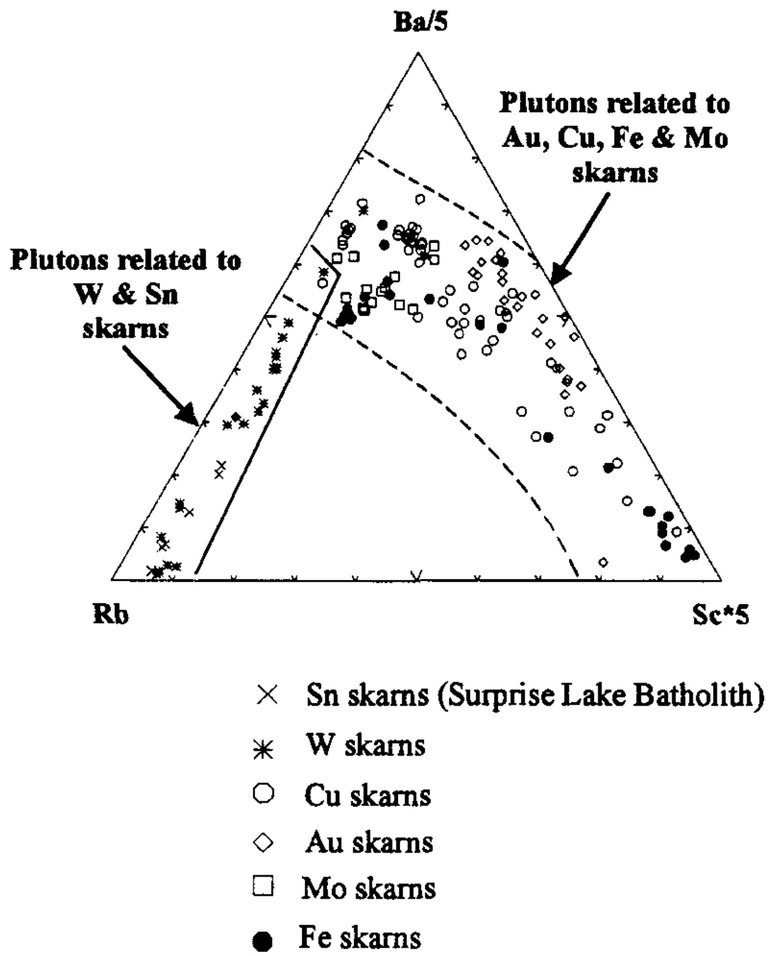

Figure 5. Triangular Rb-Ba/5-Sc*5 discrimination plot of plutonic rocks related to Sn skarns (Surprise Lake Batholith) and W, Au, Cu, Mo and Fe skarns in B.C. (data from Ray and Webster, in press).

altered package of sheared greenstone, talcose and serpentinized ultramafic rocks and biotite hornfels. The marginal phase of the batholith is a rusty-weathering, medium grained quartz porphyry which is texturally distinct from the coarser grained rocks seen in the more interior portions of the batholith. It hosts the Purple Rose uranium occurrence (MINFILE number 104N 005) which lies approximately 250 metres north-northeast of the Atlin Magnetite skarn (Figure 3).

Mineralization is dominated by layers and masses of massive magnetite, up to 0.6 metre thick, that have replaced the moderately dipping marble layers. Massive magnetite is both intimately intergrown with garnet and cut by veinlets of amber-coloured garnet. Locally, both the magnetite layers and the marble display a cleavage which strikes northwest and dips 40 degrees northeast. Lesser amounts of chalcopyrite and sporadic pyrrhotite and pyrite occur within the magnetite. Azurite and malachite staining is widespread. Assays of sulphide-bearing magnetite samples presented in Table 2B indicate that the Atlin Magnetite mineralization contains up to 646 ppb Au as well as anomalous quantities of Sn, Cu, Ag, Bi and Zn. However, in contrast to both the Silver Diamond and Daybreak skarns, it is not enriched in F, Te or Se.

Layers, masses and veins of garnet are present with lesser amounts of pyroxene, actinolite, coarse green epidote and some late veins of rhodonite. In hand sample, garnets vary in colour from red, orange and yellow-green to dark green, brown, amber and black. Some of the sugary textured marbles contain euhedral crystals of black garnet up to 1 centimetre across. Immediately east of the main showing is an area of purple-brown coloured, fine grained biotite hornfels. The hornfels is cut by veins of bright green pyroxene and dark green garnet, which in turn are cut by veins containing radiating crystals of wollastonite up to 3 centimetres long. Float is also seen in which the coarse wollastonite is separated from marble by thin layers of dark green garnet.

At the main occurrence, passage from hangingwall to footwall is marked by the following mineralogical and

TABLE 4: Representative microprobe analyses of garnets in the proximal wrigglite skarn, Daybreak occurrence, Atlin, B.C.

	DBB2	DBB3	DBB4	DBB5	DBB6	DBB7	DBB8	DBB9	DBB10	DBB12	DDB20
Oxide Weight Percent											
F	0.29	0.18	0.33	0.48	0.19	0.27	0.25	0.55	0.25	0.62	0.74
Na_2O	0.02	0.00	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.03
MgO	0.13	0.00	0.10	0.11	0.02	0.00	0.10	0.03	0.09	0.09	0.12
Al_2O_3	16.12	16.28	16.38	16.51	17.02	16.59	16.00	17.00	15.75	14.98	17.45
SiO_2	37.69	37.92	37.65	37.48	37.76	37.55	37.46	37.88	37.36	37.58	37.70
Fe_2O_3*	14.06	13.79	13.56	13.03	13.17	13.29	14.03	13.33	13.96	15.03	11.78
MnO	0.94	0.92	1.02	0.89	0.98	1.01	1.09	1.04	0.96	1.01	0.97
Cr_2O_3	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Sn_2O	0.07	0.11	0.09	0.15	0.12	0.15	0.09	0.13	0.07	0.09	0.09
CaO	31.54	31.66	31.34	31.77	31.24	31.25	31.04	31.09	31.60	31.04	31.45
TiO_2	0.00	0.01	0.02	0.00	0.03	0.00	0.00	0.04	0.02	0.00	0.01
Total	100.90	100.87	100.51	100.45	100.55	100.15	100.08	101.12	100.08	100.47	100.34
Number of ions per calculated formula unit on the basis of 12 oxygens and 0 OH											
F	0.07	0.04	0.08	0.12	0.05	0.07	0.06	0.14	0.06	0.15	0.18
Na	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Mg	0.02	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01
Al	1.47	1.49	1.50	1.52	1.55	1.52	1.47	1.55	1.45	1.39	1.60
Si	2.92	2.94	2.93	2.92	2.92	2.93	2.93	2.93	2.93	2.95	2.93
Fe	0.82	0.80	0.79	0.76	0.77	0.78	0.83	0.78	0.82	0.89	0.69
Mn	0.06	0.06	0.07	0.06	0.06	0.07	0.07	0.07	0.06	0.07	0.06
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	2.62	2.63	2.61	2.65	2.59	2.61	2.60	2.57	2.65	2.61	2.62
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	8.00	7.96	8.00	8.05	7.96	7.98	7.98	8.04	8.00	8.07	8.11
Pyralspite	2.85	2.26	2.93	2.63	2.50	2.49	3.10	2.70	2.72	2.91	2.88
Grossularite	79.07	80.65	80.80	80.86	85.12	82.91	79.33	85.10	77.27	74.40	86.04
Andradite	18.08	17.09	16.28	16.51	12.37	14.60	17.57	12.20	20.01	22.68	11.08

Microprobe analyses by S.B. Cornelius

Fe_2O_3* = total iron as Fe_2O_3

textural zoning: (1) cleaved ultramafic rocks and biotite hornfels, (2) a 2 metre-thick unit of massive, sugary textured and bleached marble with isolated black garnets, (3) a 15 to 20 centimetre-thick carbonate layer with calcite crystals up to 2.5 centimetres in length, (4) a 1 to 2 centimetre-thick layer of rhodonite, (5) a 0.6 metre-thick unit of massive, crystalline magnetite with minor garnet, pyroxene, sulphides and malachite staining, and (6) massive bleached marble in the footwall.

Some of the anhedral to euhedral garnets exhibit a fine optical zoning comprising thin, alternating bands of colourless and pale brown material. This zoning is matched by the mainly isotropic crystals containing numerous thin zones of weakly birefringent garnet; the garnet margins are invariably occupied by thin rims of moderately birefringent grossular garnet. Some garnet crystals are cut by veinlets of magnetite and sulphides. Microprobe analyses indicates that the garnets are low-Mn andradites (Figure 7) with an average composition of 94 mole percent andradite. In contrast to the garnets at the nearby Daybreak skarn, they show no enrichment in either F, Cr, Cl or Sn.

Pyroxenes at the Atlin Magnetite skarn form well cleaved, moderately altered crystals up to 1 millimetre long; they occur as inclusions in the garnet or as intergrowths with quartz or magnetite. Microprobe

TABLE 5: Representative microprobe analyses of distal vein garnets cutting biotite hornfels, Daybreak occurrence, Altin, B.C..

Crystal	158-3	158-5	158-7	158-9	158-10	158-14	158-15	158-21	158-27	158-23	158-24	Average of F-rich garnets n = 14	Average of F-poor garnets n = 14
F	1.43	1.15	1.64	2.07	1.73	0.00	0.03	0.05	0.18	0.42	0.69	1.47	0.03
Cr_2O_3	0.03	0.01	0.03	0.12	0.03	1.12	1.05	1.19	0.61	0.48	1.02	0.14	0.87
Na_2O	0.20	0.21	0.19	0.22	0.17	0.01	0.02	0.01	0.03	0.00	0.00	0.17	0.03
Fe_2O_3*	5.20	5.25	5.12	5.26	5.32	11.36	9.98	11.36	10.96	10.66	13.49	6.21	10.74
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
SiO_2	36.44	36.65	36.32	36.52	36.38	38.13	38.48	37.88	37.96	38.51	37.24	36.69	38.23
CaO	34.78	34.94	34.88	35.06	34.97	32.07	33.09	32.33	32.87	32.92	32.87	34.65	32.90
Al_2O_3	15.57	15.23	15.13	14.87	15.26	15.43	16.17	15.64	15.72	16.73	13.29	15.21	15.92
TiO_2	2.84	3.03	3.07	3.68	2.75	0.74	0.71	0.64	0.74	0.40	0.54	2.73	0.67
MgO	1.59	1.68	1.53	1.68	1.62	0.15	0.13	0.13	0.14	0.14	0.07	1.42	0.15
MnO	0.15	0.10	0.04	0.11	0.13	0.77	0.56	0.77	0.68	0.64	0.73	0.19	0.64
TOTAL	98.23	98.25	97.95	99.59	98.36	99.78	100.22	100.01	99.89	100.90	99.94	98.87	100.18
	Number of ions per calculated formula unit based on 12 oxygen and 0 OH												
Na	0.031	0.032	0.030	0.034	0.026	0.002	0.003	0.002	0.005	0.000	0.000	0.03	0.00
Fe	0.312	0.314	0.309	0.314	0.320	0.672	0.585	0.672	0.646	0.620	0.812	0.37	0.63
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.00	0.00
Si	2.905	2.914	2.912	2.899	2.909	2.996	2.998	2.977	2.973	2.976	2.980	2.92	2.98
Ca	2.971	2.976	2.997	2.982	2.997	2.700	2.762	2.722	2.758	2.726	2.818	2.95	2.75
Al	1.463	1.427	1.430	1.391	1.439	1.429	1.485	1.449	1.451	1.524	1.254	1.43	1.46
Ti	0.170	0.181	0.185	0.220	0.165	0.044	0.042	0.038	0.044	0.023	0.032	0.16	0.04
Mg	0.189	0.199	0.183	0.199	0.193	0.018	0.015	0.015	0.016	0.016	0.008	0.17	0.02
Mn	0.010	0.007	0.003	0.007	0.009	0.051	0.037	0.051	0.045	0.042	0.049	0.01	0.04
Sum	8.05	8.05	8.05	8.05	8.06	7.91	7.93	7.93	7.94	7.93	7.95	8.04	7.93
Mole %													
Pyralspite	7.47	7.88	7.11	8.06	7.65	2.18	1.68	2.09	1.95	1.80	1.87	6.87	1.88
Grossularite	74.95	74.10	75.12	73.53	74.14	65.85	70.06	66.24	67.25	69.29	58.81	72.86	68.01
Andradite	17.57	18.02	17.77	18.41	18.21	31.97	28.26	31.67	30.79	28.91	39.32	20.27	30.11

Microprobe analyses by S.B. Cornelius and G.E. Ray

Fe_2O_3* = total iron as Fe_2O_3

analyses indicate they are diopsidic in composition (Figure 7).

Abundant magnetite together with the garnet-pyroxene compositions suggest that the Atlin Magnetite system may have been relatively depleted in sulphur and that it formed in more oxidized conditions than the Daybreak and the Silver Diamond skarns.

Daybreak skarn

The Daybreak occurrence is situated approximately 1 kilometre south of the Atlin Magnetite skarn (Figure 3) at an elevation of 1650 to 1730 metres (approximately 5400 to 5700 feet). The area is underlain by altered greenstone, serpentinized ultramafic rocks, schistose hornfelsic metasediment and mafic tuff and thin units of

TABLE 6: Representative microprobe analyses of skarn vesuvianites, Daybreak occurrence, Atlin, B.C..

	Vesuvianites in proximal wrigglite skarn					Avg. of
Sample	29157	30157	31157	32157	33157	wrigglite skarn
F	1.77	1.45	1.50	1.48	1.52	1.54
Na_2O	0.00	0.01	0.01	0.01	0.06	0.02
MgO	0.95	1.49	1.78	0.32	1.06	1.12
Al_2O_3	15.45	14.08	14.08	15.55	16.97	15.23
SiO_2	35.63	35.55	35.43	35.48	36.12	35.64
Fe_2O_3*	8.63	9.62	9.18	10.05	6.46	8.79
MnO	0.38	0.32	0.24	0.42	0.24	0.32
Cr_2O_3	0.01	0.01	0.01	0.06	0.03	0.02
Cl	0.29	0.33	0.37	0.32	0.36	0.33
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Sn_2O	0.13	0.15	0.12	0.08	0.04	0.10
CaO	34.77	34.97	35.16	34.45	35.41	34.95
TiO_2	0.00	0.01	0.05	0.01	0.02	0.02
OH	2.40	2.39	2.39	2.40	2.45	2.41
Total	100.41	100.38	100.32	100.63	100.74	100.49

	Vesuvianites in distal vein skarn							Avg. of
Sample	10158	11158	12158	13158	14158	15158	16158	distal skarn
F	1.28	1.23	1.52	1.40	1.48	1.11	1.36	1.34
Na_2O	0.18	0.17	0.17	0.23	0.23	0.23	0.22	0.20
MgO	1.57	1.74	1.70	1.65	1.64	1.64	1.63	1.65
Al_2O_3	15.56	15.62	15.74	14.91	15.59	15.72	15.51	15.52
SiO_2	36.43	36.65	36.56	36.63	36.63	36.60	36.52	36.57
Fe_2O_3*	5.33	5.12	5.11	5.19	5.05	5.15	5.03	5.14
MnO	0.13	0.15	0.17	0.11	0.16	0.15	0.13	0.14
Cr_2O_3	0.03	0.04	0.04	0.01	0.00	0.04	0.01	0.02
Cl	0.06	0.04	0.04	0.13	0.04	0.05	0.04	0.06
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sn_2O	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01
CaO	35.03	34.97	35.12	35.00	34.67	34.93	35.09	34.97
TiO_2	2.35	2.44	2.51	3.19	2.61	2.65	2.64	2.63
OH	2.47	2.48	2.48	2.48	2.47	2.48	2.47	2.48
Total	100.44	100.66	101.19	100.94	100.58	100.76	100.66	100.74

Microprobe analyses by G.E. Ray.

Fe_2O_3* = total iron as Fe_2O_3

marble; some of the latter are associated with minor amounts of wollastonite-garnet skarn.

The occurrence includes a small area of proximal wrigglite-textured skarn and a larger extent of barren distal skarn comprising veins of garnet, pyroxene and lesser vesuvianite which partially replaces a biotite hornfels. The term "wrigglite" to describe rhythmically layered skarn was first used by Askins (1976) and later by Kwak and Askins (1981) although the texture has been recognized since the early part of this century. Kwak (1987) discusses the origin of wrigglite textures and notes it is a characteristic of Fe and F-rich tin skarns, most of which contain fluorine in excess of 9 weight per cent. Wrigglite skarn is commonly associated with fault structures and, unlike most Sn skarns which generally form at deep levels, it is believed to develop in relatively near-surface conditions such as over the cupolas of high-level granites (Kwak, 1987). Its presence in the Daybreak skarn is consistent with other high-level features in the Surprise Lake Batholith such as miarolitic cavities and the finer grained chilled margins.

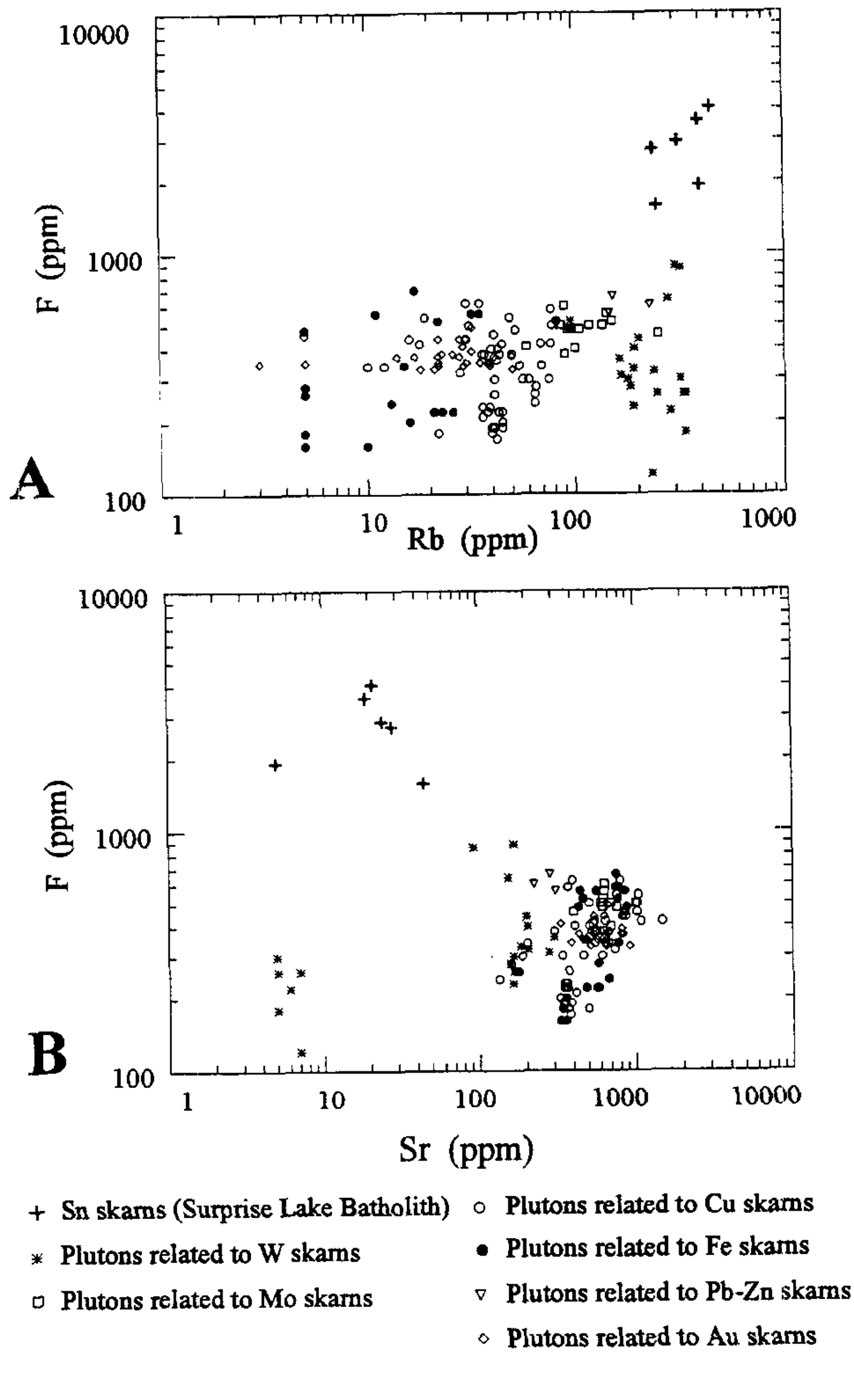

Figure 6. Geochemical plots of plutonic rocks related to Sn skarns (Surprise Lake Batholith), and W, Au, Cu, Mo, Pb-Zn and Fe skarns in B.C. (data from Ray and Webster, in press). The Surprise Lake Batholith and the plutons related to W skarns have similar Rb and Sr contents, but the batholith can be discriminated by its high F content.
(A) Log F versus Log Rb.
(B) Log F versus Log Sr.

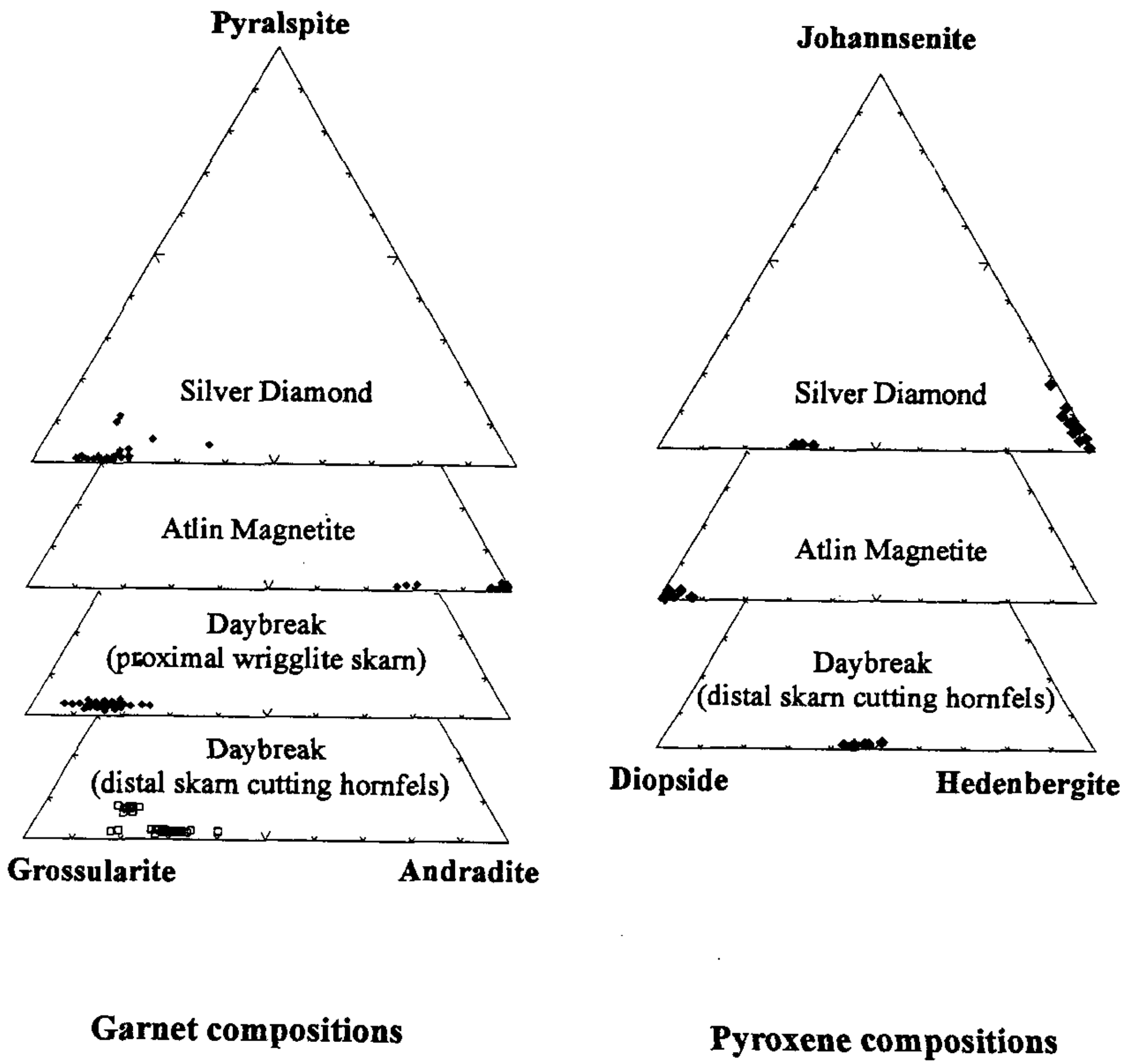

Figure 7. Mole percent compositions of garnets and pyroxenes in the Silver Diamond, Atlin Magnetite and Daybreak skarns.

The proximal wrigglite skarn at Daybreak is weakly mineralized and is developed immediately adjacent to the margin of the batholith (Figure 3). It occurs as large frost-heaved angular boulders up to 3 metres in diameter; a talus trail of wrigglite-bearing float is traceable for several hundred metres downslope from the boulders (Figure 3). The wrigglite is characterized by thin, rhythmic layering that ranges between 0.25 mm and 1 cm thick; each layer is dominated by either pale green to colourless fluorite, black magnetite, white to pale brown vesuvianite or clear reddish-brown garnet (Webster *et al.*, 1992). The gneiss-like mineral layering is locally crosscut by veins of garnet, and is complexly deformed. There are spheroid structures as well as open to tight disharmonic and irregular fold-like structures, some of which appear to have sheared limbs. Rare vugs up to 10 cm in diameter are present; these contain calcite and elongate, green crystals of clinozoisite. Sulphides are generally rare but microprobe and x-ray diffraction studies indicate the wrigglite skarn contains traces of scheelite, cassiterite (SnO_2), canfieldite ($4Ag_2S.SnS_2$), gahnite ($ZnAl_2O_4$), acanthite (Ag_2S) and stannite (Cu_2FeSnS_4). No beryl has been identified although the wrigglite is enriched in beryllium (up to 394 ppm Be; Table 2B), possibly as a non-essential element in the vesuvianite or garnet.

Assay results of magnetite-rich garnet-fluorite-vesuvianite wrigglite skarn are presented in Table 2B. These show that the proximal skarn at Daybreak contains anomalous amounts of Sn, Cu, W, Te, Se, Be and Bi, as well as up to 660 ppb Au and 26 ppm U. An assay of a single grab sample of distal garnet skarn with minor

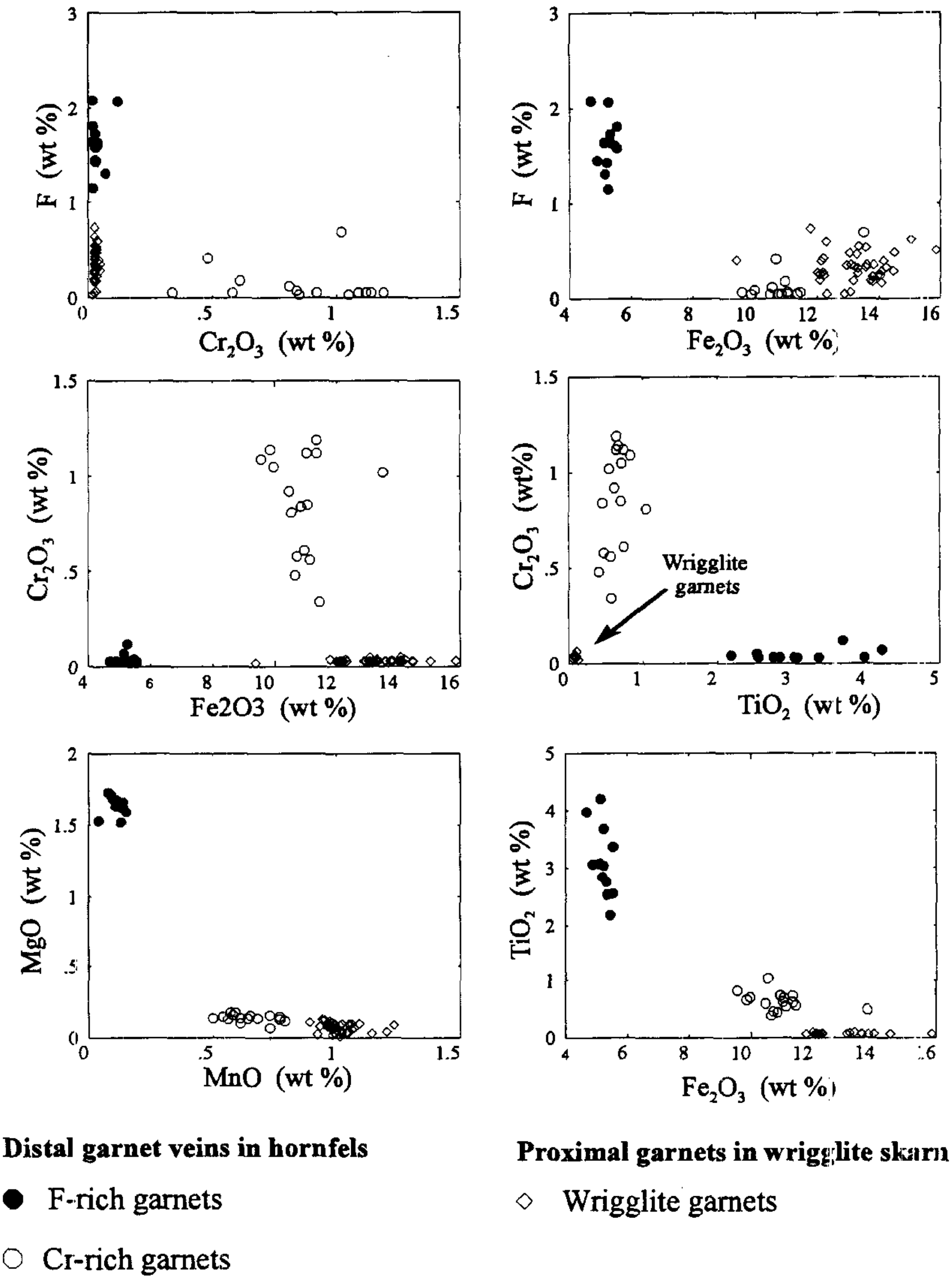

Figure 8. Plots illustrating the variable F, Cr, Fe, Mg, Mn and Ti chemistry of garnets in the proximal wrigglite and distal vein skarn, Daybreak occurrence.

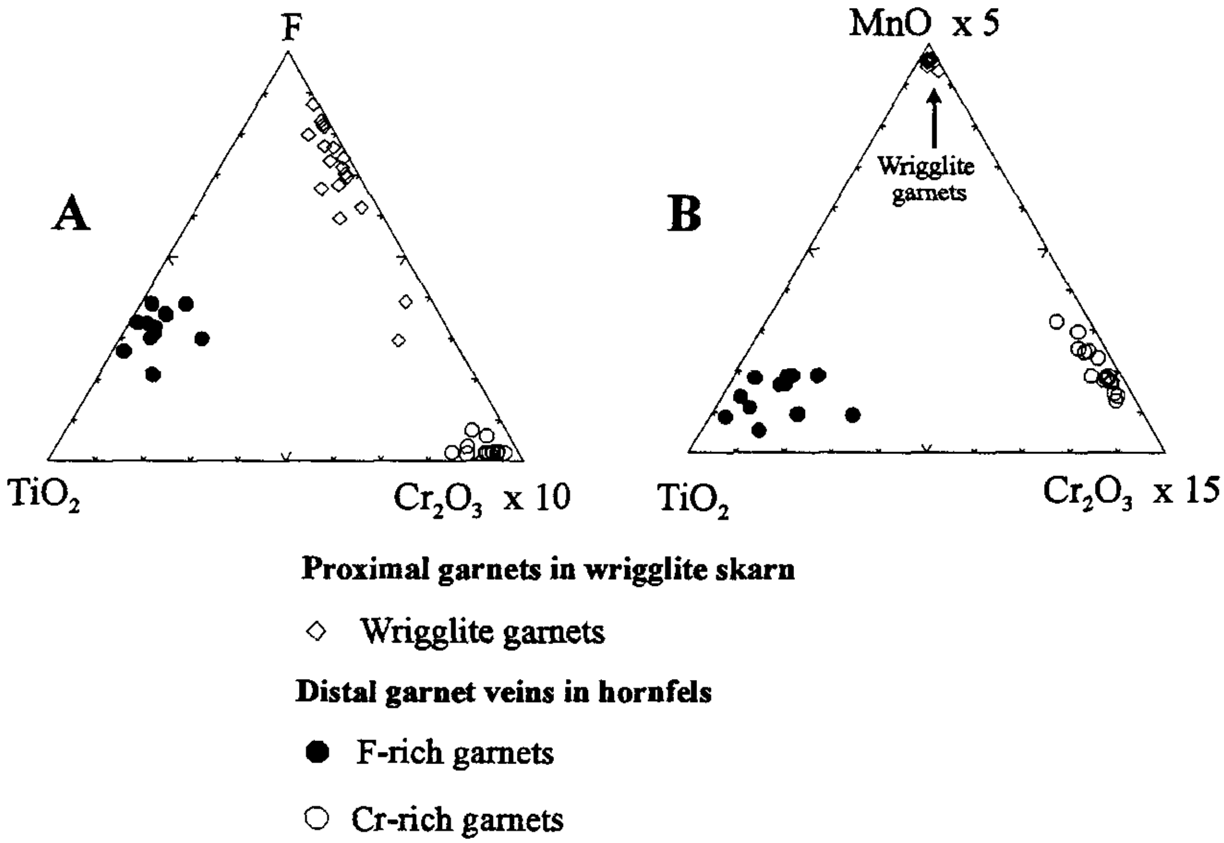

Figure 9. Triangular plots illustrating the contrasting F, Ti, Cr and Mn chemistry of garnets in the proximal wrigglite and distal vein skarn, Daybreak occurrence.

disseminated sulphides contains anomalous amounts of Cu, Bi and Sn (Table 2B).

Most of the garnets in the wrigglite skarn occur as massive, anhedral layers that are pale pinkish brown and isotropic to moderately birefringent. They contain small inclusions of quartz, plagioclase and fluorite. Where individual and euhedral garnet crystals are present, they seldom exceed 1 millimetre in diameter. They are optically similar to the massive garnet except they commonly contain minute opaque inclusions. The vesuvianite, which occurs as low birefringent crystals up to 3 millimetres in size, contains some small inclusions of pyroxene. Generally, however, pyroxene is very rare in the wrigglite skarn. Fluorite occurs as a colourless, well cleaved mineral. Accessory silicates identified petrographically include quartz, plagioclase, sericite, chlorite and epidote.

The distal veined skarn overprints an area of hornfels and extends up to 400 metres west and southwest of the wrigglite skarn (Figure 3). Protoliths of the fine grained, schistose biotite hornfels are probably argillites and minor basaltic tuffs. Vague layering in the hornfels may represent remnant bedding. The rocks are intruded by several irregular sills and dikes of leucogranite and aplite, that are in turn cut by thin quartz veins, some of which carry minor fluorite. The sills, dikes and quartz veins are believed to be related to the nearby batholith. The hornfels is also cut by numerous irregular layers and veins of skarn up to 0.5 m thick. This distal vein skarn alteration consists largely of pale green pyroxene and orange-red garnet with lesser amounts of brown vesuvianite, plagioclase, quartz, chlorite, zoisite and trace fluorite. The pale green, anhedral to subhedral crystals of pyroxene are generally less than 0.2 millimetres in diameter, and many are partially altered to chlorite. Garnet generally postdates the pyroxene and commonly contains small pyroxene inclusions. It occurs as irregular masses, blebs and veinlets; it is pale pinkish brown in colour and is mostly isotropic although some weakly birefringent crystals are also present.

Microprobe analyses of pyroxenes in the distal skarn indicate they are low in Mn and range between 48 and 55 mole percent diopside (Table 3; Figure 7). Garnets in the

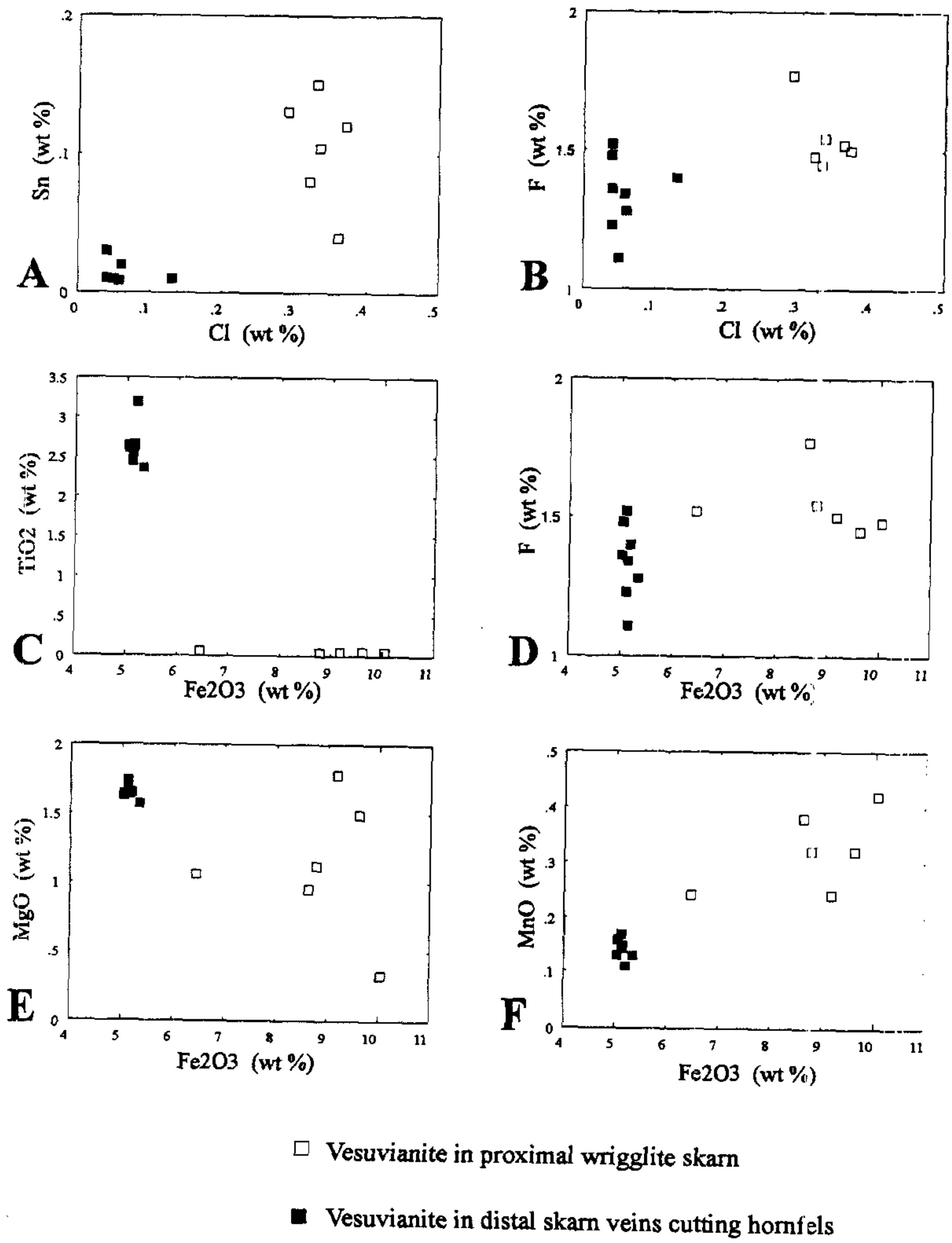

Figure 10. Plots illustrating the variable Sn, Cl, F, Fe, Mg, Mn and Ti chemistry of vesuvianites in the proximal wrigglite and distal vein skarn, Daybreak occurrence.

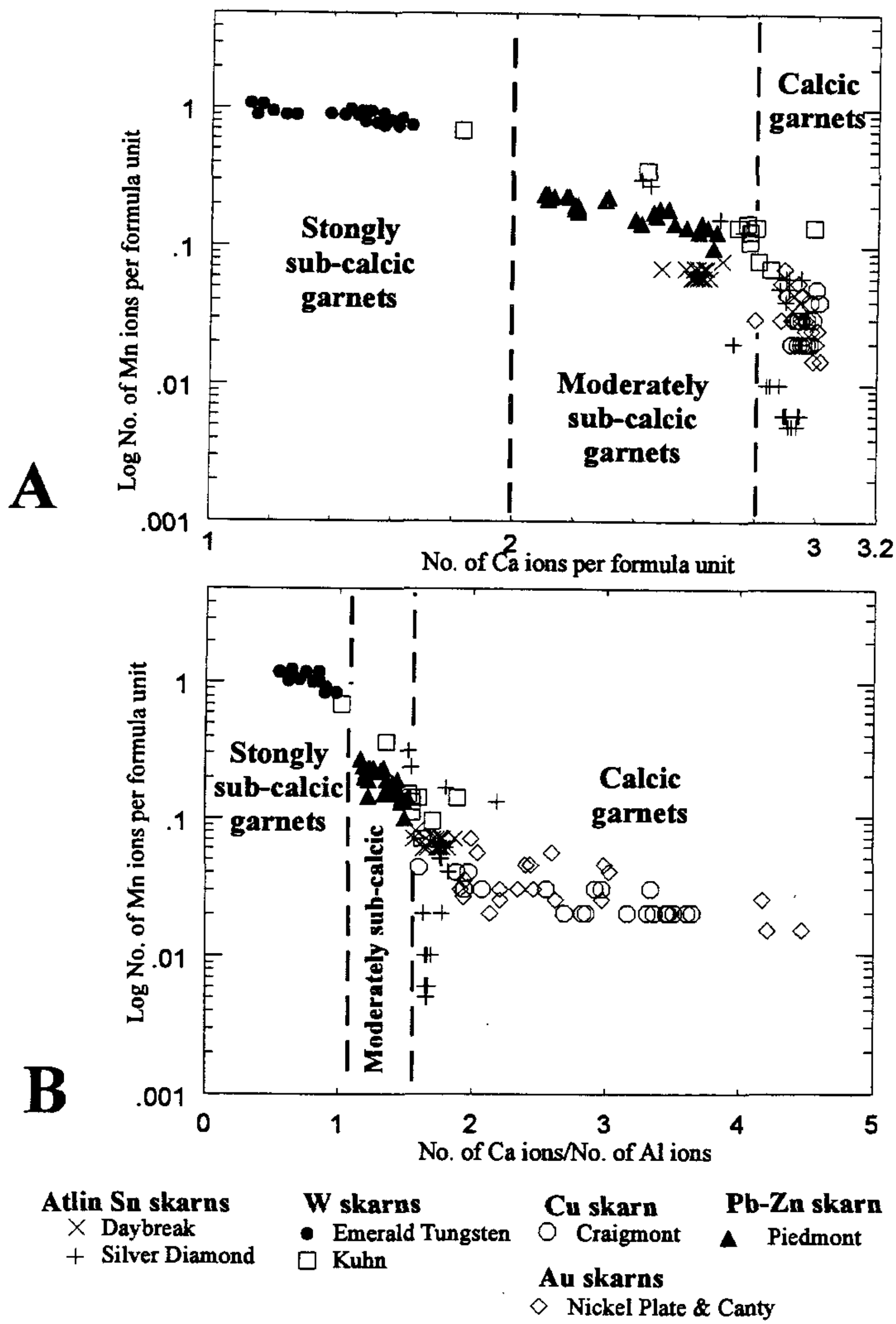

Figure 11. Plots comparing the Ca and Mn contents of garnets from selected skarns in B.C. (data from Ray and Webster, in press).
(A) Log number of manganese atoms per formula unit versus number of calcium atoms per formula unit.
(B) Log number of Mn atoms per formula unit versus number of calcium atoms per formula unit/number of aluminum atoms per formula unit.
Note that the garnets at the Daybreak skarn are moderately sub-calcic, whereas most of those at the Silver Diamond skarn are calcic and have very low quantities of manganese.

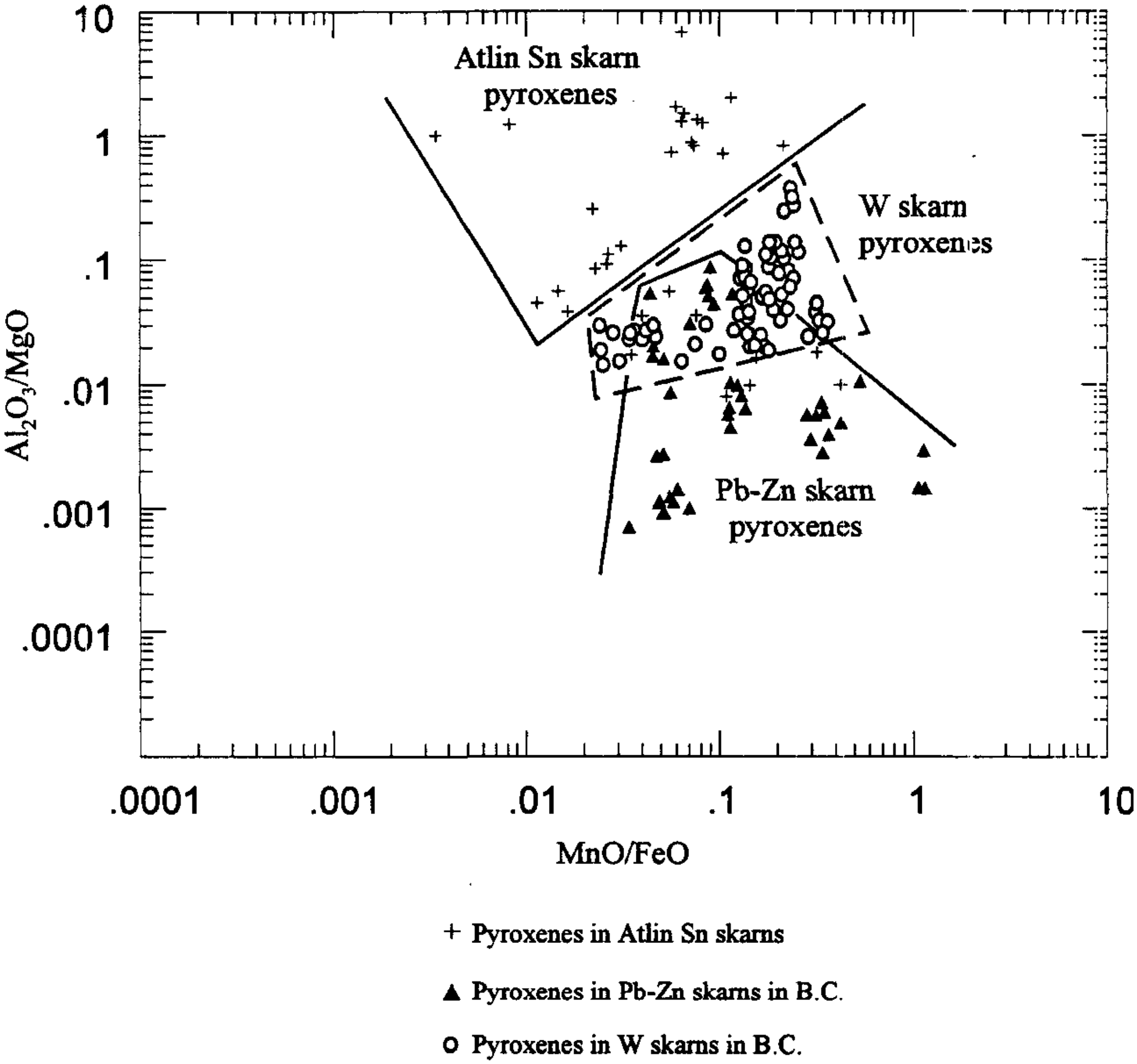

Figure 12. Plot of weight percent Al_2O_3/MgO *versus* MnO/FeO illustrating different compositional fields for pyroxenes in the Atlin Sn skarns and W and Pb-Zn skarns in B.C. (data from Ray and Webster, in press). Note: pyroxene compositional fields have been empirically drawn around main clustering of points.

proximal and distal skarns are similar in their overall compositions, being low in Mn and grossularitic (Tables 4 and 5; Figure 7). However, in some of their major and trace element chemistry they show great differences. Compared to some of the garnets in the distal skarn, those in the proximal wrigglite generally contain very low quantities of Cr and Ti, low to moderate amounts of F (maximum is 0.74 weight percent F), and higher quantities of Fe and Mn (Table 4; Figure 8). By contrast, garnets in the distal vein skarn contain two chemically distinct populations, one of which is F-rich and the other is Cr-rich (Table 5; Figure 8). As well as containing up to 1.21 weight percent Cr, the latter population has higher amounts of Mn and Fe and no Cl whereas the F-rich garnets (with up to 2.07 weight percent F) contain higher quantities of Ti, Mg (Figure 8) and Cl (up to 0.19 weight percent Cl). Some of the chemical differences between the garnets in the wrigglite and distal vein skarn are illustrated in Figure 9.

The distribution of the two chemically distinct garnet populations in the distal skarn is interesting because they are optically and texturally indistinguishable in thin section. Indeed, single garnet masses often contain zones of both F-rich, Cr-poor and F-poor, Cr-rich material. Because garnets only occur as irregular blebs, masses and veinlets, it is difficult to identify positively any chemical zoning that may exist in individual crystals. However, the most Cr-rich and F-poor material tends to occur in the core portions of a garnet mass.

Comparative microprobe analyses were completed on vesuvianites present in the proximal wrigglite and distal vein skarn (Table 6). Although the latter contains considerably less fluorite than the wrigglite, vesuvianites in both the distal and proximal skarns are rich in F, averaging 1.54 and 1.34 weight percent respectively (Table 6). However, in other elements, the vesuvianites in the two types of skarn show significant differences and, on average, vesuvianites in the wrigglite contain more Fe, Mn, Sn and Cl but less Ti and Mg than those in the distal skarn (Figure 10). There appears to be no correlation between Sn, Cl or F in the vesuvianites in either skarn-type.

GARNET COMPOSITIONS OF THE ATLIN AND OTHER SKARNS.

Microprobe analyses of garnets from a number of Au, Fe, Cu, Mo, Pb-Zn, W and Sn skarns in British Columbia indicate that the majority contain less than 1 weight percent MnO and are andradite-grossularite solid solutions with less than 3 mole percent pyralspite (Ray and Webster, in press). However, a few Sn, W and Pb-Zn skarns include some garnets that contain more than 5 mole percent pyralspite. These include the Daybreak and Silver Diamond skarns as well as the Piedmont Pb-Zn skarn (082FNW 129) and the Kuhn and Emerald-Dodger W skarns (104P 071; 082FSW 010 and 011 respectively). Garnets from the Emerald Tungsten-Dodger deposits in the Salmo district of southeastern British Columbia (Ball *et al.*, 1953; Rennie and Smith, 1957; Fyles and Hewlett, 1959; Webster *et al.*, 1992) are distinct in being the most manganiferous skarn garnets identified in the province (Figure 11); they contain up to 25 weight percent MnO and up to 48 mole percent pyralspite (Ray and Webster, in press).

Most garnets in Cu, Au, Mo and Fe skarns in British Columbia are calcic and, on the basis of 12 oxygens and 0 OH, typically contain three calcium ions per calculated formula unit (Figure 11). Garnets in the Atlin Magnetite Sn skarn are calcic and average 3 calcium ions. However, some garnets in the Daybreak and Silver Diamond skarns are moderately subcalcic and contain between 2 and 2.8 calcium ions per calculated formula unit (Figure 11; Tables 4 and 5).

The garnets in some Pb-Zn and W skarns in British Columbia are also subcalcic (Figure 11), a feature that appears to be more common in skarns formed in reducing environments and/or where dolomitic hostrocks are present. The most subcalcic garnets yet recognized in any skarn in British Columbia, with less than two calcium ions per calculated formula unit, occur in the Emerald Tungsten-Dodger W skarns (Figure 11), a feature that was first recognized by Newberry (1983). This, together with the fact that these deposits were the largest tungsten metal producers in the province, is consistent with the conclusions of Newberry (1983) that a relationship exists between subcalcic garnets, reduced states and the size and grade of W skarn deposits. Most skarn garnets in British Columbia contain less than 0.4 weight percent MgO (Ray and Webster, in press). However, some garnets in the Daybreak distal vein skarn (Table 5; Figure 8) and at the Emerald Tungsten-Dodger deposit contain more than 1 weight percent MgO.

PYROXENE COMPOSITIONS OF THE ATLIN AND OTHER SKARNS

Microprobe analyses presented by Meinert (1984), Ettlinger and Ray (1989), Ettlinger (1990), Ray and Dawson (1994) and Dawson (1994) and Ray and Webster (in press) indicate that most skarn pyroxenes in British Columbia are diopside-hedenbergite solid solutions, although varying amounts of the johannsenite component are present in the pyroxene of some Fe, Au, Pb-Zn and W skarns

Nakano *et al.* (1994), in a study of 46 skarn deposits in Japan, has noted that most pyroxenes in Cu-Fe skarns have low Mn/Fe ratios (<0.1), those in Pb-Zn skarns have high Mn/Fe ratios (>0.2) and those in W skarns have intermediate ratios (*circa* 0.15). Data collected from British Columbia skarns (Ray and Webster, in press) indicates that the pyroxenes in Pb-Zn skarns have the highest MnO/FeO ratios (average 0.22), similar to Nakano's (1994) data for Japan. Pyroxenes in the Coxey Mo skarn (082FSW140) have the lowest MnO/FeO ratios (average 0.02) whereas those in W, Cu and the Atlin Sn skarns have intermediate ratios. The study also suggests that the pyroxenes in W, Pb-Zn and the Atlin Sn skarns can be differentiated on their Al_2O_3/MgO ratios (Figure 12). Essentially, pyroxenes in the Atlin Sn skarns are characterized by high Al_2O_3/MgO and low MnO/FeO ratios, those in Pb-Zn skarns have low Al_2O_3/MgO and higher MnO/FeO ratios whereas the W skarn pyroxenes cluster in an intermediate field (Figure 12). The oxidation state of these skarns, as estimated from their mineralogy, also appears to correlate with variation in Al_2O_3/MgO ratios of the pyroxenes. The Pb-Zn skarns with pyroxenes having the lowest Al_2O_3/MgO ratios have mineral assemblages suggesting they formed in oxidized environments, whereas the Silver Diamond and Daybreak occurrences are more reduced and have the highest Al_2O_3/MgO ratios in their pyroxenes.

CONCLUSIONS

The Cretaceous Surprise Lake Batholith is a highly differentiated subalkaline body of adamellite-granite composition. The Rb, Y and Nb contents indicates it to be a "within plate" granitoid as defined by Pearce *et al.* (1984). This, together with the batholith's high F content and its genetic association with Sn-bearing skarns suggests that the pluton was derived as a melt from continental crust, although a lack of inheritance in zircons and its anomalously low initial Sr ratios (Mihalynuk *et al.*, 1992; Mihalynuk, personal communication, 1996) does not support this conclusion. The contrast in chemistry between the Cretaceous Surprise Lake Batholith and the Jurassic Fourth of July Batholith, which plots as a "volcanic arc granitoid" (Figure 4D; Mihalynuk *et al.*, 1992), raises problems and implications regarding the tectonic history of the Cache Creek Complex and the character of its basement rocks at Atlin.

The Surprise Lake Batholith is chemically distinct from other plutons associated with Cu, Au, Fe, and Mo skarns in British Columbia, but it shows many chemical similarities to the peraluminous intrusions related to W skarns. However, the Surprise Lake Batholith averages more than 2700 ppm F, whereas plutons related to W skarns average less than 400 ppm F (Ray and Webster, in press).

The Silver Diamond, Atlin Magnetite and Daybreak Sn skarns are all related to the high level Surprise Lake plutonic suite, although there are significant differences in their mineralization, oxidation states and garnet chemistry. All three skarns contain sporadically anomalous amounts of Cu and Bi. The Daybreak and Atlin Magnetite skarns are enriched in Sn, and cassiterite is reported from parts of the Silver Diamond occurrence. Unlike the other two skarns, the Atlin Magnetite has very low amounts of W and F whereas the Silver Diamond mineralization contains elevated quantities of Ag, Pb, Zn, Cd, Se. The Daybreak magnetite-garnet-wrigglite skarn is enriched in Be and U.

Garnet-pyroxene chemistry and skarn mineralogy suggest that the Atlin Magnetite occurrence formed in more oxidized conditions than the other two skarns. Its garnets are calcic and andraditic; by contrast, garnets at the Daybreak are grossularitic and are moderately subcalcic, averaging 2.8 calcium ions per calculated formula unit. The Silver Diamond includes both calcic and moderately subcalcic garnets. Pyroxenes in the Atlin Sn skarns can generally be discriminated from many pyroxenes in W and Pb-Zn skarns by their higher Al_2O_3/MgO ratios and lower MnO/FeO ratios.

Some garnets at the Daybreak skarn contain anomalous amounts of Cr, F and Cl, and there are distinct differences in the major and trace element chemistry (notably Cr, F, Ti and Mg) of garnets formed in the proximal and distal skarns. Optically indistinguishable garnets in the distal skarn are separable into two chemically different populations that are either rich in Cr or F. It is possible that the Cr-rich material represents early hornfels garnets that crystallized during batholith emplacement and that Cr was derived from ultramafic rocks in the Cache Creek complex. The F-rich and Cr-poor material, which also contains minor amounts of Cl, represents skarn garnet related to the Daybreak hydrothermal system that possibly overgrew the earlier hornfels garnet.

Although many Sn-W skarns world-wide contain F-bearing garnets, Cr-rich garnets in such rocks are highly unusual. Their presence at the Daybreak occurrence reflects a tectonic history that enabled oceanic and ultramafic rocks of the Cache Creek Terrane to be intruded by the highly evolved and peraluminous Surprise Lake Batholith.

ACKNOWLEDGMENTS

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THE TAURUS PROJECT, A BULK TONNAGE GOLD PROSPECT NEAR CASSIAR, BRITISH COLUMBIA, NTS 104P/5

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KEYWORDS: Gold, economic geology, Cassiar, quartz veins, bulk tonnage, mineralization, alteration, Sylvester allochthon, Cretaceous intrusions.

INTRODUCTION

The Taurus project is a large tonnage, low grade gold prospect in the vicinity of the past producing Taurus gold mine, the surrounding quartz vein systems and auriferous massive pyritic replacement zones to the west of the mine. The property is about eight kilometres east of the former townsite and asbestos mill of Cassiar (Figure 1). The area of interest is alongside Quartzrock Creek and straddles the paved Cassiar access road, about 5.5 kilometres from its junction with the Stewart Cassiar highway (Highway 37). Taurus mine, previously know as the Cornucopia or Hanna workings, on the Copco claims, produced 1 102.5 kilograms gold from 288 863 tonnes of ore for Taurus Resources Limited between 1981 and 1988. This includes production of about 5,000 tons of ore from the Plaza adit and some material from a small open cut on veins at 88 Hill (B. Spencer, personal communication, 1996).

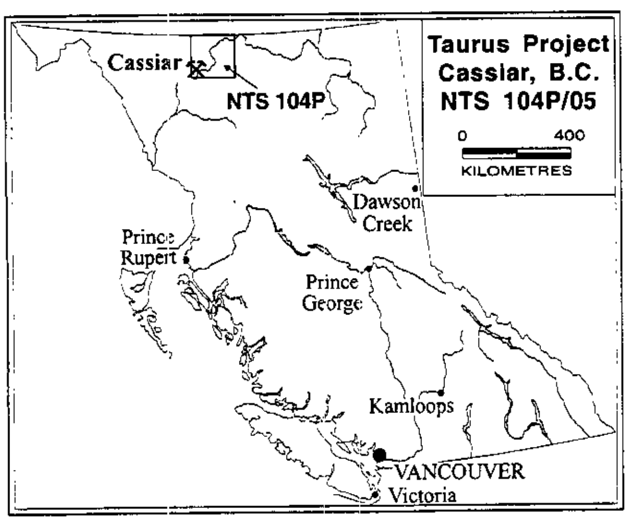

Figure 1. Location map.

Taurus is just one of a number of gold mines in the Cassiar gold belt. Gold production in the Cassiar district began in 1874 from placer deposits on McDame Creek. The Cassiar, or McDame camp, is one of British Columbia's major placer districts with recorded production of 74,500 ounces gold, mainly between 1874 and 1895 (Holland, 1950). Placer gold from the Cassiar valley in the Taurus mine area was won from Snowy and Troutline (Trout) Creeks, and Quartzrock Creek at Wings Canyon. Most of the production came from further downstream in the drainage system of McDame Creek, its tributaries and some high river benches between Cassiar road junction with Highway 37 and Centerville, 15.5 kilometres to the east.

Gold production from bedrock sources has come from a number of the auriferous quartz veins that occur over a distance of 15 kilometres along a northerly-trending belt; the commonly used names of some of the quartz vein workings are shown on Figure 2. Erickson Gold mine at Erickson Creek on Table Mountain produced 7 232 kilograms of gold from 507 215 tonnes of ore between 1979 and 1988. Most of the production was from steeply dipping, volcanic-hosted quartz veins carrying about 15.6 grams gold per tonne in the Erickson Creek vein system but about 110 000 tonnes came from the ribboned, carbonaceous, flat-lying Vollaug vein at an argillite-volcanic and altered ultramafic pod (listwanite) contact. The Vollaug vein material contained, on average, about 10.5 grams gold per tonne. The currently operating Table Mountain mine of Cusac Gold Mines Limited started operating in 1993. It has produced approximately 900 kilograms of gold from 52 500 tonnes of ore to the end of 1995, and is expected to achieve a 600 kilogram gold production target in 1996. Additional reserves are being developed at the mine as well as from the formerly producing Vollaug vein.

In addition to these larger milling operation a small amount of gold production (mainly unrecorded) has come from open cuts at Quartzrock Creek where a stamp mill was operated by John Hope and family at the Mack and Hopeful property; open cuts and a short adit at the Hanna (Cornucopia) workings; and hand workings at Pete's vein on the north flank of Needlepoint Mountain, the Rich vein on Snowy Creek, veins on Troutline Creek, and probably other veins as well. A summary of the 1930s to 1980s mining history is given in Diakow and Panteleyev (1981).

The area surrounding the Taurus mine was explored by the property owners during operation of the mine in the 1980s. More widespread exploration and drilling starting in 1993 demonstrated the expansive nature of the gold mineralization. Compilation of exploration data

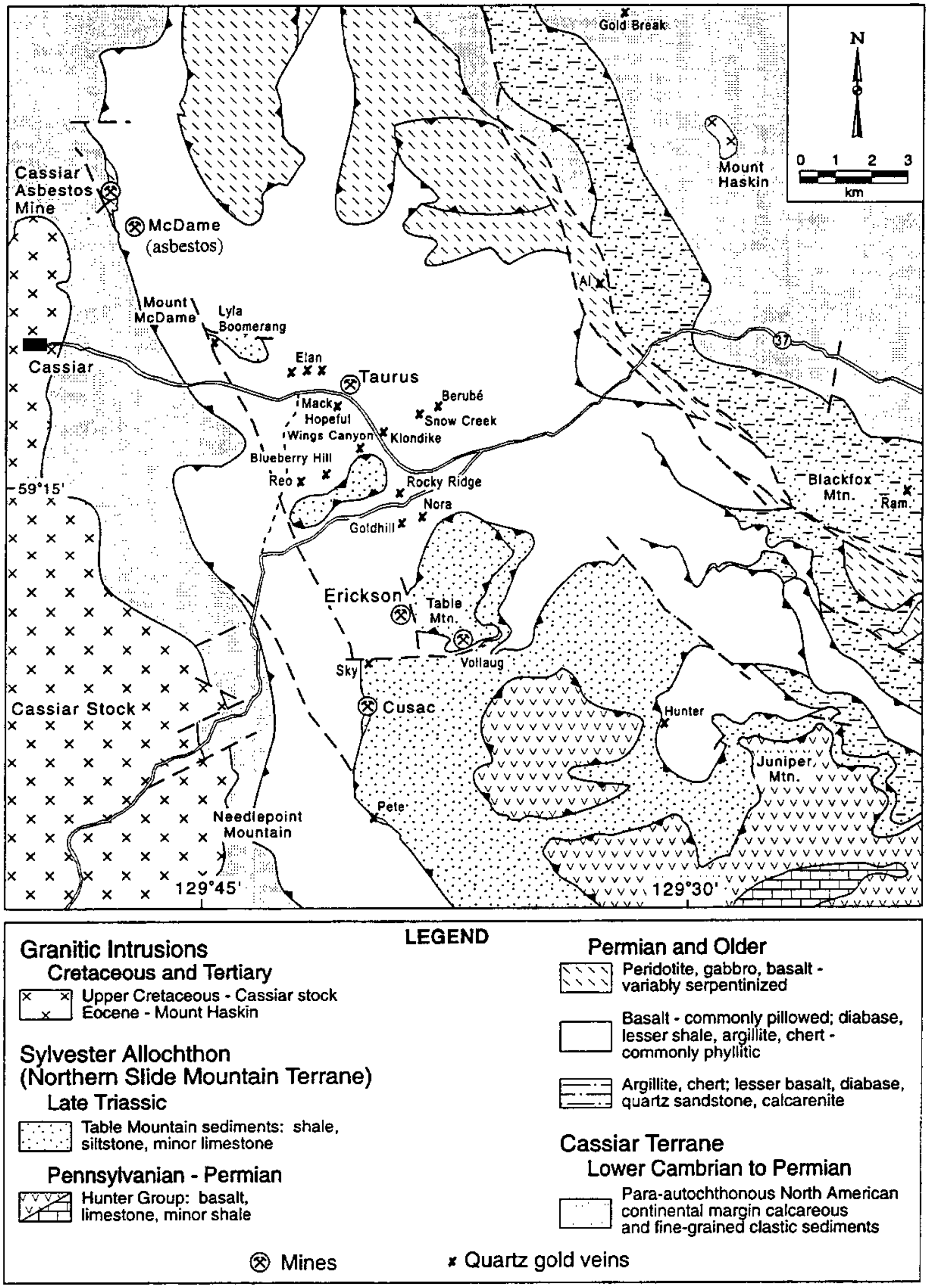

Figure 2. Generalized geology of the Cassiar area, with location of mines and quartz vein gold prospects; modified from Ash *et al.* (1996) after Harms (1989) and Nelson and Bradford (1993).

revealed that gold mineralization occurs at shallow depths in an area of at least 500 by 1500 metres and this led to the realization that a potentially bulk mineable gold deposit might be developed. In 1995 Cyprus Canada Incorporated became involved with the property under joint ventures with International Taurus Resources Incorporated, Cusac Gold Mine Limited and Douglas Busat. Cyprus conducted a $2.8 million program in 1995 consisting of 13,496 metres drilling [12,670 core, 826 metres reverse circulation] as well as trenching, geophysical surveys, geochemical sampling and geological mapping (Broughton, 1996). Drill holes were mainly at 100 metre intervals on lines spaced 200 metres apart. In 1996 an additional 12 drill holes [1457 metres core drilling] and some trenching were completed. Most work has been concentrated in three areas: 88 Hill, Taurus West and Taurus mine. In mid July 1996 Cyprus withdrew from the property and subsequent exploration was conducted by International Taurus. Their work was mainly in the 88 Hill zone and consisted of 36 in-fill reverse circulation holes [3950 metres] and 5 step out diamond drill holes to the west. Since 1993 a total of 29 505 metres of drilling has been completed on the property (Figure 3). Based on drilling to the end of 1996, a drill indicated reserve of 13.7 million tonnes with 1.01 grams gold per tonne has been estimated in the 88 Hill area, with additional inferred reserves of 25.1 million tonnes at 0.67 grams gold per tonne (International Taurus Resources Incorporated news release, 1996).

The concept that a potentially bulk mineable gold deposit could be developed at the Taurus property stems in large part from the concurrence of significant placer gold production in the region and the widespread distribution of near surface swarms of closely spaced auriferous quartz veins. The presence of nearby Cretaceous granitic bodies, and an apparent Cretaceous age of the vein mineralization, suggest additional similarities to the geological settings of the bulk mineable, unoxidized gold mineralization at Fort Knox mine, near Fairbanks, Alaska (Bakke, 1995) [161 million tonnes at 0.86 grams per tonne gold, A.A. Bakke, personal communication, 1996] and Dublin Gulch prospect, Yukon (Hitchins and Orssich, 1995). At Dublin Gulch a mineable reserve of 36 million tonnes containing 0.92 grams gold per tonne has been identified in the Eagle zone, within a larger area of mineralization (Smit *et al*, 1996]. Another example of a gold-quartz vein camp with unoxidized, primary sulphide ores that are being bulk mined is the Dome mine, Canada. At Dome, open pit reserves of about 26 million tonnes with 2.0 grams gold per tonne and 0.5 grams per tonne cutoff were developed in an area selectively mined in the 1940s. At the long-lived vein camp at Kalgoorlie, Australia, open pit (oxidized) reserves announced by Kalgoorlie Consolidated Gold Mines in 1989 at the inception of the 'superpit' were 68.1 million tonnes with 2.9 grams gold per tonne (D.I Groves, personal communication, 1996). This resulted in gold production in 1990 of 231,000 ounces gold, making it the 4th largest gold producer in the state in that year (*Engineering and Mining Journal*).

This study conducted some geological mapping to determine trends of major lithologic units to relate them to regional stratigraphy and to confirm the Triassic age by sampling for microfossils of the sedimentary unit north of Highway 37 along Troutline Creek. Extensive use was made of company geological and drill information. The main effort was to determine the age of vein mineralization and resolve its relationships to various rock units, notably the Cretaceous intrusions. A suite of hydrothermal mica samples from veins has been submitted for Ar $^{40/39}$ step heating studies, as well as other samples for conventional K-Ar and U-Pb (zircon) dating.

GEOLOGY

REGIONAL GEOLOGY

The first regional geological mapping completed in Cassiar area was by Gabrielse (1963) who named the volcanic-rich Sylvester Group that hosts the Taurus deposit. The description of the Sylvester allochthon by Gordey *et al.* (1982) provided a three-fold subdivision of the Paleozoic assemblages of greenstone, chert, clastic and ultramafic rocks (Slide Mountain Terrane), and outlined a model for their thrusting in mid-Jurassic to Early Cretaceous time over autochthonous strata of North America (Cassiar Terrane). The Sylvester rocks are preserved in the core of the gently southeasterly plunging McDame synclinorium that overlies Lower Cambrian to Permian autochthonous rocks of Cassiar Terrane, mainly Ingenika, Atan, Kechika and Road River Group rocks. To the west of the synclinorium are Cretaceous granitic rocks of the Cassiar Batholith (Figure 2).

Detailed studies of stratigraphy, structural style and tectonic history of the Sylvester allochthon are discussed by Harms (1989) and Nelson and Bradford (1989). Geological mapping is presented on maps by Harms *et al.* (1989) and Nelson *et al.* (1989). This and other recent work is summarized in Nelson and Bradford (1993). They describe the Sylvester allochthon as having three structurally stacked divisions. Division I, the lowest, is primarily a sedimentary sequence that is similar to Earn Group rocks and overlying Mississippian to Early Permian chert and argillite of the Cassiar Terrane. The middle, Division II, is an ophiolitic assemblage comprising fragments of oceanic, ultramafic-gabbroic basement and stratified early Mississippian to Early Permian sequences of interbedded basalt, sediments and diabase intrusions. The sequences of basaltic flows and tuffs in this unit are characteristically interbedded

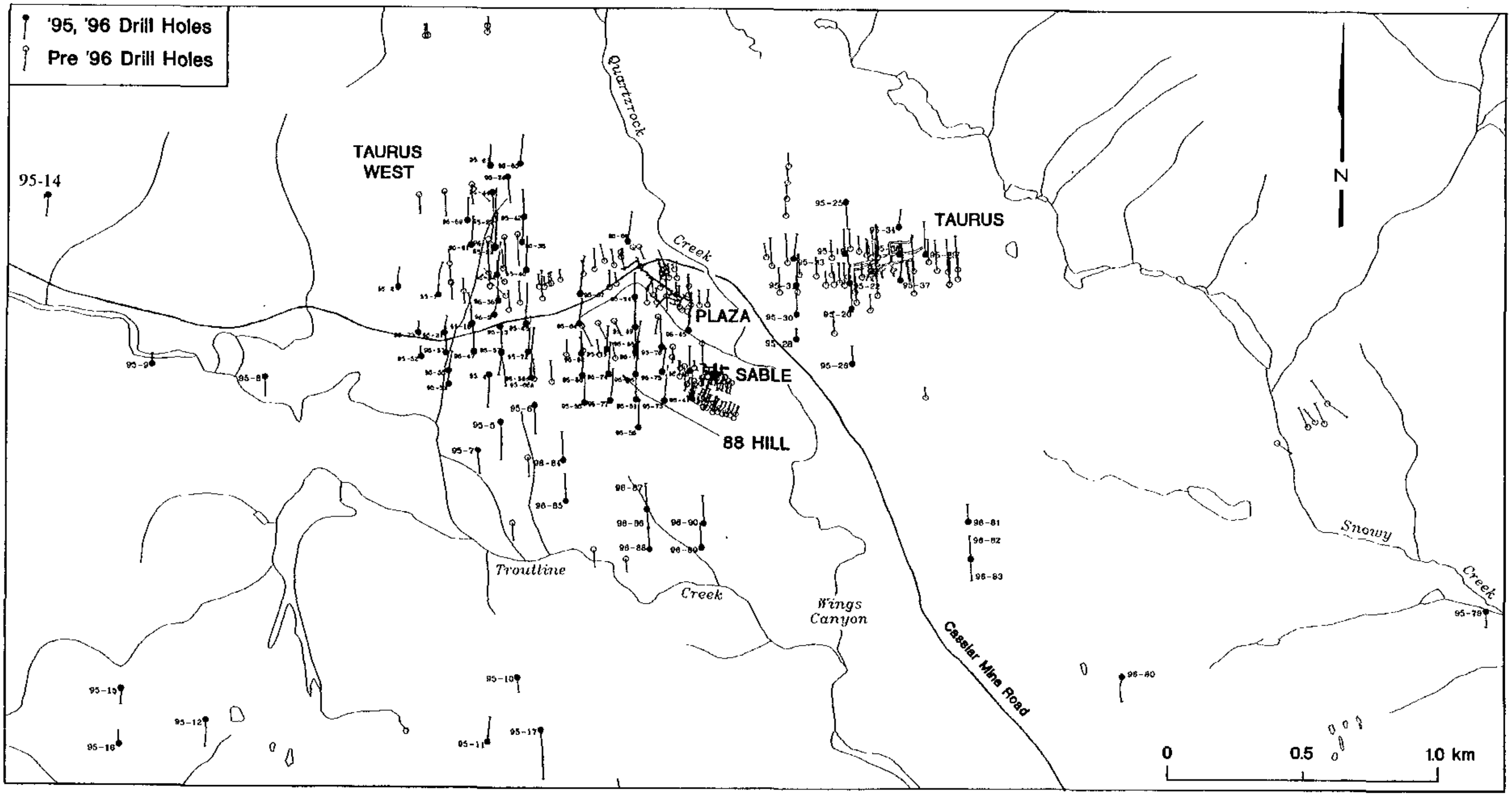

Figure 3. Locations of drill holes and adit sites, Taurus property. The location of underground workings (Taurus, Plaza, Sable adits) and drill hole pattern indicate the distribution of the main gold mineralized areas.

with siliciclastic rocks. Triassic sediments form a discrete map-unit within this division. The Triassic rocks occur above thrust planes at the highest structural level of Division II. The Division III rocks comprise a late Paleozoic island-arc unit that resembles Yukon Tanana and Harper Ranch Terrane assemblages. The unit consists of three distinct suites of volcanic, epiclastic and sedimentary rocks and at least two Paleozoic plutons. According to Nelson and Bradford, igneous rocks of Divisions II have mid-ocean ridge geochemical signature and are chemically distinct from rocks of Division III which have an island arc signature.

The Cassiar batholith intrudes stratified units of Cassiar Terrane to the west of the Sylvester rocks. The batholith has been considered to be a single intrusive mass about 100 Ma in age, based mainly on radiometric dating done by the Geological Survey of Canada. These K-Ar cooling data, as well as the roughly 130 Ma age of quartz vein mineralization, are summarized by Sketchley (1986) and Sketchley *et al.* (1986). Christopher *et al.* (1972) identified younger rocks of the Cassiar batholith along the east side of the intrusion. The younger phase called the Cassiar stock or Troutline Creek quartz monzonite by Panteleyev (1983) is about 72 Ma in age. Another younger suite of granitic stocks recognized by Christopher, and co-workers, is 50 Ma in age. These small intrusions near Reed and Haskin Mountains, approximately 20 kilometres east of Cassiar, contain molybdenum-bearing quartz stockworks and have associated base metal skarn mineralization.

DEPOSIT GEOLOGY

The Taurus veins are hosted by massive to pillowed basaltic flows belonging to the middle structural unit of the Sylvester allochthon. The basalts, referred to as map-units IIb and IIPPvs by Nelson and Bradford (1993), are Permian or older in age. The basaltic rocks are the most widespread unit and crop out over most of the Taurus property. They are present in the collar of every 1995 and 1996 drill hole shown on Figure 3, except the most remote southeast drill hole (T96-80), which was started in graphitic argillite. Chert, siliciclastic rocks and graphitic argillite underlie the basaltic rocks and form the ridges in the northeast part of the property to the east and northeast of Snowy Creek (Figure 3). All major rock units strike northwesterly in the property area and dip southwesterly. The siliceous rocks on the northeast ridges, and their overlying basalt units, dip moderately to steeply southwest but in the Taurus mine area, and further to the west, the rocks seem to be relatively flat lying.

The basalts now consist of uniform, aphanitic grey-green to dark green greenstone with mainly flow and lesser diabasic (subvolcanic) intrusive and locally volcaniclastic origins. Pillows, rare amygdules and relict fragmental textures are locally preserved primary structures. Chloritic fracture fillings and streaks are common and rarely impart a weak foliation. At depth in many drill holes jasperoid nodules a few to tens of centimetres in size are present sporadically throughout the basalt. The nodules, probably in pillow interstices, are composed of mainly orbicular to massive red chert but magnetite is also present. Where it is abundant it can impart a mesh to intersertal fabric to the jasperoid nodules. This magnetite-rich jasperoidal chert basalt forms a subunit at depth in the basalt sequence. It consistently underlies the massive pillowed basalts in the 88 Hill area, and undoubtedly elsewhere on the property. The jasperoidal basalt has a pronounced magnetic geophysical response.

In thin section (Read and Psutka, 1983) little remains of the original basalt mineralogy and fabric beyond outlines of relict, fine grained to sparsely porphyritic plagioclase and augite grains. Metamorphic minerals are chlorite, actinolite, clinozoisite-epidote, carbonate, albite and rare stilpnomelane, muscovite, iron-rich pumpellyite and quartz. Read and Psutka have recognized scattered dark green diabase, meta-gabbro and quartz diorite bodies in the volcanic rocks. These rocks are similar in colour and weathering characteristics to the volcanic rocks but lack pillows, are slightly coarser grained and generally are not carbonate altered.

The metasedimentary sequence in the northeast part of the property, and at depth in drill holes in Taurus mine area, consists of chert, phyllitic chert, siliceous phyllite and graphitic argillite. The rocks are Pennsylvanian/Permian in age based on microfossils (conodonts) in samples taken two kilometres southeast of the mine by J.F. Psutka in 1983 and reported on by M.J. Orchard *in* Nelson and Bradford (1993). One sample of pale grey-green chert is Late Carboniferous (Pennsylvanian) and the other, a grey bedded chert and argillite, is Late ? Carboniferous (Pennsylvanian) in age. In outcrop these rocks are massive to thin-bedded with thin phyllitic layers separating cherty beds between one and three centimetres in thickness. In thin section predominant quartz, 0.02 millimetres or less in size, is accompanied by muscovite, minor chlorite and 'dustings' of carbonaceous material.

Triassic sedimentary rocks, the Table Mountain sediments (unit IITRTMS) of Nelson and Bradford, 1993), crop out along the southernmost part of the property along Highway 37 west of Troutline Creek, south on Table Mountain, and to the north on McDame Mountain. The sequence of thin bedded slaty siltstone, sandstone and calcareous mudstones forms thin klippen that overly the pillowed basalt unit. Locally the base of this map unit has a listwanite (quartz-carbonate-fuchsite) alteration assemblage, presumably derived from thin structurally emplaced slivers of ultramafic rock, but some of the carbonate-mica alteration extends into the Triassic sedimentary rocks as well.

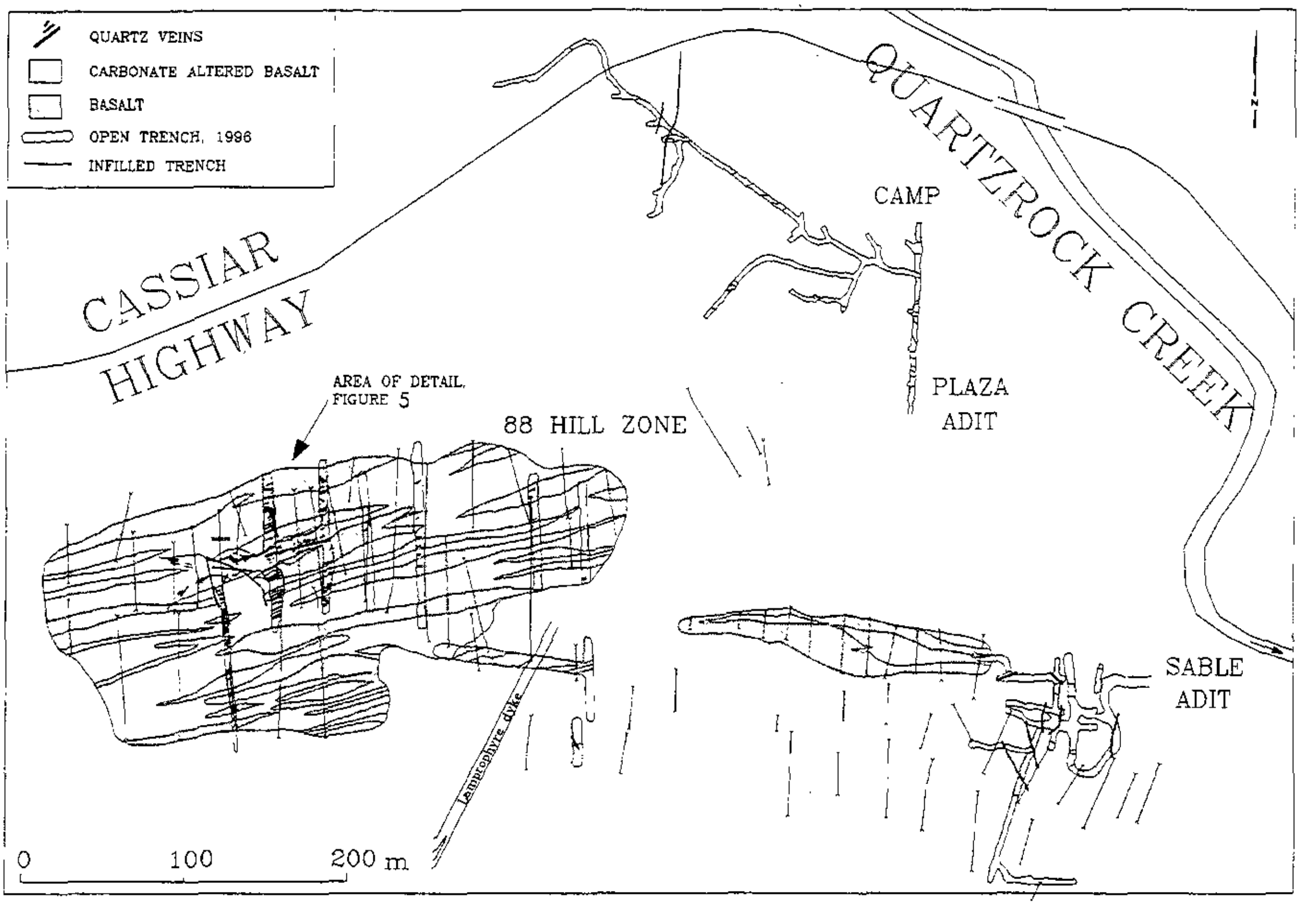

Figure 4. Generalized alteration patterns in trenched areas in the 88 Hill zone showing relationships between unaltered and carbonate altered basalts, after company plans. Sampling data are shown on Figure 5.

Lamprophyre and dioritic dikes, from less than 1 to 5 metres in thickness, trend northerly or east-west and are abundant in the Taurus mine area. The lamprophyre dikes crosscut both the quartz veins and their carbonate-altered alteration envelopes. The lamprophyres are classified by Read and Psutka (1983) as spessartite or camptonite on the basis of their augite or titanaugite phenocryst compositions. They also contain abundant biotite, some amphibole, a metamorphic assemblage or amygdales with albite, orthoclase, calcite, chlorite, prehnite, and abundant accessory apatite. Lamprophyre dikes locally contain a few scattered grains of quartz but can have up to 30 per cent granitic xenoliths. The inclusions are commonly rounded and range from less than a centimetre to a metre in size. Two granitic types are present. The more common type is a pink porphyritic granite with embayed and partly resorbed quartz phenocysts up to 6 millimetres in size in a matrix of plagioclase, orthoclase, fine grained quartz and accessory chlorite, stilpnomelane and allanite. It closely resembles lithologically similar pink granitic rocks of the 72 Ma Cassiar stock. The less common clast type is a dark grey, porphyritic granodiorite with abundant coarse grained amphibole.

A structural study in the mine area by Read and Psutka (1983) confirms that polyphase deformation has taken place in the region, based mainly on the presence of folded foliations. Beds in the metasedimentary map units strike northwesterly and have moderate southwesterly dips with steeply southwest dipping to vertical axial-plane foliation. In greenstone foliation is developed only here and there. Mesoscopic and minor fold axis orientations indicate that the rocks lie on the southwest limb of a gentle northwesterly plunging antiform. Faulting described by Read and Psutka (1983) and Gunning (1988) defines four main trends. The sequence, from oldest to youngest, consists of northwest-trending, gently dipping (thrust) faults, and east to east-northeast striking and steeply south dipping, northwesterly subvertical, and northerly with moderate to steep easterly dipping faults. The first two fault sets apparently formed during emplacement of the Sylvester allochthon and the east-northeasterly faults provided sites for quartz vein development; the latter two sets offset the quartz veins and cut the east-northeast faults and lamprophyre dikes.

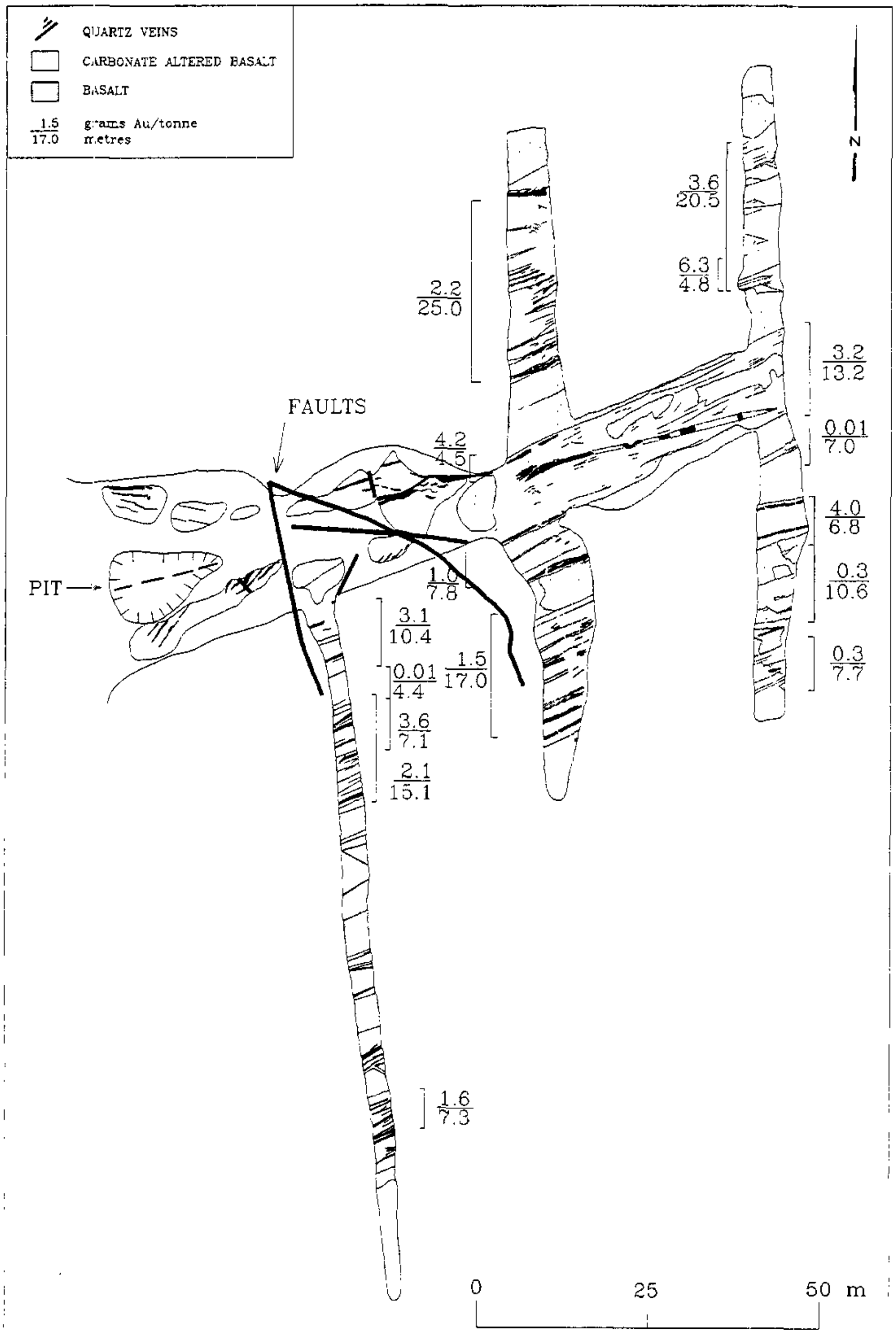

Figure 5. Detail of selected 1996 trenches in western 88 Hill zone shown on Figure 4, illustrating quartz vein distribution, alteration patterns and gold assay data; modified from company plans.

MINERALIZATION

Gold mineralization occurs in the hostrock basalts in two styles - in quartz veins and pyritic replacement zones. In the 88 Hill and Taurus mine area the gold vein mineralization bottoms at an average depths of about 100 metres against a flat lying to shallow dipping chert unit that is separated from the overlying basalt sequence by a thrust-faulted contact. The cherts contain few quartz veins, little pyrite, and are of no apparent economic interest. The mineralized zones are cut locally by lamprophyre dikes and by northwest trending faults with small displacements.

Most of the gold is found in zones of pyritic quartz in the larger quartz veins within the pyritic bleached, carbonate altered zones that are commonly between 2 and 30 metres in width. The veins strike roughly east-west and dip steeply; individual quartz veins are rarely more than 30 centimetres wide, although locally thicker vein and large quartz knots are present. Most veins are lenticular in shape, with strikes of a few metres at best, and they commonly display typical sinuous, sigmoidal and small-scale cymoid loop geometries with bifurcating and horsetailing or, less commonly, sharp wedge-like terminations. Closely spaced, parallel, stacked arrays of veins are typical, commonly with en-echelon patterns at vein terminations. The quartz veins occupy from about 5 to 15 per cent of the altered zones within the carbonate-altered basalts. The veins contain mostly milky white quartz in coarse to fine-grained crystalline intergrowths. There are rare, vuggy patches in the veins with clear crystalline quartz and clear crystal terminations that form the coarsest-grained parts of the veins. Carbonate minerals (ankeritic to dolomitic carbonate) in quartz veins generally form discrete grains up to two centimetres in size, or finer grained crystal intergrowths with quartz, commonly at or alongside vein margins. The carbonate characteristically weathers to a bright orange-red, powdery, amorphous limonite. Other minerals in the veins are small amounts of pyrite, chalcopyrite, tetrahedrite, sphalerite, rare galena and gold; locally seams and fracture fillings have fine grained, flaky, pearly-lustrous sericite. Chlorite can be present in the margins of quartz veins, and locally, black tourmaline (schorlite) is present in abundance in the veins. The wallrock alteration of basalt produces a dense, massive bleached rock with euhedral pyritohedrons that vary from fine grained up to one centimetre in size; they can constitute up to 10 per cent of the rock. Pyrite in the wallrocks is accompanied locally near vein margins by fine grained crystals of arsenopyrite. Ribs of barren, little-altered, dark green basalt occur between the carbonate altered and quartz veined zones. Mesoscopic alteration in the basalt is mainly dark green to black chloritic fractures that locally impart a reticulate hairline stockwork to the rock.

The second type of gold mineralization, the extent and economic importance of which has been recognized only recently at the Taurus West zone, is the disseminated to 'dusty' semi-massive to massive pyritic replacement mineralization in shear or fault zones. The pyrite forms between 10 to 40 per cent of the altered basaltic material, is generally very fine grained but locally is banded and contains narrow quartz veins; the veins are generally unmineralized. The overall distribution of the pyritic zone(s) appears to be in a panel of shallow east-dipping mineralization, similar in attitude to the enclosing thrust faults. The geophysical expression (induced polarization) suggests a northerly strike to the (Taurus West) mineralization at surface, probably following the outcrop expression of a fault zone with a gentle eastward dip, similar to underlying thrust faults. Trenching and drilling reveal that individual pyritic bodies within the mineralized panel occupy shear and fault zones that trend east-west and have steep dips, a geometry similar to the quartz veins systems elsewhere on the property. Similar pyritic material was noted in the lower level of the Taurus mine along the main decline where it forms a zone about 3 to 5 metres thick as an apparent replacement along a shallow-dipping thrust fault. The abundance of the auriferous highly pyritized material makes it an important exploration and economic target. More work is required to define the distribution and geometries of the pyritic bodies. Also additional metallurgical work is needed; preliminary bench tests using conventional milling and cyanide leaching methods suggest that the pyritic gold mineralization is refractory.

Gold Distribution

Most gold is associated with pyrite, mainly in quartz veins but also in the altered pyritic wallrocks. Some of the gold is present in the larger veins as coarse grains. The overall gold content of the altered zones, including the quartz veins contained in them, constitutes the bulk mineable resource. Some gold mineralization intersected in the 88 Hill areas illustrates some highlights of the 1995 drilling program. The results reported are: 1.42 grams gold per tonne over 54 metres; 1.59 grams gold per tonne over almost 55 metres; and 1.65 grams gold per tonne over 46 metre drill intercepts. Gold distribution and the relationships between altered zone and unaltered barren rocks are shown on Figures 4 and 5. In pyritic replacement zones at Taurus West some of the better 1995 drill intercepts contained 2.47 grams gold per tonne over 86 metres, 1.64 grams over 44 metres and 1.78 grams gold over 24 metres (Broughton, 1996).

A study of gold distribution in the (narrow) veins from the Taurus mine workings by Gunning (1988) illustrates the distribution of gold and the variations between quartz veins, their sulphide-rich margins and the alteration halos. For the seven veins studied by Gunning, average quartz vein widths are 50 centimetres, vein margins almost 10 centimetres and alteration halos about 41 centimetres. The weighted mean gold content over the total width of about 100 centimetres is 3.81 grams per tonne. The quartz vein centres with 1.81 grams gold per tonne contain 24 per cent of the gold, the alteration halos with 2.2 grams gold per tonne contain 23 per cent, and the remaining 53 per cent of the gold occurs in the sulphide-rich vein margins. The 1995 and 1996 trench samples shown on Figures 4 and 5 illustrate similar patterns of gold distribution, but over much wider zones of carbonate alteration that contain more closely spaced quartz veins within them.

Pyritic mineralization, probably similar to the West Taurus pyritic zone, was studied by Gunning (1988) and sampled where it was exposed in the Taurus mine decline at the 3300 level. This mineralization is part of a 15 metre-thick alteration zone that has formed along a north-northwest striking, moderately east dipping reverse fault in the hanging wall, and parallel to, the basal thrust fault at the underlying basalt-chert unit contact. Within the sheared, brecciated and clay-chlorite-graphite altered zone there is a 3 metre thick massive pyrite to highly pyritic auriferous zone. Sampling returned assay values of 2.06 grams gold per tonne from the upper half of the zone, and 15 grams per tonne from the lower part.

DEPOSIT MODEL

A general model for 'mesothermal' gold-quartz veins applicable to the Cassiar gold deposits proposes that the veins form where abundant fluid flow has been focused in structurally complex zones especially where thick, competent volcanic blocks are present in alternating sequences of competent/less competent rocks. Also chemical precipitation is induced by wallrock-fluid reactions. This commonly occurs in basaltic sequences, notably where there are also ophiolitic rocks that are tectonically emplaced along major crustal breaks, and where high Fe/Fe+Mg rock compositions facilitate gold precipitation by sulphidation of the wallrocks. This setting for gold-quartz vein mineralization is similar to other greenstone belts throughout the world. Ash *et al.* (1996; in preparation) present a similar tectonically influenced model for ophiolite-related (mesothermal) gold mineralization in the Cordillera. Their model suggests that the Cassiar veins are mesothermal type, are related to tectonic activity during emplacement of the Sylvester allochthon, and they could be as old as 170 Ma in age.

Most other workers in the Cassiar district, including Read and Psutka (1983) at Taurus mine, have used conventional structurally influenced mesothermal vein models to interpret the Cassiar quartz vein mineralization. This model suggests that the east-northeasterly striking faults and joints that contain most of the auriferous quartz veins developed during the (mid-Jurassic to early Cretaceous) emplacement and deformation of the allochthon. The other related veins and pyritic auriferous bodies formed in the faults and subparallel structures separating the thrust sheets. The gold mineralization is post-Triassic because the Triassic rocks are hydrothermally altered and apparently acted as an effective chemical and physical barrier that localized the veins.

However, the style of mineralization in mesothermal districts related to major, crustal-scale fault zones can produce large vein systems in which quartz veins have large vertical extent, for example the California Motherlode or Bralorne districts. In contrast, the Cassiar veins occur in relatively small fracture zones with short strike length and limited vertical extent. More germanely, Nelson and Bradford (1989) have identified the main problem with a conventional mesothermal vein origin for the Cassiar district. They observe: *'The pattern of east-west veins at Taurus mine area in an overall regional north-south distribution of quartz veins in the Cassiar belt does not fit the configuration of en echelon fracture sets and extensional dilations formed during strike-slip motion on the northwest-trending large faults in the area. Similarly compression during emplacement of the Cassiar batholith that might have generated large scale joint and fracture zones occurred at approximately 100 Ma and therefore appears to post date the age of vein development by about 25 Ma.'*

The alternative proposal offered by Nelson (1990) is that the gold mineralization is intrusion-related and is associated with a cryptic intrusion. If indeed there is a genetic relationship between gold mineralization and a cryptic intrusion, then the age of that intrusion should be about 130 Ma, the same as the apparent age of the vein mineralization. K-Ar dating of alteration minerals provides apparent mineralization ages of 137 Ma at Taurus mine and dates of 112, 122 and 127 Ma from Erickson Gold mine (Sketchley, 1986). Panteleyev and Diakow (1982) report a 131 Ma K-Ar date on sericite from a Snowy Creek quartz vein; similar-looking, tourmaline-bearing quartz vein material from Quartzrock Creek near the Sable adit portal has returned a 131 Ma $Ar^{40/39}$ plateau age (Chris Ash, personal communication, 1996). The lamprophyre dikes in the region are observed to cut the quartz vein mineralization. K-Ar dating of a lamprophyre dike in the Huntergroup and Pooley Creeks area, near Needlepoint Mountain has returned an age of 110 Ma from the biotite-rich dike. Nelson and Bradford (1990) report a 77.6 Ma age from a dike at Erickson Gold mine and a 63.7 date from a granite clast-bearing dike in the Berubé vein prospect. In order to further investigate the relationships between intrusive rocks and the gold mineralization, samples of hydrothermal micas from veins in the Taurus area have been submitted for

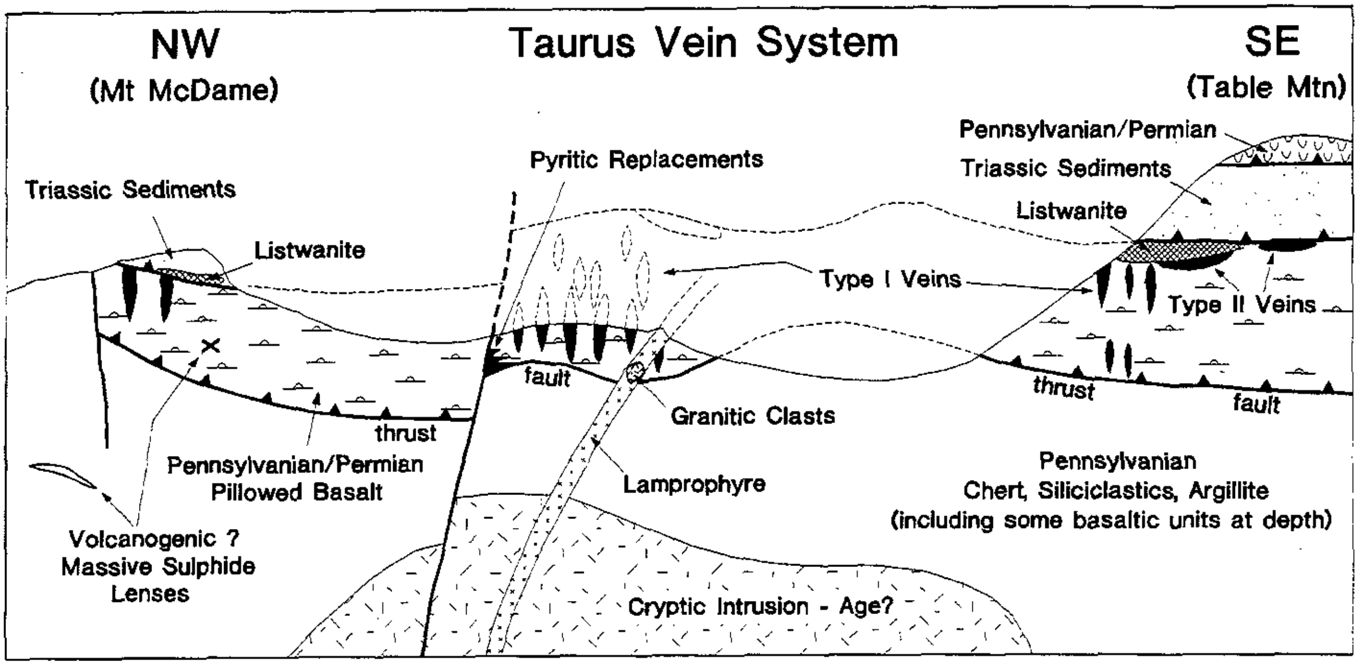

Figure 6. Schematic model for gold mineralization in the Cassiar district showing relationship between Type I steep, volcanic-hosted veins and Type II ribboned, carbonaceous veins at volcanic-sediment contacts, commonly thrust faults, with listwanite alteration. A hypothetical cryptic intrusion (Nelson, 1990) is shown, as suggested by the presence of granitic clasts in lamprophyre dikes that cut mineralization.

additional dating by $Ar^{40/39}$ and conventional K-Ar methods. Also some intrusive rocks and two samples of the granitic clasts in lamprophyre dikes in the Taurus mine area have been submitted for U-Pb zircon work.

A schematic model showing the distribution of quartz veins in basaltic rocks, with a classification of veins according to Panteleyev and Diakow (1982) as Type I and Type II veins, is shown on Figure 6. The figure shows a hypothetical intrusive body, the cryptic intrusion of Nelson (1990), that might underlie the Cassiar gold deposits and is in evidence as clasts in lamprophyre dikes that cut the auriferous quartz veins. If the age of the intrusion is the same as the apparent 130 Ma age of mineralization, there could be a genetic connection between it and the veins. If the intrusion post-dates the veins, the relationship is simply a structural one in which the intrusion has uplifted the veins, notably in the Taurus mine area where the underlying cherty rocks are near surface.

As matter of additional interest to exploration geologists, it is noteworthy that a drill intersection in basalts (drill hole T96-14) cut an approximately 1 metre-thick cupriferous, pyrrhotite-bearing massive pyritic body (or vein ?). Other massive sulphide mineralization occurs at Lang Creek (MINFILE 104P 008) in sedimentary rocks at the base of the Sylvester allochthon. The potential for volcanogenic massive sulphide mineralization in Sylvester rocks has not been extensively tested.

ACKNOWLEDGMENT

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MINERAL RESOURCE ESTIMATION THE MINERAL POTENTIAL PROJECT: AN EVALUATION OF ESTIMATOR RESPONSES FOR SELECTED MINERAL DEPOSIT TYPES FOR THE PROVINCE

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KEYWORDS: mineral potential, probability, confidence, mineral deposit model, resource assessment

INTRODUCTION

The Mineral Potential project has completed resource assessment for all areas of British Columbia with the exception of the Queen Charlotte Islands. During the past year, the northwestern portion of the province was covered as described by Kilby (1996, this volume). Resource assessment is carried out on specified tracts of land, known as, Mineral Assessment tracts which are generalizations of contiguous geological tracts that share a common tectonic assemblage and metallogeny. The boundaries between tracts reflect differences in lithology, structure and/or geological history (*see* Grunsky *et al*, 1994; Church, 1995; Massey, 1995). This report provides a partial summary of results from estimates obtained from the Mineral Resource Assessment Workshops held throughout the province.

The overall potential value of a mineral assessment tract is the sum of known and predicted mineral resources. Known resources have been compiled from a number of sources (Kilby, 1995). Predicted resources were obtained using a method adapted from the three-part assessment methodology of the United States Geological Survey (Singer, 1993). The modified methodology used in the Mineral Potential project is described in this paper.

The Mineral Assessment tracts were created to define areas that contain specific characteristics related to metallogeny (*see* Kilby, 1995). Each tract is evaluated by a geologist who has knowledge about the area and the types of mineral deposits that might be expected there.

GRADE AND TONNAGE MODELS

Grade and tonnage data are required by the estimator in order to provide information on the range of the grade and tonnage that is typical for a mineral deposit type. Estimators were asked to base their estimates on the median values of the grade and tonnage ranges for each deposit type in order to standardize the process. Grade and tonnage data were obtained from three sources; the BC Geological Survey Branch, United States Geological Survey, and the Geological Survey of Canada. In several cases, grade and tonnage models assembled by the USGS were not considered to be applicable for British Columbia. In those cases, grade and tonnage data were compiled by the BC Geological Survey Branch (Lefebure and Hoy, 1996). The Geological Survey of Canada contributed a tungsten skarn model which was considered preferable for use in the estimation process for British Columbia.

In many cases, grade and tonnage data do not exist for many of the deposit types that were predicted. Grade and tonnage data were available for some of the USGS deposit models (Cox and Singer, 1986) but, in many cases the data was not publicly available. In these cases, "simulated" grade and tonnage data were generated by using data from the USGS Bulletin 1693 (Cox and Singer, 1986).

For the industrial mineral deposit models, a median grade and tonnage were provided by GSB staff (D. Hora and G. Simandl, personal communication). These median grade and tonnage data were used as substitutes for actual grade and tonnage data. Tables 1 and 2 provide a list of metallic and industrial mineral deposit models used across the province for the Mineral Potential Project. The tables are subdivided based on the sources of the information

ESTIMATE OF EXPECTED UNDISCOVERED DEPOSITS

The resource assessment process is based on subjective probability applied to the prediction of undiscovered resources. Added to the assessment is the value of known resources. The subjective approach to resource estimation requires that geologists make estimates on the likelihood of finding deposits based on their knowledge of the geology and other pertinent information within a specific mineral assessment tract. These assessments were carried out in Mineral Resource Assessment Workshops (*see* Kilby, 1995, 1996; Grunsky 1996).

For each estimate, estimators were asked to provide, on a scale from 0 to 100, the likelihood of finding at least one or more deposits for a specific mineral deposit model and, the degree of confidence of their estimate (see Grunsky 1996). Estimators worked in groups of 2 to 4 as outlined by Grunsky (1996). For each estimate, each estimator was asked to indicate a level of confidence on a scale of 0 to 100 for their own estimate. The estimators were also asked to base their "estimate of confidence" on their confidence of their own knowledge, not on the likelihood of the presence of a mineral deposit. Thus, the confidence and the

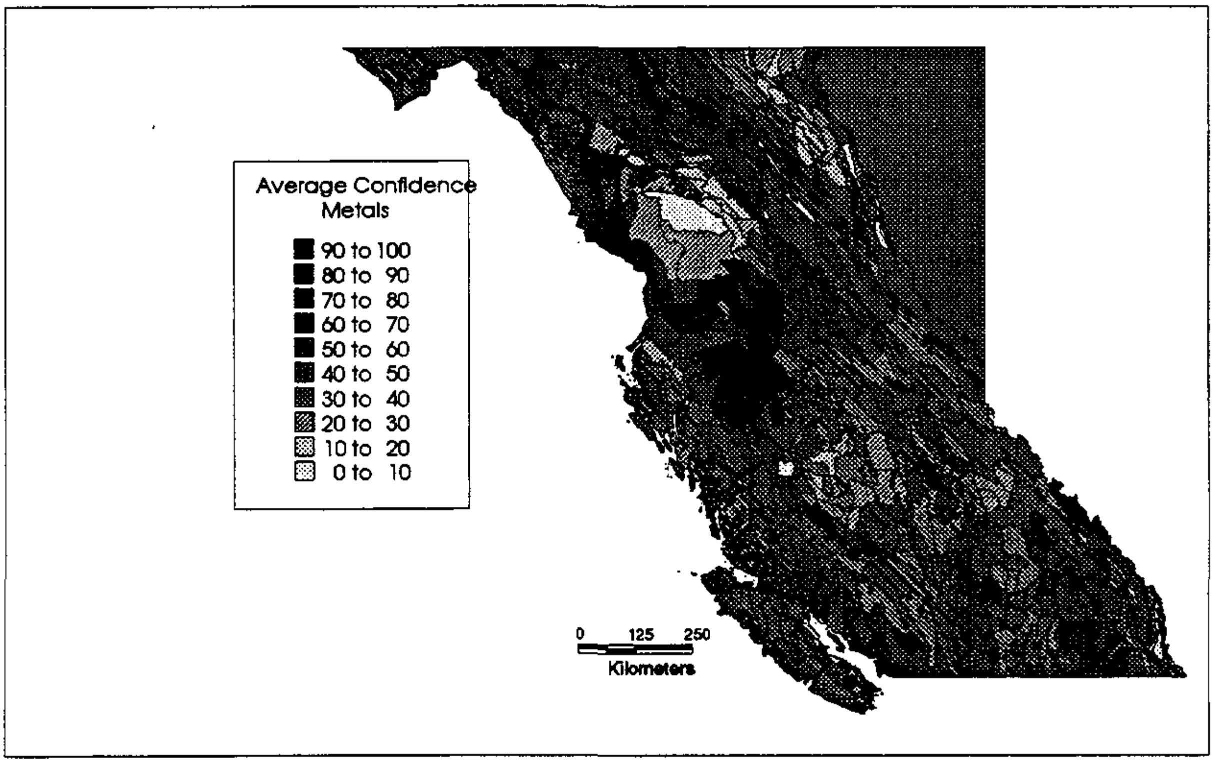

Figure 1. Map of mineral assessment tracts indicating the average confidence expressed for each tract for all metallic deposits.

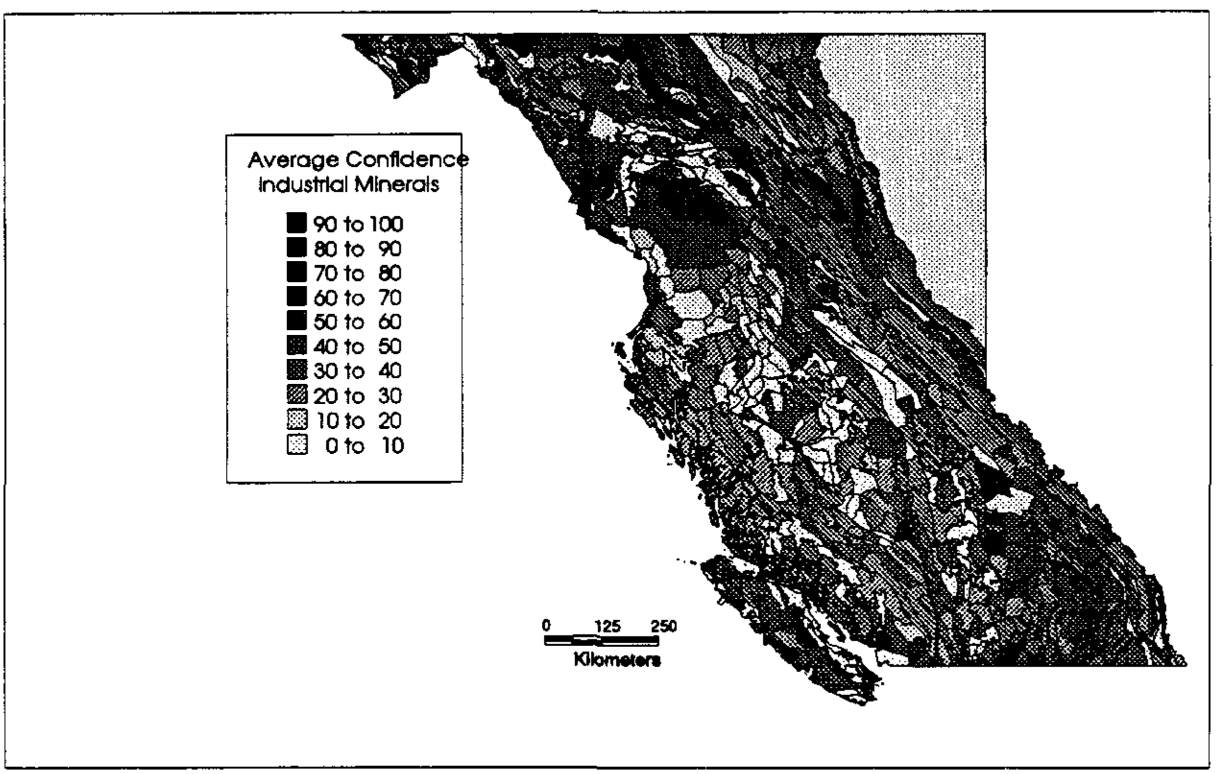

Figure 2. Map of mineral assessment tracts indicating the average confidence expressed for each tract for all industrial mineral deposits.

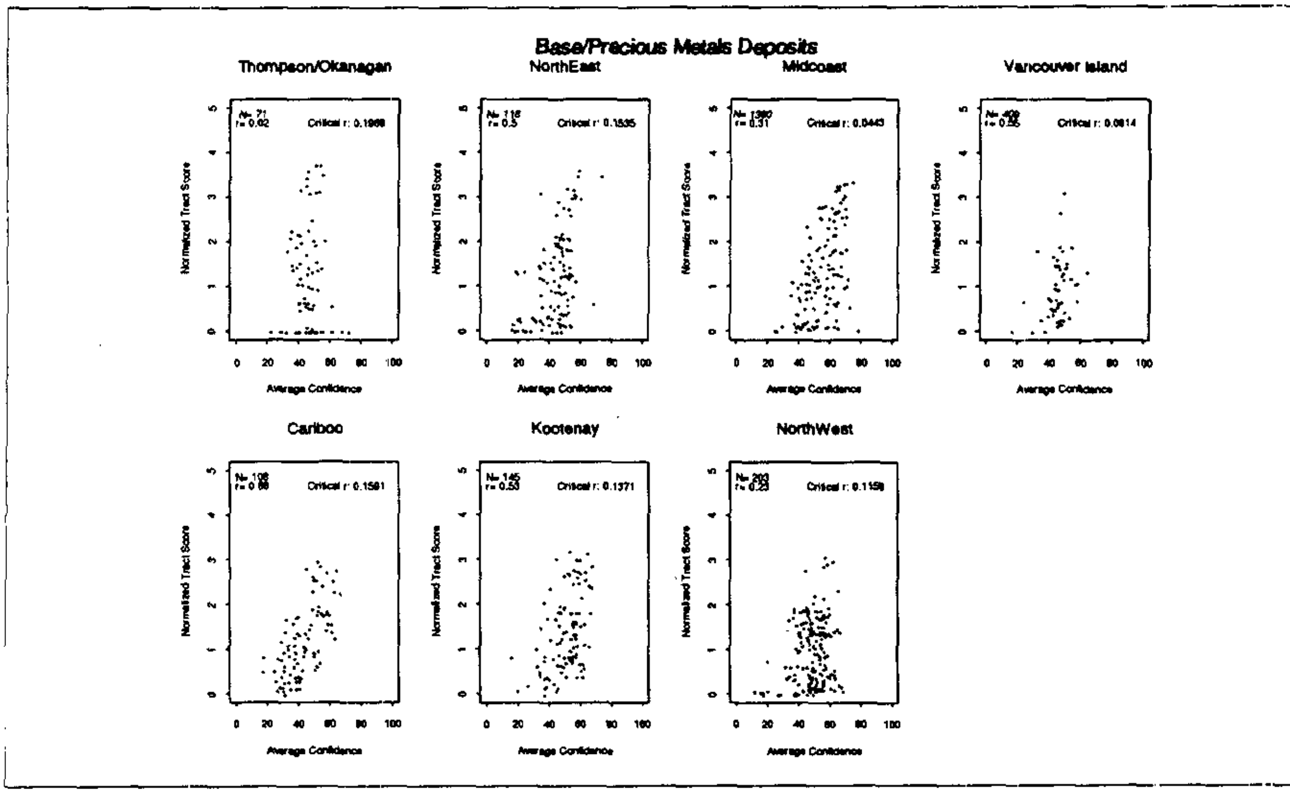

Figure 3. Plot of normalized tract score versus average confidence expressed by the estimators for each tract for precious and base metal deposits within each workshop area. See text for explanation.

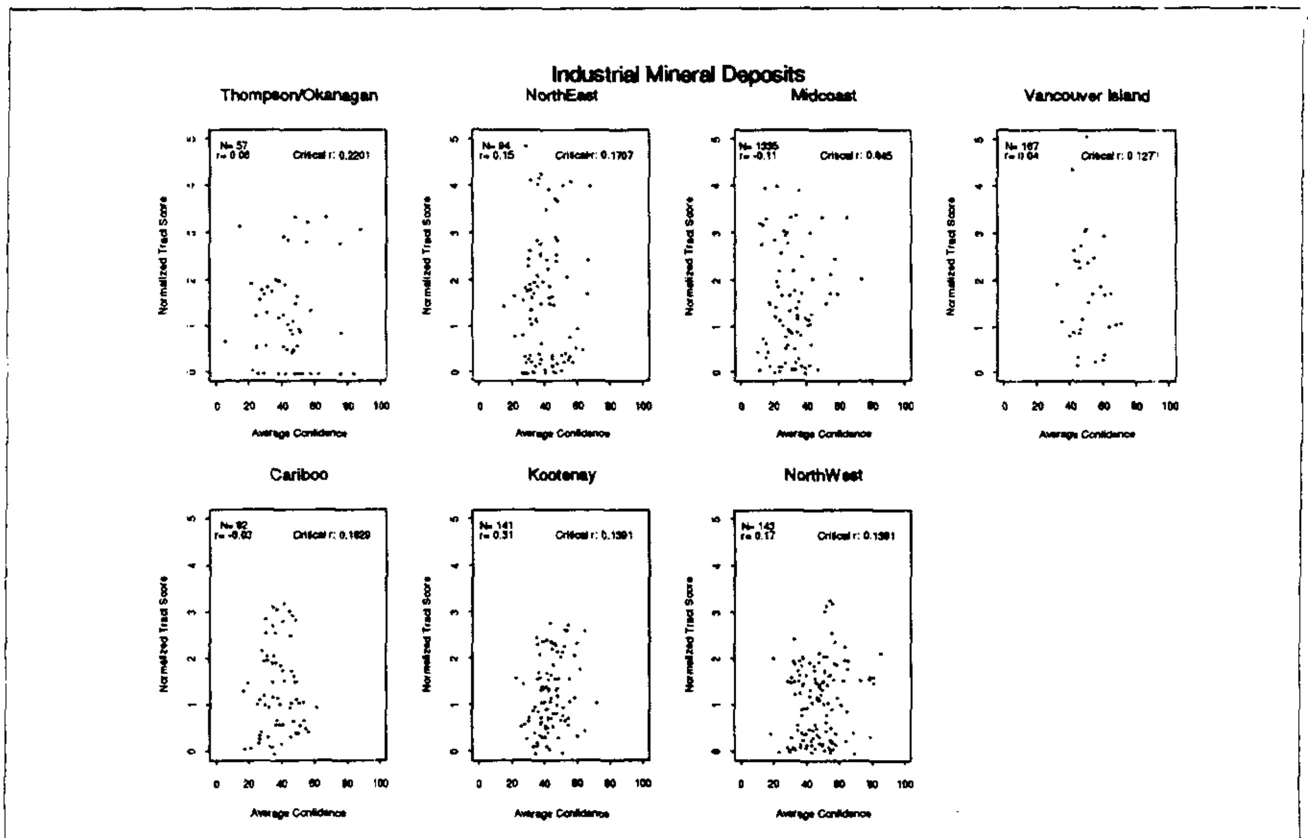

Figure 4. Plot of normalized act score versus average confidence expressed by the estimators for each tract for industrial mineral deposits within each workshop area. See text for explanation.

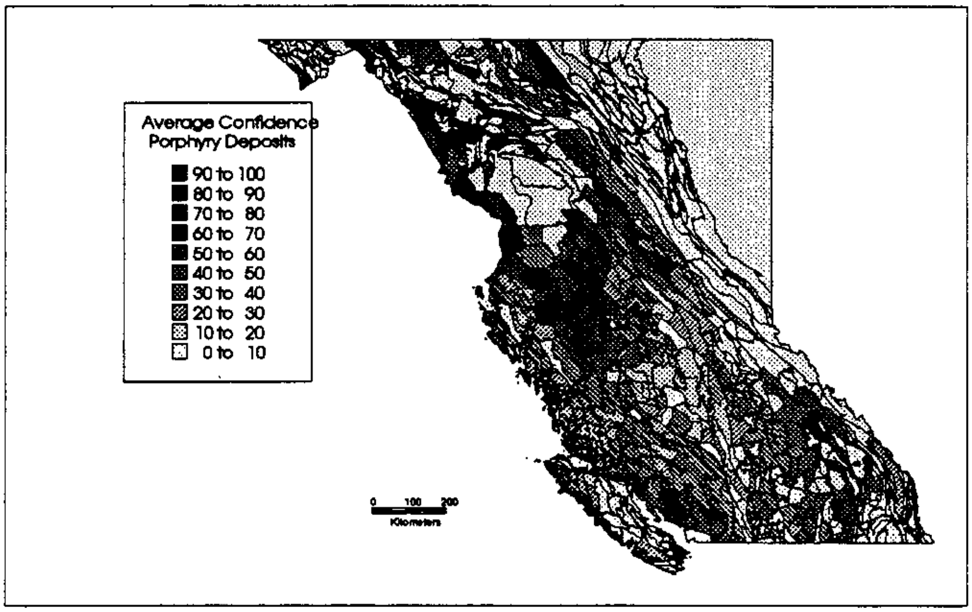

Figure 5. Map of average confidence for each tract for porphyry deposit types. Tracts with a value of 0 to 10 indicate tracts in which no porphyry deposit types were estimated.

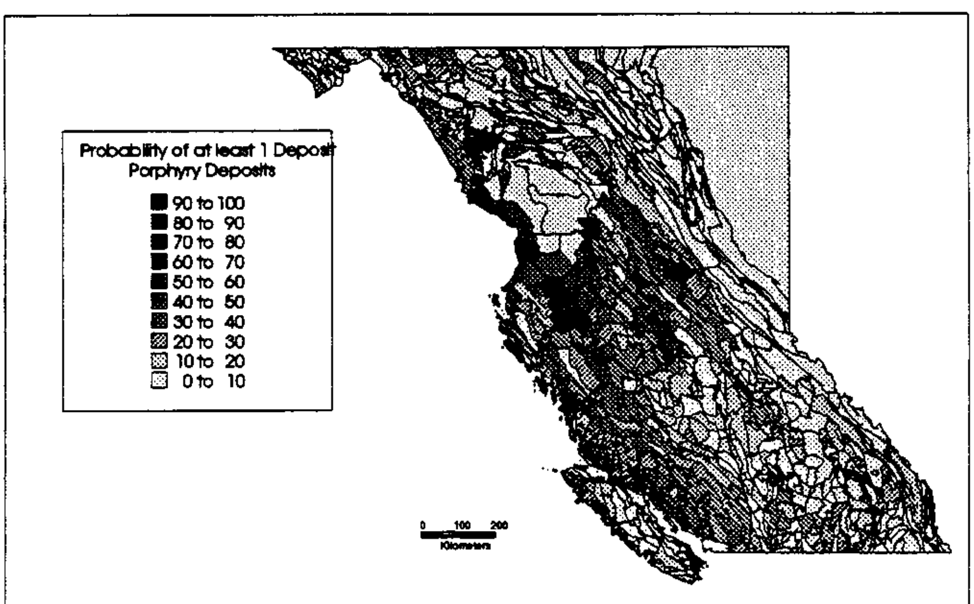

Figure 6. Map of the probability of at least one porphyry deposit occurring in each tract. Tracts with a value of 0 1o 10 indicate tracts in which no porphyry deposit types were estimated.

estimate of deposit probability were assumed to be independent.

Estimators were also asked to "weight" their confidence with respect to each other. The probability estimates for the likelihood of finding deposits were used as input in a Monte Carlo computer simulation program, Mark3, which was provided by the USGS (Root *et al*, 1992). The output of the Mark3 computer program consisted of a probability curve indicating the tonnes of commodity based on the input probabilities. The weights assigned to each estimator were then applied to the output values so that the confidence of each estimator with respect to each other was factored into the results.

A total of 19023 estimates were made for 762 tracts. The estimates associated with each region, in order of the date the workshop was carried out, are as follows:

Region	*# of Estimates*
Thompson/Okanagan	1836
Northeast BC	2855
Midcoast/Skeena-Nass	3460
Vancouver Island	1475
Cariboo	2203
Kootenay	2913
Northwest BC	4281

The following sections summarize and present a preliminary interpretation of the responses covering the entire province.

AN EVALUATION OF 'CONFIDENCE OF THE ESTIMATE'

For each mineral assessment tract, a summary confidence value was calculated based on the average of confidences expressed by all estimators for all deposit models. These values are summarized in Figures 1 and 2.

Figure 1 is a map of the mineral assessment tracts across the province. The tracts are shaded according to the average confidence for all of the base and precious metal deposit models. The map combines the results from the 7 different workshop regions (Thompson-Okanagan, Northeast BC, Skeena-Nass-Midcoast, Vancouver Island, Cariboo, Kootenay, and Northwest BC areas (*see* Kilby, 1995). Areas of very low confidence (0 to 10) reflect tracts in which there were very low estimates and/or no estimates for metallic deposits.

Figure 2 shows a map of the same tracts but is shaded according to confidences expressed for industrial minerals. In both figures there are areas in which relatively low

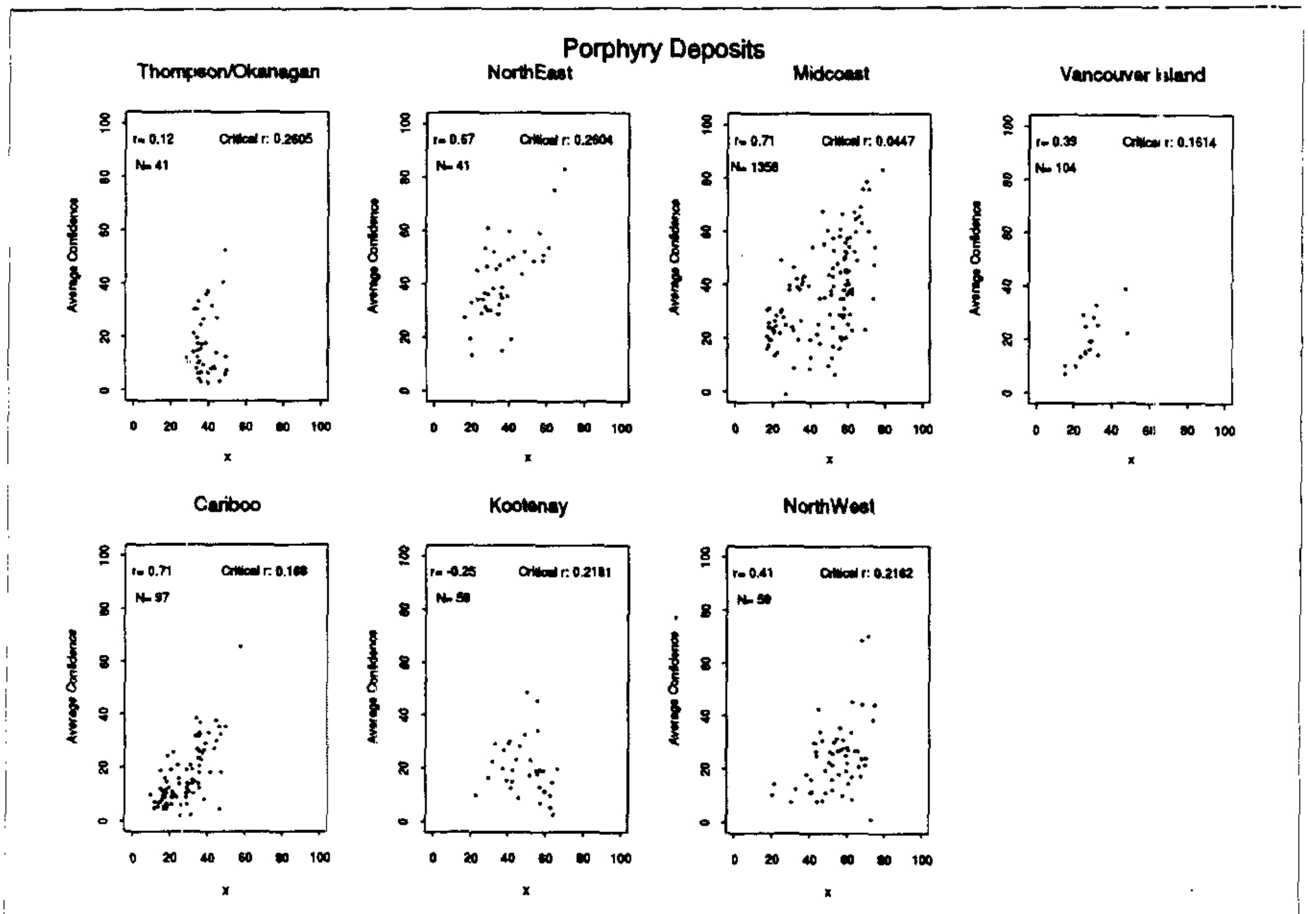

Figure 7. Plot of the average probability of at least one deposit versus the average confidence for each tract for porphyry deposits. There is a positive correlation for all seven areas however the Midcoast area indicates higher probabilities of at least one deposit with a corresponding high level of confidence.

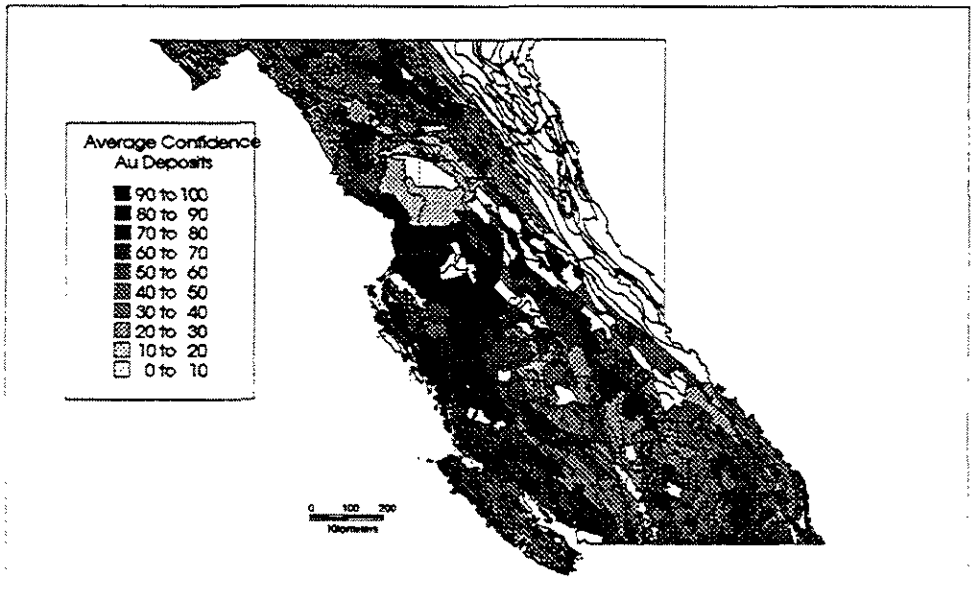

Figure 8. Map of average confidence for each tract for Au deposit types. Tracts with a value of 0 to 10 indicate tracts in which no vein deposits types were estimated.

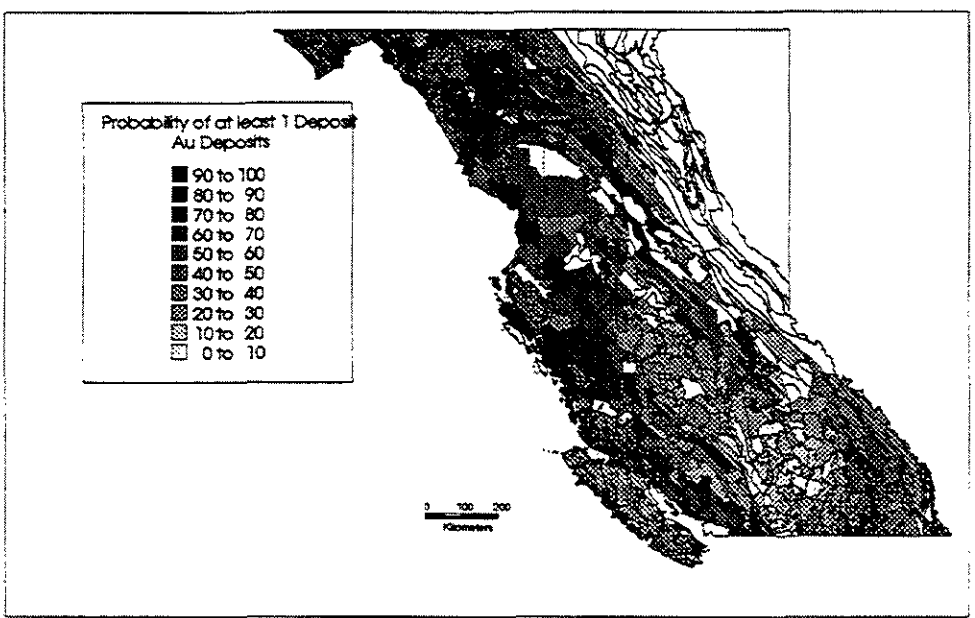

Figure 9. Map of the probability of at least one Au deposit occurring in each tract. Tracts with a value of 0 to 10 indicate tracts in which no Au deposits were estimated.

confidences were expressed by workshop participants. For the metallic deposits, areas of low confidence were expressed for the Bowser basin area and the northeast of the province. For the industrial mineral deposits there were many more tracts that were either not assessed or had very low confidences.

An attempt to explain the variation of confidence was made by examining the relationships between the final tract score and the probability of at least one deposit being present for each tract and deposit model. Figures 3 and 4 show plots of average confidence for each tract with the tract score. The tract score is assigned by combining known reserves with predicted reserves (Kilby, 1996). As the tract score is dependent on the area and number of tracts within each assessment area (Vancouver Island, Kootenay, Cariboo, Midcoast, Thompson-Okanagan, Northeast, Northwest), the tract score is normalized so that the scores between areas can be compared.

Figure 3 contains plots by area, of average confidence for each tract plotted against the normalized tract score for precious and base metal deposits. Each plot contains a value N, indicating the number of points; the value, r, the correlation coefficient; and, the value Critical r, the value of the correlation coefficient at which the value is significant at the 95% confidence level. This statistic can only be considered reliable if the population being tested are normally distributed. The data analyzed here have not been examined for the nature of their distributions.

Areas with a significant correlation between the normalized mineral tract score and the average confidence include, the Northeast, Midcoast, Vancouver Island, Cariboo, Kootenay, and Northwest. Only the Thompson/Okanagan area fails to show any significant corrrelation. Tract scores are a combination of known reserves and estimated reserves from the mineral potential workshops. The relationship between mineral inventory and average confidence was examined for both the metal and industrial mineral deposit groups. No significant correlation was noted. This lack of correlation suggests that any observed correlation between average confidence and tract score is due primarily to the predictive estimates.

The positive correlation between tract score and confidence can be interpreted as the estimators placing more confidence in tracts where they believe there is a greater

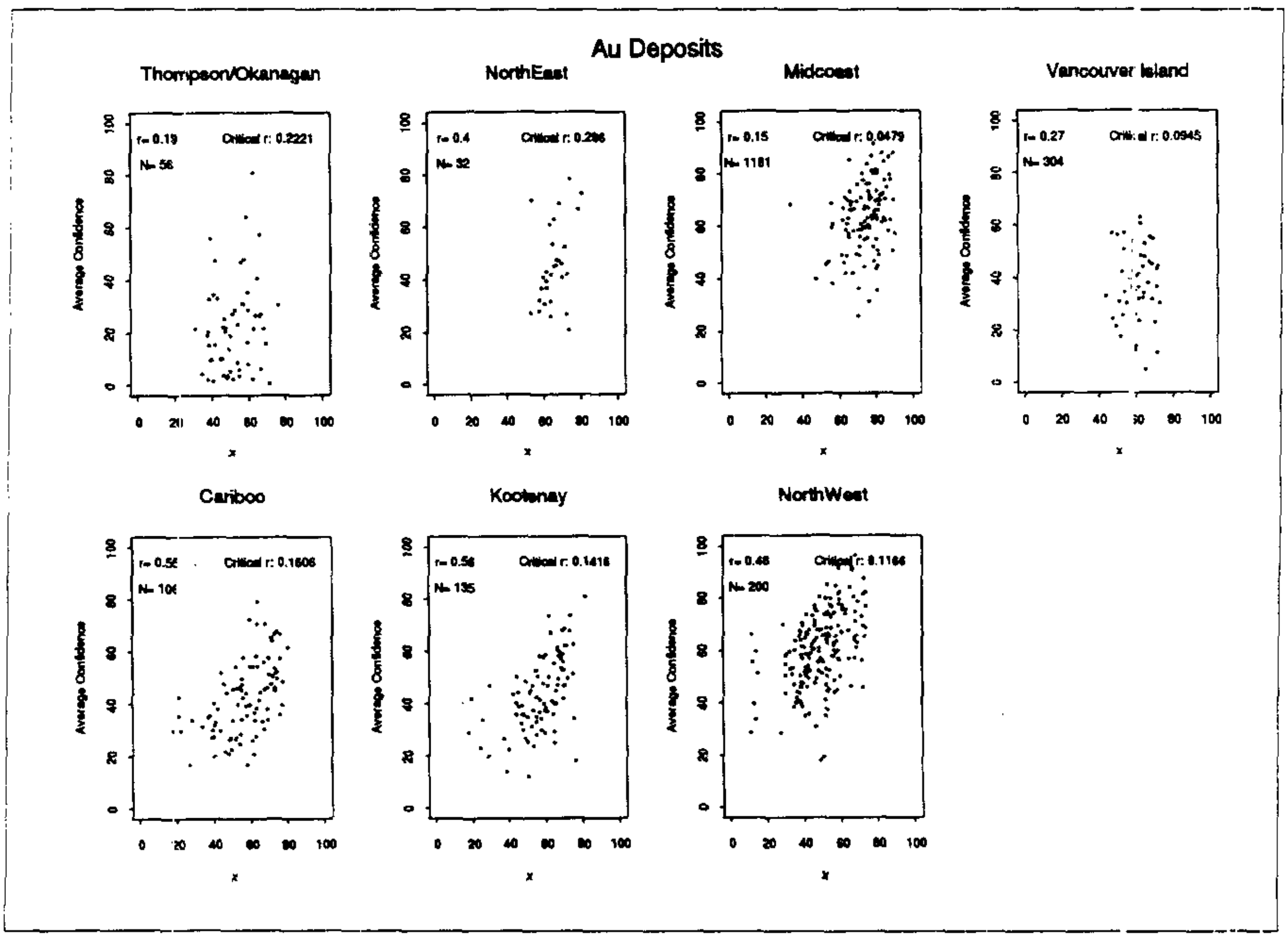

Figure 10. Plot of the average probability of at least one deposit versus the average confidence for each tract for Au deposits. There is a positive correlation for the Midcoast, Cariboo, Kootenay and Northwest areas. Vancouver Island, the Thompson/Okanagan and the Northeast areas display a poor to no correlation.

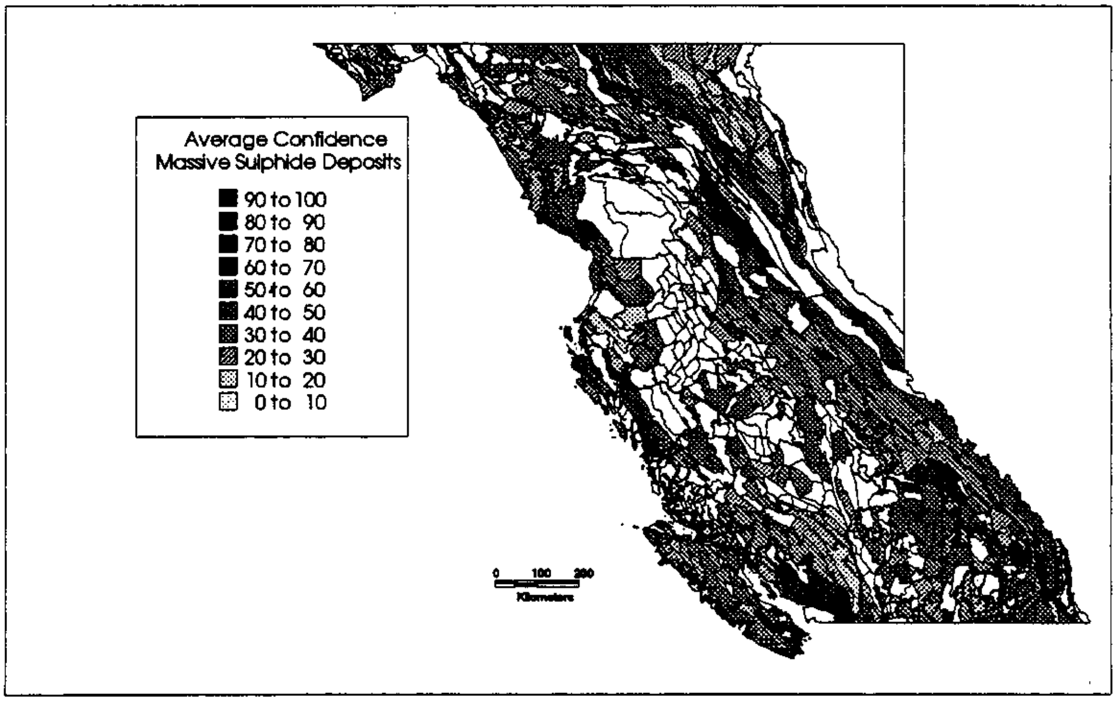

Figure 11. Map of average confidence for each tract for massive sulphide deposit types. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

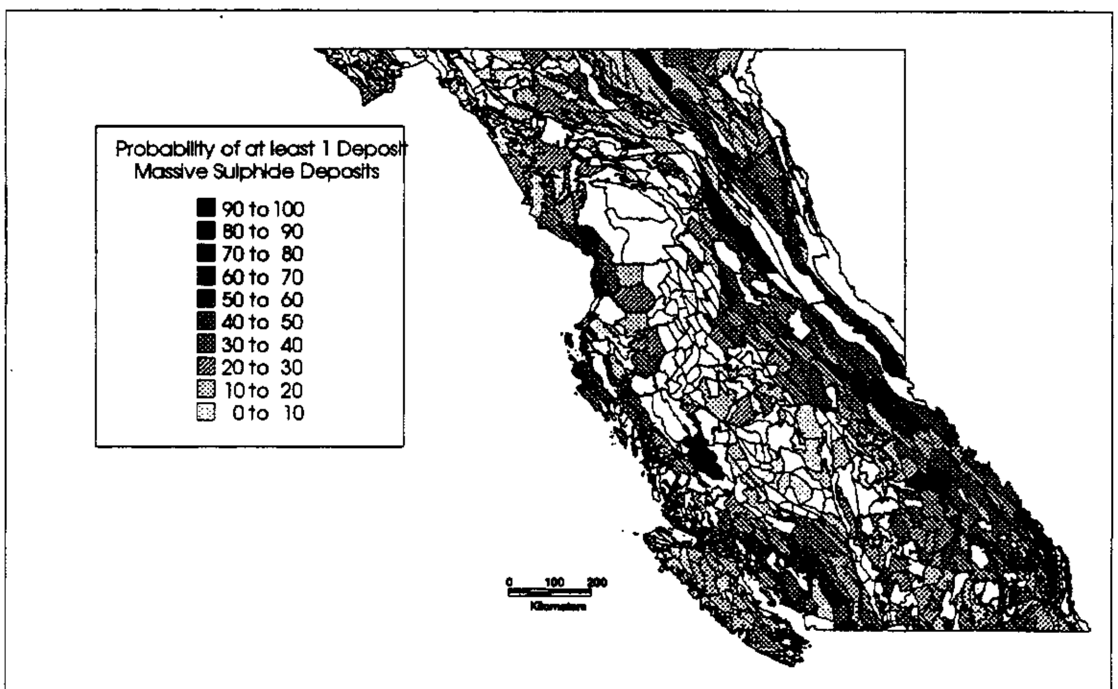

Figure 12. Map of the probability of at least one massive sulphide deposit occurring in each tract. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

likelihood of finding additional deposits. In areas where there is a low tract score, the estimators also show a low degree of confidence. This also implies that rarely do the estimators place a high confidence on tracts where they do not believe there are additional metallic deposits. This also implies that areas of low confidence also indicate a degree of uncertainty of finding additional metallic deposits. It does not suggest that there are no additional deposits.

In Figure 3, although most areas show a positive correlation between normalized tract score and average confidence it is difficult to explain the variation in slope. In the areas where there is a poor correlation, it can only be inferred that the estimators did not use their measure of confidence as an indicator of resource potential. In almost all cases, there was no indication that high confidences were placed on areas of low metal resource potential.

Figure 4 shows plots of normalized tract score with average confidence for each tract over each workshop area for the industrial minerals suite of deposits. Areas in which significant correlations occur include the Midcoast, Kootenay, and Northwest regions. The correlations are not as strong as those shown for the base metal and precious metal deposit types of Figure 3. This suggests that the estimators did not consider their measure of confidence in assigning the industrial mineral potential of a tract.

AN EVALUATION OF DEPOSIT TYPE GROUPS

A number of deposit types were grouped together to study the areas in which specific mineral deposit types were predicted to occur with associated estimator confidences. Deposit type groups that were studied were porphyry deposits, Gold deposits, massive sulphide and skarn deposits. A measure of resource potential can be made by examining the probability for the presence of at least one deposit for each tract for each of the porphyry models. This measure was used in place of the tract score which indicates the resource potential for all metallic or all industrial mineral deposit types.

PORPHYRY DEPOSITS

Figure 5 shows a map of the average confidence associated with each tract that was estimated to contain porphyry deposits. The porphyry deposits include (calcalkalic

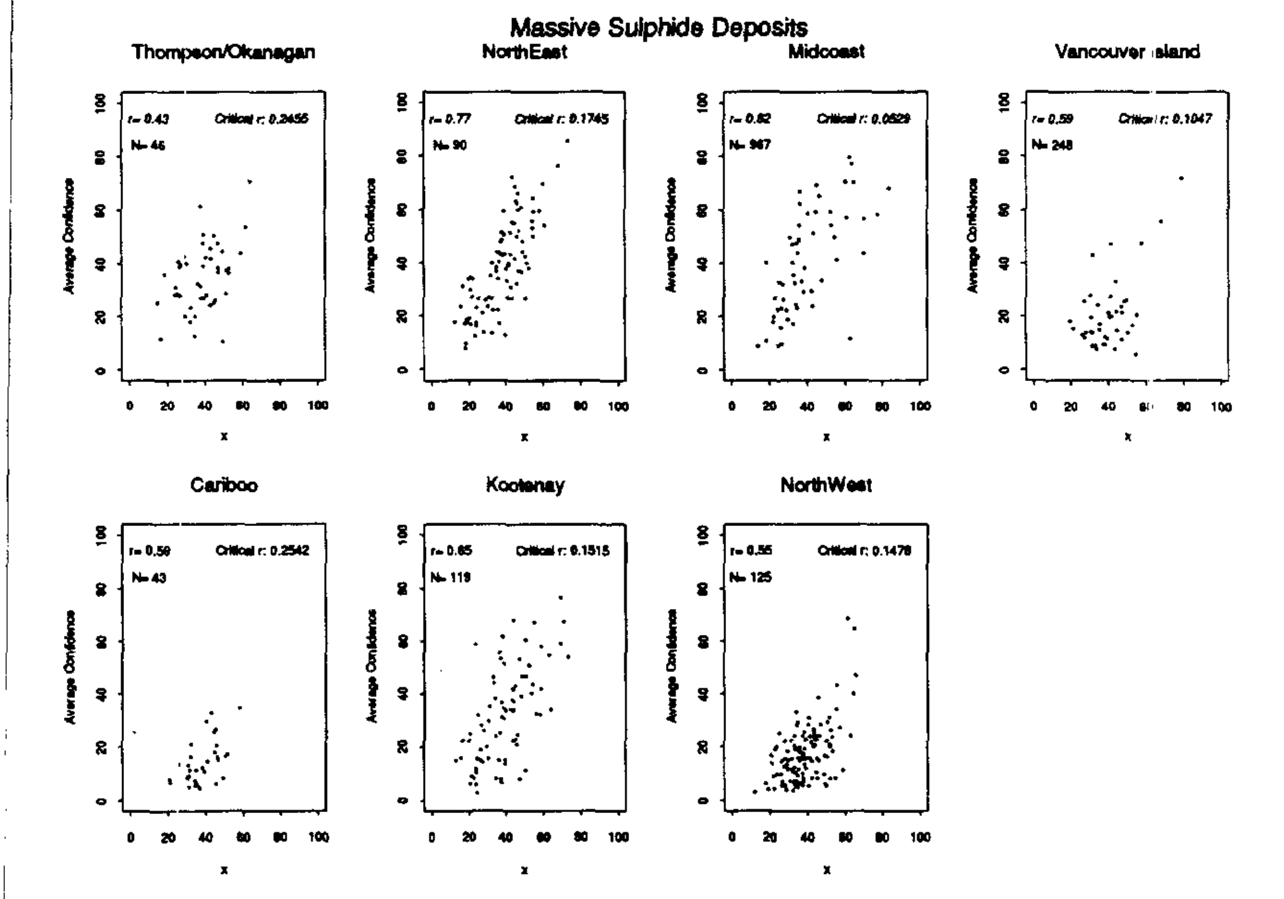

Figure 13. Plot of the average probability of at least one deposit versus the average confidence for each tract for massive sulphide deposits. There is a positive correlation for the Midcoast, Cariboo, Thompson Okanagan, Kootenay and Northwest areas.

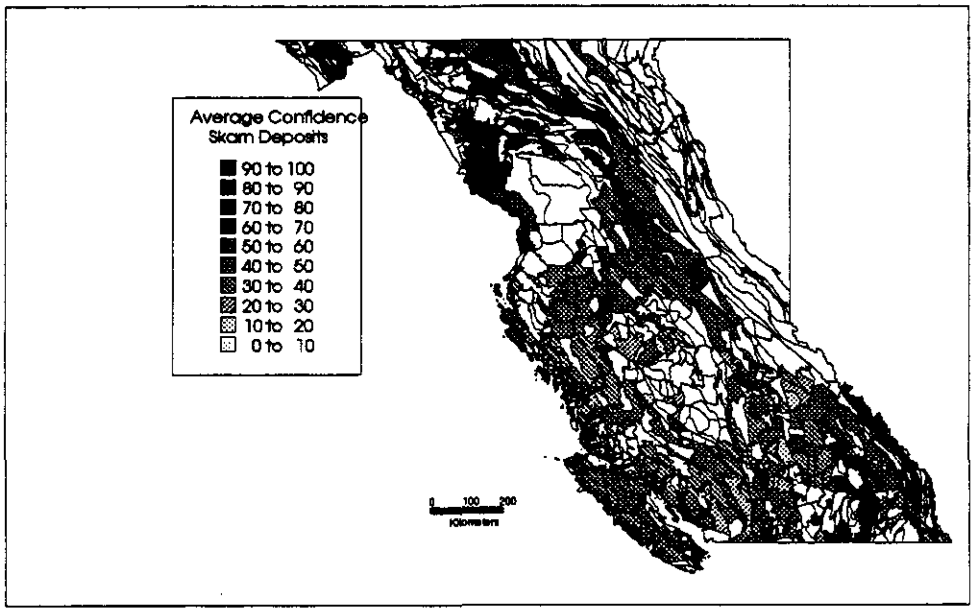

Figure 14. Map of average confidence for each tract for skarn deposit types. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

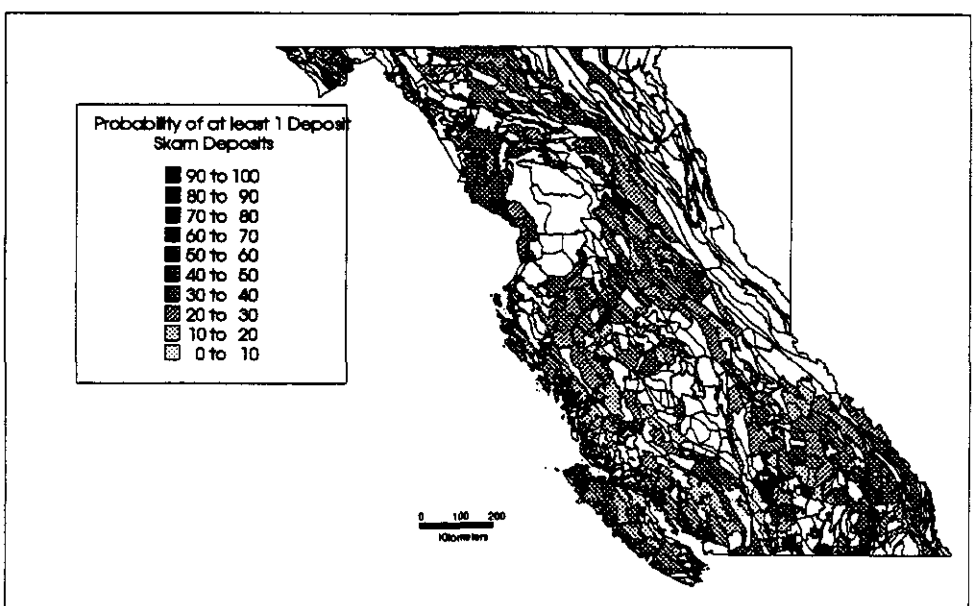

Figure 15. Map of the probability of at least skarn depost occurring in each tract. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

Cu, alkalic Cu, Cu-Au, and Mo deposits). As well, for each tract, the average probability at which at least one deposit was estimated was also summarized as shown in Figure 6. Areas with high confidences in Figure 5 correspond with areas of high probabilities of at least one deposit in Figure 6.

Figure 7 shows a positive correlation between average confidence and the average probability of at least one deposit within each tract. Areas with significant correlation coefficients between confidence and the probability of at least one deposit include Northeast, Midcoast, Vancouver Island, Cariboo and Northwest areas. The Kootenay area results exhibit a negative relationship between confidence and the probability of at least one deposit. This result is possibly an artifact of what appears to be two clusters. The detailed investigation required to explain the differences between the areas is beyond the scope of this report. In part these differences may be explained by the workshop dynamics and attitudes of the estimators about their placing confidences with their estimates.

GOLD DEPOSITS

The following gold deposits were grouped together for this report: subvolcanic shear hosted veins, gold quartz veins, Eskay Creek type, hot spring Au-Ag, iron formation Au, and epithermal Au-Ag (high sulphidation). Figure 8 is a map of the average confidence expressed for these deposits for each tract. Figure 9 is a plot of the probability of at least one deposit occurring in each tract. Areas that indicate a lack of confidence and low probabilities of occurrence include the Bowser Basin area, the northeast. Figure 10 shows plots of the probability of at least one deposit versus the average confidence for each of the assessment areas. In contrast with the porphyry estimates, overall probabilities are higher. Figure 10 shows plots of average confidence versus the average probability of at least one deposit for the 7 areas. Significant correlations occur for the Northeast, midcoast, Vancouver Island, Cariboo, Kootenay and Northwest areas. The Thompson/Okanagan area data show no definitive relationship.

MASSIVE SULPHIDES

Massive sulphide deposits were grouped as follows: Mississippi Valley type Pb-Zn, Shushwap type, Kootenay arc type, Broken Hill type, Sullivan type, Besshi type, Kuroko type and Cyprus type. The average confidence and the associated probability of at least one deposit occurring in each tract is shown in Figures 11 and 12. These two

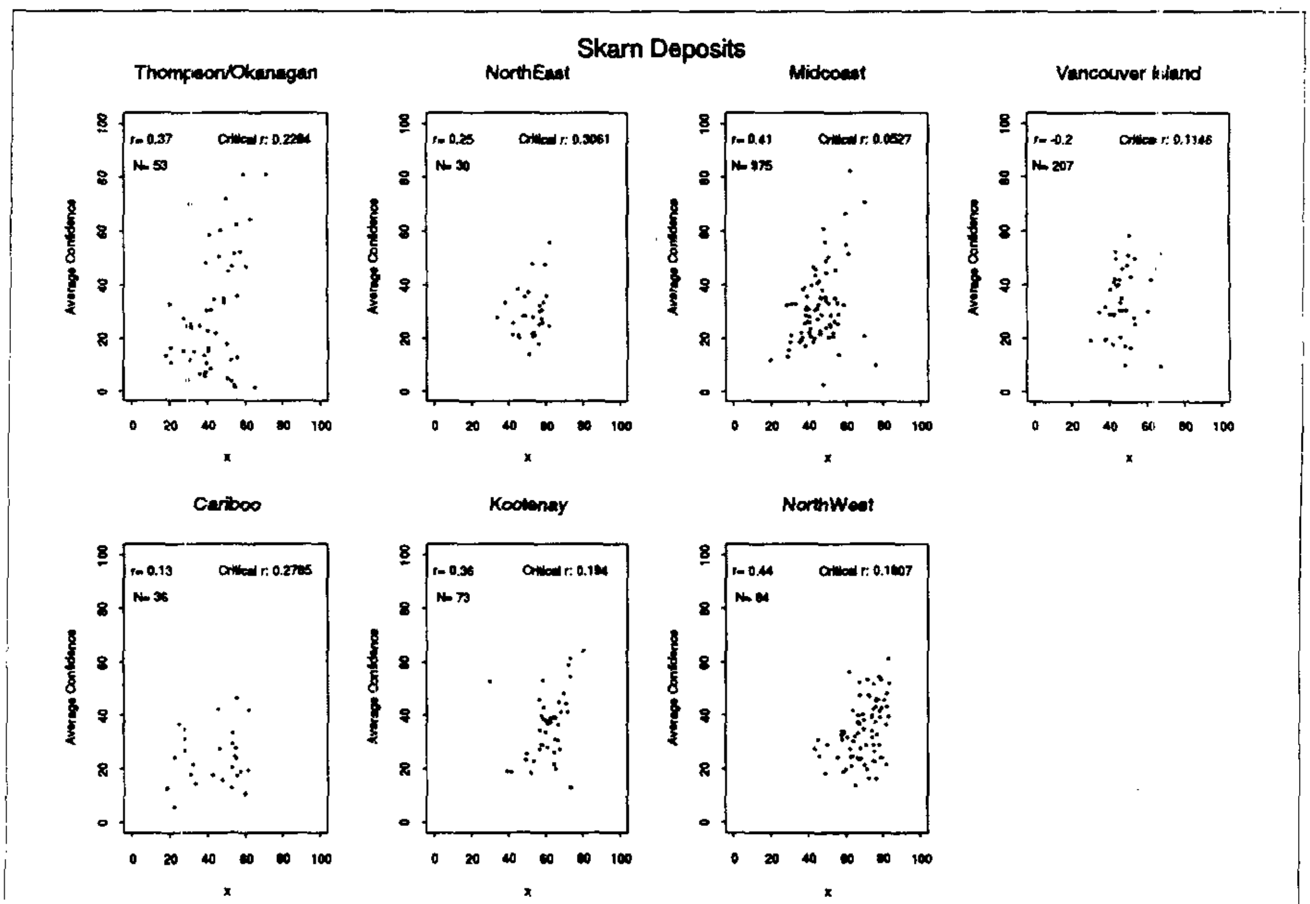

Figure 16. Plot of the average probability of at least one deposit versus the average confidence for each tract for skarn deposits. There is a positive correlation for the Midcoast, Cariboo, Thompson Okanagan, Kootenay and Northwest areas.

TABLE 1
METAL DEPOSIT MODELS USED IN THE MINERAL POTENTIAL PROJECT

Model No.		Commodities					
Metallic/Precious Minerals BC Deposit Grade/Tonnage Data							
5	Basaltic	Cu	Ag	Au	Cu		
7	Unconformityl U	U3O8					
9	Mississippi Valley Type Carbonate Hosted	Au	Ag	Cu	Pb	Zn	
80	Mississippi Valley/Kootenay Arc Type	Au	Ag	Cu	Pb	Zn	
84	Shushwap Mississippi Valley Type	Au	Ag	Cu	Pb	Zn	
109	Broken Hill Type Massive Sulphide	Ag	Cu	Pb	Zn		
21	Sullivan Type Massive Sulphide Zn-Pb-Ag	Au	Ag	Pb	Zn		
22	Besshi Type Massive Sulphide	Au	Ag	Pb	Zn		
23	Kuroko Type Massive Sulphide	Au	Ag	Cu	Pb	Zn	
28	Epithermal Au-Ag Low Sulphidation	Au	Ag				
30	Almaden Hg	Hg					
38	Silica-Hg Carbonate	Hg					
33	Subvolcanic Shear Hosted Gold Veins	Au	Ag	Cu			
108	Au deposits blended	Au	Ag	Cu	Pb	Zn	
34	Gold Quartz Veins	Au	Ag	Cu	Pb	Zn	
43	Polymetallic Ag-Pb-Zn	Au	Ag	Cu	Pb	Zn	
45	Polymetallic Manto Ag-Pb-Zn	Au	Ag	Cu	Pb	Zn	
47	Cu Skarn	Au	Ag	Cu	Pb	Zn	
49	Fe Skarn	Au	Ag	Cu	Fe		
50	Au Skarn	Au	Ag	Cu			
79	Transitional	Au	Ag	Cu	Pb	Zn	
54	Porphyry Cu (calcalkalic)	Au	Ag	Cu	Mo		
55	Porphyry Cu	Au	Ag	Cu	Mo		
56	Porphyry Cu (Alkalic)	Au	Ag	Cu			
59	Porphyry Mo (Low F)	Mo					
Metallic/Precious Minerals Simulated Deposit Grade/Tonnage Data							
106	PaleoPlacer Au	Au					
4	Placer U-Au-PGE-Sn-Diamond-Magnetite-Garnet	Au	Ag				
103	Eskay Creek Type	Au	Ag				
85	U-Th Pegmatite	U3O8					
102	Cu-Ag Veins						
83	Li in Pegmatite	Li					
104	Mississippi Valley Type	Zn	Pb	Ag			
78	Mo Skarn	Mo					
87	Alaskan PGE	PGE					
98	Nb/Ta Hosted Carbonatites	Nb					
105	Serpentinite Cu Ni	Cu	Ni				
Metallic/Precious Minerals GSC Deposit Grade/Tonnage Data							
51	W Skarn	W					
Metallic/Precious Minerals USGS Deposit Grade/Tonnage Data							
2	Terra Rosa Au-Ag	Au	Ag				
6	Sediment Hosted Cu	Cu	Co	Ag			
8	Volcanic Hosted U	U	Mo				
10	Sediment Hosted Au-Ag [Carlin type]	Au	Ag				
11	Sandstone Pb	Au	Ag	Cu	Pb	Zn	
14	Sedimentary Mn	Mn					
18	Volcanogenic Mn	Mn					
20	Algoma Fe	Fe	P				
24	Cyprus Type Massive Sulphide	Au	Ag	Cu	Pb	Zn	
25	Hot Spring Hg	Hg					
26	Hot Spring Au-Ag	Au	Ag				
27	Epithermal Au-Ag High Sulphidation	Au	Ag	Cu	Pb	Zn	
29	Epithermal Mn	Mn					
32	Sitbnite Veins and Disseminations	Sb	Au	Ag			
35	Iron formation -hosted Au	Au	Ag				
36	Volcanic Hosted magnetite	Fe	P				
39	Mn Veins and Replacements	Mn	Fe	P	Cu		
40	W Veins	W					
41	Sn Veins	Sn					
42	Sn Greisens	Sn					
46	Zn-Pb Skarn	Sn					
53	Wollastonite Skarn	Wollastonite					
48	Zn-Pb Skarn	Au	Ag	Cu	Pb	Zn	
52	Sn Skarn	Sn					
58	Porphyry Mo	Mo					
60	Basaltic subvolcanic Cu-Ni-PGE	Cu	Ni	Co	Pd	Au	Pt
61	Gabbroid Ni-Cu	Cu	Ni	Co	Pd	Ir	Au
62	Podiform chromite	Cr2O3	Pd	Pt	Rh	Ir	Ru
63	Carbonatite nephelinite hosted deposits	Nb	REE	P	Zr		
64	Carbonatite nephelinite hosted deposits	Nb	REE	P	Zr		
65	Au-Ag-Te-F Veins	Au	Ag				
67	Diamonds	Diamond					
Metallic/Precious Minerals Combined USGS/BC Grade/Tonnage Data							
57	Porphyry Au	Au					
107	Blended vein deposits	Au	Ag	Cu	Pb	Zn	

TABLE 2
INDUSTRIAL MINERAL DEPOSIT MODELS USED IN THE MINERAL POTENTIAL PROJECT

Industrial Minerals BC Deposit Grade/Tonnage Data

Model No.	Descriptions	Commodities (%)			
15	Bedded Gypsum/Anhydrite	Gypsum			

Industrial Minerals USGS Deposit Grade/Tonnage Data

Model No.	Descriptions	Commodities (%)			
3	Silica Sand	SiO2			
1	Residual Kaolin	SiO2	Al2O3	Fe2O3	Kaolin
13	Sedimentary Kaolin	SiO2	Al2O3	Fe2O3	
12	Bentonite	SiO2	Al2O3	Montmorillonite	
16	Lacustrine Diatomite	SiO2	Quartz		
17	Phosphate Upwelling Type	P			
19	Sedimentary Bentonite	SiO2	Al2O3	Montmorillonite	
31	Hydrothermal Kaolin	SiO2	Al2O3	Fe2O3	Kaolin
82	Silica Veins	SiO2			
66	Kyanite-Silliminate-Andalusite schists	Al2SiO5	Al2O3	SiO2	Kyanite
74	Silica Sandstone	SiO2			

Industrial Minerals Simulated Deposit Grade/Tonnage Data

Model No.	Descriptions	Commodities (%)			
86	Lamproite Hosted Diamonds	Diamond			
89	Placer Garnet	Garnet			
91	Zeolites	Clinoptilolite		Chabazite	
81	Sediment Hosted Stratiform Barite	Barite			
96	Kuroko Barite	Barite			
101	Anhydrite/Gypsum	Gypsum			
37	Vein Barite	Barite			
92	Feldspar Pegmatite	Feldspar			
88	Garnet Skarn	Garnet			
93	Asbestos	Asbestos			
94	Ultramafic Magnesite/Talc	Magnesite	Talc		
44	Alkalic Flourite Veins	Flourite			
95	Alkalic Flourite Veins	Flourite			
90	Metamorphic Mica	Mica			
68	Cement Shale	Shale			
99	Nepheline Syenite	Nepheline Syenite			
97	Lava Rock	Volcanic Cinder			
69	Expanding Shale	Shale			
70	Dimension Stone Granite	Granite			
71	Dimension Stone Marble	Marble			
100	white Marble	Marble			
72	Dimension Stone Andesite	Andesite			
73	Dimension Stone Sandstone	Sandstone			
75	Flagstone	Flagstone			
77	Limestone	Limestone			
76	White Limestone	Limestone			

figures indicate that massive sulphides are more likely to occur in the Vancouver Island and south coast regions, the northwest and the tracts west of the Rocky Mountain Trench. The Kootenay and Thompson/Okanagan areas also show a higher probability of massive sulphide (Mississippi Valley Type) deposit potential. Figure 13 shows plots of average confidence versus the probability of at least one deposit for each of the assessment areas. Significant correlations occur for all of the regions. The plot for Vancouver Island shows two clusters of points which perhaps indicates different perspectives used by the workshop participants in that area.

SKARN DEPOSITS

Figures 14-16 show the results of grouped skarn deposits which include, Cu, Fe, Ag, W, Mo, Zn-Pb, wollastonite and Sn skarns. Figure 14 is a map of the average confidence expressed for these deposit types over all of the tracts. Figure 15 shows the average probability of the presence of at least one of these deposit types for each tract. The confidence and probability of at least one deposit is lowest in the Interior Plateau, Bowser Basin, and northeast parts of the province. Higher confidence and estimates occur in the Kootenay, Vancouver Island, Midcoast, Iskut, Quesnel and portions of the northwest regions. Figure 16 shows the relationship between confidence and probability of at least one deposit for each of the areas. Significant correlation coefficients occur for the Thompson/Okanagan, Midcoast, Kootenay, and Northwest areas. The data for Vancouver Island exhibit a negative correlation that represent clusters of data points associated with different workshop estimators and/or skarn deposits.

DISCUSSION

An exhaustive summary and analysis of the data cannot be presented in this report. However an overview and summary of selected areas and mineral deposit type groups provides some insight into the data collected for the Mineral Potential Project.

The maps presented in this report summarize the following features of the mineral potential project:

- Confidence of the estimators in their estimates as a function of tract for metallic and industrial mineral deposits.
- Confidence by tract for porphyry, massive sulphide, gold and skarn deposit types.
- Maps of the probability of at least one deposit for each deposit type group for each tract.
- Plots of estimator confidence versus the probability of at least one deposit for each deposit type group.

Comparison between Figures 3 and 4 indicates that there is a better correspondence between average confidence for each tract versus normalized tract score for precious and base metal deposits than with the industrial mineral deposits. The patterns of Figure 4 suggest that the estimators did not have the same degree of confidence with respect to tracts where higher estimates of probability were assigned.

Figures 5, 8, 11 and 14 indicate the confidence that the estimators have in their assessment of the mineral assessment tracts. This can be interpreted as a measure of the state of knowledge that exists for those deposit types over the province.

Figures 6, 9, 12 and 15 highlight where workshop participants believe there is additional potential for the four mineral deposit groups. Almost all areas show perceived potential for mineral resources. Exceptions are the Bowser Basin area and the northeast area of the province.

Figures 7, 10, 13 and 15 which show the plots of average confidence versus the average probability of at least one deposit for each tract, provide some insight into the confidence for specific areas and deposit model groups. Where a positive correlation between confidence and the probability of at least one deposit exists, the estimators have knowledge about the area and the potential resources. In the case of poor correlation it would appear that the estimators are not confident about their knowledge of the area and the possible resources. The lack of any correlation may also be the result of uncertainty of the estimation process and the application of confidence. It is possible that both explanations may account for the observed patterns in the data.

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British Columbia Geological Survey
Geological Fieldwork 1996

STRATIGRAPHY OF THE TATOGGA LAKE AREA NORTHWESTERN BRITISH COLUMBIA (104H/12&13, 104G/9&16)

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KEYWORDS: stratigraphy, economic geology, porphyry copper-gold, Red-Chris, Tatogga Lake, Stikine Assemblage, Stuhini Group, Hazelton Group.

INTRODUCTION

This report summarizes preliminary results from the third year of field mapping as part of the Tatogga

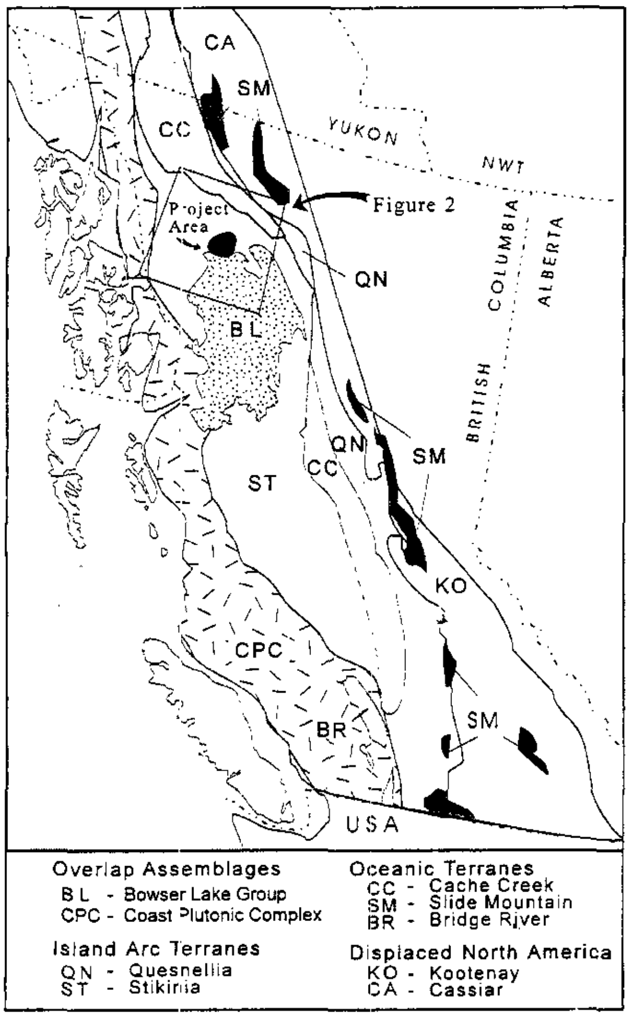

Figure 1. Regional geological setting of the Tatogga Lake project area.

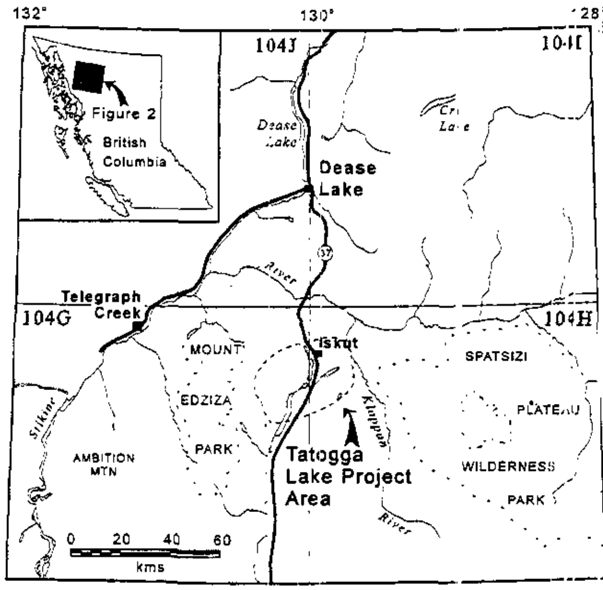

Figure 2. Geographic location of the Tatogga Lake project showing area covered in this report.

Lake project. This is a geologic and metallogenic mapping program initiated in 1994 to investigate the geology and associated mineral deposits of the Stikine Terrane along the northern margin of the Bowser Basin in northwestern British Columbia (Figure 1; Ash *et al.*, 1995, 1996a). The project area is located 80 kilometres south of Dease Lake and is transected by the Stewart-Cassiar Highway (Highway 37; Figure 2)

During 1996, fieldwork was conducted from July 6th to September 12th and focused on completing 1:20 000 scale mapping of the project area and evaluating selected mineral occurrences. Results of mapping for the Tatogga Lake area will be available in Open File format at a 1:50 000 scale (Ash *et al.*, in preparation).

Based on this years mapping, combined with newly obtained geochronological and geochemical data, an updated stratigraphic framework is presented. General descriptions of the various rock units throughout the map area have been given previously (Ash *et al.*, 1995, 1996a and references therein). For discussions of previous work, physiography and regional setting of the project area, refer to Ash *et al.* (1995).

GEOLOGIC SETTING

Mesozoic volcanic rocks underlie most of the study area and also host all known mineral occurrences (Figure 3). These rocks are divisible into three distinctive stratigraphic successions (Figure 4). The oldest of these is represented by the Middle(?) to Upper Triassic Stuhini Group which is dominated by marine clastic sediments with lesser mafic volcanics that are most prevalent in the southern half of the map area. The overlying Hazelton Group comprises two Lower Jurassic stratigraphic sequences. The oldest, Hettangian to Sinemurian, volcanic succession is dominated by thick, massive sections of intermediate volcaniclastic rocks which unconformably overlie the Triassic stratigraphy. A related suite of monzonitic subvolcanic stocks and sills (*ca.* 205 to 198 Ma) intrude the underlying Triassic rocks. Larger monzonitic stocks host porphyry Cu-Au mineralization, such as the Red Chris deposit.

The younger Pliensbachian to Toarcian succession comprises interstratifed bimodal basalt-rhyolite along with clastic sediments. This upper succession disconformably overlies the older Jurassic volcaniclastic rocks in the northwest and unconformably overlies Late Triassic rocks in the southwest and central parts of the map area. Subvolcanic dikes of alkali granite and felsite intrude and alter the volcaniclastic rocks in the northwest and central portions of the map area. These intrusions are commonly associated with impressive pyritiferous gossans containing elevated abundances of copper and gold.

Mesozoic volcanics are faulted against, and in part overlie metasedimentary and metavolcanic rocks of the Paleozoic Stikine Assemblage in the northeastern part of the Tatogga Lake map area. Along their southern margin the Mesozoic arc-volcanics are overlain by, and faulted against, Middle Jurassic, Bowser Lake Group sediments (Figure 3). A number of isolated, recent basaltic volcanic centers overlie the Lower Jurassic stratigraphy in the northwestern region of the map area.

PALEOZOIC STRATIGRAPHY

Foliated and deformed metasedimentary and metavolcanic rocks form a northwest-trending belt in the northeast corner of the Tatogga Lake map area (Ash *et al.*, 1995). Rock types include phylitic mafic and felsic metavolcanics, argillites as well as massive limestone and banded marbles. This deformed stratigraphic succession was previously designated as Permian or older (?) by Gabrielse and Tipper (1984) and Read (1984). More recently Read and Psutka (1990) and Evenchick and Thorkelson (1993) suggested a Carboniferous or possibly older age. A tonalitic intrusion, north from the confluence of Summit Creek clearly cuts the foliated host stratigraphy. The pluton is medium grained, equigranular to moderately foliated and varies from leucocratic to melanocratic with mafic minerals typically altered to chlorite. U-Pb zircon dating of the tonalite reveals an age of at least 365 Ma (Friedman, 1995), confirming that its deformed host rocks are older than Upper Devonian.

Direct constraints on the age of this Paleozoic succession are being evaluated by both biostratigraphic and isotopic methods. A sample of the massive limestone collected in 1994 contained poorly preserved conodonts that were tentatively interpreted to be of possible Middle Ordovician age (Mike Orchard, personal communication, 1995). In 1996, a number of different areas of the massive limestone were sampled for more diagnostic fossils; results are pending. Felsic metavolcanic rocks identified within the deformed Paleozoic section were collected for U-Pb dating. Initial processing indicates that sufficient zircon is present to provide an isotopic age.

MIDDLE (?) - LATE TRIASSIC STUHINI ARC SUCCESSION

Triassic strata are dominated by clastic sedimentary rocks, with lesser, though locally extensive mafic volcanics and their related epiclastics. Sediments include laminated to well bedded siltstone, mudstone, fine volcanic sandstone with lesser siliceous siltstone and chert, as well as extensive intervals of massive fine to medium grained feldspathic wacke/volcanic sandstone and rare limestone.

Mafic volcanic rocks comprise dark-green and maroon, monolithic augite phyric basalt with or without olivine and plagioclase phenocrysts. These occur mostly as flow and pillow breccia with lesser massive and pillowed flows. Near the top of the volcanic succession, augite phyric basalts are interbedded with, and overlain by, bedded maroon mudstone and coarse immature crystal-lithic wackes. Mafic volcanics occur most extensively along the southern margin of exposed Triassic rocks, elsewhere they form narrow discontinuous intervals within the sedimentary sequence. Throughout the western half of the map area the sedimentary rocks display a prominent east-trending bedding orientation. There is also a consistent southerly dip in the southwest part of the map area which contrasts with a consistent northerly dip in the northwest, suggesting a broad anticline.

Direct constraints on the age of the Triassic succession are based on a variety of fossil data. Radiolarian fauna recovered from cherts and siliceous

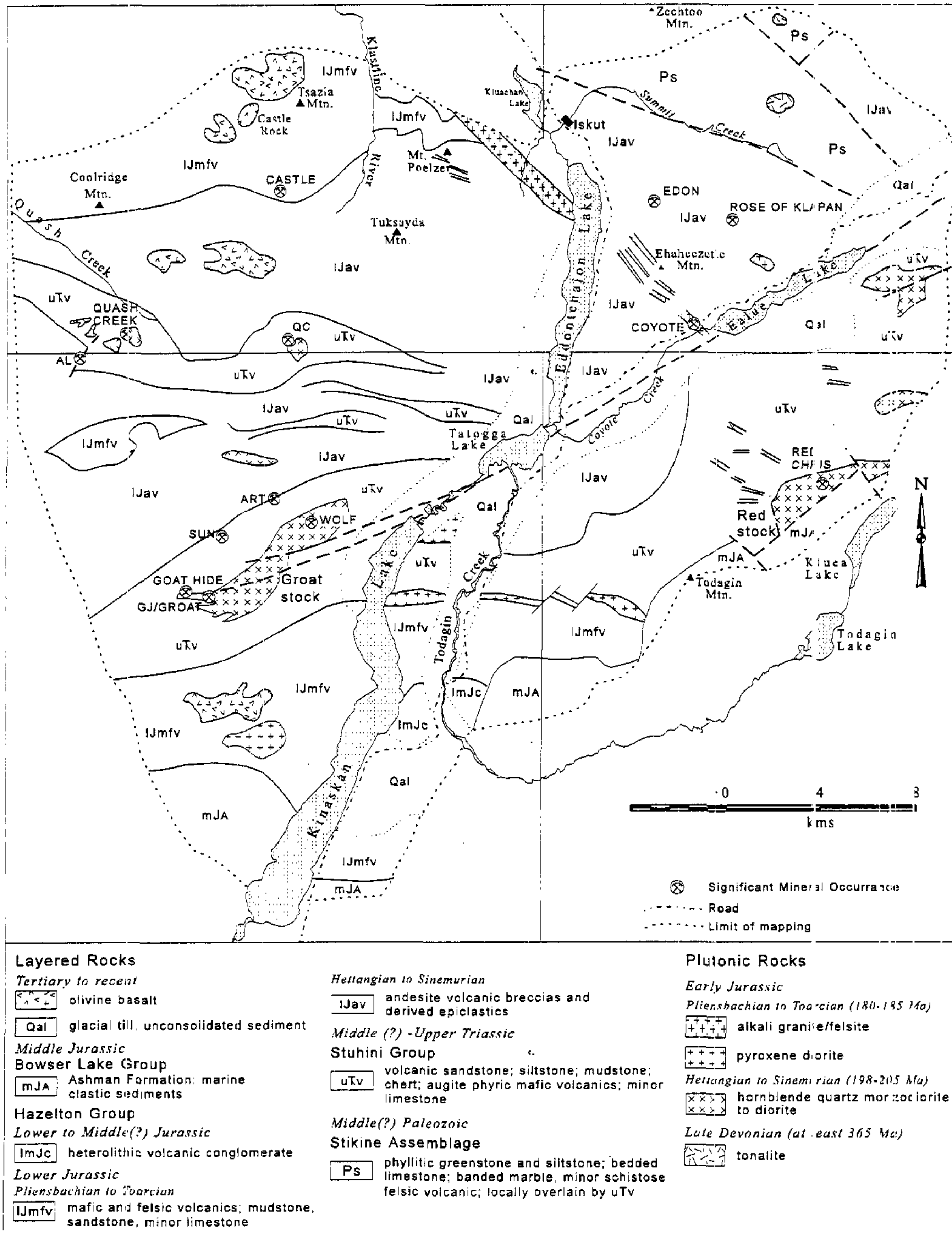

Figure 3. Generalized geology of the Tatogga Lake area.

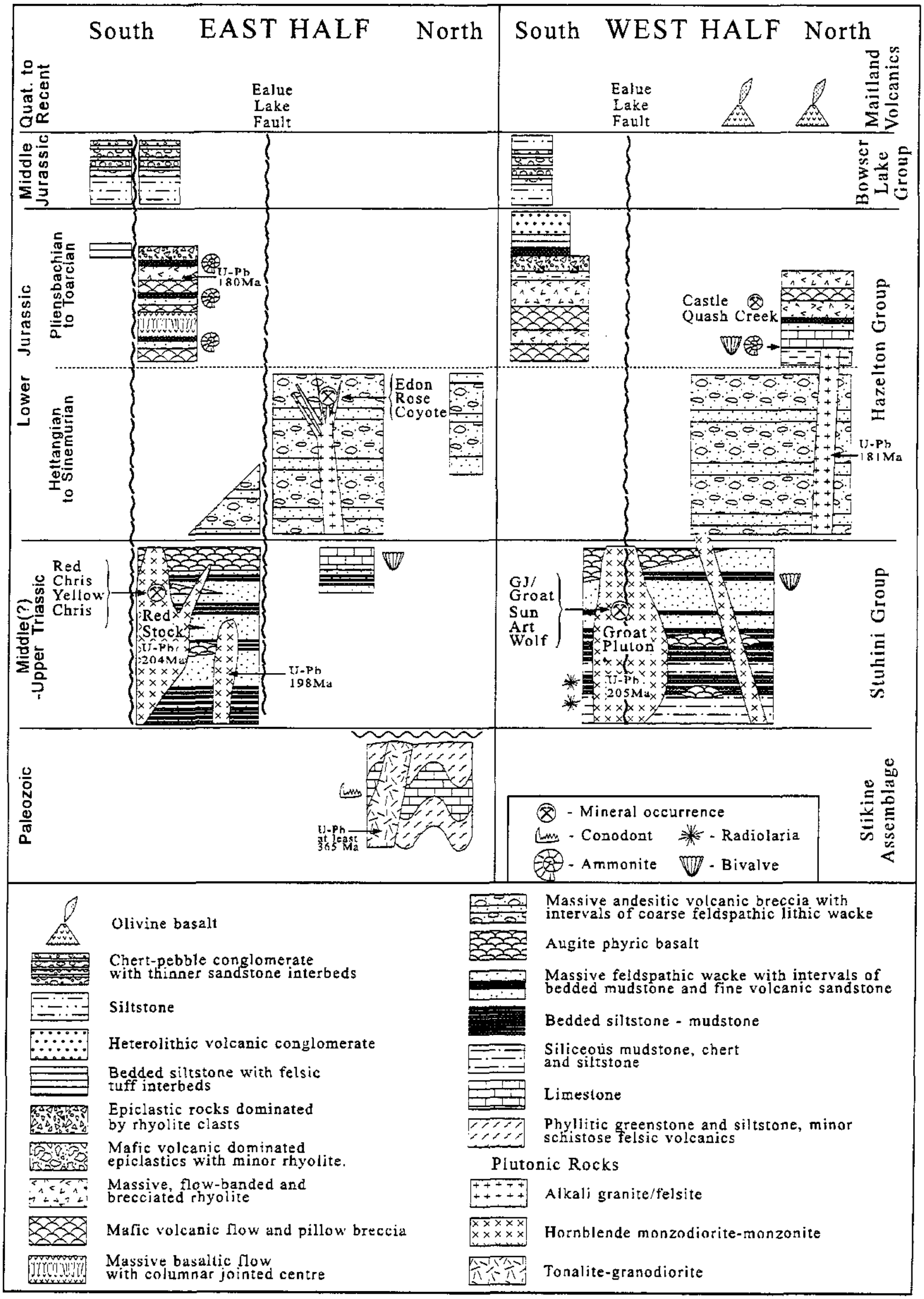

Figure 4. Schematic stratigraphic sections for the Tatogga Lake map area

mudstones near the southwestern end of the Groat pluton (Figure 3) are Middle(?) to Late Triassic (Ladinian(?)-Norian) in age (Ash *et al.*, 1996a). Souther (1972) reports Upper Norian bivalves from several localities on the Klastline Plateau near the headwaters of Quash Creek. An upper age limit is provided by an Early Jurassic hornblende monzodiorite-monzonite suite which intrudes the Triassic strata and returned dates of 205-198 Ma (Ash *et al.*, 1996b; Friedman 1995; Friedman and Ash, this volume).

A number of samples of black mudstone from inferred Late Triassic bedded sedimentary sequences are being evaluated for possible radiolarians. In addition, a sample of interpillow micrite from the augite phyric basaltic unit is being processed for possible conodonts.

LOWER JURASSIC STRATIGRAPHY

Two distinctive volcanic-plutonic suites are identified within the Lower Jurassic Hazelton Group in the Tatogga Lake map area. The older of the two is of predominantly intermediate composition and of Hettangian to Sinemurian age. The younger is a bimodal, basalt-rhyolite suite of Pliensbachian to Toarcian age.

HETTANGIAN TO SINEMURIAN VOLCANIC-PLUTONIC SUITE

Volcanic rocks of lowermost Early Jurassic age dominate the map area. These are mainly green and maroon, massive trachyandesitic volcanic breccias with occasional intervals of massive crystal-lithic tuffs/wackes and rare related epiclastic conglomerates and mudstones. Breccias vary from matrix to clast supported with subrounded to subangular clasts that comprise from 15 to 45% of the unit. Clasts vary from 1 to 20 centimetres but average 3 to 8 centimetres in size. They are usually plagioclase-hornblende phyric, with 15 to 35% subhedral to euhedral phenocrysts. Typically plagioclase is the dominant phenocrysts phase. Medium to coarse-grained immature, poorly sorted, feldspar-rich crystal lithic wacke/tuff dominates the matrix. Locally, fine to medium-grained, massive, maroon mudstone or fine-grained wacke comprises the matrix.

A sample of quartz-phyric alkali trachyte clasts from the volcanic breccia unit, returned a U-Pb zircon date of 202.1±4.2 Ma (Friedman, 1995). This sample was collected from an Ealue Lake roadside exposure that is intruded and chlorite-calcite-epidote altered by a swarm of felsite dikes, 2 to 4 metres wide.

Subvolcanic intrusive rocks interpreted to be cogenetic with the trachyandesitic volcanic unit occur throughout the map area. These intrusions form elongate stocks and dikes that cut Upper Triassic Stuhini Group clastic sediments and mafic volcanics. They are typically leucocratic, medium-grained, hornblende quartz monzodiorites to monzonites. Smaller dike-like bodies are usually hornblende-plagioclase porphyritic and may be rarely quartz porphyritic. Larger bodies, such as the Red stock and Groat pluton, contain both porphyritic and equigranular phases.

Five individual intrusive bodies from this suite, yield U-Pb zircon dates that range from 198 to 205 Ma (Friedman and Ash, this volume) and are coeval with the trachyandesitic volcanic breccia unit. Mineralogical and geochemical similarities between both the volcanic and intrusive rocks also supports a co-genetic relationship (Ash, unpublished data).

A previously assigned Late Triassic age (Souther, 1972; Cooper, 1978; Ash *et al.*, 1996), was based on interfingering of the volcanic breccia unit at its base with fossiliferous Upper Triassic sedimentary rocks. The new isotopic age data is consistent, within the limits of error, with the 208±7.5 Ma Triassic-Jurassic boundary assignment of Harland et al. (1990).

PLIENSBACHIAN TO TOARCIAN VOLCANIC-PLUTONIC SUITE

Bimodal mafic-felsic volcanic rocks and derived sediments of uppermost Early Jurassic age alternate over intervals of metres to several tens of metres in well exposed sections along the southwestern and northwestern margins of the map area (Figure 3). Basalt occurs most commonly as flow and pillow breccias with occasional massive and pillowed flows. The flows are dark grey-green to black, typically aphyric, fine-grained to aphanitic and commonly contain calcite filled amygdules. Felsic volcanics vary from pink to buff-white to lime-green and are locally gossanous. Rock types include ash and dust tuff, lapilli tuff-breccia, autobreccia and aphyric to quartz porphyritic massive and banded flows. Sedimentary rocks include interbedded or homogeneous intervals of mudstone, siltstone, sandstone and limestone.

Lithologic and stratigraphic differences are evident between southwestern and northwestern bimodal volcanic belts. In the southwest, these units form a relatively homoclinal, moderately inclined, southwest-facing succession that unconformably overlies Upper Triassic rocks. In contrast, the northwest belt has moderate to shallow dips, faces northeast and disconformably overlies Lower Jurassic intermediate volcaniclastic rocks. The southwestern section is much thicker, containing more extensive intervals of fine-grained clastic sediments that are only a minor component in the northwest. As well, mafic volcanic rocks are more voluminous in the south. A relatively continuous limestone interval, containing the diagnostic bivalve *Weyla,* occurs at the base of the section in the northern belt and has only been identified in one isolated locality in the southern belt.

The disconformable contact of the northwestern bimodal volcanic belt with the underlying intermediate volcaniclastic unit is exposed in a continuous west-facing cliff section, due east from Castle Rock (Figures 3 and 4). Maroon, andesitic lapilli-tuff breccias comprise the bottom 200 metres of the section. These are overlain by several metres of thin bedded maroon mudstone which are succeeded upwards by well-bedded limestone. The base of the limestone is extremely fossiliferous, with abundant bivalves over the first 20 to 30 centimetres. The limestone is overlain by interbedded siltstone and felsic lapilli-tuff breccia that is capped by several metres of autobrecciated rhyolite.

Northwest-trending alkali-granite to felsite dikes from several metres to over a kilometre wide, are interpreted to be coeval with the felsic volcanic rocks. They intrude and alter intermediate volcaniclastic rocks within the north-central region of the map area. Narrower dikes are aphanitic and vary from aphyric to locally quartz-alkali feldspar porphyritic. The widest dikes, located west of the north end of Eddonatenajon Lake, display the most textural variability. The core zone consists of medium-grained, equigranular alkali granite which grades to a medial zone of quartz ± alkali feldspar porphyry, then outward to a marginal phase of aphanitic, aphyric to locally quartz porphyritic massive and flow banded felsite.

Age control for the bimodal mafic-felsic volcanic succession is provided by both biostratigraphic and isotopic data. Ammonites of interpreted Pliensbachian age (Tipper, 1995; J. Palfy, personal communication, 1996) are common in mudstone intervals throughout the southern volcanic belt. Rare ammonites are also found with abundant bivalves in bedded limestone at the base of the bimodal succession in the northwestern corner of the project area. Radiolarian fauna (F. Cordey, personal communication, 1996) have been identified in a well bedded siliceous mudstone unit which occurs near the top of the southern bimodal volcanic succession. The bedded mudstone contains felsic tuff layers that appear to be immediately associated with, and most likely represent distal equivalents of the felsic volcanism. Radiolarian fauna from this unit are currently being evaluated and results are pending.

Preliminary U-Pb isotopic ages are 181.0 +5.9/-0.4 Ma, obtained from a massive fine-grained quartz porphyritic alkali rhyolite (CAS95-404c) from the south central portion of the map area, and a 180.0 +10.1/-1.0 Ma age from an alkali granite dike (CAS95-829) in the northwestern volcanic belt.

There is a notable discrepancy between the ~180 Ma calculated age of the felsic volcanic rocks compared to the interpreted Pliensbachian age (~ 190Ma) of ammonites found intercalated with the volcanic succession. The maximum isotopic dates for both of these rocks, however, closely approximates the fossil ages of the host sediments. The current calculated age for sample CAS95-404c is based on data from only 3 zircon fractions. Further fractions will be extracted from another sample collected in 1996.

During the 1996 field season the bimodal volcanic succession on the southwestern end of the Todagin Plateau (Ash *et al.*, 1996) was examined by József Pálfy as part of his Ph.D. thesis research at the University of British Columbia. This work combines biostratigraphic and isotopic age dating of suitable stratigraphic sections to refine calibration of the Jurassic time scale. New ammonite fossil localities were identified and an additional sample of the felsic volcanic unit was collected for an isotopic age determination. These data will be summarized elsewhere (Pálfy, in preparation).

BOWSER LAKE GROUP: ASHMAN FORMATION

Middle Jurassic (Bathonian to early Oxfordian) marine clastic sedimentary rocks (Gabrielse and Tipper, 1984; Poulton *et al.*, 1991) of the Bowser Lake Group are exposed along the southern margin of the map area. These are assigned to the basal Ashman Formation and comprise siltstone, chert-pebble conglomerate and sandstone (Evenchick and Thorkelson, 1993). The Bowser Lake rocks become progressively younger to the south as deposition was sourced in the north and deposited onto the tectonically active northern margin of the Bowser Basin (Ricketts, 1990; Ricketts and Evenchick, 1991; Green, 1991).

ECONOMIC GEOLOGY

Two distinct styles of intrusion-related, porphyry copper-gold mineralization are recognized in the Tatogga Lake map area. The first is characterized by intense quartz-ankerite-sericite alteration in zones of quartz stockwork associated with an Early Jurassic (*ca.* 205 to 198 Ma) suite of hornblende quartz diorite to monzonite subvolcanic intrusions. These intrude Late Triassic rocks and produce broad peripheral ankerite alteration halos. The Red Chris is the most significant deposit of this type and has been described previously (Ash *et al.*, 1995; Newell and Peatfield, 1995). A number of comparable, though smaller showings are associated with the Groat pluton (Figure 3). These include the GJ/Groat (MINFILE 104G-034), Sun (MINFILE 104G-087), Wolf (MINFILE 104G-045) and Goat Hide (MINFILE 104G-086).

The second type of mineralization is associated with a suite of (*ca.* 180 Ma) alkali granite/felsite dikes. It is characterized by finely disseminated pyrite±chalcopyrite in zones of silicification within the dikes and their immediate hostrocks. It forms prominent, rusty brown, iron oxide stain zones. The felsic rocks generally intrude andesitic breccias that are characterized by localized concentrations of epidote±potassic alteration surrounded by broad chlorite alteration halos with zones of pyritiferous gossan. Ankerite alteration or veining has not been identified in this type. Examples include the Edon (MINFILE 104H-004), Coyote (MINFILE 104H-012), Al (MINFILE 104G-044), Castle (MINFILE 104G-076), and possibly much of the Rose of Klappan group of showings.

CONCLUSIONS

- Mesozoic volcanic rocks in the Tatogga Lake map area comprise three distinct stratigraphic intervals; (1) Upper Triassic Stuhini Group clastic sediments and augite phyric mafic volcanics, (2) an older Lower Jurassic, Hettangian to Sinemurian intermediate volcaniclastic and coeval subvolcanic monzonitic intrusive suite, and (3) a younger Lower Jurassic, Pliensbachian to Toarcian bimodal basalt-rhyolite suite with cogenetic alkali granite/felsite subvolcanic intrusions.
- On the basis of mineralization, age of related intrusions, alteration type and lithological association, two distinct styles of porphyry copper-gold mineralization are recognized in the area. One is associated with a *ca.* 205 to 198 Ma suite of hornblende quartz diorite to monzonite intrusions which contain quartz stockwork zones hosting chalcopyrite±bornite mineralization associated with potassic to quartz-ankerite-sericite alteration. Another is characterized by pervasive pyritization and silicification associated with a *ca.* 180 Ma alkali granite/felsite dikes and stocks that intrude and epidote and chlorite alter intermediate volcaniclastic hostrocks.

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U-Pb AGE OF INTRUSIONS RELATED TO PORPHYRY Cu-Au MINERALIZATION IN THE TATOGGA LAKE AREA, NORTHWESTERN BRITISH COLUMBIA (104H/12NW, 104G/9NE)

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KEYWORDS: uranium-lead, geochronology, Red stock, Groat stock, porphyry copper-gold, Red-Chris deposit.

INTRODUCTION

U-Pb isotopic data and interpreted ages are presented for two intrusions that host porphyry Cu-Au mineralization within the Stikine Terrane in the Tatogga Lake map area, northwestern British Columbia (Ash *et al.*, this volume; Figures 1 and 2). The Red stock, located northwest of Kluea Lake hosts the Red-Chris deposit, and the Groat stock, located west of the north end of Kiniskan Lake is associated with a number of smaller, similar mineral occurrences. These intrusions belong to, and comprise the largest members of, a 205 Ma to 198 Ma magmatic suite which intrudes Middle(?) to Late Triassic Stuhini Group sediments and volcanics. Both of these intrusions have been the focus of interest since their potential for hosting economic Cu-Au mineralization was recognized in the early 1970's (Newell and Peatfield, 1995; Ash *et al.*, 1995, 1996a).

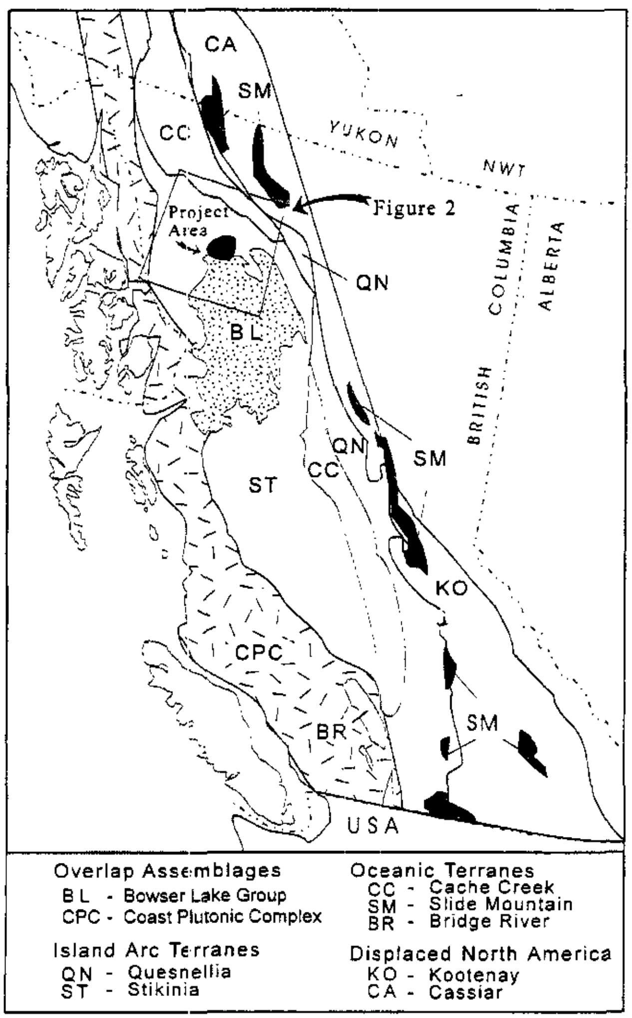

Figure 1. Regional geological setting of the Tatogga Lake project area.

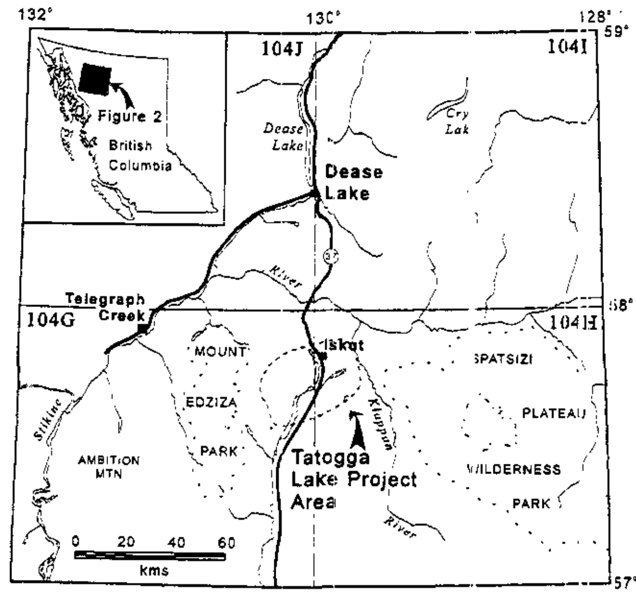

Figure 2. Geographic location of the Tatogga Lake project showing area covered in this report.

This work comprises a component of a U-Pb geochronology study which is part of a regional mapping and mineral deposits study of the Tatogga Lake map area (Ash *et al.*, 1995, 1996a, b, this volume). U-Pb dating was carried out at the Geochronology Laboratory of the Department of Earth and Ocean Sciences at the University of British Columbia.

GEOLOGICAL SETTING

The Tatogga Lake map area lies within the central part of the Stikine Terrane, along the northern margin of the Bowser Basin in northwestern British Columbia (Figure 1). This terrane is underlain by a regionally extensive, northwest-trending belt of mainly Lower Mesozoic and lesser Paleozoic, island-arc volcanic rocks that were accreted to the North American continental margin during Middle Jurassic time (Brown *et al.*, 1986). The Tatogga Lake map area is dominated by Lower Mesozoic arc volcanic rocks (Figure 3). These strata are faulted against, and in part unconformably overlie Paleozoic Stikine assemblage metavolcanic and metasedimentary rocks in the northeast part of the map area and are overlain by, or are in fault contact with Middle Jurassic Bowser Lake Group clastic sedimentary rocks to the south. Isolated, recent mafic volcanic deposits unconformably overlie Mesozoic volcanic rocks in the northwest.

Lower Mesozoic strata are divisible into three distinctive volcanic sequences (Ash *et al.*, this volume). The lowest and oldest of these comprise Middle(?) to Upper Triassic Stuhini Group strata, which in the study area are represented by marine clastic and pelagic sediments, and by lesser mafic volcanic rocks. A suite of variably hydrothermally altered and Cu-Au mineralized subvolcanic monzonitic porphyry stocks and sills intrude these strata. This intrusive suite is thought to represent hypabyssal stocks and feeders to an earliest Lower Jurassic (Hettangin to Sinemurian) succession of compositionally intermediate volcaniclastic and rélated epiclastic rocks which rest unconformably on Triassic strata, and have been assigned to the Hazelton Group. An upper volcanic sequence in the map area, also assigned to the Hazelton Group, is Lower Jurassic in age (Pliensbachian to Toarcian). This sequence is composed of a bimodal basalt-rhyolite suite which unconformably overlies Stuhini Group rocks in the southwest and disconformably overlies, and locally intrudes, earliest Lower Jurassic volcaniclastic rocks within the northwestern portion of the map area.

QUARTZ MONZODIORITE TO MONZONITE SUITE

A suite of elongate, high-level, hornblende quartz monzodiorite to monzonite stocks and dikes intrude Middle (?)-Late Triassic Stuhini Group rocks within the Tatogga Lake area. The largest intrusions of this suite include the Red and Groat stocks, situated in the southern half of the area. These intrusions are southwest-trending, compositionally variable, hornblende-plagioclase porphyritic to equigranular bodies. Intrusive contacts of both stocks are characterized by wide zones of densely packed sheeted dikes or sills with intervening screens of country rock. Both stocks display similar styles of hydrothermal alteration and associated Cu-Au mineralization, however there is a marked contrast between the intensely altered and well-mineralized Red Stock and the relatively fresh, less mineralized Groat stock.

These intrusions are characteristically medium grained, porphyritic to equigranular and weather a buff-white to light grey. Porphyritic varieties have medium to coarse-grained hornblende and plagioclase phenocrysts randomly oriented, to rarely trachytic in texture, in an aphanitic grey groundmass. Plagioclase is the dominant phenocryst phase (25 to 60 modal %), occurring as 2 to 5 millimetre subhedral tabular grains. Hornblende phenocrysts (3 to 20 modal %) generally occur as 2 to 5 millimetres grains, but locally form distinctive, coarse tabular phenocrysts up to 1 centimetre in length. The groundmass mineralogy comprises microcrystaline, anhedral, granular quartz and feldspar.

RED STOCK

The Red stock (Schink, 1977; Newell and Peatfield, 1995; Ash *et al.*, 1995, 1996a, b) is an elongate, east-northeasterly trending, subvolcanic, hornblende monzonite to quartz monzodiorite porphyry intrusion which is pervasively altered and faulted and hosts Cu-Au mineralization at the Red-Chris deposit. Mineralization within this porphyry Cu-Au deposit is characterized by chalcopyrite and localized concentrations of bornite within and marginal to quartz stockwork zones, which in turn lie within intensely carbonate-sericite altered Red stock host rock. Mineralized quartz stockwork zones dip steeply to the north and parallel the long axis of the stock. Deposit reserves are currently estimated at 494 million tonnes, grading 0.323% copper and 0.254 g/t gold (The Norther Miner, Vol. 82, No. 16, 1996).

The Red stock intrudes and alters Late Triassic massive volcanic wackes, siltstone and augite-porphyritic basalt in the southwestern area of the Todagin Plateau (Figure 3). The southern margin of the stock is faulted against Middle Jurassic sedimentary rocks of the Bowser Lake Group (Figure 3). Augite phyric basalts, locally termed the "Dynamite Hill volcanics" on the Red-Chris property, underlie the area directly north of the Red stock. They consist cheifly of monolithic flow and pillow breccias. Sedimentary rocks comprise thick sections of medium-grained, massive feldspathic volcanic wacke with occasional thinner intervals of bedded mudstone and fine volcanic sandstone. Both wackes and mafic volcanic rocks are pervasively carbonate altered, with mafic minerals in both typically replaced by ankerite or iron-magnesite.

GROAT STOCK

The Groat stock is a faulted, northeast trending, coarse grained porphyritic to fine grained equigranular

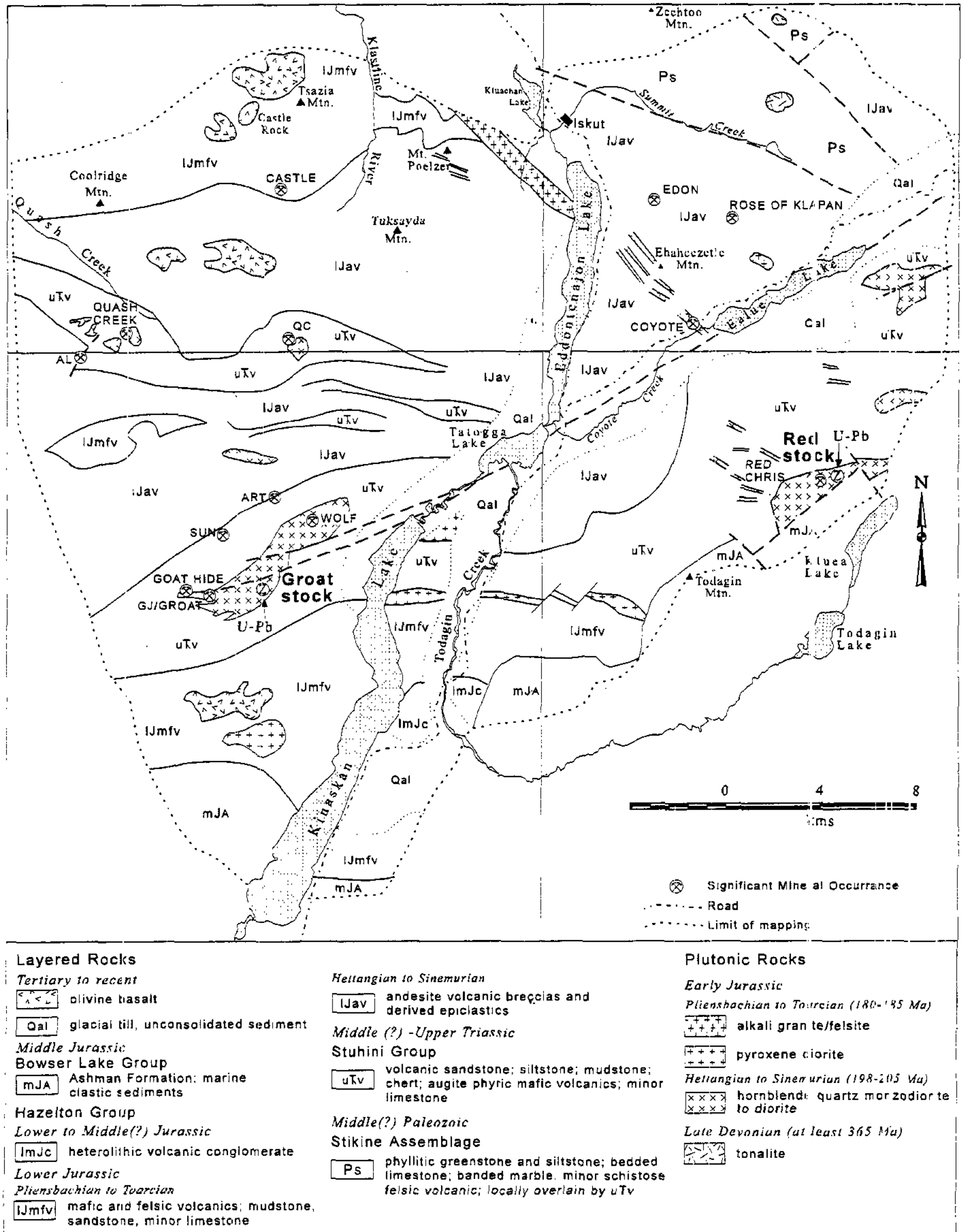

Figure 3. Generalized geology of the Tatogga Lake area.

intrusion with granodiorite to quartz monzonite modal compositions (Schmitt, 1977; Ash *et al.*, 1996a). This body intrudes Middle(?) to Upper Triassic, fine-grained clastic and pelagic sedimentary rocks several kilometres west of the northern end of Kiniskan Lake. Overall, the Groat stock is fresh relative to the intensely altered Red stock, however the intrusion and its immediate host rocks have locally been altered, silicified, brecciated and Cu-Au mineralized. The main minerals present in the relatively fresh portions of the intrusion are plagioclase, quartz, hornblende and orthoclase, with augite and biotie occurring as minor constiuents of the more mafic phases of the body. Primary accessory minerals include titanite, apatite, magnetite and zircon (Schmitt, 1977).

GEOCHRONOLOGY

In the following section we report new U-Pb zircon and titanite data and interpreted crystallization ages for the Red and Groat stocks. Zircons grains were selected for analysis on the basis of their magnetic susceptibility, clarity, colour, grain size and morphology. In general only high quality (i.e., crack- and inclusion-free) grains were chosen. All fractions are then air abraded (Krogh, 1982), to remove about 10-20 volume % of the outer part of each grain. Complete U-Pb analytical procedures employed at the UBC Geochronology Laboratory are reported in Mortensen *et al.* (1995).

Below, brief descriptions of the rock samples are followed by discussions of the U-Pb geochronology, including zircon descriptions and data interpretation. U-Pb data are plotted on concordia diagrams in Figures 4 and 5 and presented in Table 1.

RED STOCK

A sample of Red stock weighing approximately 25 kilograms was collected from diamond drill core, DDH95-224 (at about 105 metres depth) (Figure 3; diamond drill hole 95-224; also see Ash *et al.*, 1996b). An attempt was made to obtain material which has not undergone intense alteration. The sample is of monzonitic composition, with variably albitized plagioclase and chloritized hornblende phenocrysts in a ground mass consisting of microcrystalline alkali feldspar and quartz. Accessory minerals include pyrite, apatite and zircon.

Abundant, high quality, clear, pale pink, zircons of euhedral to subhedral, prismatic morphology were recovered from this sample. In general, aspect ratios of crystals varied from approximately 2 to 5. Four zircon fractions were analysed, two of which are concordant (fractions C and D) and provide the best estimate for the crystallization age of the Red stock: 203.8±1.3 Ma. The precision is based on the total overlap of concordant fractions C and D with the concordia curve (Figure 4).

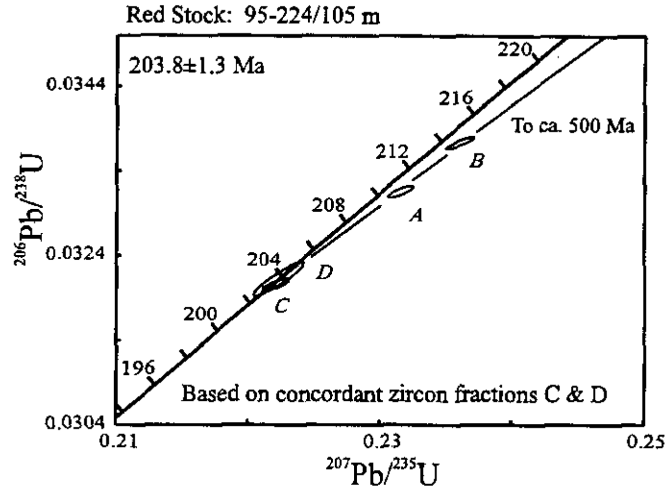

Figure 4. Concordia diagram for sample DDH95-224/105 m of the Red stock. Ellipses are plotted at the 2σ level of precision. See text for discussion.

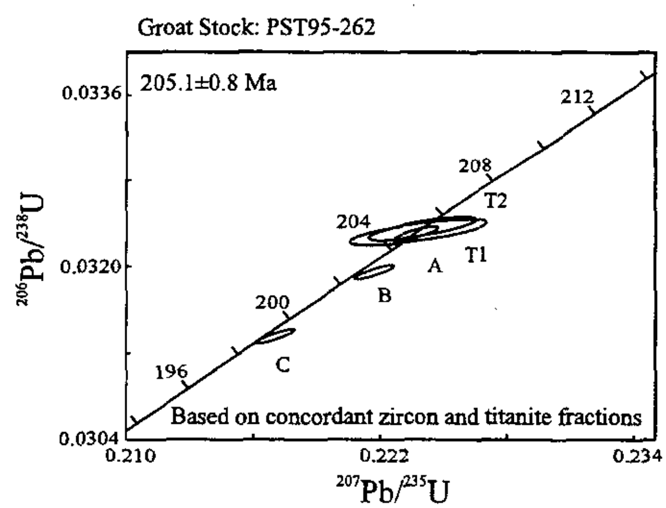

Figure 5. Concordia diagram for sample PST95-262 of the Groat stock. Ellipses are plotted at the 2σ level of precision. See text for discussion.

Relatively coarse fractions A and B are discordant, with somewhat older Pb/U and Pb/Pb ages, indicating the presence of a minor inherited zircon component (Figure 4, Table 1). A chord through all four ellipses gives an upper intercept of approximately 500±100 Ma, which provides an indication of the average age of this inherited zircon component in fractions A and B.

An Early Jurassic crystallization age of 203.8±1.3 Ma for the Red stock provides a firm maximum age for mineralization at the Red-Chris deposit. This age is considerably younger than a previously determined K-Ar whole rock date for the Red stock, (215±14 Ma; Schink, 1977), although the error envelopes of the U-Pb and K-Ar ages do overlap. An imprecise K-Ar biotite date of 200±16 Ma, for a post-mineral dyke at Red-Chris still provides the best minimum age estimate for mineralization. A post-mineral, late hydrothermal dike

TABLE 1. U-Pb ANALYTICAL DATA FOR THE RED AND GROAT STOCKS

Fraction[1]	Wt	U^2	Pb*[3]	$^{206}Pb^4$	Pb[5]	^{208}Pb [6]	Isotopic ratios (1σ,%)[7]			Apparent ages (1σ,Ma)[7]	
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Red stock: 95-224/105 m											
A cc,N2,p	0.069	192	6	4342	6	7.9	0.03315(0.11)	0.2315(0.21)	0.05064(0.13)	210.2(0.4)	224.6(6.1)
B c,N2,p	0.074	209	7	2114	16	9.3	0.03373(0.10)	0.2361(0.23)	0.05075(0.14)	213.9(0.4)	229.7(6.7)
C m,N2,p	0.068	257	8	3592	10	9.3	0.03205(0.12)	0.2221(0.23)	0.05024(0.15)	203.4(0.5)	206.3(6.9)
D f,N2,p	0.071	236	8	2059	17	9.6	0.03212(0.32)	0.2223(0.43)	0.05019(0.18)	203.8(1.3)	203.6(8.2)
Groat Stock: PST95-262											
A m,N20,p	0.058	290	10	2840	12	12.0	0.03230(0.10)	0.2237(0.24)	0.05023(0.16)	204.9(0.4)	205.5(7.5)
B m,N20,p	0.067	445	15	3808	16	13.7	0.03195(0.11)	0.2217(0.21)	0.05034(0.12)	202.7(0.4)	210.5(5.8)
C f,N20,p,e	0.178	383	13	4332	30	14.1	0.03135(0.10)	0.2170(0.21)	0.05021(0.12)	199.0(0.4)	204.6(5.7)
T1 c,N20,b	0.730	70	3	292	382	22.3	0.03231(0.18)	0.2238(0.73)	0.05023(0.60)	205.0(0.7)	205.6(28.1)
T2 c,N20,b	0.700	76	3	405	282	23.7	0.03235(0.17)	0.2240(0.57)	0.05022(0.45)	205.2(0.7)	205.3(20.9)

Notes: Analytical techniques are listed in Mortensen *et al.* (1995).

[1] Upper case letter = fraction identifier; T1, T2 = titanite fractions; All zircon fractions air abraded; Grain size, intermediate dimension: cc= >180μm, c= <180 μm and >134μm, m= <134μm and >104μm, f= <104μm; Magnetic codes:Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1=nonmagnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: b= broken fragments, e=elongate, eq=equant, p=prismatic, s=stubby, t=tabular, ti=tips.

[2] U blank correction of 1-3pg ±20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3]Radiogenic Pb

[4]Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 10pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

[5]Total common Pb in analysis based on blank isotopic composition

[6]Radiogenic Pb

[7]Corrected for blank Pb, U and common Pb. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the $^{207}Pb/^{206}Pb$ age of the fraction.

sampled for U-Pb geochronology should provide a more precise minimum age estimate for mineralization at the Red-Chris deposit (T. Baker, personal communication, 1996).

GROAT STOCK

Approximately 25 kilograms of equigranular hornblende quartz monzonite was collected from the southeastern part of the Groat stock for U-Pb geochronology. This sample is massive, medium to coarse grained and contains euhedral andesine laths which are poikilitically enclosed within larger hornblende and orthoclase grains.

Abundant, high quality zircon and titanite were recovered from this sample. The zircon is clear, colourless to pale amber and varies from prismatic to acicular in morphology, with aspect ratios of about 2 to 8. Only clear inclusions were observed (apatite and/or fluid inclusions) and no cores or zoning were visible in grains selected for analysis. The titanite is clear, pale yellow to nearly colourless, and occurs mainly as broken pieces of euhedral grains.

Three zircon and two titanite fractions were analysed from this sample. Both titanite analyses and zircon fraction A are concordant at approximately 205 Ma. The average $^{206}Pb/^{238}U$ age for these fractions provides the best estimate for the crystallization age of this rock, 205.1±0.8 Ma. The reported precision represents the total overlap of error envelopes for the three concordant analyses with the concordia curve (Figure 5). Zircon fractions B and C appear to have undergone minor Pb loss and B may also contain a minor component of inherited zircon.

The U-Pb age of this sample, 205.1±0.8 Ma, is interpreted as the crystallization age of the Groat stock, and it therefore provides a maximum age for ankerite alteration and mineralization hosted within this intrusion. A previously reported K-Ar hornblende cooling age of 200±16 Ma for the Groat pluton (Schmitt, 1977) is within error of the new U-Pb age.

DISCUSSION

The Red and Groat stocks belong to a suite of sills, dikes and subvolcanic intrusions recognized within the

Tatogga map area, which have been dated at 205 to 198 Ma (Ash *et al.*, 1996b). This suite is interpreted to represent the intrusive equivalents of an earliest Jurassic volcano-stratigraphic succession recognized within the map area, and is assigned to the lower Hazelton Group.

U-Pb crystallization ages for the Red and Groat stocks determined in this study, 203.8±1.3 Ma and 205.1±0.8 Ma, respectively, also represent maximum ages for alteration and Cu-Au mineralization hosted within these intrusions. Although these ages do not directly determine the timing of mineralization, the high level nature of these intrusions strongly suggest that they underwent rapid cooling. Furthermore, the style of mineralization and alteration suggests formation from magmatic-hydrothermal processes which likely followed primary igneous crystallization.

The Red and Groat stocks are broadly the same age as a suite of ca. 200-210 Ma mineralized porphyry Cu-Au intrusions which are widely distributed throughout Stikinia and Quesnellia (Mortensen, *et al.*, 1995). Regionally these deposits are considered to represent either the latest phase of magmatism associated with Triassic Stuhini/Takla/Nicola arcs or reflect a magmatic episode which post-dates these arcs. Field and temporal relationships within the the Tatogga map area indicate that these mineralized porphyry intrusions are related to earliest Jurassic magmatism associated with the lower Hazelton Group.

CONCLUSIONS

- The Red and Groat stocks belong to a suite of variably hydrothermally altered Early Jurassic 205 to 198 Ma quartz diorite to monzonite plutons in the Tatogga Lake area.
- Early Jurassic crystallization ages of 203.8±1.3 Ma for the Red stock and 205.1±0.8 Ma for the Groat stocks provides a firm maximum ages for mineralization hosted within these intrusions.
- Field and temporal relationships within the Tatogga map area indicate that these mineralized porphyry intrusions are related to earliest Jurassic magmatism associated with the lower Hazelton Group.

ACKNOWLEDGMENTS

Brian Thurston of American Bullion Minneral Ltd. is thanked for providing the sample of drill core use to date the Red stock. This report has been improved from reviews by Jim Mortensen, John Thompson, Tim Baker, Robert Macdonald and Dave Lefebure.

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SOME NEW DIMENSION STONE PROPERTIES IN BRITISH COLUMBIA PART III

By Z.D. Hora and K.D. Hancock

KEYWORDS: Industrial minerals, dimension stone, building stone, granite

INTRODUCTION

The first two parts of this project were published in Exploration in British Columbia 1992 and Geological Fieldwork 1994. In 1996 the industry has grown again (Figure 1). A new processing plant has been opened by the Garibaldi Group Inc. in Squamish (Figures 2, 3 and 4) and Margranite Industries Ltd. has added a hydraulic splitter to its tile processing plant in Surrey. During 1995 and 1996 more quarries, prospects and potential sites were visited. The descriptions presented here are based on site visits, polished slabs (typically 400 square centimetres) and thin section analysis. Rock names in the petrographic descriptions are based on Streckeisen's classification (1976).

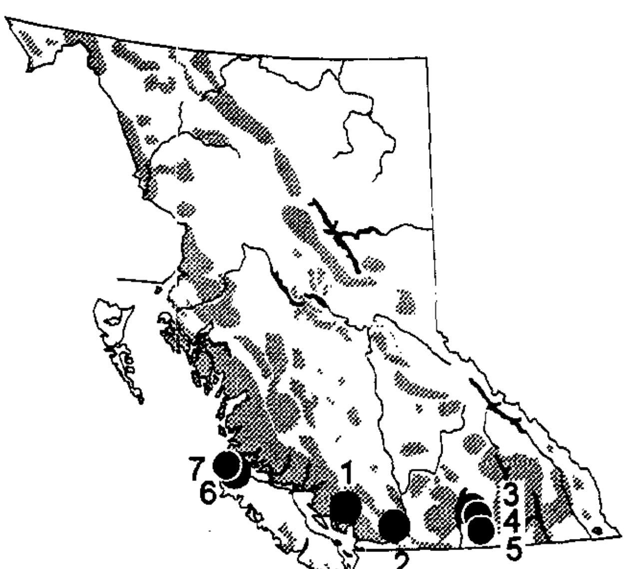

Figure 1. Location of stone properties in British Columbia. 1: Ashlu River; 2: Raven Black; 3: Grano Creek; 4: Gabe claims; 5: San Pedro Black; 6: Tsitika Grey; 7: Port McNeil. The shaded areas are major granitic terranes in the province.

PROPERTY DESCRIPTIONS

Ashlu River Quarries

Location: lat.: 49°59'30" long.: 123°32'00"; 92G/13, Vancouver Mining Division. At mile post 25 on the Ashlu River forestry road.

Access: From Squamish by logging road upstream along the Squamish and Ashlu rivers.

Owners: Garibaldi Group Inc.

Operator: Garibaldi Group Inc.

Commodities: Dimension stone - granite

LOCAL GEOLOGY

Both Ashlu River properties are located in the lower part of the Ashlu River valley. It is broad and U-shaped with many bedrock outcrops. The two properties are in a similar type of granite only 100 metres apart. Because of its distinctive colour, the stone on the west side of the river is called "Garibaldi Golden" while stone on the east side is called "Garibaldi Grey". The granite on the west side is covered by thin patches of clayey till with water seepage along the till/bedrock interface. While the clayey till is dark grey in colour, the seepage is characterized by a rusty yellow layer a few centimetres thick. This yellow, clayey material has soaked into the bedrock along joints and microcracks, resulting in the unusual colour of the stone when it is cut and polished. Both quarry site display widely spaced natural fracturing and allows quarrying of 5 to 10 cubic metre blocks with a minimum of waste (Figure 5). In outcrop, the stone has a smooth, slightly pitted surface indicating absence of microfractures and exfoliation features (Figure 6). The stone has a uniform look without dark knots or inclusions. The granite is part of the Coast Plutonic complex.

PETROGRAPHY

Garibaldi Gold is a grey-blond, fine-grained granite. The rock is distinguished by a slight, pervasive yellow staining and some "banding" of a darker stain. This appears to be related to successive weathering/ alteration fronts that introduced stain from overlying till. The authors and the operator anticipate staining will diminish with depth. Major mineral constituents are orthoclase, quartz, plagioclase and microcline. Minor constituents are magnetite, biotite, clinopyroxene (augite), chlorite, apatite, sphene and clinozoisite. Most crystals are cracked at the microscopic scale and appear to be the conduits through which the surface waters can migrate. The mafic minerals are fairly fresh with minor chloritization and the feldspars are weakly sericitized. The rock takes a fair polish (7-8/10) with some pitting at biotite grains. There is no fabric or fracturing and the microcracking of grains is not visible macroscopically.

Garibaldi Grey is a fine-grained, grey, salt and pepper granite. Major constituents are white plagioclase and orthoclase, grey quartz and black biotite. Minor constituents are chlorite, pyroxene, magnetite, pyrite and clinozoisite. The texture is uniform with a coarse sugary appearance and no fabric. The rock polishes well (7-8/10) to a bright finish with minor, shallow pitting at the corners of biotite grains. The rock appears quite fresh with minor chlorite after biotite and some sericitization of the feldspars. There is a trace of pyrite present but no visible staining.

Raven Black Quarry

Location: lat.: 49°36'00" long.: 121°37'00", 92G/12, Vancouver Mining Division. Approximately 42 kilometres northeast of Harrison Hot Springs.

Access: From Harrison Hot Springs north on the east side of the lake and then east on Cogburn Creek road.

Owner: W. Streicek

Operator: Granite Creations and Stonework

Commodities: Dimension stone - black granite

LOCAL GEOLOGY

Large, blocky outcrops are exposed in the bottom part of a V-shaped valley. The stone is sound, lacking microfractures. The homogeneity is affected by scattered, long, 1 to 2 millimetre wide, very dark green veinlets (Figures 7 and 8). The anorthosite is part of the Coast Plutonic complex.

PETROGRAPHY

Raven Black is a medium black, medium-grained anorthosite. It has an even texture and uniform colour. The rock is comprised of plagioclase with very small amounts of biotite, chlorite and trace magnetite. It has no alteration, staining or fabric. It takes a fair to good polish (7-8/10) with some minor pitting on biotite. There are some narrow (1-2 mm), through going black to very dark green fractures, healed with chlorite, that mar the uniformity of the rock.

Grano Creek

Location: lat.: 49°33'00" long.: 118°47'00", 82E/7, Greenwood Mining Division. At the confluence of Grano Creek and Kettle River on the east side of the valley, 57 kilometres north of Rock Creek.

Access: North on Christian Valley road and then east on Grano Creek road across the Kettle River bridge.

Owner: C. H. Maddin

Operator: Quadra Stone Co. Ltd.

Commodities: Dimension stone - granite

LOCAL GEOLOGY

The quarry is located at the base of a large rock outcrop, almost free of joints, about 50 meters high and 150 metres long in steep cliffs on Kettle River (Figure 9). It is comprised of porphyrytic, pink granite of the Okanagan Batholith suite. The stone is sound, with smooth surface and no exfoliation features. The orthoclase megacrysts, mostly 1 by 2 centimetres in size, exhibit preferential orientation, probably reflecting flow during emplacement. The stone is uniform in texture with no inclusions or agglomerations of mafic minerals.

PETROGRAPHY

Grano Creek stone is a classic porphyritic, pink granite. The matrix is grey and medium to coarse-grained with pink orthoclase megacrysts, mostly 1 to 2 centimetres long. The matrix comprises quartz, plagioclase and orthoclase with minor biotite, magnetite, chlorite and sericite. The orthoclase megacrysts show some perthitic texture and are frequently cracked. Alteration is minor with some chlorite and iron staining after mafic minerals (<<½%). The rock has a moderately developed linear(?) fabric defined by a general preferred orientation of the orthoclase megacrysts. The polish of the rock is fair (7/10) with narrow (±0.25 mm) cracks up to 40 millimetres long and some pitting. This is largely from preferred cracking parallel to cleavage in orthoclase megacrysts that persists into the matrix. Pitting is generally due to small fragments of matrix that have fallen out of the cracks.

San Pedro Black Quarry

Location: lat.: 49°19'30" long.: 118°35'30", 82E/7, Greenwood Mining Division. On Almond Creek, 3 kilometres northeast of Almond Mountain.

Access: From Grand Forks north on the North Forks road and Pass Creek Forest Service road to the 23 kilometre sign and then 2 kilometres up a branch road to the left.

Owners: San Pedro Stone Inc.

Operator: San Pedro Stone Inc.

Commodities: Dimension stone - black granite

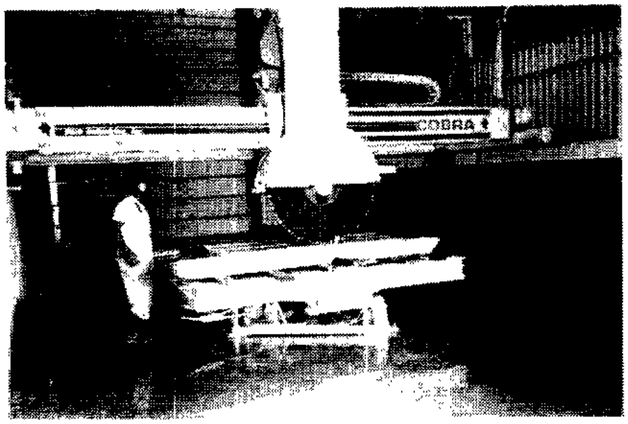

Figure 2. Garibaldi Group Inc.'s Squamish plant. Cutting granite slabs

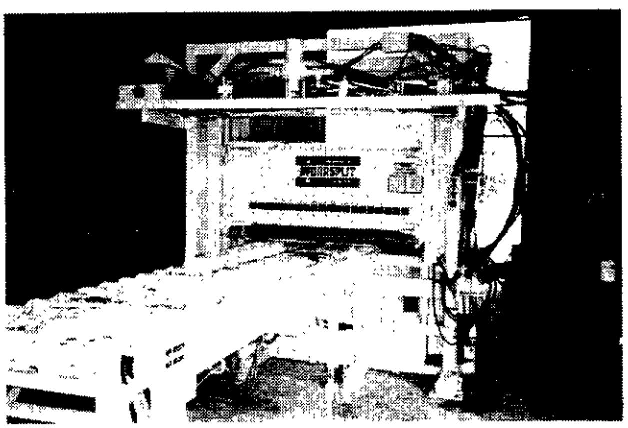

Figure 3. Garibaldi Group Inc.'s Squamish plant hydraulic splitter.

Figure 4. Garibaldi Group Inc.'s palletized split stone product, Garibaldi Grey.

Figure 5. Garibaldi Golden quarry, Garibaldi Group Inc.

Figure 6. Slightly pitted but otherwise sound weathered surface of Garabaldi Golden granite.

Figure 7. Raven Black quarry site at Cogburn Creek.

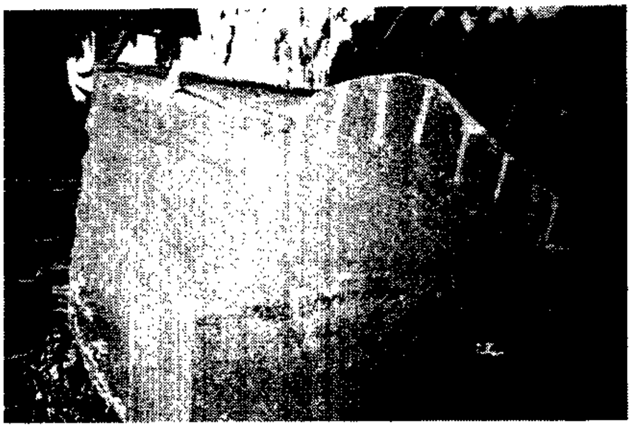

Figure 8. Raven Black split face with crosscutting vein.

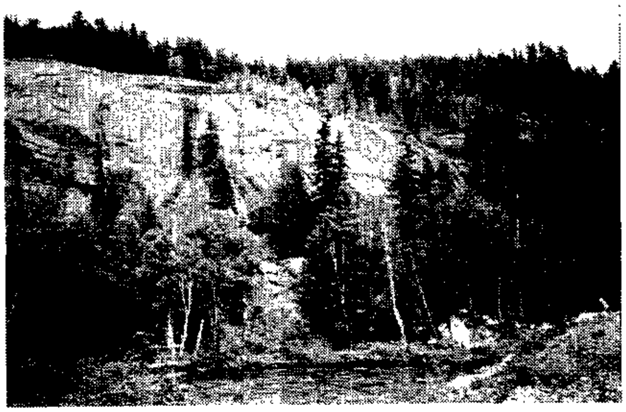

Figure 9. Grano Creek prospect.

Figure 10. San Pedro Black quarry.

Figure 11. San Padro Black quarry showing large block size.

Figure 12. Tsitika Grey granite - typical texture with common dark inclusions.

Figure 13. Port McNeil andesite prospect.

LOCAL GEOLOGY

A small group of outcrops, of coarse-grained gabbro, along a logging road lead to stripping and test quarrying which has exposed the gabbro over a 30 by 50 metre area (Figure 10). The stone has a moderate, irregular fracture pattern which allows quarrying of commercial sized blocks with estimated waste of up to 50 percent (Figure 11). The stone is uniform without any foreign rock inclusions. It may be part of a Nelson Plutonic suite pendant in a Coryel Syenite pluton.

PETROGRAPHY

Stone from the San Pedro prospect is a uniform, dark black with a slight greenish cast, medium-grained gabbro. Major constituents are plagioclase, clinopyroxene (augite) and biotite. Minor constituents are orthoclase, chlorite, apatite, magnetite and pyrite (±1%). The mafic minerals are slightly altered to chlorite, plagioclase is slightly albitized and pyrite is fresh. There is no quartz. The rock takes an excellent, bright, glassy, polish (9/10) with very minor pitting at mafic minerals. The rock looks fresh with no visible alteration, staining or fabric. There are a few, tight cracks, typically 1 to 3 centimetres long.

Gabe Claims Prospect

Location: lat.: 49°28'00" long.: 118°35'00", 82E/7, Greenwood Mining Division. Eight kilometres east of Gable Mountain.

Access: Seventy five kilometres north from Grand Forks on the North Forks road then along the Pass Creek Forest Service road, then up the Gable Creek Forest Service road.

Owners: J. Kemp and D. Hairsine

Operator: none

Commodities: Dimension stone - granite

LOCAL GEOLOGY

This rose pink rock occurs in a boulder field approximately 1 by 2 kilometres and an outcrop about 30 by 50 metres across. The stone is uniform, pink quartz syenite of the Okanagan Batholith suite and has no inclusions or inhomogeneities. Part of the area is underlain by porphyritic rock. No exfoliation features, joints or microfracturing have been observed.

PETROGRAPHY

The Gabe claims stone is a light pink, fine to medium-grained quartz syenite. The texture is fairly uniform and even with no large phenocrysts. Major constituents are orthoclase, plagioclase and quartz. Minor constituents are biotite, chlorite, magnetite, pyrite (<0.5%), apatite, zircon and clinozoisite. The rock shows no staining and only a little alteration in the form of green dots of chlorite after biotite. There are a few short (<2 cm), tight cracks scattered in the rock.

Tsitika Grey Prospect

Location: lat.: 50°16'00" long.: 126°22'00", 92L/8, Nanaimo Mining Division. Ten kilometres south of Woss on the Island Highway.

Access: One to two hundred metres, north and south, to each side of the Island Highway on logging roads.

Owners: T. Henneberry

Operator: Tsitika Stone Industries

Commodities: Dimension stone - granite

LOCAL GEOLOGY

The stone is found as scattered outcrops and boulder fields between the Island Highway and the Tsitika River. It is fresh and boulders vary in size up to several tons of tonnes. There are no visible microfracture or exfoliation features. Rounded inclusions of darker facies rock are a common feature in the whole area (Figure 12). The stone is part of the Vancouver Island intrusive suite.

PETROGRAPHY

Tsitika Grey is a fairly uniform, medium to coarse-grained quartz monzonite. The colour is medium grey with black 'peppering' by coarse-grained mafic minerals. Major constituents are plagioclase, quartz, hornblende, biotite and orthoclase. Minor constituents are magnetite, apatite and clinozoisite. The mafic minerals are unaltered and feldspar has minor sericitization. The rock looks fresh with no alteration, fabric or staining on the polished face. It takes a good, bright polish (8/10) with rare pitting on biotite. Magnetite grain aggregates, up to 3 millimetres across, give a scattered metallic glint. Mafic knots are rare, small, less than 2 centimetres across, and consist of mats of hornblende, biotite and feldspar.

Tsitika Black Prospect

Location: lat.: 50°19'00" long.: 129°29'00", 92L/8, Nanaimo mining Division. Eighteen kilometres northeast of Woss on the Tsitika River.

Access: On the Tsitika River forestry road, 30 kilometres east of Woss at the Island Highway.

Owners: T. Henneberry

Operator: Tsitika Stone Industries

Commodities: Dimension stone - granite

LOCAL GEOLOGY

The rock is found as scattered outcrops and boulder fields in the Tsitika River valley. This stone is a more fractured and darker phase of Tsitika Grey. Because of the high fracture density, it has limited use other than for masonry blocks.

PETROGRAPHY

Tsitika Black is light black with grey-pink highlights. It is a uniform, (fine) medium-grained diorite (gabbro). Major constituents are plagioclase, biotite and clinopyroxene (augite). Minor constituents are chlorite, magnetite, pyrite (±3%), quartz and apatite. Pyroxene is strongly altered to chlorite, biotite is generally unaltered and plagioclase shows weak albitization. Pyrite is fresh and unaltered. The rock takes a good polish (8/10) and has minor pitting on biotite. The rock has a well developed planar fabric but no visible alteration or staining. There is no macroscopic fracturing and only minor microfracturing of primarily plagioclase.

Port McNeil (Haddington Island) Andesite Prospect

Location: lat.: 50°34'00" long.: 127°11'00", 92L/11, Nanaimo Mining Division. Seven kilometres west of Port McNeil on top of Cluxewe Mountain.

Access: From the Island Highway, 4 kilometers south on a road that leads to a radio tower/transmitter.

Owners: T. Henneberry

Operator: Tsitika Stone Industries

Commodities: Dimension stone - andesite

LOCAL GEOLOGY

The Port McNeil site occurs as a flat, horizontal lava flow that caps the table shaped Cluxewe Mountain. The stone is exposed in cliffs 5 to 10 metres high (Figure 13). The flow is vertically fractured with spacing up to several metres apart. The surface is smooth, very homoneneous, light grey in colour and almost aphanitic in appearance. This volcanic rock, because of its texture, colour and splitting characteristics, could be used in applications where sandstone would normally be used. In contrast to British Columbian sandstones, Haddington Island andesite has an excellent performance record and durability in the coastal climate.

PETROGRAPHY

The Port McNeil andesite is a buff, very fine-grained andesite. The rock is made up of a dense mat of feldspar laths with biotite disseminated or forming small clumps throughout creating a slight speckle to the appearance. Minor constituents are magnetite and quartz with weak sericite alteration of the feldspar. The cut, unpolished rock has a very uniform texture with no alteration, staining and minor, tight cracking visible. The rock has uniform void space (vugs) about 0.2 millimetres in diameter and form approximately 1 percent of the rock. Thin section work indicates the rock is not microfractured and so is probably quite impermeable, though slightly porous.

ACKNOWLEDGEMENTS

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PALEOMAGNETISM OF THE MOUNT BRUSSILOF MAGNESITE DEPOSIT AND ITS CAMBRIAN HOST ROCKS, SOUTHEASTERN BRITISH COLUMBIA (NTS 82 J/11, 12, 13)

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Keywords: Mount Brussilof, paleomagnetism, magnesite, industrial minerals

INTRODUCTION

This study was undertaken to date the formation of the Mount Brussilof magnesite deposit. It is located about 35 km northeast of Radium Hotsprings in southeastern British Columbia (Figure 1). It is the only operating magnesite mine in Canada with proven and possible reserves of >40 Mt of >92% magnesia in 1980 (Simandl *et al.*, 1992). The deposit lacks minerals suitable for radiometric age dating and hence its age is uncertain. Geological relationships suggest that the magnesite postdates early diagenesis of the host Middle Cambrian Cathedral dolostone and pre-dates sparry dolomite, based on the field observations (Simandl and Hancock, 1996). Cross cutting field relationships indicate that sparry magnesite is at least slightly older than sparry dolomite. Restriction of magnesite to the Cathedral Formation, contrary to sparry dolomite which is present in both the Cathedral and younger overlying Eldon formations, further suggests that sparry magnesite may be linked to a specific time or depositional environment and possibly to the composition of the protolith. The deposit is hosted by the same rocks as nearby Mississippi Valley-type (MVT) lead-zinc deposits (Simandl *et. al.*, 1991; Nesbitt and Muehlenbachs, 1994). Most of the major MVT districts in North America have been successfully dated in the past few years using paleomagnetism, and most of these studies have been done in the paleomagnetic laboratory at the University of Windsor (Symons *et al.*, 1996).

Therefore it was decided to test the paleomagnetism of the Mount Brussilof deposit and its host rocks. The two prevailing hypothesis on the origin of the Mount Brussilof deposit are replacement of dolomitized permeable carbonates by magnesite due to interaction with a metasomatic fluid, assuming an appropriate aCa^{2+}/aMg^{2+} ratio, salinity, temperature, high fluid/rock ratio, *etc.* or post early-diagenetic recrystalliation of a magnesia-rich protolith of chemical, possibly evaporitic origin that may have consisted of fine-grained magnesite, hydromagnesite, huntite or other low temperature magnesia-bearing minerals. (Simandl and Hancock, 1996) The main difference between these hypotheses is the source of magnesia. The source is external in case of metasomatic replacement and *in situ* in the case of diagenetic recrystallization of magnesia-rich protolith.

Although this study was unsuccessful in directly dating the magnesite ore, as the first such attempt it is useful to describe the results obtained. The results provide evidence of a regional hydrothermal fluid flow that remagnetized the host rocks in Laramide time.

GEOLOGY

The Mount Brussilof mine is located in the Foreland tectonostratigraphic belt of the Canadian Cordillera about 400 metres east of the Cathedral escarpment (Simandl and Hancock, 1991; Figure 1). The escarpment separates deeper-water Middle Cambrian shales of the Chancellor Group on the west side from their shallow-water carbonate platform equivalents on the east side. The escarpment has been described variously as a paleoescarpment, an erosional facies change, a faulted facies change or a facies change on a fault ramp (Leech, 1966; Aitken, 1971, 1989; Ludwigsen, 1989; Aitken and McIlreath, 1990; Fritz, 1990).

East of the Cathedral escarpment, the stratigraphic sequence from oldest to youngest is: 1) >250 m of massive tan coarse-grained quartz sandstone of the Lower Cambrian Gog Formation; 2) 65-170 m of thin-bedded brown and green shale of the Middle Cambrian Naiset Formation; 3) ~340 m of buff and grey dolostone and limestone of the Cathedral Formation; 4) ~16 m of brown to grey fossiliferous shale of the Stephen Formation; 5) ~500 m of black, grey and buff dolostone of the Eldon and Pika formations and 6) green, purple and red shales with beige dolostone interbeds of the Middle Cambrian Arctomys Formation (Simandl and Hancock, 1991; Simandl *et al.*, 1992).

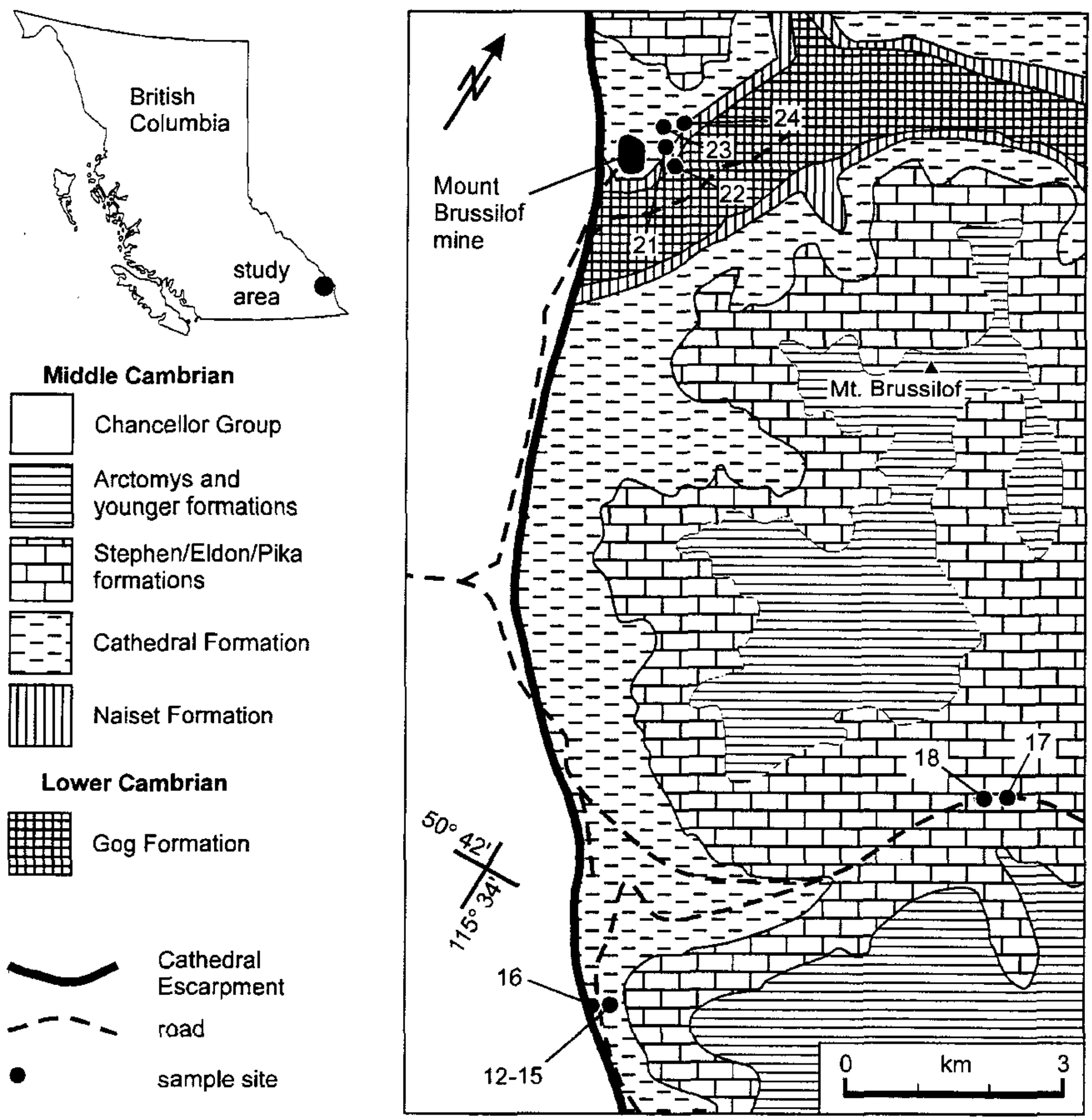

Figure 1. Location of the study area and sites (solid circles) with geology simplified from Simandl *et al.* (1992).

West of the escarpment the Chancellor Group is complexly folded and to the east forms a homoclinal sequence. The rocks cropping out in the proximity of the mine, immediately east of the Cathedral Escarpment strike 168/21 SW. Rocks south of the mine area strike approximately east-west and dip 10° to the south. (Simandl *et al.*, 1991).

The Mount Brussilof magnesite ore is composed of coarse, white to grey, sparry magnesite crystals in the lower Cathedral Formation. There is a small percentage of impurities such as dolomite, calcite, pyrite, ankerite and about a dozen other relatively uncommon minerals (White, 1972).

PALEOMAGNETIC METHODS

Drill cores from sites 1 to 11 and 16 to 20 were oriented by sun compass and sliced into specimens. Block samples from the remaining sites were oriented by magnetic compass and specimens were later drilled from them in the laboratory (Figure 1). The 409 specimens were stored for several months and then measured inside a three-layer steel magnetically-shielded room with a field of ~0.2 percent of the Earth's ambient magnetic field to allow viscous remanent magnetization (VRM) components to decay.

Remanence measurements were done on an automated Canadian Thin Films model DRM-420 cryogenic magnetometer that is one of the world's most efficient and sensitive for this type of research. After measuring the natural remanent magnetization (NRM) of each specimen, two or more specimens from each site were alternating field (AF) step demagnetized at 5, 10, 15, 20, 25, 30, 40, 50, 60, 80 and 100 milliTesla (mT) using a Sapphire Instruments model SI-4 demagnetizer. Next two or more specimens from each site were thermally step demagnetized at 250, 350, 400, 450, 500, 530, 555 and 580°C using a Magnetic Minerals model MM-1 demagnetizer. The remaining specimens from each site were AF demagnetized in four to six steps. Those with NRM intensities of $<2 \times 10^{-5}$ Ampere/metr (A/m) were started at 15 mT and the rest at 20 mT with steps of 10 or 20 mT up to 60 to 100 mT.

Saturation isothermal remanence magnetization (SIRM) analysis was done on 11 representative specimens by pulse magnetizing them in 11 direct field steps up to 900 mT using a Sapphire Instruments model SI-6 pulse magnetizer, and then AF demagnetizing them in six steps to 50 mT. A further nine specimens were pulse magnetized at 900 mT and then thermally demagnetized in nine steps to 670°C.

Characteristic remanent magnetization (ChRM) components were identified from the step demagnetization data using both orthogonal vector plots (Zijderveld, 1967) and the least-squares fitting method of Kirschvink (1980). Site mean and unit mean statistics were done using Fisher (1953) statistics. It is most convenient to group the results of these analyses by rock type for discussion.

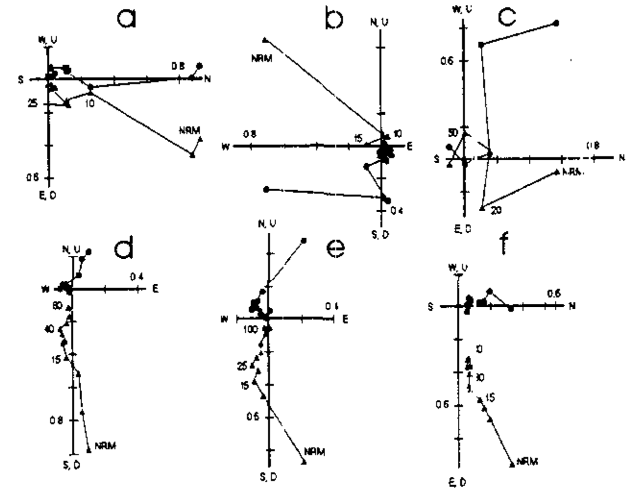

Figure 2. Orthogonal demagnetization diagrams showing example specimens on AF step demagnetization of: a) magnesite ore, site 1, $J_0 = 7.98 \times 10^{-5}$ A/m; b) magnesite ore, site 7, $J_0 = 4.61 \times 10^{-5}$ A/m; c) Gog sandstone, site 22, $J_0 = 1.20 \times 10^{-3}$ A/m; d) Cathedral dolostone, site 19, $J_0 = 1.51 \times 10^{-4}$ A/m; e) Cathedral dolostone, site 20, $J_0 = 1.29 \times 10^{-4}$ A/m; and, f) Eldon dolostone, site 17, $J_0 = 8.50 \times 10^{-5}$ A/m. The axes are north (N), east (E), south (S), west (W), up (U) and down (D). Circles (triangles) denote projections onto the horizontal (vertical) plane. The axes show the J/J_0 ratio. The AF steps are in millitesla (mT).

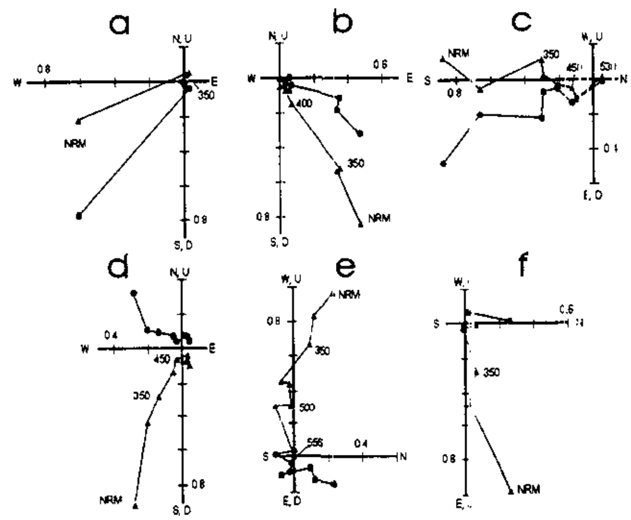

Figure 3. Orthogonal demagnetization diagrams showing example specimens on thermal step demagnetization of: a) magnesite ore, site 2, $J_0 = 3.62 \times 10^{-4}$ A/m; b) magnesite ore, site 6, $J_0 = 4.80 \times 10^{-4}$ A/m; c) Gog sandstone, site 22, $J_0 = 1.03 \times 10^{-3}$ A/m; d) Cathedral dolostone, site 19, $J_0 = 2.14 \times 10^{-4}$ A/m; e) Cathedral dolostone, site 21, $J_0 = 1.87 \times 10^{-3}$ A/m; and, f) Eldon dolostone, site 18, $J_0 = 4.88 \times 10^{-4}$ A/m. Conventions as in Figure 2 except the steps are in degrees Celsius (°C).

TABLE 1. SITE MEAN REMANENCE DIRECTIONS

Site	Unit	Strike	Dip	Sampling B	N	n	r	Demagnetizing Range H_{af}	°C	Decl. °	Incl. °	a_{95} °	k
1	m			6	11	6	1	15 - 25	250 - 400	323.2	30.0	14.7	18
2	m			6	12	6	0	15 - 25		47.6	-7.6	20.3	10
3	m			7	13	6	0	15 - 25	250 - 450	4.4	35.3	10.9	39
4	m			5	8	3	2	15 - 25		255.4	41.3	18.1	19
5	m			7	12	4	2	15 - 40		248.7	46.0	14.5	22
6	m			6	11								
7	m			7	12								
8	m			7	13	7	1	15 - 25		32.4	64.7	13.4	18
9	m			6	12	8	1	15 - 25		49.0	49.9	10.8	24
10	m			7	12								
11	m			7	13								
12	b*			6	47	47	0	20 - 80	250 - 530	344.1	74.9	5.4	157
13	b*			7	34	34	0	20 - 100	250 - 400	286.7	74.7	9.5	42
14	b*			4	22	22	0	15 - 80	250 - 350	312.8	79.0	12.3	57
15	s			2	18	15	0	20 - 100	500 - 555	181.0	-52.5	13.2	9
16	b*			13	24	23	0	20 - 130	250 - 450	358.9	71.2	10.4	17
17	e	52	16	6	14	14	0	20 - 100	250 - 400	10.7	75.1	4.2	92
18	e	57	10	5	11	11	0	20 - 100	250 - 350	338.1	79.1	5.6	68
19	c	132	81	7	12	11	0	20 - 100	250 - 400	315.0	76.0	7.9	35
20	c	159	13	6	17	17	0	20 - 80	250 - 400	292.8	71.0	3.4	111
21	c	297	30	4	14	6	2	15 - 60	500 - 530	345.9	76.9	14.5	16
22	g	168	30	4	18								
23	c	167	38	4	12	12	0	20 - 110	250 - 530	330.0	67.9	8.6	26
24	s			4	36								

Notes:

Geologic units are: Gog (g), Cathedral (c) and Eldon (e) formations; magnesite ore (m); breccia clasts (b) with the asterisk denoting that the site mean is derived from the clast mean directions; secondary dolomite (s). Strike and dip are given by a right-hand convention. Sampling gives the number of: cores or blocks (B); specimens measured (N); and specimen end points (n) and reversed end points (r) used to obtain the site mean. Demagnetizing range of alternating field intensities (H in millitesla) and temperatures (°C); the steps of specimen ChRM directions are averaged. Declination (Decl.), inclination (incl.), radius of cone at 95 percent confidence (a_{95}) in degrees (°C) of arc and precision parameter (k) from Fisher (1953).

RESULTS

Magnesite Ore

The 11 sites of magnesite ore were distributed quite uniformly along the mining faces of the Mount Brussilof open pit. The median NRM intensity of the 120 specimens is a very weak 2.7 x 10^{-5} A/m. On AF step demagnetization the NRM decays rapidly, giving consistent ChRM directions down to <3 x 10^{-6} A/m (Figure 2 a,b). Thermal step demagnetization also results in a rapid decay of the ChRM to <3 x 10^{-6} A/m by 450°C for most specimens without defining an obvious Néel or Curie temperature to identify the remanence carrier (Figure 3a). A few specimens with stronger NRM intensities appear to define a ChRM that is unblocked between about 350 and 500°C (Figure 3b). The SIRM acquisition curves show a steady increase up to 900 mT (Figure 4a) and slow decrease on AF step demagnetization (Figure 4b) that is typical of either goethite or hematite. These minerals, however, have not been observed in the ore in sufficient abundance to yield the observed intensities. Similarly, thermal step demagnetization of the SIRM shows no evidence of these minerals (Figure 4c). Thus the source of the remanence in the magnesite ore remains uncertain. Seven magnesite sites show some degree of clustering of their specimen ChRM directions (Table 1) but their mean directions are widely scattered (Figure 5a). The reason for this dispersion is also unclear.

Gog Formation

The 22 specimens from site 22 in the Gog sandstone have a strong median NRM intensity of 1.0 x 10^{-3} A/m. All undergo rapid AF demagnetization, reaching ~10% of their initial NRM intensity by 30 mT and giving inconsistent directions thereafter (Figure 2c). A few specimens appear to give consistent ChRM directions over a broad unblocking temperature spectrum (Figure 3c). Unfortunately, however, the 22 specimens give random ChRM directions, yielding no useful paleomagnetic data.

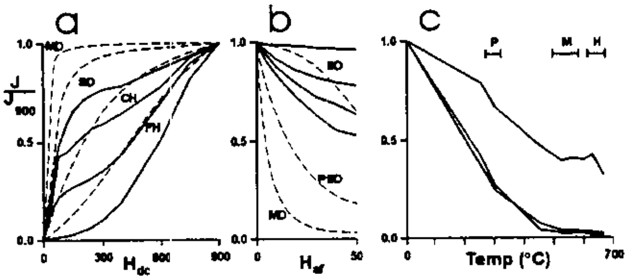

Figure 4. Saturation isothermal remanent magnetization (SIRM) curves for magnesite ore specimens showing: a) acquisition of SIRM; b) AF demagnetization of SIRM; and, c) thermal demagnetization of SIRM. J/J_{900} is the ratio of the measured remanence intensity to the SIRM intensity at 900 mT. H_{dc} and H_{af} are the applied direct and alternating fields in millitesla (mT). T is the temperature in degrees Celsius (°C). The dashed line curves are typical for single domain (SD), pseudosingle domain (PSD) and multidomain (MD) magnetite and for fine-grained (FH) and coarse-grained (CH) hematite from Dunlop (1973, 1981). P, M and H show the diagnostic temperature range in which pyrrhotite, magnetite and hematite, respectively, are magneticaly unblocked so that the J/J_{900} ratio decreases rapidly. The saturation intensities, J_{900}, for specimens from sites 1, 5, 6, 7, 9, 10, and 11 are 2.54, 2.05, 2.48, 57.0. 7.01, 7.02, and 16.6 x 10^{-3} A/m respectively.

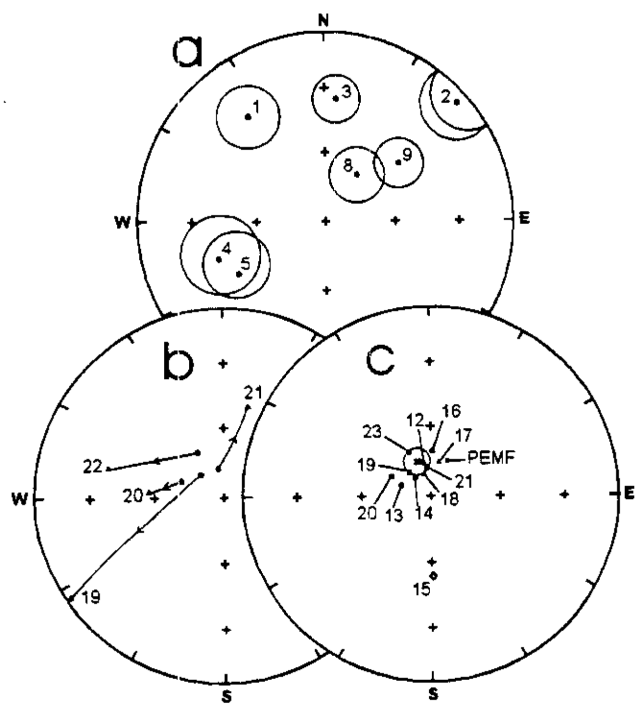

Figure 5. Equal-area stereograms showing the site mean ChRM directions for: a) magnesite ore; b) Cathedral dolostone before (circles) and after (triangles) tectonic tilt correction; and, c) all reliable host-rock sites before tilt correction. On (c) the rock types are Cathedral dolostone (square), Eldon dolostone (triangle), breccia clasts (circle), and secondary dolomite (diamond). The unit mean (x) is circumscribed by its cone of 95% confidence. The star is the present Earth's magnetic field direction.

Cathedral Formation

FOLD TEST

Sites 19, 20, 21 and 23 are in fine-grained dolostones and limestones of the Cathedral Formation with dips ranging from 13° to 80°. They were collected to provide a paleomagnetic fold test (Graham, 1949). If their ChRM directions are better grouped after tilt correction, then the ChRM predates folding and is likely primary, and if the converse is true then the ChRM is postfolding and secondary. The 55 specimens from the four sites have a median NRM intensity of 1.7 x 10^{-4} A/m. AF step demagnetization up to ~20 mT removes a VRM that appears to record mostly the present Earth's magnetic field direction, and from ~20 mT to 100 mT a well-defined ChRM is isolated (Figure 2d,e). Thermal step demagnetization results in a steady decay of the NRM intensity down to ~10% at ~450°C, followed by constant or slightly increased intensities thereafter (Figure 3d). On both AF and thermal step demagnetization most ChRMs give normal directions that are directed northerly and steeply downwards except for a few from site 21 that are reversed, being antiparallel and upwards to the south (Figure 3e).

The SIRM acquisition curves for the Cathedral specimens show a rapid initial increase up to ~300 mT which is indicative of either magnetite or pyrrhotite, followed by a slow increase from ~300 mT to 900 mT which suggests that goethite or hematite is present (Figure 6a). AF demagnetization of the SIRM yields decay rates that show that the magnetite or pyrrhotite is in the single domain to pseudosingle domain size range (Figure 6b) and thermal demagnetization of the SIRM gives unblocking temperatures that suggest that pyrrhotite, magnetite and hematite are present (Figure 6c).

All four sites of the Cathedral host rocks give well-clustered specimen ChRM directions that yield reliable site mean directions (Table 1, Figure 5b). Before tilt correction, they are tightly clustered with a precision parameter (k, Fisher, 1953) of k_u=111 whereas after tilt correction the ChRM directions are widely dispersed with a k_c value of 3.4 (Table 2). Using the fold test of McElhinny (1964), this results in a k ratio (k_u/k_c) of 32.6 that is very much greater than the 99% confidence comparison statistic of 8.47. Thus the fold test shows clearly that the ChRM is post-folding in origin with >>99% confidence, as does the more sophisticated test of McFadden and Jones (1981).

BRECCIA TEST

South of the Mount Brussilof mine there is a chevron fold in the Cathedral dolostones next to the Cathedral escarpment. In the nose of the fold is an "I saddle reef" trough of sparry dolomite with numerous clasts of the host rock. Sites 12, 13, 14, and 16 are located in different areas of the "reef" structure and provided 128 specimens from 30 breccia clasts. The breccia test asserts that the

TABLE 2. UNIT MEAN DIRECTIONS

Unit			Sites	N	Decl. °	Incl. °	a_{95} °	k
A	Cathedral Fm. -	uncorrected	19-21, 23	4	319.3	73.9	8.7	111
B	Cathedral Fm. -	corrected	19-21, 23	4	280.2	52.1	59.2	3.4
C	Eldon Fm. -	uncorrected	17, 18	2	357.0	77.6		198
D	A + C -	uncorrected	17-21, 23	6	329.9	75.7	6.8	98
E	B + Eldon Fm. -	corrected	17-21, 23	6	283.9	69.1	38.5	4.0
F	Breccia clasts		12-14, 16	4	328.9	76.7	10.1	83
G	Secondary dolomite		15	1	1.0	52.5		
H	F + G		12-16	5	341.7	72.6	13.7	32
I	All sites -	uncorrected	12-21, 23	11	335.8	74.4	6.2	54

Notes: N - number of site mean ChRM directions. Other abreviations as in Table 1

clasts will have random ChRM directions if they retain their pre-brecciation magnetization and aligned directions if they have been remagnetized since brecciation. The 128 specimens have a median NRM intensity of 8.1 x 10^{-4} A/m. This is much more intense than the other Cathedral dolostone specimens, suggesting that a more intense remagnetization ioccurred.

After removal of a VRM by about 20 mT, AF step demagnetization isolates either a well-defined normal ChRM direction or an initial normal ChRM that swings to a reverse ChRM direction (Figure 7a,b). The clast specimens respond more erratically to thermal step magnetization with most giving a normal ChRM direction up to ~450°C and then defining an erratic direction in magnetite up to ~570°C in the residual 5% of NRM intensity (Figure 8a). Two thermally demagnetized specimens give remagnetization circles towards the

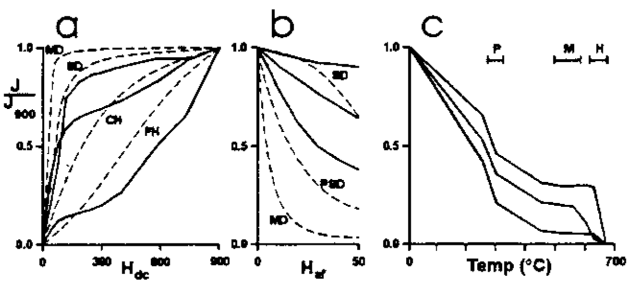

Figure 6. Saturation Isothermal Remanent Magnetization curves for Cathedral and Eldon dolostone specimens from sites 17, 17, 19, 20, 21 and 23 with J_{900} intensities of 3.05, 1.98, 2.52, 1.66, 4.59 and 5.24 x 10^{-2} A/m respectively. Conventions as in Figure 4.

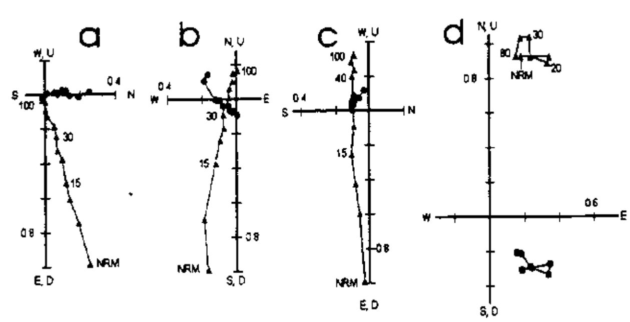

Figure 7. Orthogonal demagnetization diagrams showing example specimens on AF step demagnetization of: a) dolostone breccia clast, site 13, J_0 = 3.51 x 10^{-4} A/m; b) dolostone breccia clast, site 14, J_0 = 7.55 x 10^{-4} A/m; and, c) sparry dolomite, site 15, J_0 = 1.73 x 10^{-5} A/m. Conventions as in Figure 2.

reversed ChRM direction but do not reach an end point before becoming erratic. The SIRM acquisition curves show the rapid initial rise to 300 mT that is attributable to either magnetite or pyrrhotite and then a slow rise to 900 mT from goethite or hematite (Figure 9a). Alternatively, the curves show a steady rise denoting the presence of goethite or hematite only. AF demagnetization of the SIRM indicates that the magnetite or pyrrhotite is single domain to pseudosingle domain in character (Figure 9b). The SIRM thermal demagnetization results indicate the presence of pyrrhotite and hematite (Figure 9c).

The several ChRM directions for each clast were averaged to get the clast mean directions which were mostly well clustered (Table 3). When necessary, reverse directions were switched to their antiparallel normal direction to compute the mean directions. The mean directions of the four sites form a coherent directional cluster, as do the clast directions when grouped irrespective of site (Table 3). The high degree of clustering yields a negative breccia test, meaning that the clasts were remagnetized when the breccia was formed or at some later date.

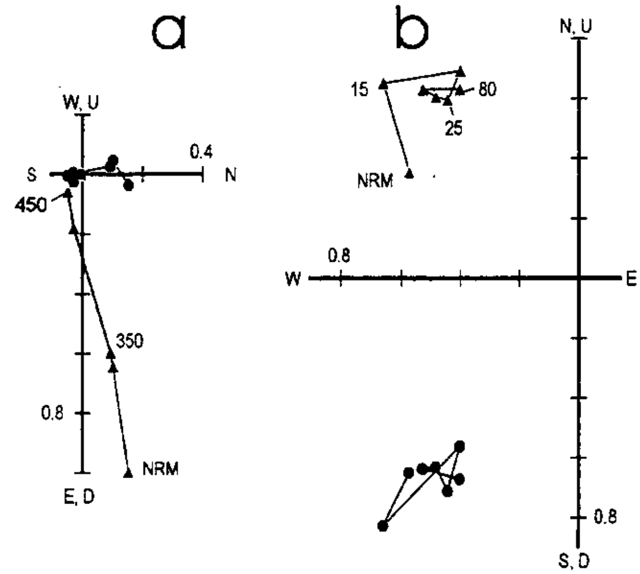

Figure 8. Orthogonal demagnetization diagrams showing example specimens on thermal step demagnetization of: a) dolostone breccia clast, site 12, J_0 = 2.39 x 10^{-3} A/m; and, b) sparry dolomite, site 15, J_0 = 2.38 x 10^{-3} A/m. Conventions as in Figure 3.

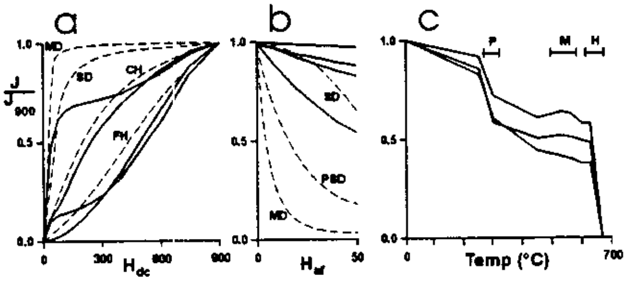

Figure 9. Saturation Isothermal Remanent Magnetization curves for dolostone breccia clast and secondary sparry dolomite specimens from sites 12, 13, 14, 15, 15, 16 and 16 with J_{900} intensities of 14.1, 7.58, 13.5, 21.6, 7.39, 21.9 and 28.9 x 10^{-2} A/m, respectively. Conventions as in Figure 4.

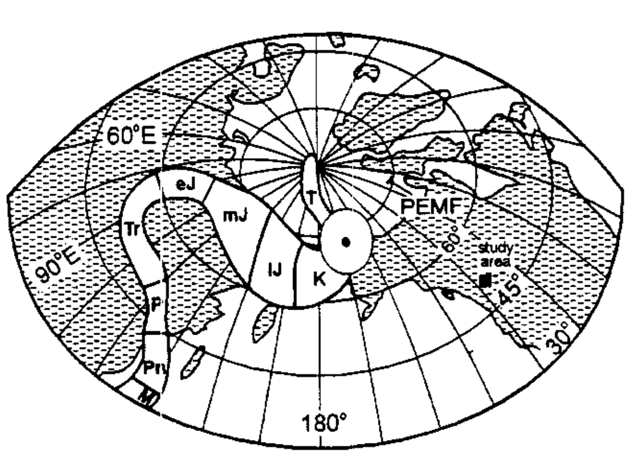

Figure 10. Apparent polar wander path for the North American craton with the host rock pole position of this study. The path for the Mississippian (M), Pennsylvanian (Pn), Permian (P), Triassic (Tr), and Early Jurassic (eJ) is from Van der Voo (1990); the path for the Middle Jurassic (mJ) and Late Jurassic (lJ) is simplified from Van der Voo (1992); and, the path for the Cretaceous (K) and Tertiary (T) is from Irving and Irving (1982). The pole is circumscribed by its oval of standard deviation, and the C pole from modern weathering is next to the present pole of the Earth's magnetic field (PEMF).

Eldon Formation

Sites 17 and 18, yielding 25 specimens with a median NRM intensity of 1.1 x 10^{-4} A/m, were collected from gently dipping dolostone of the Eldon Formation. Their behaviour on AF and thermal step demagnetization is essentially the same as found for the Cathedral dolostone specimens except that only normal ChRM directions were isolated (Figures 2f and 3f). The one SIRM acquisition curve suggests the presence of either goethite or hematite (Figure 6a) and thermal demagnetization of the SIRM shows unblocking in both the goethite (70-130°C) and hematite (600-675°C) range (Figure 6c). Note, however, that goethite can dehydrate to hematite on heating to about 350°C (Dekkers, 1990). Both sites give coherent site mean ChRM directions (Table 1).

TABLE 3. REMANENCE DATA FOR BRECCIA CLASTS

Site Clast	N	n	Decl °	Incl °	a_{95} °	k
12-1	10	10	344.5	77.4	1.5	976
2	6	6	356.3	79.3	1.6	1666
3	9	9	342.5	75.1	2.7	383
4	6	6	333.2	74.7	2.8	594
5	7	7	319.6	71.1	3.6	288
6	9	9	7.3	67.7	1.3	1485
A		*6	344.1	74.9	5.4	157
13-1	8	8	284.4	70.9	4.8	133
2	4	4	308.9	71.6	12.5	55
3	5	5	324.4	81.2	5.4	203
4	6	6	224.9	75.6	7.9	74
5	4	4	287.6	75.5	11.3	67
6	4	4	247.5	65.7	7.9	137
7	3	3	322.8	62.0	24.9	26
A		*7	286.7	74.7	9.5	42
14-1	6	6	287.3	85.4	3.4	400
2	3	3	327.1	66.5	4.5	753
3	7	7	295.7	74.0	9.4	42
4	6	6	341.6	87.9	4.3	237
A		*4	312.8	79.0	12.3	57
16-1	3	2	168.2	-62.5		
2	2	2	192.6	-62.8		
3	2	2	182.7	-58.6		
4	2	2	11.8	81.7		
5	2	2	287.8	77.4		
6	1	1	134.9	-71.1		
7	2	2	180.6	-59.8		
8	3	3	187.2	-63.8	10.4	141
9	1	1	315.1	50.9	5.2	557
10	3	3	291.2	76		
11	2	2	162.6	-63.7		
12	1	1	173.7	-61.4		
13	1	1	99.6	52.8		
A		*13	358.9	71.2	10.4	17
All	30		333.7	75.1	5.4	25

Notes: N, n - number of specimens measured and used in clast average. * - number of clast mean directions averaged. Other abbreviations as in Table 1.

Secondary Dolomite

Secondary dolomite was sampled at site 15 in the breccia zone and at site 24 next to the Mount Brussilof ore zone. The 54 specimens have a very weak median NRM intensity of only 2.0 x 10^{-5} A/m. At site 15 the more intense specimens swing from normal to a reverse ChRM, whereas the weaker specimens are virtually unchanged in either direction or intensity suggesting minor goethite or hematite (Figure 7c,d). In contrast, the specimens from site 24 show moderate to rapid rates of demagnetization but isolate normal ChRM directions. Thermal step demagnetization of site 15 specimens isolates first a normal ChRM direction up to ~400°C and then a reversed direction at higher temperatures (Figure 8b). The specimens from site 24 define part of a normal to reverse remagnetization great circle, but define neither end point. The SIRM acquisition and demagnetization curves for a site 15 specimen are typical for fine-grained goethite or hematite, with the SIRM thermal demagnetization curve showing clearly that hematite is present (Figure 9). The specimens from site 15 give a reasonable site mean direction (Table 1), but those from site 24 are too widely scattered.

POLE POSITION OF THE HOST ROCKS

Useful site mean remanence directions have been obtained from four sites in the Cathedral Formation (sites 19, 20, 21 and 23), two in the Eldon Formation (sites 17 and 18), four in remagnetized breccia clasts (sites 12, 13, 14 and 16), and one in secondary dolomite (site 15). The negative fold and breccia tests both confirm that the remanence is post-folding in origin and, therefore, that the site mean ChRM directions should not be corrected for tilt. When these 11 sites are plotted together, they form a coherent population that has a unit mean direction of 335.8°, 74.4° (N=11, a_{95}=6.2°, k=54) (Figure 5c, Table 2). This unit mean gives a pole position of 159.5°W longitude, 73.2°N latitude (dp=10.2°, dm=11.2°, semi-axes of the oval of 95% confidence (Fisher, 1953)). This pole falls directly atop the Late Cretaceous portion of the apparent polar wander path (APWP) for the North American craton (Figure 10).

DISCUSSION

Extending northwestward for about 300 km from Mount Brussilof and southeastward for about 100 km is an area containing hydrothermal dolomites that is about 50 km wide along the northeastern side of the Cathedral escarpment. The sparry dolomite occurs as stratabound lenses, veins and irregular masses, with an earlier light gray, dark brown-black planar dolomite. Westervelt (1979) argued that the dolomite sheets were folded and faulted during the Laramide orogeny and thus predate the Late Jurassic. Yao and Demicco (1995) noted that Cambrian limestone boulders in Ordovician shales are unaltered whereas those on a Late Devonian erosional surface are dolomitized, suggesting that dolomitization occurred between the Ordovician and Late Devonian. They tied the dolomitization to a regional fluid flow event during Silurian to Devonian time from orogenic uplift in the Purcell anticlinorium and Kootenay arc on the west side of the escarpment (Okulitch, 1985). Based on field data from the Mount Brussilof area and available published information on MVT deposits, Simandl *et al.* (1991) pointed to a possible genetic link between the Mount Brussilof deposit and the Monarch-Kicking Horse and other MVT deposits in the secondary dolomite zone, suggesting also that they may be equivalent in age. Based on limited fluid inclusion salinities, homogenization temperatures, and $d^{18}O$, $d^{13}C$ and dD values, Nesbitt and Muehlenbachs (1994, 1995) further suggested that the dolomites and ore deposits were formed during a Late Devonian to pre-Laramide paleoflow event.

Contrasting with the preceding views for fluid flow in the Western Canada Sedimentary Basin (WCSB), several lines of evidence support a major Laramide paleoflow event in the WCSB. Oliver (1992), in an overview of interior North America, summarized extensive evidence for correlating regional fluid flows from orogenic events to the formation of petroleum deposits, dolomitization, MVT deposits and remagnetization of carbonate sediments. Qing and Mountjoy (1992, 1994) have provided extensive geologic, petrologic and geochemical data supporting a major Laramide paleoflow event in the WCSB. Machel *et al.* (1995) have used organic geochemistry to support a Laramide flow event. A mathematical hydrogeologic model for Laramide fluid flow in the WCSB has been given by Garven (1985). Paleomagnetic studies have shown that all major MVT deposits studied to date are coeval with a major adjacent orogenic event and that the Pine Point MVT ores in the WCSB are Laramide in age (Symons et al., 1993, 1996). Also, Enkin (1995) has reported that Paleozoic dolostones in the Front Ranges to the east of the secondary dolomite zone carry a Laramide remanence.

The results of this study provide strong evidence that at least some dolomitization is post-folding and therefore Laramide or Late Cretaceous to early Paleocene in age. The paleomagnetic data can not discriminate between metasomatic replacement or recrystallization theories for the origin of the magnesite ore. The source of the remanance in the magnesite ore remains uncertain. Although seven magnesite sites show some degree of clustering of their ChRM directions, their mean directions are widely scattered. One can only speculate about the reasons for this scatter. It may be linked to lower temperatures of recrystalization of magnesite relative to dolomite. Magnesite rock could have been relatively impermeable to Laramide fluids and therefore its paleomagnetic signature was not completely reset. Future work on other magnesite deposits that are less pure may resolve the age issue.

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British Columbia Geological Survey
Geological Fieldwork 1996

A NEW SODALITE OCCURRENCE: MOUNT MATHER CREEK, BRITISH COLUMBIA (82N/10W)

Z. D. Hora and K. D. Hancock

KEYWORDS: Sodalite, alkaline intrusions, sodalite syenite.

INTRODUCTION

The Mount Mather Creek sodalite prospect is located 30 kilometres north of Golden at latitude 51°33'00" north and longitude 116°53'12" west (Figure 1). The property is delineated by the Hope group of four claims. The site can be accessed via the Blaeberry River Forestry Road thence following a trail north at kilometre 39½. Sodalite outcrops in a steep, narrow canyon cut by a small Blaeberry River tributary called Mount Mather Creek. The creek is a typical snow-fed stream with high flow in the early summer changing to a trickle in the fall. During a typical summer day, the morning flow is small compared to the water flow in the afternoon.

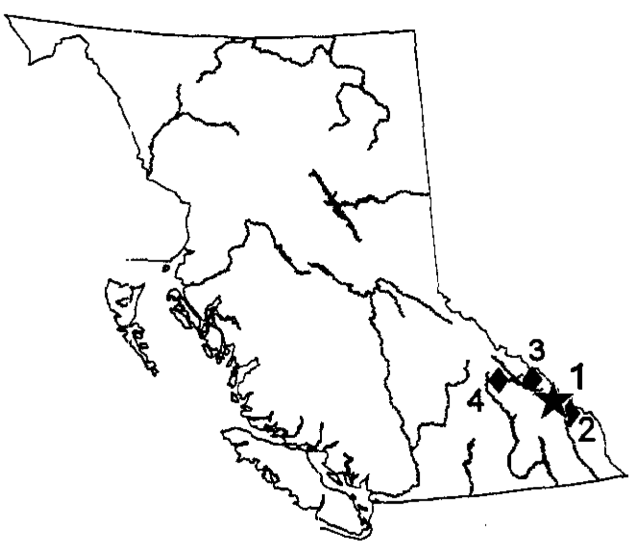

Figure 1. Location of alkaline syenites in the Golden area. 1: Mount Mather Creek; 2: Ice River complex; 3: Solitude Mountain; 4: Trident Mountain

GEOLOGICAL SETTING

The Mount Mather Creek area is within a syncline of the western "shaly facies" of Middle and Upper Cambrian Chancellor Group carbonate rocks (Price, 1967). Although the broad regional structure is a syncline, the beds exhibit complicated folding at the proprty scale.

The lower units of the Chancellor Group, which host the sodalite showing, are massive, well-bedded, fine-grained carbonates. One main breccia dike of sodalite syenite with two tributary dikelets cut the carbonate host rock across bedding planes. The syenite dikes weather brown due to the presence of pyrite and the host limestone exhibits a yellow to buff weathering alteration halo in contrast to its otherwise grey weathered surface. The yellow weathering is often more extensive along some bedding planes. Freshly broken rocks, altered and unaltered, have the same dark grey colour and can not be distinguished macroscopically from each other.

MOUNT MATHER CREEK SODALITE (MINFILE NUMBER 082N090)

Sodalite is a major component of the syenite/carbonate breccia body. It is up to 10 metres wide and outcrops over a distance of approximately 80 metres in a vertical rocky cliff on the western side of the creek (Figures 2 and 3). It is also present as a minor component in the two thin independent dikes as fine-grained disseminations where albite is the dominant mineral.

While the main breccia outcrop is practically inaccessible, large boulders that have fallen off the cliff and accumulated along and within the creek channel provided material for thin sections and are the source of most macroscopic observations. The main body is part breccia and part stockwork The host rock consists of fine-grained, bedded carbonate made of very fine-grained (5-25 microns) calcite, variable amounts of feldspar (0-50%) and possibly very small amounts of quartz. Bed thickness varies from about one to 10 millimetres and in thin section is poorly defined. It is characterized by slight average grain size differences and is sometimes accented by iron staining either along bedding planes or throughout individual beds. Breccia clasts, from 1 to 10 centimetres long and 1 to 4 centimetres in diameter, are comprised of the same rock. The fragments exhibit features usually observed in plastic flow regimes, such as boudinage, rounded shapes and preferential orientation of clasts (Figure 4).

Figure 2. Sodalite syenite breccia outcrop. View looking southwest.

Figure 4. Sodalite syenite breccia with limestone clasts.

Sodalite syenite occurs as veins, breccia matrix and disseminations in the host rock. The veins consist of coarse, blocky albite crystals up to 2 millimetres in width with calcite as a secondary vein filling. Calcite often forms secondary veinlets that branch from a central, albite rich "trunk" vein. The calcite grains typically grow perpendicular to vein walls and are up to one millimetre long. The breccia matrix comprises a

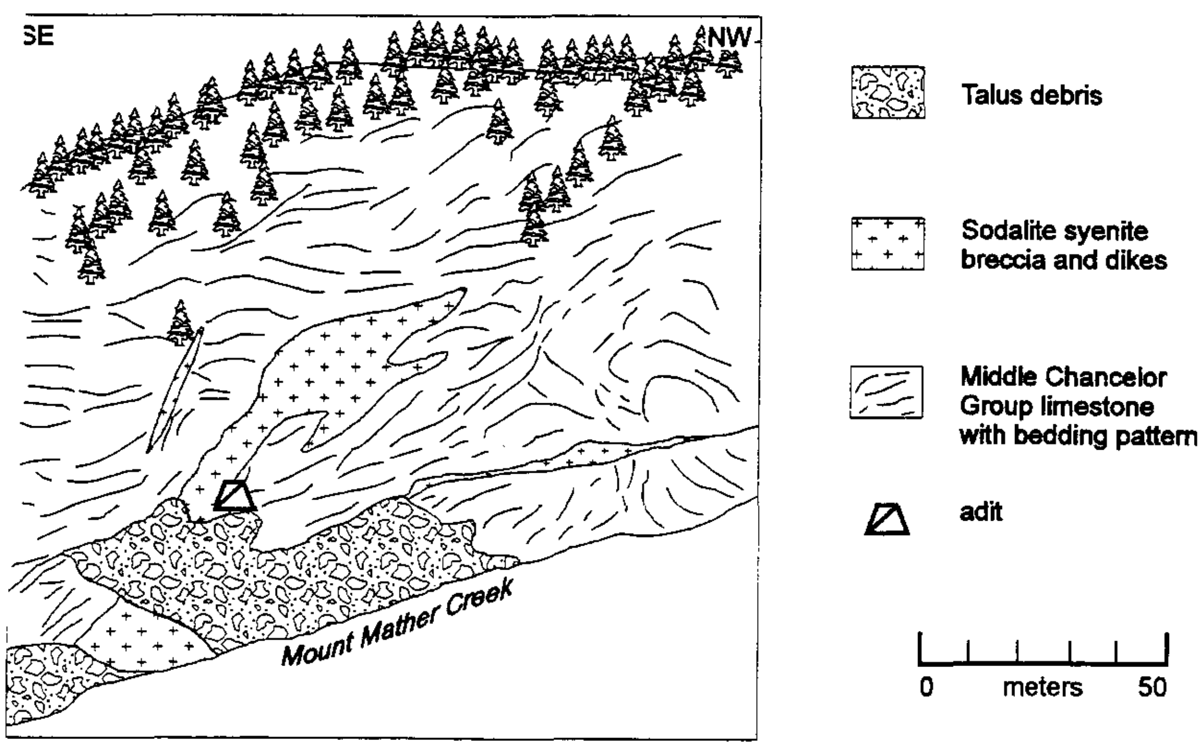

Figure 3. Mount Mather Creek sodalite syenite. View looking southwest at cliff face.

Figure 5. Sodalite syenite veining along bedding planes in limestone.

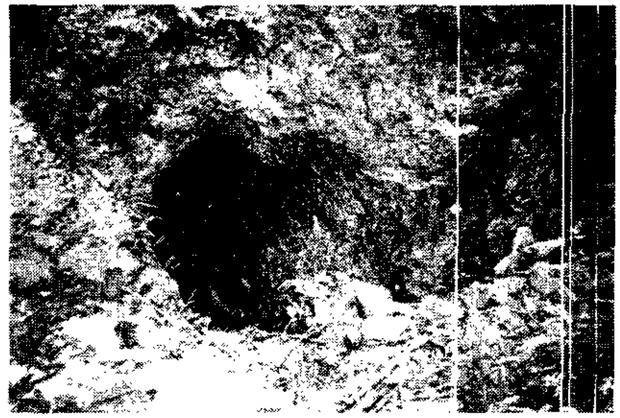

Figure 6. An old adit in sodalite syenite breccia.

highly variable mix of albite, calcite, sodalite and scattered grains of pyrite, galena and magnetite. The albite and calcite grains are often 1 to 2 millimetres across and the calcite grains often have well formed twins.

Sodalite is ubiquitous in most of the syenite. It varies from coarse grain aggregates in breccia matrix to fine disseminations that give a blue hue to both thin sections and rock fragments. Coarse sodalite appears restricted to veinlets and pockets within the breccia matrix. It forms anhedral to subhedral grains and grain aggregates that make up 5 to 15 percent of the syenite. Occasionally, sodalite forms aggregates up to several centimetres in size. It can also impregnate large host rock blocks along the bedding planes (Figure 5). As disseminated grains, sodalite is characterized by small euhedral grains ¼ to ½ millimetres in size that make up to 10 percent of the rock. Pyrite is a common accessory in many samples. It occurs as disseminated crystals up to 2 millimetres in size. A few samples contained galena grains up to 1 millimetre in diameter that, seen under the microscope, were corroded and rimmed by euhedral pyrite. Magnetite occurs as small, approximately ¼ millimetre in diameter, disseminated euhedral grains. While not mineralogically confirmed, the syenite probably also contains sphalerite. Some old assays provided to the authors by Mr. Lefurgey indicate similar values of zinc and lead.

The absence of syenite on the eastern side of the valley, an abrupt end of the dike in the Mount Mather Creek bed and a distinct bedding pattern on each side of the canyon makes the authors suspect that a fault with substantial displacement exists under the creek bed.

The property owner discovered this sodalite occurrence in 1957. At that time, there was already an old, short adit blasted into the main sodalite syenite breccia body (Figure 6). In the summer of 1996, the current owner, Dave Lefurgey, started to develop the site and mined about 3 tonnes of low grade sodalite breccia from loose boulders to market the stone for lapidary and ornamental use.

DISCUSSION

The Mount Mather Creek sodalite syenite is another occurrence of alkaline igneous rocks discovered in the Canadian Rocky Mountains and adjacent areas on the west side of the Rocky Mountain and Tintina Trench (Figure 1). The Ice River Complex, within similar host rocks, lies 50 kilometres to the southeast. A similar distance to the northwest is a group of nepheline syenite dikes in the Kinbasket Lake - Solitude Mountain area.

Sodalite is known at several localities in British Columbia. The Ketchika River area, Wicheeda Lake, Bearpaw Ridge, Paradise Lake, Trident Mountain and Moose Creek on the south edge of the Ice River Complex all have sodalite as a common accessory (Pell, 1994). In none of these sites has it been found in a similar quantity as at Mount Mather Creek. If the Mount Mather Creek site is eventually proven a non-commercial sodalite source, due to its rather disseminated nature, it is still the richest accumulation that the senior author is aware of in British Columbia. K.L. Currie (1976) in his Memoir 239 also mentioned, without any site description, Mt. Laussedat as a sodalite locality. It is our opinion, that because of the circumstances of the initial discovery, the Mount Mather Creek is the same occurrence (D. Lefurgey, personal communication, 1996).

One characteristic phenomenon common to a number of alkaline intrusions in the Rocky Mountains is their yellow to brown weathering halo. It is a striking feature of the Aley carbonatite and Rock Canyon Creek Rare Earth element showings, particularly because these two localities are not covered by vegetation. It is also a feature of the Mt. Mather Creek sodalite occurrence. Such a colour anomaly is a very clear feature on low level colour air-photos and can be used as a prospecting tool for finding yet unknown alkaline intrusives. While, because of its location, the Mount Mather Creek site cannot be recognized on air-photos, large, unprospected brownish zones to the northwest and east of the sodalite showing are clearly visible.

ACKNOWLEDGMENTS

The authors would like to express appreciation to Dave Lefurgey for his hospitality and help in visiting the property. Also, thanks are expressed to Dick Player of the B.C. Geological Survey Branch for lapidary support.

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KLINKER PRECIOUS OPAL DEPOSIT, SOUTH CENTRAL BRITISH COLUMBIA, CANADA - FIELD OBSERVATIONS AND POTENTIAL DEPOSIT-SCALE CONTROLS

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KEYWORDS: Industrial minerals, opal, agate, zeolites, gemstones.

INTRODUCTION

This paper describes the geology and mineralogy of the Klinker opal deposit in south-central British Columbia. The deposit is located within the Tertiary basin that extends 150 km from Okanagan Lake northwest to Kamloops. The area was mapped by Jones (1959) and substantial contributions to the general knowledge of these rocks were made by Church (1979, 1980, 1982), Ewing (1981), Evans (1983), Read (1996a) and Okulitch (1979). It produces both natural precious and common opals. Opal is widespread within the Tertiary basins of British Columbia (Leaming, 1973) and the Klinker deposit is within such a basin. It is located approximately 30 kilometres northwest of Vernon (Figure 1). In 1995 and 1996, the deposit was bulk-sampled using mechanized equipment. Klinker is the first precious opal deposit under development in Canada. Although it is hosted by a volcanic sequence, it may have some similarities with sediment-hosted deposits because of a possible association with an unconformity and intense weathering. Opal extracted from the Klinker

Figure 1. Location of the Klinker precious opal deposit, British Columbia.

deposit typically does not have a tendency to crack or craze when exposed to the atmosphere and is referred to as "stable". It has excellent brightness and multicolour "flash" to "broad flash" patterns. It may be water-clear, orange, honey, red-brown, orange or white in colour. Clarity of the stones varies from transparent through translucent to opaque. At present, doublets, triplets, solid and boulder opal are produced from the bulk sample extracted from the Klinker deposit and are being test-marketed within the Vernon area of British Columbia.

Opal is an amorphous form of silica ($SiO_2 \cdot nH_2O$) containing typically 3 to 10 percent water, although some opals contain as much as 20 percent water. X-ray analyses of many opals give weak patterns of cristobalite or tridymite. Common opal may occur mixed or alternate with agate, forming stripes or bands. Precious opal is defined as opal with a "play of colour", caused by diffraction of white light by regular packing of silica microspheres within the mineral structure (Darragh *et al.*, 1976). Common opal has a less ordered packing of silica microspheres within the mineral structure and has no "play of colour". The term "common opal" groups all opals without play of color. The term "fire opal" describes a common opal having a transparent orange to red-orange base color (Downing, 1992). Therefore, precious opal is not a synonym for "fire opal".

Worldwide, precious opal is rare in comparison to common opal. There is a relatively good market for precious opal. Australia produces approximately $CDN 44 million worth of precious opal and the prices of most commercial opal exceed $CDN 40 per gram of rough material. The best grades are valued at more than $CDN 1400 per gram. Good to excellent quality, stable common opal, used as faceting material, such as the orange, transparent variety (also called "fire opal"), ranges in value from $CDN 5 to 300 per gram depending on color. The cherry-red variety is the most expensive. The market for facet-grade opal is smaller than that of precious opal.

Deposits that contain precious opal can be divided into two major categories based on host lithologies: sediment-hosted and volcanic-hosted. Australian deposits of the Coober Pedy, Andamooka and Mintabie areas are excellent examples of sediment-hosted deposits. Deposits such as Spencer (Idaho, USA), Tevern (New South Wales, Australia), La Carbonera and Iris mines (Mexico) and the deposits in the Gracios à Dios area (Honduras) are excellent examples of the volcanic-hosted category. The source of silica for sedimentary-hosted deposits is

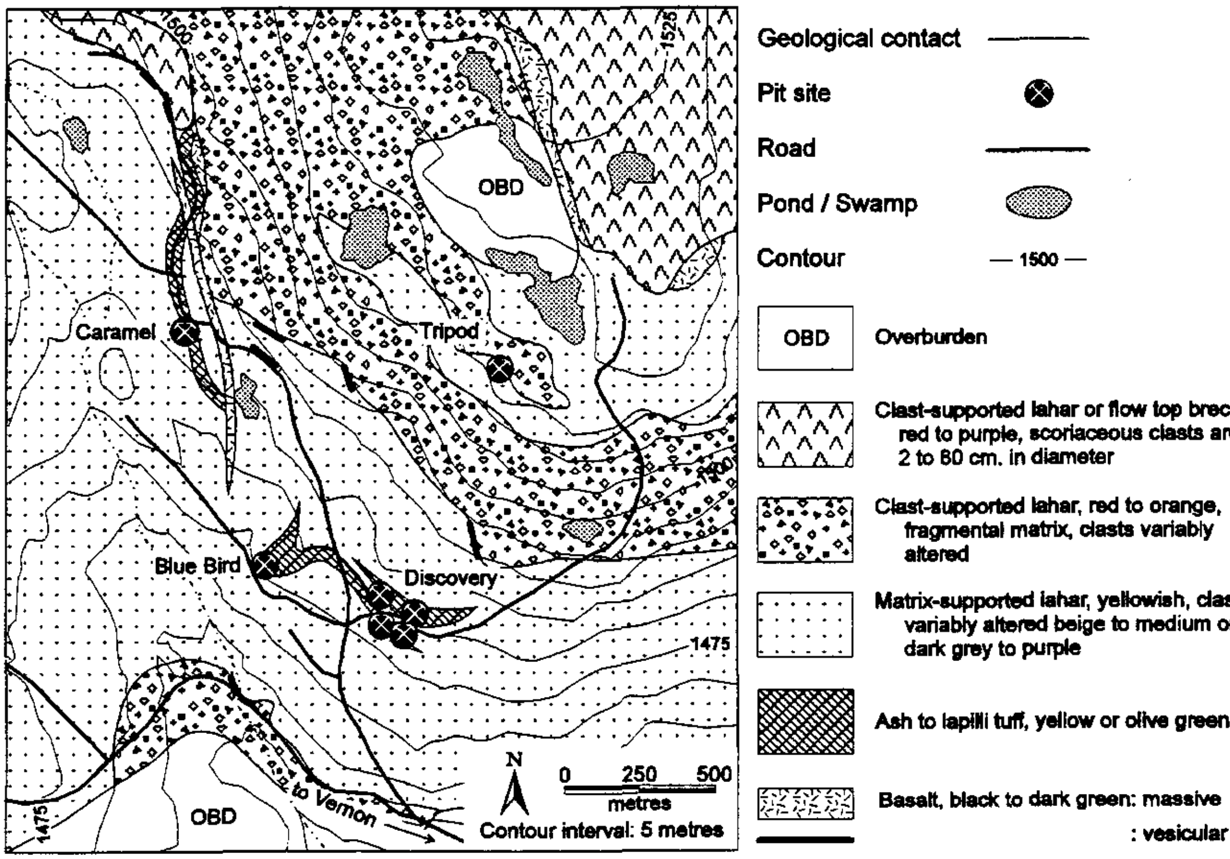

Figure 2. Geology of the Klinker deposit area.

linked to deep and intense weathering while, in general, volcanic-hosted deposits are believed to be genetically associated with hydrothermal activity.

GEOLOGY OF THE KLINKER DEPOSIT

The opal occurrences at the Klinker property are well exposed in an area of clear-cut logging. Most of the exposed rock, with the exception of mafic dikes and the massive portions of lava flows, is strongly hydrothermally altered or weathered. The depth of alteration or weathering is expected to vary substantially, but may be several metres deep as indicated by the presence of fresh rock exposed in the Discovery level 1477 open cut. The Klinker deposit is hosted by clast and matrix-supported lahars and ash to lapilli tuff units of the Eocene Kamloops Group that were initially assigned to the Dewdrop Flats Formation (Read, 1996a) but later interpreted as the Tranquille Formation (Read, 1996b). In the type localities, near Kamloops, the Dewdrop Flats Formation comprises a section of more than 1000 metres thick with nine members. The dominant lithologies are palagonitic basalt and andesite lava flows, flow top breccias, mudflows and dacitic ash flows. aphiric basalt, andesite and dacite flows and tephras (Ewing, 1981a; 1981b and 1982). Radiometric dates reported from Dewdrop Formation vary from 48.6 to 50.5 million years (Ewing, 1981b; Church and Evans, 1983). Typically, the Tranquille Formation underlies the Dewdrop Flats Formation. It comprises andesitic and basaltic tuffs, tuffaceous sediments, palagonite breccia, mudflows, lithic wackes and grey-black shale (Ewing, 1981a and 1982).

Samples of bedded, unconsolidated sediments found in topographic lows overlying the opal-bearing lahars at the Klinker deposit contain Middle Miocene palynomorph assemblages (conifer pollen, angiosperm pollen, fungal spores and cysts) that are similar to assemblages in the Fraser Bend Formation, near Quesnel (Rouse and Mathews, 1979). The samples are assigned to the Barstovian mammalian stage of the Western North American Tertiary, *circa* 13-17 Ma. These palynomorphs, derived from surrounding shore-line habitats, indicate shallow stream or lake edge sediments. Another sample of partly consolidated, bedded tuffaceous sediments containing broad leaf fossils, collected a few kilometres away contains palynomorphs of the same age. A sample of lithified yellow to olive green, ash to lapilli tuff (Figure 2) within the opal-bearing lahars yielded small quantities of conifer palynomorphs that are probably of similar age.

If the Middle Miocene age of the tuff containing opal is confirmed, then the precious opal-hosting rocks are substantially younger than previously thought. On the other hand, if the opal-bearing tuff and lahars belong to the Dew Drop Flats Formation, as suggested by Read (1996a), then an important unconformity could be expected between the opal-bearing sequence and overlying, partly consolidated tuffaceous sediments of mid-Miocene age.

Opal Occurrences

Rock types can be divided into five major lithologies, including matrix and clast-supported lahars, scoriaceous lahar or flow top breccia, ash to lapilli tuff and lava flows or dikes and sills. The lahar units may be relatively thin and possibly repeated, by block sliding, as they dip shallowly (0 to 20°) and closely follow topography (Figure 2). Due to the undulating surfaces of the successive lahars, the strike directions are highly variable over short distances. No drilling has been done on the property and so it is not yet possible to establish the total thickness of overlapping lahar flows and depth to underlying massive and brecciated, unmineralized volcanic rocks that outcrop 500 metres east of the mapped area. Also, it is unknown to which depth precious opal can be found.

Lahars and debris flows are the most abundant of the five major rock types exposed at the Klinker deposit. In general, the lahars are inhomogenous, poorly sorted, unstratified and are nearly tabular on the large scale but have irregular contacts at the outcrop scale. In some lahar layers, the clasts are well sorted. Some flows have as little as 5 percent interstitial material.

Fine-grained, yellow or olive green, ash to lapilli tuff is typically 20 centimetres to 3 metres thick. It is characterized by centimetre-scale bedding, some cross bedding, reverse and normal grading and may form a series of lenses rather than a continuous layer. It appears that this rock forms a single marker unit, however it is possible, due to limited exposure down section, that there may be more than one layer. Near surface, this rock is characterized by loose, yellow, sandy debris and where fresh surfaces are available the rock is olive green. Locally, the bottom contact of this unit is highly irregular. Individual clasts are less than four millimetres in size and typically less than 0.5 to 2 millimetres in size. Precious opal is commonly found within this unit and in matrix-supported lahar immediately above or below it.

Matrix-supported lahar is characterised by a yellow matrix which makes up 10 to 25 percent of the rock. The composition of the sandy matrix is identical to that of the ash to lapilli tuff. Clasts are subrounded to subangular, 2 centimetres to 1 metre in diameter and typically 5 to 10 centimetres across. Clasts consist mainly of massive or vesicular basalt and scoria in various proportions. The colour of the clasts varies from beige to medium or dark grey to purple.

Clast or coarse matrix-supported lahar is more altered or weathered than the previous unit and has a red to orange matrix. The matrix is light red-brown or salmon pink in zones where white zeolite is abundant. Typically, the matrix forms less than 10 percent of the rock. In some instances, small clasts (<3 cm) form the matrix between coarse fragments that are 5 centimetres to 1 metre in diameter. In some areas, chabazite and other zeolites (probably heulandite and stilbite), completely fill vesicles and fractures and locally, zeolites are a major component of the matrix. This unit only contains agate or common or precious opal where zeolites are absent.

Scoriaceous, strongly oxidized, red to purplish, clast-supported lahar or flow top breccia outcrops in the northeast corner of the study area (Figure 2). Due to the flat, rubbly nature of the outcrops, low relief and similarity of clasts, it is not possible to determine if this unit is a lahar or flow top breccia. Over 80 percent of the clasts are scoriaceous, typically ½ to 3 centimetres in diameter and red in colour. However, pumice fragments may be as much as 60 centimetres in diameter. Twenty to eighty percent of the rock is void space and is not known to contain opal or the zeolites chabzite, heulandite or clinoptilolite. However, loose pieces of agate were found on several outcrops.

Basalt is dark green to black on fresh surfaces and medium green or beige-brown on altered surfaces. It is mostly massive but, in some places, moderately vesicular and more altered near the tops of flows or sills. Mafic phenocrysts are typically less than 3 millimetres in size and form less then 8 percent of the rock. Outcrops of the massive variety are characterized by flat polished surfaces, except where it coincides with breaks in slope and then is blocky to angular. Because of the flat nature of basalt outcrops, it is often difficult to determine if it forms sills, dikes or flows. This unit normally does not contain any opal. However, in one outcrop near the Caramel pit, a mafic dike contains rare opal fracture fillings. This shows that some dikes post-date lahar flows and predate opal mineralization. In some areas, stretched vesicles are filled by radiating zeolite crystals that may be thompsonite.

Cross Sections

Sections of the Caramel and Blue Bird pits are illustrated on Figures 3 and 4 respectively and located on Figure 2. They show the detailed geology in the pits and illustrate the subhorizontal to shallow dipping aspect of the lahar units. They also illustrate the relationship between individual lahar flows and the enclosed ash to lapilli tuff. In the Caramel pit, the oldest unit appears to be coarse, matrix supported, opal-bearing lahar, with a very irregular upper contact. This is overlain by centimetre-scale, bedded tuff, which is, in turn, overlain by another coarse, matrix-supported, opal-bearing lahar. Above that is a dark green to black lava flow, massive near its base and very vesicular near its top. The vesicles are elongate and filled with common opal or agate. This flow is overlain by a yellow, matrix supported lahar. In the Bluebird pit, reworked ash to lapilli tuff is discontinuous and appears to have been eroded by the overlying lahar flow. The mud seams in the pit face (Figure 4) consist of very fine-grained layers of soft material, probably a mix of clay and feldspar, ½ to 5 centimetres thick. In the Bluebird and Caramel pits, opal is found immediately above, below and within the ash to lapilli tuff. It is important to note that the ash to lapilli tuff occurs in all precious opal bearing pits.

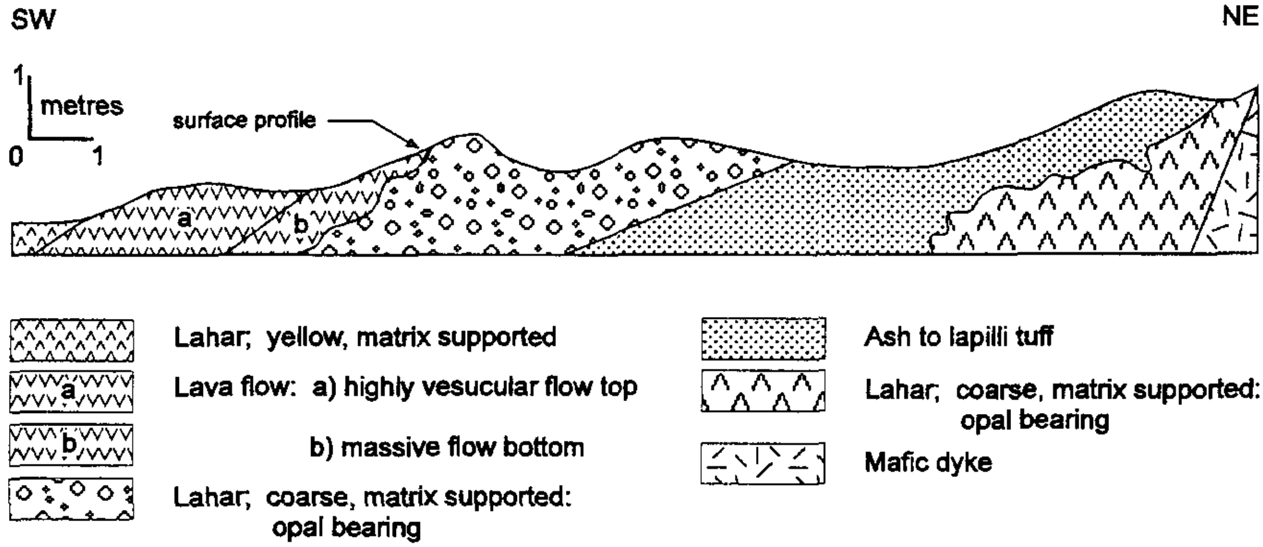

Figure 3. Cross section of the Caramel Pit, looking northwest. For location see Figure 2.

MINERALIZATION

Precious opal occurs as open space fillings, mainly within fractures, voids and vesicles. Other fracture fill minerals at the Klinker deposit are agate, non-precious facet-grade opal, common opal, quartz, celadonite, amorphous manganese oxides, clinoptilolite, heulandite, stilbite, clays and rarely, calcite. Non-precious, facet-grade opal is typically orange and honey coloured, similar to Mexican "fire opal". Common opals occur as transparent, translucent and opaque types in white, honey, brown, amber, orange and grey colours. Quartz can occur as small, inward facing, terminated crystals within vugs. X-ray diffraction analysis reported by Awram (1996) notes that kutnahorite and saponite co-exist with opal. Opal from the Klinker property is classified as opal-CT, using Jones and Segnit's (1971) grade classification (Awram, 1996). Most stones from deposits with precious and common opal are classified as opal-A (Frye, 1981). Detailed studies of opal microstructure are underway to confirm and refine Awram's findings.

CONTROLS ON OPAL DISTRIBUTION

Mineralogical Zoning

The first and most readily apparent control on opal distribution is stratigraphy and rock porosity. As previously mentioned, opal occurs within ash to lapilli tuff and immediately adjacent matrix-supported lahar. However, at the scale of the property there are also mineralogical controls. Opal and agate have a complex relationship with zeolites. They do not exist in zeolite-rich zones that contain chabazite, the most abundant, heulandide, clinoptilolite and stilbite. These are the most significant vesicle and fracture fillings and matrix

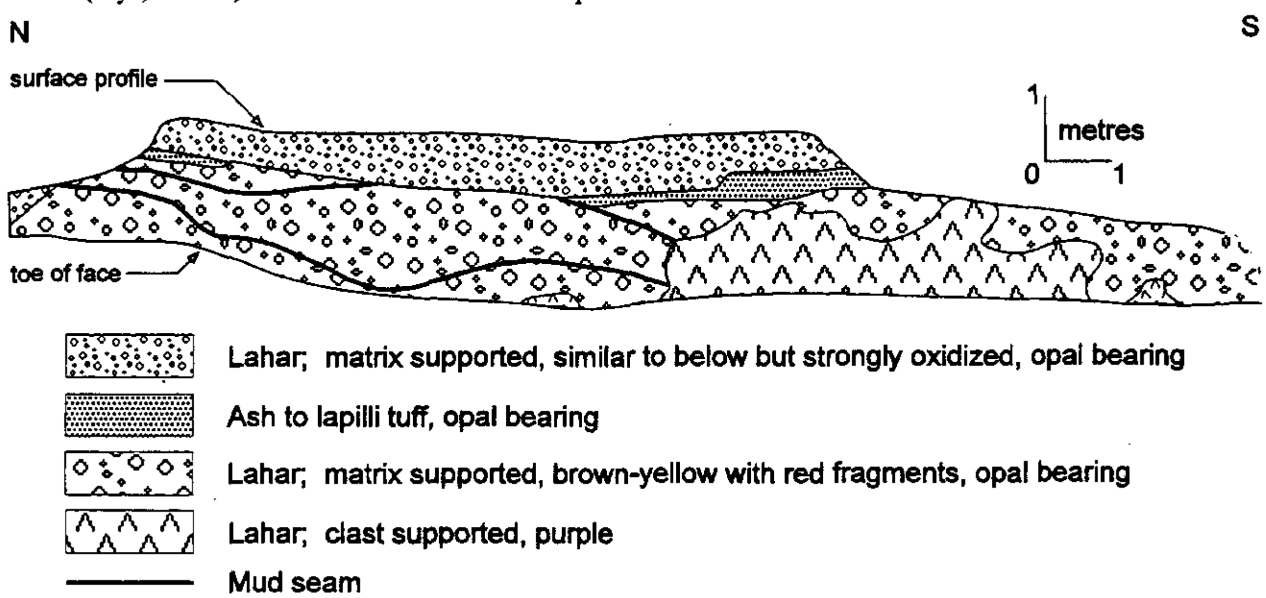

Figure 4. Cross section of the Blue Bird Pit, looking southeast. For location see Figure 2.

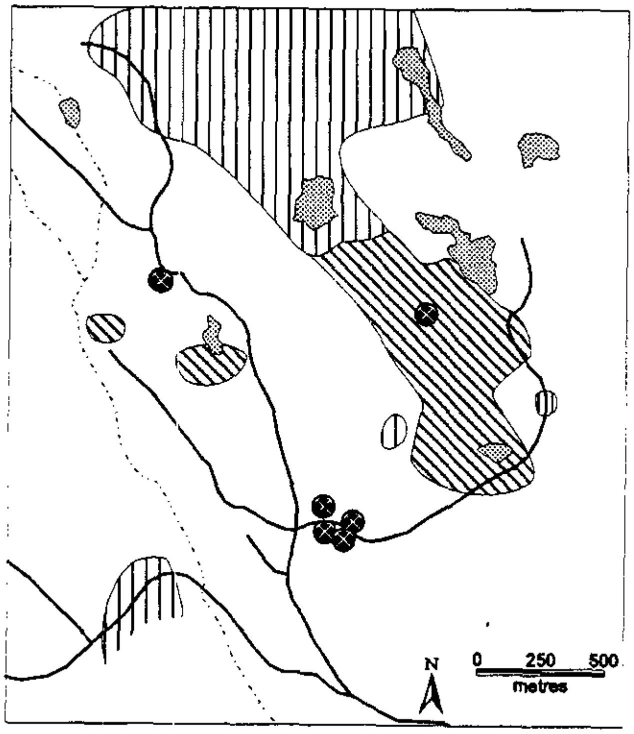

Figure 5. White zeolite-bearing zone (vertical lines) and yellow-sugar coating zone (angle lines); Klinker area.

cement in the north central part of the map area (Figure 5). Opal and agate occur where the zeolite-rich fillings give way to a yellow, sugary coating in fractures and vesicles, towards the southeast (Figure 5). X-ray diffraction patterns of this yellow coating yield weak peaks for tridymite with minor clinoptilolite(?). This coincides broadly with the change of red, strongly oxidized coarse matrix-supported lahar to yellow, fine-grained matrix-supported lahar. The yellow, sugary coating coexists with agate and possibly opal in the east central part of the map area. The only exception to the mutually exclusive relationship of white zeolites and silica is in the Caramel extension zone. There the *subhorizontal, undulating contact between two distinct* lahar flows parallels the current erosional surface. It may be that one flow contains agate, common and precious opal, while the other flow contains white zeolite-filled vesicles.

Another *major mineralogical control* is that opal occurs only within broad areas of agate mineralization and precious opal only in small areas within common opal mineralization (Figure 6). Agate has the widest distribution, forming a northwest trending belt. White, opaque common opal, brown or honey opal, transparent opal and precious opal occupy successively smaller, more restricted areas. Precious opal is known to occur at only a few locations (Figure 6). A similar range in mineralogy exists in individual fractures. Some are filled only by agate, by agate and common opal, by common opal and transparent common opal and finally by non precious orange, honey or yellow facet-grade transparent opal and precious opal. In general, agate and precious opal do not coexist in a given fracture without the presence of one or both of common opal and common transparent facet-grade opal.

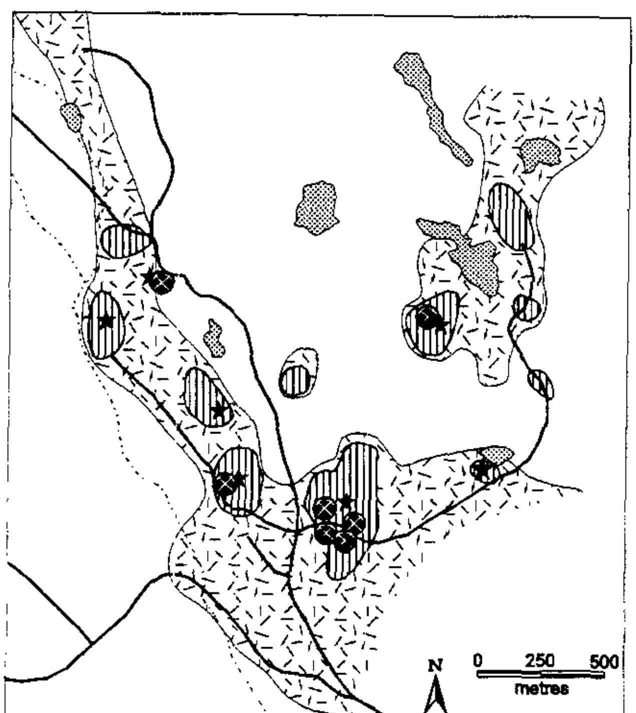

Figure 6. Distribution of agate (random lines), common opal (vertical lines) and non-precious facet-grade opal and precious opal (stars); Klinker deposit area.

Structural Controls

Most of the precious opal on the property occurs as vesicle and fracture fillings. Consequently, the *distribution and orientation of fractures is important*. The orientation of the fractures is summarized on comparative stereographic plots (Figure 7). Most data comes from the Discovery, Blue Bird, Caramel and Caramel Extension pits because intense weathering makes acquisition of structural data elsewhere difficult. Figure 7a indicates most of the fractures in the Klinker area are steeply dipping to subvertical and strike 170°, regardless of fracture fillings. Figure 7b indicates that the same pattern holds for fractures filled by silica minerals, agate, common and precious opals; there are two other less pronounced orientations at 073° and 035°. Figure 7c shows similar orientations for precious and transparent common opal filled fractures with another subset at 060°, based on very limited data. In summary, there is no obvious statistical correlation between fracture orientations and mineral fillings. The main fracture set is roughly 170°, but minor subsets may be important. The 170° preferred orientation coincides the major lineaments that may have acted as solution channels and extend beyond the property boundaries. These lineaments were detected by air-photo interpretation by R. Yorke-Hardy and confirmed by Penner and Mollard (1996). Both the mineralogical and structural findings can be used as exploration guides on the property, but it is not known if it can be applied beyond there.

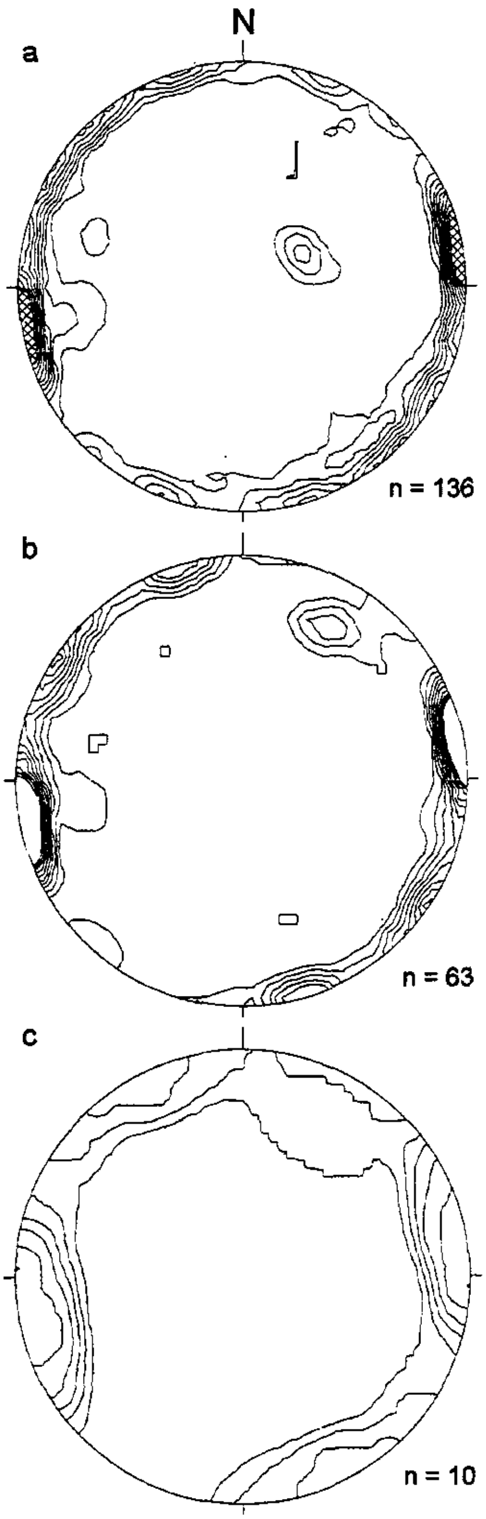

Figure 7. Preferred orientations of poles to fracture planes sorted by fracture fillings: a) all fractures; b) fractures with silica filling only; c) fractures filled by facet-grade and precious opal. Lower hemisphere plot. n = number of poles. Contours are 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 times unity. Cross-hatching in areas greater than 10 times unity. Comparative plots made using the method of Starkey (1970, 1977, 1993).

SUMMARY

The most significant findings of our fieldwork are the mineralogical guides to the potential distribution of precious opal at the property. Precious opal mineralization occurs within ash to lapilli tuff and adjacent lahar units and is surrounded by larger zones that contain agate and common opal. Opal mineralization does not occur within lahar that contains white zeolite fracture and vesicle fillings or matrix cement. There is no preferred strucutral control to opal mineralization. Rock types are divided into five major lithologies, including matrix and clast-supported lahars, scoriaceous lahar or flow top breccia, ash to lapilli tuff and lava flows or dikes and sills. We have established that ash to lapilli tuff overlying the opal-bearing lahar sequence is of mid-Miocene age and is substantially younger than previously believed. Opal-bearing lahars are probably of the same age, but if they belong to the Dewdrop Flats Formation, as postulated by Read (1996a), one would expect a major unconformity between the opal-bearing sediments and overlying mid-Miocene, partly consolidated tuffaceous sediments.

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NEW SPLITSTONE AND OPAL OCCURRENCES, NIPPLE MOUNTAIN, BEAVERDELL AREA (82E/11E)

By B.N. Church, P.Eng. and Z.D. Hora, P.Geol.

KEYWORDS: Industrial minerals, splitstone, flagstone, ashlar, opal, Nipple Mountain, Beaverdell area.

INTRODUCTION

Nipple Mountain is located 35 kilometres southeast of Kelowna at latitude 49°36.2' north, longitude 119°07.8' west (Figure 1). Access is from the Dale Creek road, about 16 kilometres south of the main forest access road that connects Idabel Lake to Highway 33.

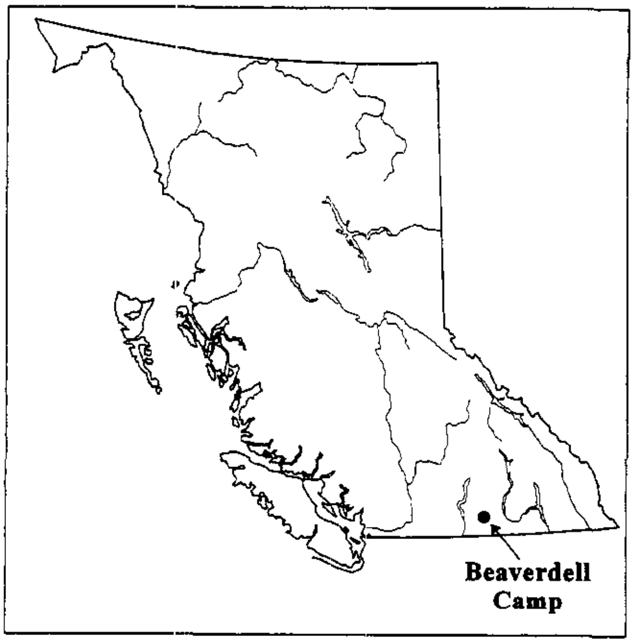

Figure 1. Location map of the Nipple Mountain area in the Beaverdell Mining Camp

This report describes new opal and splitstone localities on Nipple Mountain in the northwest part of the Beaverdell mining camp. The area was first mapped in detail by Reinecke (1915) and visited by the author in September, 1996.

The Beaverdell camp is centred on a number of silver, gold and copper prospects discovered in 1897 and a few rich veins of silver-lead ore mined from 1913 to 1991. Most of this mineralization is associated with the Westkettle quartz diorite that is believed to be related to the Nelson plutonic complex of Jurassic age. Until recently no mineral localities were identified in the surrounding Tertiary rocks.

In 1995, Don Sandberg of Kelowna discovered opal on the upper slopes of Nipple Mountain and splitstone outcrops in the Tertiary rocks on the flanks of Nipple Mountain underlying the Queen and Glory claims.

Interest in opal occurrences in British Columbia has increased significantly since 1993 when the Klinker deposit was discovered near McGregor Creek, northwest of Vernon. Other opal occurrences are known in the Kamloops, Salmon Arm, Spences Bridge, Keremeos and Kelowna areas (Read, 1995, and Church, 1996).

Flagstone and ashlar (splitstone) products are a significant part of the provincial dimension stone industry. Annually, 500 to 1000 tonnes of flagstone are produced in British Columbia and sold throughout western Canada. In the Kootenay area of British Columbia, the Hamill micaeous quartzite (Cambrian) is quarried for flagstone on Porcupine Creek, 17.5 kilometres northeast of Salmo. The quartzite is sold locally and used in building facings and for various other decorative and architectural purposes (Bowels, 1960). Also, granite is split into 'ashlar' blocks and slabs by several producers in the Vancouver area and used locally for masonary and facings on residential and commerical buildings.

The term 'splitstone', as used in this report, is a general term for rocks that manifest a platy habit resulting from primary or secondary structures, such as bedding, flow banding or cleavage. Unlike the Hamill quartzite, the characteristic banding and fabric of the Nipple Mountain volcanic rocks is non-sedimentary in origin. Volcanic splitstone is lighter weight and less dense than quartzite, however, quartzite flagstone tends to have greater strength because of recrystallization due to metamorphism.

GEOLOGICAL SETTING

The Tertiary rocks of Beaverdell area occur principally on Nipple Mountain and on several peaks and summits to the east and southeast. These rocks are mostly volcanic in origin and comprise Reinecke's 'Nipple Mountain Series' consisting of dacite, andesite, trachyte and basalt lavas and breccias. The Marron Formation (Eocene), consisting of brown andesites and light coloured trachytic lavas, is best developed on Wallace Mountain, where the volcanics are intruded by Chilcotin basalt dikes, and underlain by Kettle River (Eocene) sandstones and conglomerates. The Chilcotin basalt (Miocene-Pliocene) is uppermost in the stratigraphic sequence and consists of columnar lava flows that form small outliers on China Butte and in the Lassie Lake and Cup Lake area.

The volcanic rocks on Nipple Mountain are mostly light grey coloured, buff, and mauve dacites and dacitic andesites. The unit includes breccias and massive lava flows. In thin section, feldspar is the chief mineral and is accompanied by fine grained matrix and accessory quartz, biotite and/or amphibole. In places the dacite flows split into narrow bands, sometimes only a few centimetres thick. In polished sections, the bands are thin and closely spaced (several per centimetre). Flat vesicles lie with their longer directions parallel to the bands in the direction of flow; dips range from vertical to less than 20 degrees. The rocks are generally fresh, but may be silicified and clay altered along fissures, and rusted at surface.

The Nipple Mountain series is about 1300 m thick and rests directly on the Westkettle quartz diorite and the Anarchist greenstone - metasedimentary complex (Permian / Triassic). According to Reinecke (1915), the lava sequence has been folded into a syncline that pitches southwest. Although there is no direct evidence of major faulting, the north-trending elongation of the Nipple Mountain Tertiary outlier suggests some horst or graben control trending subparallel to the Kettle River extension of the Toroda Creek graben (Tempelman-Kluit, 1989).

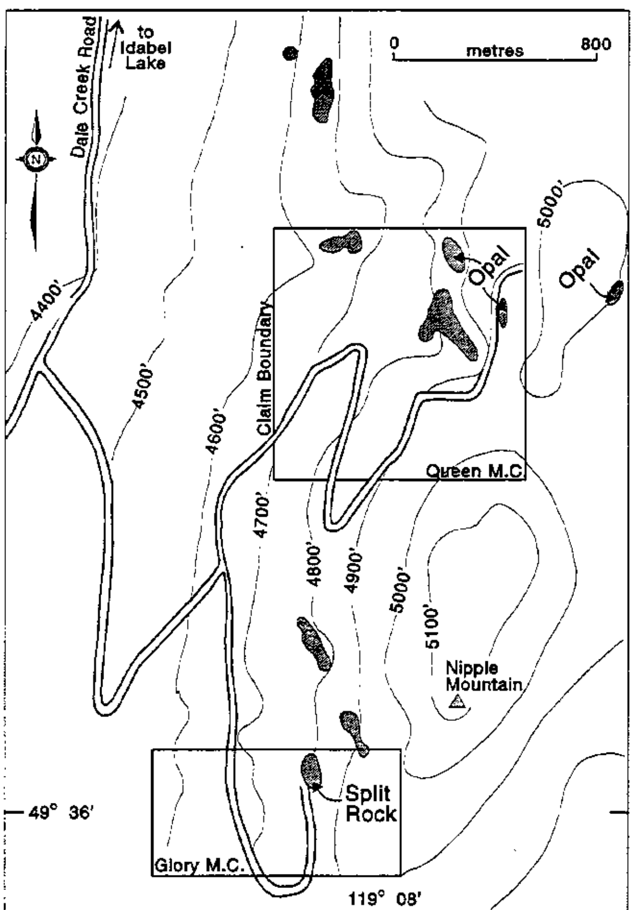

Figure 2. Nipple Mountain map-area; outcrrop areas (dacitic rocks) shown by stippled pattern.

The original lava flows were limited in extent - especially the viscous dacitic lava. Consequently lateral correlation of these rocks across the map area is uncertain. An Eocene age for the Nipple Mountain volcanic suite is indicated by Tempelman-Kluit (1989), although there is no firm correlation with the Marron Formation. Possibly, the Nipple Mountain dacite is source for felsic volcanic clasts in the nearby Kettle River Formation (Church, 1996). This is consistent with evidence suggesting the Nipple Mountain volcanics and the Kettle River Formation are both basal Tertiary units that rest unconformably on older rocks, such as the Anarchist Group.

NIPPLE MOUNTAIN SPLITSTONE (MINFILE 082ENW109)

Splitstone outcrops on the Glory claims 1500 m east of the Dale Creek road on the west slope of Nipple Mountain (Fig. 2). At this locality, broadly jointed dacite is exposed in a 150 metre long, northerly-trending cut on a logging road. The dacite is flow banded, dips gently westerly, and is intersected by two sets of widely divergent, steeply-dipping cross joints. Blocks of dacite up to 0.5 metres across can be readily levered from the cut face, rotated, then split with a mason's chisel into slabs 3 to 5 cm thick (Photo 1). The splits occur on clay

Photo 1. Don Sandberg splitting flow banded dacite, Nipple Mountain.

partings and planar concentrations of gas cavities. Surfaces of the slabs range from finely rippled and flat to grooved with gas cavities. Some slabs are hacky and somewhat undular. The weathered surface colour ranges from pale mauve to buff; less commonly, the rock is light rusty colour with minor manganese oxide stain. The natural outcrops and road cuts have fresh-looking surfaces which appear to be resistant to weathering.

Several truck loads of this splitstone have been shipped to Kelowna by Don Sandberg for personal use and test marketing with building supply stores as slabs for garden walkways and patio construction. The advantages of the product are durability, pleasant pastel colours and good surface traction for outdoor use. The large potential resource of the rock on Nipple Mountain could supply the major population centres in the Okanagan Valley.

NIPPLE MOUNTAIN OPAL (MINFILE 082ENW110)

Opal was first discovered by Don Sandberg in a logging road cut in the area now covered by the Queen claims on the ridge extending north from Nipple Mountain, 1500 metres east of the Dale Creek road (Figure 2). Subsequently other localities were located, on a rock bluff 150 metres to the northwest of the road on the west slope of the ridge, and another locality 400 metres to the east on the east side of ridge.

At the three localities opal occurs in flow banded dacite filling cavities in the bands, in breccia pods and on cross joints. The opal occurrences associated with banding are commonly almond-shaped lenses 1 to 3 cm in diameter, roughly elongated in the direction of flow (Photo 2). The opal on cross-fractures includes translucent coatings a few millimetres thick, covering areas up to 0.5 m^2 on the walls of the fissures.

The largest opals occur on the east side of the ridge. These weigh as much as 23 kg (opal plus some rock inclusions) and fill breccia cavities several centimetres thick. The opal is commonly waxy and amber coloured but it can be flesh, peach, honey-hues; less commonly grey and rarely green in colour. Fire opal, containing a rainbow of colours, such as described at the famous African, Mexican and Australian localites (Downing, 1996) has not been found. However, some of the watery fissure-lining opal displays a weak play of colours.

In some instances white plume opal is associated with quartz and chalcedony that forms variegated horizontal or concentric bands on cavity floors or walls. Chalcedony is believed to form within gas cavities of volcanic host rocks when microcrystalline chalcedony fibres nucleate on vug walls and grow inward (O'Donoghue, 1983). Oscillatory zoning and iris banding, as seen in thin section, are the result of variations in silica concentrations in solutions at the tips of the growing chalcedonic fibers. This can result in smooth and regular or botryoidal surfaces parallel to the banding (Heaney and Davis, 1995; Church, 1996).

A possible source of the silica-rich solutions is the host Nipple Mountain volcanics. Analyses of these rocks shows marked excess silica based on norm calculations. For example, a fresh dacite sample from the Glory claims contains 74.06% SiO_2, 0.24% TiO_2, 14.13% Al_2O_3, 2.00% Fe_2O_3, 0.02% MnO, 0.49% MgO 1.76% CaO, 3.65% Na_2O and 3.65% K_2O (major oxides recast to 100) that yields 34.3% free silica/quartz (CIPW norm). Thin sections reveal an estimated 7% plagioclase phenocrysts, 1% amphibole microlites and 1% opaque minerals in a glassy and devitrified fine grained matrix, leaving a large amount of unaccounted (excess) silica. It is concluded that part of the excess silica, accompanied by fluids and gases, moved from the dacite lava to gas cavities and fracture openings, during the original magma cooling process, to form the opal, quartz and chalcedonic fillings.

Photo 2. Opal lenses parallel to flow banding, Nipple Mountain dacite.

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AMBER IN BRITISH COLUMBIA

By Andrew Legun

KEYWORDS: Amber resin, British Columbia, Tertiary basins

INTRODUCTION

Amber is best known for the excellent preservation of fossil life. The public interest in amber is heightened by the success of the movie Jurassic Park. In the movie dinosaurs were cloned from dinosaur DNA extracted from the blood of mosquitoes which had become trapped in tree resin. Though this degree of preservation is unlikely, fragments of fossil DNA have in fact been successfully recovered from insect remains in amber. These remains up to 125 million years old attest to some of the unique qualities of this substance.

Amber resin represents fossil resins and waxy substances secreted by paleoflora (Broughton, 1974). Recent to modern resins are termed gums and copals. For example Kauri gum is a type of copal found in New Zealand. The gum is the hardened resin of the Kauri pine, Agathis australis.

Historically amber was collected and valued as an organic gemstone. Today amber in Europe is often heated, melted and pressed, or even mixed with synthetic material as a precursor to jewelry making. Copal was collected in New Zealand by the Maori and used for fuel, insecticide, tattooing, teeth cleaning, and as an antiseptic. Later immigrants mined it as a base for varnish. Today both amber and copal have potential to be used in an expanded specialty market within the ink, rubber, paint and thermoplastic industries.

Plant remains and pollen are associated with amber. These remains include fossil leaves and pollen of the resin-producing trees. In B.C. due to climatic changes most of these resin- producing trees no longer grow here (see Appendix).

Amber is associated with coal. In the United States approximately 180000 tonnes of resin in coal with a value of 200 million U.S. dollars is combusted yearly in electric power generation. The potential value of the resin is much greater than that of the associated coal (Yu *et al.*, 1991).

Descriptions of the geologic setting and occurrences of amber in B.C. are scattered in numerous publications. The following notes attempt to summarise some of this data and put it in context.

Amber resin and Coal Resinite

Amber resin should be distinguished from resinite described in higher rank bituminous coal. Resinite is chemically and physically distinct from amber resin. It is dark, like its opaque coal host, and not easily distinguished with the naked eye. It is a secondary product resulting from geochemical changes in the coal, and is intimately associated with other coal macerals.

OCCURRENCE

Amber resin in British Columbia is most commonly found as small nodules and beads in low rank coals (brown coal and lignite) within limnic Tertiary basins. It has also been reported in carbonaceous shales, paleosols and siltstones associated with these coals. Amber in Alberta is collected from tailings from coals of the Late Cretaceous Foremost Formation (Brown and Pike, 1990). The Alberta coal swamps developed in a delta-lagoonal environment behind a barrier bar. Interestingly this amber is associated with dinosaur remains (Poinar & Poinar, 1994).

Amber is often retrieved from both fresh water and marine beach placers. In Manitoba Late Cretaceous amber was found in beach sediments of Cedar Lake, opposite the mouth of the Saskatchewan River. It extended along two kilometres of shoreline and to a depth of a metre. The locality is now flooded. The most famous and abundant amber placers are along the Baltic coast where amber of Eocene age is found (see Baltic amber below).

In the Dominican republic amber of Oligocene to Eocene age is mined from "veins" in sediment and blue soil. The geologic setting of these "veins" is not clear in Poinar & Poinar (ibid.). Amber there can occur in a variety of colors, even pink and blue, but commonly is yellow to red.

In New Zealand Kauri gum was found as lumps in soil, in swampy depressions, and in peat basins. Lumps (the largest found was 185 pounds) were dug out by hand. Dating of kauri wood associated with copal provides a range of 850 to 45000 BP for these deposits (Poinar & Poinar, 1994).

CHEMICAL PROPERTIES

Resins are very complex mixtures of mono-, sequi-, di- and tri-terpenoids. The carbon skeleton unit of these terpenoids is called isoprene. Different forms of terpenes may result from the polymerisation of isoprene (3,4, or 6 unit). Most fossil and recent resins discussed in the literature are dominated by diterpenoids (C20). In addition to terpenoids, alcohols, aldehydes, esters, and resenes may be present to a lesser degree (Broughton, 1974). During diagenesis the more volatile fraction is liberated and the non-volatile fraction becomes fossilised. Relatively modern resins like the New Zealand Kauri gums, retain appreciable volatiles.

PHYSICAL PROPERTIES

Over 2500 years ago, Thales of Miletos discovered that when amber was rubbed against cloth, sparks were produced and then the amber attracted husks and small wooden splinters. This force was given the name electricity after the Greek word electron which means amber. Amber resin is recognised by its hardness, brittleness, amorphous nature, conchoidal fracture, and lustrous translucent color.

Amber is very close to the density of seawater. In saturated salt water it floats, and this method has been used to separate amber in some deposits.

Amber from coastal erosion is transported along the shores of all the countries around the southern Baltic sea. When the storms begin in the autumn, the local people head for the beach to search for the "Gold of the North". Amber drifts on the bottom of the shallow sea, following the currents, until it comes up on the shore. It is easy to find a pebble, but rare pieces can be more than one kilogram.

Baltic amber occurs naturally in a variety of colors: white, yellow, brown, black, red, green and blue. The most common are honey-colored and milky. A small percentage is bone white, due to microscopic gas bubbles. Some amber shows layers from successive flows on already dried resin. The black and dirty brown colors are caused by a mix of resin, soil and plant fragments. The most uncommon have a tone of green or blue caused by gas or inclusions. Most true Baltic amber is milky and pale under the crust. The warm amber color occurs after it has been exposed to oxygen for about a hundred years.

Copal differs in properties from amber resin. It is a transparent champagne color and very brittle. It has a lower melting point and turns sticky if heated (and smells like fresh resin). It does not take a good polish and the crust comes back in a few years.

Copal and amber resin may or may not contain inclusions. There are almost no inclusions in the New Zealand Kauri gum or copal; unlike the very fossil-rich copal from East Africa and Columbia. Whether resin contains inclusions is dependent in part on the source of the resin. For example resin that forms below the bark of the tree is unlikely to contain inclusions.

A remarkable variety of organisms have been found embedded in amber. For example well preserved remains of wasps, termites, ants, midges, are found in deposits of Dominican amber. Inclusions in amber have included a gecko, a frog, a feather and fragments of flowers and mushrooms. The variety of inclusions and their significance is colorfully described in a recent issue of Scientific American (Grimaldi, 1996). Grimaldi notes amber resin somehow fixes tissue so that it retains its original size in spite of dehydration.

Amber Jewelry: Enhancements and Deceptions

To make amber more attractive to purchasers, today's industrial amber jewelry producers manipulate the raw amber to get the warm brown-reddish amber color, which often includes discs, called sunspangles. First the amber is made clear by putting it under pressure and heat in an autoclave together with nitrogen. After this procedure, it is put into an oven to obtain the sunspangles and the characteristic cognac color.

It is possible to melt amber pebbles and press them to bigger lumps. It then becomes harder, and less brilliant when cut. Any color can be added in this procedure. This pressed amber is still considered to be natural amber by some producers.

Since the bakelite and plastic era began early this century, fake amber jewelry has appeared in the commercial market. For example bakelite necklaces were sold in Europe in the early twenties, when amber was in fashion.

In the markets in Morocco, North and East Africa, as well as in the Middle East and India, amber-colored plastic necklaces are very common. They are often sold as antique trade beads. Sometimes they are old, very beautiful, large egg-yolk colored strands, but they are still plastic, and tend to be heavier than amber.

The original trade beads, which were distributed from northern Europe around 300 years ago, are rare. It is difficult to see the difference with fake amber but there are easy tests to distinguish amber and plastic beads. If a heated needle is put into the hole of a bead, the smell of burned plastic immediately appears. Baltic amber smells like pine resin. Also plastic is elastic, and the needle will get stuck in the material, but true amber is brittle and small pieces will chip off under the pressure.

BRITISH COLUMBIA AMBER OCCURRENCES BY AGE

Late Eocene

BOWRON

The Bowron basin, about 20 km long and 2.5 km. wide, extends along the Bowron River, 50 km. east of Prince George. It contains coal measures toward the base of 700 metres of a poorly exposed unnamed unit comprising sandstone, conglomerate, carbonaceous shale, siltstone and mudstone. The sequence is interpreted as a lacustrine mudstone facies overlain by coarser sediments representing alluvial fans prograding (upward coarsening) into the basin. Drilling has delineated two coal seams of which the lower generally consists of up to 15 metres of interbedded coal and rock, occasionally represented by a single seam to 5 metres thick. This seam lies 50 to 100 metres above basement. The upper coal zone is within 50 metres of the lower. It is thinner and discontinuous. The coal is high volatile B and C bituminous. A high content of amber occurs in the seams, both in outcrop along the Bowron River and in drill core. An average content of 1.2% amber resin is reported in coal assessment report 787 (Norco Resources, 1982) with values to 2.5% in the commercial (i.e. lower?)seam. Values to 4% are reported by Versoza (1981). Matheson and Sadre (1991) noted that amber occurs not only in the coal but also in adjacent podzols and carbonaceous shales.

The clear amber colored resin which is up to 1.5 cm. in diameter, is normally elongate and occurs as flattened blebs. It is reported to have a high melting point but its chemical characteristics are not well known.

According to Sweet (personal communication 1996) a late Eocene age is indicated by palynomorphs within the coal measures.

Poorly preserved plant remains include Pinus and Metasequoia (Holland, 1949).

QUESNEL BASIN

The narrow Quesnel basin, about 40 km. long and 4 km. wide extends along the Fraser River near the town of Quesnel. It contains about 560 metres of poorly consolidated sediments within a fault trough. The Lower Fraser River Formation consists of 360 metres of mudstone, silty mudstone, with minor sandstone, conglomerate and coal ascribed to a fluvial-limnic-peat swamp environment.

The 1930 report of the Minister of Mines notes that seams in the area have a high resin content. Subsequent reporting provides little detail. Two rock core logs from British Columbia Ministry of Highways cable tool drilling (in McCullough, 1980) indicate inclusions of amber with lignite fragments in dark brown shale (particularly RMH6). Amber beads are noted in coal intersections (graphic log of G.S.C. BH Q1, Long and Graham, 1993). Goodarzi and MacFarlane (1991) apparently collected relatively large pieces of pale-yellow transparent resin from this formation.

The lower Fraser Creek Formation is dated as Late Eocene based on a reassignment of mammal data previously considered to be Oligocene (Art Sweet, 1996, personal communication). The spore and pollen assemblage indicates a flora and climate comparable to central China and southeastern United States (Rouse and Matthews, 1979).

HAT CREEK

Hat Creek valley, located 20 km. west of Cache Creek, is underlain by Cretaceous and Eocene sediments. Eocene Kamloops Group rocks consist of a basal volcanic sequence overlain by 1600 metres of fluvial-lacustrine sediments. The coal-bearing Hat Creek member lies 400 metres above the base of the fluvio-lacustrine sequence. It consists of coal, mudstone, minor siltstone and coarser beds. On average 65% of the formation is coal, representing a vast accumulation of organic material within a long lived shallow lake in a subsiding basin. About 350-550 m. of sub bituminous to lignitic coal have been defined in A zone of Deposit One by B.C. Hydro. Within 'A' zone amber occurs in at least 3 coal layers and in associated carbonaceous shale.

Hand-picked samples of the resin were studied to determine the influence of weathering by Goodarzi & MacFarlane (1991). They are described as yellow to yellow-orange to black and white lumps (table 1, p.286). Campbell *et al.* (1977) noted that "relatively continuous horizons of resin beads and petrified wood fragments are common in the coal". McKay (1926) also noted "Parts of the coal are characterised by small lenses, globules and irregularly shaped masses of light yellow, semi-transparent, fossilised amber". The percentage of amber in the coal interval is unknown.

Dominant plant remains in Hat Creek coal are of Metasequoia and Glytostrobus (Goodarzi and Gentzis, 1987). Hat Creek is provisionally dated as Late Eocene based on 82 palynology samples (Read, 1990).

Early to Middle Eocene

TULAMEEN (COALMONT)

The Tulameen basin, 20 kilometres northwest of Princeton, is approximately 15 square kilometres in surface area and oval shaped. A truncated synclinal structure preserves 790 metres of interbedded sandstone, siltstone, mudstone, coal and local tuff layers. These beds are assigned to the fluvial-lacustrine Allenby Formation. The lower member consists of 110 metres of basal sedimentary breccia, sandstone and shale, and the upper unit consists of 590 metres of quartzose sandstone and conglomerate with minor shale. The 90 metre medial section is dominated by interbedded mudstone and coal.

rock that may have a pegmatitic affinity. Work is in progress to better evaluate the potential of the 76 zone of the Empress deposit and overlying overburden as a source of sapphire and to explain the origin of the corundum.

Andalusite-pyrophyllite

The andalusite crystals from the Empress deposit have relatively low iron content (Table 2) and could satisfy current refractory specifications. However the andalusite-bearing rocks are generally too fine-grained to be processed into high-grade concentrates that could compete with South African material.

A large number of drill core samples were analyzed for metallic elements (Lambert, 1988, 1989, 1991a and b), but little major element data is available from the property. Table 3 shows the composition of andalusite-pyrophyllite-muscovite-bearing rocks compiled from Madeisky (1994). Unfortunately, these analyses are not supported by detailed petrographic or X-ray diffraction studies. The table indicates that these rocks are relatively rich in alumina, low in silica and that there are large variations in the concentrations of other major oxides. Typical properties of American and South Korean refractory and whiteware grade pyrophyllite are given in Table 4 for comparison. Most of the rocks from the Empress deposit appear to be high in Fe_2O_3, CaO, Na_2O and K_2O. Unfortunately, detailed sample and petrographic descriptions were not done, so it is not known if the high Fe_2O_3 content is due to the presence of sulphides and iron oxides or other sources. It is assumed that the relatively high CaO, Na_2O and K_2O contents are due to the presence of feldspar and mica. Although the andalusite-pyrophyllite bearing rocks from the Empress deposit do not meet current specifications for traditional North American refractory or ceramic applications, they may have industrial applications in domains with less stringent specifications. Two samples analysed by McMillan (1976) (Table 3) have similar compositions to andalusite-pyrophyllite products currently in the market place but are slightly high in TiO_2. Because pyrophyllite has a low unit value, \$20.00 to \$300.00 per tonne FOB depending on grade and degree of processing, it is important to consider transportation costs to markets.

Rare Earth Minerals

A rare reddish brown, rare earth element (REE) - bearing mineral, with brownish irradiation halos up to 0.5 centimetres in radius occurs within plagioclase-pyrophyllite-andalusite-bearing lithologies. Its distribution is erratic and it is present in trace amounts. This mineral was tentatively identified as bastnaesite ((Ca, La) CO_3F). A carbonate-phosphate-sulphide boulder, 30 by 30 by 25 centimetres was found by Westpine geologists near the corundum-bearing zone and probably contains rare earth elements. Furthermore, REE-bearing phosphate was described in concentrations of up to five percent with tennantite, energite, chalcopyrite and sphalerite in two main veins at the nearby Taylor-Windfall gold deposit (Price, 1986). These occurrences indicate that the area may have some exploration potential for REE's.

SUMMARY

The copper, gold and molybdenum potential of the Empress deposit was discussed by Osborne and Allen (1995). The non-metallic mineral potential of this deposit remains to be established. Corundum crystals from the Empress deposit are typically dark blue, subhedral to euhedral and a fraction of a millimetre to one centimetre in cross section. Some transparent, colourless crystals were found in overlying sediments. Coarse crystals contain numerous inclusions of pyrophyllite, but parts of them, up to several millimetres in size, are fracture and inclusion-free. The potential of this deposit as a source of corundum depends on the proportion and quality of coarse corundum crystals, their abundance and distribution either in residual soils, placers or primary host rock. Andalusite-pyrophyllite rocks may have industrial applications if produced as a by-product of metal mining, although the cost of transportation to markets may be prohibitive. Andalusite crystals within the Empress deposit area are too fine grained to be economically upgraded to compete with South African and French concentrates currently on the market. The area might also have Rare Earth element exploration potential.

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The authors thank Westpine Metals Ltd. for their co-operation and access to the property. Thanks are given to D. Lefebure, W. McMillan and V. Preto of the B.C. Geological Survey who contributed constructive comments.

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CONCLUDING REMARKS

Amber in British Columbia is more common than surmised by Mustoe (1985), both in age and location. It is doubtful however that amber of the size and quality found in the Baltic coast or Dominican Republic will be found. On the other hand the geologic setting of amber producing deposits is not well understood or documented.

No insect fossils have been observed in British Columbia amber. However insect remains are known from a number of Eocene sediments associated with plant remains, for example in the Princeton area (Handlirisch, 1910), Horsefly area: (Wilson, 1977), and Driftwood Creek: (Rouse et al., 1970). A diligent examination of known occurrences could reveal fossil bearing amber in British Columbia.

Placer amber, while unknown in British Columbia, may yet be found in beach sediments representing the margins of Eocene Lakes.

Some opportunity presents itself for small scale production of amber jewelry from pressed amber. The Tulameen amber appears to show some natural color variation that might be attractively marketed. Small scale extraction of coal and separation of amber resin for a cottage jewelry industry might be considered.

Larger scale industrial applications of amber await further studies. The amber content of Hat Creek coal should be assessed. Amber in specific basins may have particular properties that would be advantageous for specific purposes. For example the high melting point of Bowron amber may be applicable for high speed printing inks or heat resistant plastic coating. Further studies could be done on some of the traditional uses of resin and its naturopathic qualities.

ACKNOWLEDGEMENTS

Barry Ryan and Neil Church provided some inspiration as well as initial research material. George Owsiacki proved the merits of Minflie by finding references to amber even though it is not listed as a commodity. Many of the facts on Baltic amber are drawn from an internet site at the Swedish museum of amber http://www.brost.se/ .The article benefitted from reviews by Bill McMillan.

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APPENDIX

Trees Associated with Resins

In B.C. the following plant remains are typically associated with amber resin.

- Glyptostrobus: Glyptostrobus, related to the bald cypress of SE United States, is confined to China in its natural habitat. Also known as the water pine, it grows in well drained areas by lakes and rivers.
- Metasequoia: Metasequoia, the dawn redwood, was considered extinct until about 1945 when it was discovered growing in isolation in China. It is a deciduous conifer, anually shedding its needles.

In New Zealand the tree associated with Kauri gum is Agathus Australis. This tree belongs to the family Araucariaceae which today comprises two living genera Agathis and Araucaria. The well known species of the latter are the Norfolk Island pine and the monkey puzzle tree. The genus Agathis dates back to the Jurassic (175 million years) from remains in Australia. Pionar and Pionar (1994) note Agathis Australis or Kauri pine 'bears no resemblance to the pines we are used to seeing in North American forests. Kauri pines don't have needles, but thick broad leaves shaped similar to those of acacias.

Dominican amber is associated with Hymenaea protera. This fossil tree closely resembles Hymenaea verucosa now found in East Africa. These flowering trees are members of the legume family.

THE EMPRESS CU-AU-MO DEPOSIT - GEMSTONE AND INDUSTRIAL MINERALS POTENTIAL

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KEYWORDS: Gemstones, corundum, sapphire, pyrophyllite, andalusite, industrial minerals, Rare Earth elements

INTRODUCTION

This article describes the geology and industrial mineral potential of corundum, pyrophyllite and andalusite at the Empress deposit in the Taseko Lakes area (Figure 1). The Empress is a copper-gold-molybdenum porphyry deposit located 225 kilometres north of Vancouver and 50 kilometres northwest of Goldbridge and the Bralorne mining camp. Fine-grained corundum, in association with andalusite-pyrophyllite rock, was reported in several drill holes (Lambert, 1989, 1991a and b) and a boulder containing coarse corundum was found in a trench in 1990. The potential of corundum mineralization has not been previously investigated. Corundum is closely associated with andalusite/pyrophyllite-bearing rocks that may also have commercial applications.

Corundum is an alumina-rich mineral (Al_2O_3) that may be of variable color due to substitution of metal ions for Al^{3+}. It is usually grey, blue-grey, brown, yellow, green or colourless. Its gemstones are known by their colours, red for ruby and blue for sapphire. The red color is linked to Cr^{3+} content, while blue and green corundum have significant Ti^{4+}, Fe^{3+} and Fe^{2+} and in some cases V^{5+}, Co^{2+} or Ni^{2+} (Phillips and Griffen, 1981). Most corundum gemstones are produced from placer or residual deposits derived by weathering and reworking of primary deposits. Primary sapphire and ruby are formed at depth in association with intrusive rocks such as syenites, nepheline syenites and monzonites or quartz-free, "desilicated" pegmatites emplaced into ultramafic rocks or carbonates. Sometimes corundum is found as xenocrysts, from the above sources, in alkaline dikes, lava flows or diatremes that originated at depth. They may also be formed by regional or contact metamorphism of alumina-rich sediments and paleoregoliths. Primary corundum, typically not of gem quality, also has been reported in several relatively shallow porphyry or epithermal deposits by Gustafson and Hunt (1975), Lowder and Dow (1978), Brimhall (1977), Wojdak and Sinclair (1984) and Price (1986). The Empress porphyry occurrence may be of this type.

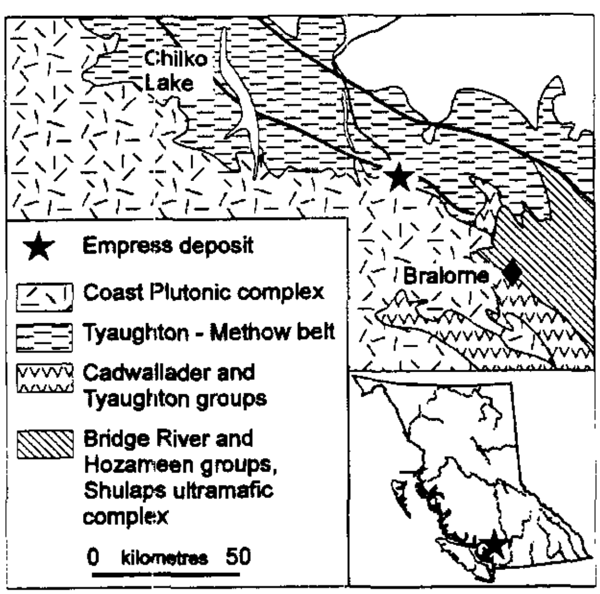

Figure 1. Location and regional setting of the Empress deposit.

Andalusite and pyrophyllite are minerals with industrial applications including refractories, whiteware, chemical and agricultural uses. Andalusite-pyrophyllite-quartz rock has been mined in the United States for ceramic applications. Since pyrophyllite is commonly associated with other minerals from which it may not be readily separated, mineral assemblages and chemical composition are important parameters that may limit or enhance a potential market from any given source. Refractory grade pyrophyllite presently sold in the United States comprises 40 to 50 percent pyrophyllite, 30 to 45 percent quartz, 5 to 15 percent kaolinite and 1 to 3 percent muscovite. Low-grade pyrophyllite-quartz rock with trace kaolinite, diaspore, muscovite, andalusite and corundum is sometimes used in ceramics, tiles, agricultural-grade pesticide carriers, fertilizer and animal feed preparations (Ciullo and Thompson, 1994).

GEOLOGICAL SETTING

The Empress deposit is located near the eastern margin of the Coast Plutonic Complex in rocks of the Tyaughton basin (Figure 1). The regional geology of the area has been described by Tipper (1978), Glover *et al.* (1986), McLaren and Rouse (1989) and Schiariazza *et al.*

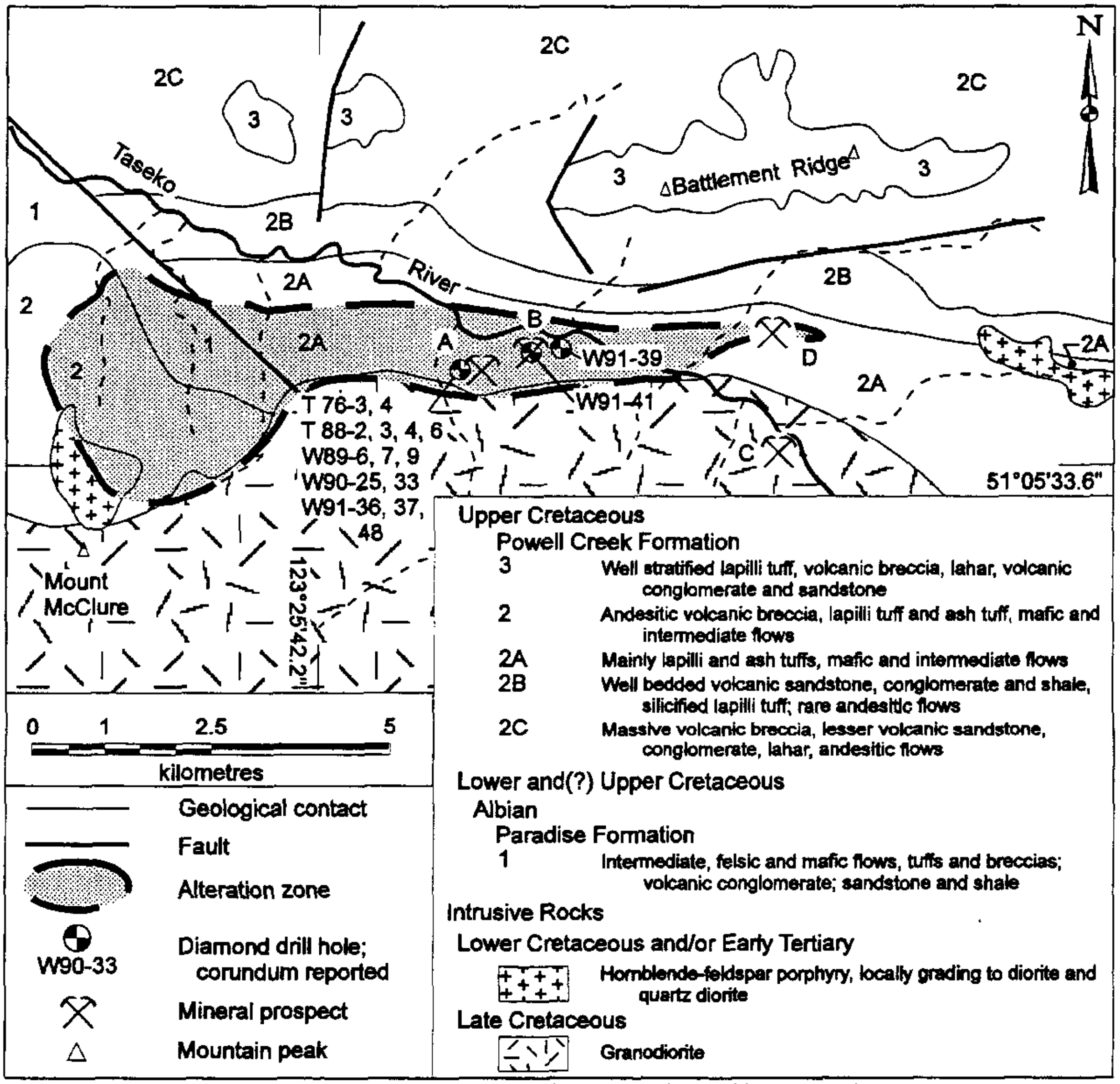

Figure 2. Geology of the Empress deposit (modified from Schiariazza *et al.*, 1993).

(in press). Rocks outcropping in the deposit area belong to the Upper Cretaceous Powell Creek and Lower to Upper(?) Cretaceous Paradise formations. The deposit is located within an alteration zone that is 11 kilometres long and up to 3 kilometres wide (Figure 2). There are substantial changes in the nature and intensity of alteration within the outlined area (McMillan, 1976; Bradford, 1985; Price, 1986). Because of the high degree of alteration and few outcrops, the nature of the protolith within the alteration zone in the Empress area is not well established. Rocks hosting the Empress deposit are believed to be mainly volcaniclastic rock and mafic to intermediate flows (McMillan, 1976; Schiariazza *et al.*, 1993). Large masses of Late Cretaceous granodiorite of the Coast Plutonic complex outcrop south of the alteration zone. Smaller intrusions of Lower Cretaceous to Early Tertiary age consist of hornblende-feldspar porphyry which locally grades into diorite and quartz diorite.

DEPOSIT GEOLOGY

The Empress deposit is in an area with very little outcrop and nearly all information was acquired from drill core. Near surface, the contact between rocks of the Powell Creek Formation and the Late Cretaceous granodiorite is nearly subvertical. Drilling indicates that it is sub-horizontal at depth, towards the Taseko River (Figure 3). Westpine Metals Ltd. geologists divide the host rocks into four alteration assemblages and one intrusive unit: quartz rock, quartz-magnetite rock, plagioclase-quartz-pyrophyllite-andalusite rock, quartz-andalusite-pyrophyllite rock and granodiorite-quartz monzonite (Osborne and Allen, 1995). These rock types are the product of alteration, in a porphyry system, of a volcanic or volcaniclastic protolith (McMillan, 1976).

Quartz rock (QR) is typically light grey and weathers brown. It consists of quartz grains (90 to 95%) that are equigranular and subrounded. It contains minor quantities of magnetite (1 to 5%) and trace amounts of pyrophyllite, clay, chlorite, carbonate, sphene, pyrite and chalcopyrite. There is no consensus on the origin of this lithology. In various areas of the property, Westpine geologists interpret QR as an altered volcanic rock and they interpreted relict planar textures as banded rhyolite and welded tuff (Lambert, 1988, 1989, 1991a and b). Other workers interpret the protolith as volcaniclastic rocks (McMillan, 1976) or altered volcaniclastic tuffs (Madiesky, 1994).

Quartz magnetite (QM) rock consists mainly of quartz and magnetite. The magnetite content varies from 5 to 70 percent by volume, but typical content varies from 10 to 20 percent. Chlorite and hematite are minor constituents. The distinction between the QM and QR units is based on the magnetite content. Magnetite occurs as interstitial grains, fracture fillings and cement. The interstitial nature of magnetite and its occurrence as fracture fillings suggests that the protolith of QM was identical to QR and that iron came in at a later stage.

The plagioclase-quartz-pyrophyllite-andalusite (PQSA) unit is very heterogeneous. It consists of several distinct alteration assemblages that are too limited in extent to be treated separately at the current scale. The most characteristic lithology of this unit is relatively coarse-grained (2 mm to 150 mm) cream-coloured, grey or white plagioclase lenses, layers or irregular masses. These masses are rarely more than a few metres in apparent thickness in drill core. At surface, large blocks

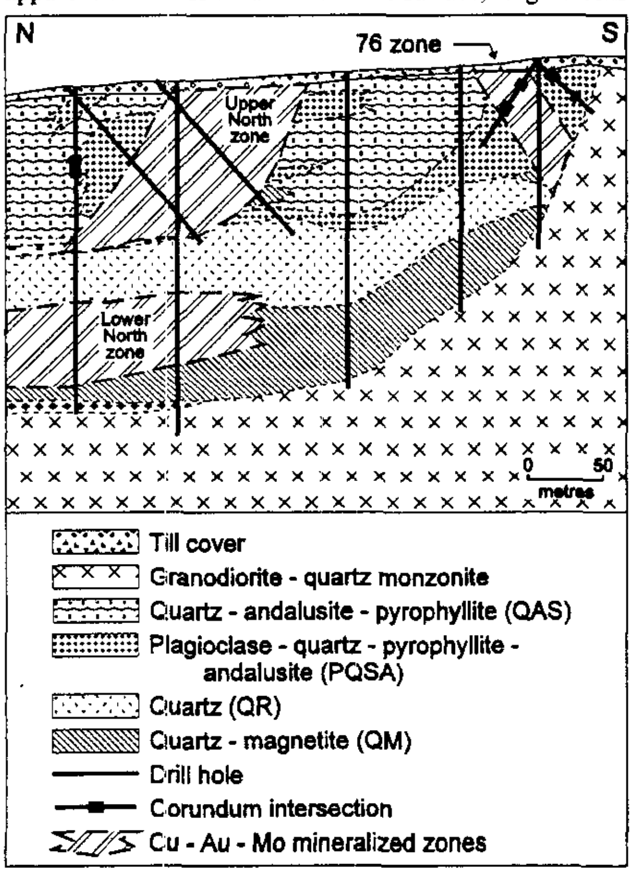

Figure 3. Cross section of the Empress deposit. For location see Figure 2; A - Empress deposit, B - East Zone, C - Buzzer occurrence, D - Taylor Windfall deposit (modified from Osborne and Allen, 1995).

of this material are several metres across. They are intimately associated with pale green, fine-grained to aphanitic zones consisting mainly of muscovite and pyrophyllite, fine sericite and andalusite-rich areas that are highly irregular in shape. The pyrophyllite-andalusite zones are typically bluish grey. Corundum, magnetite and chlorite are the most common accessory minerals. Corundum typically occurs in quartz-free zones within this rock unit.

Quartz-andalusite-pyrophyllite (QAS) *rock* is equigranular with grains less than 1 millimetre in size to aphanitic. Minor mineral constituents include magnetite, clay, chlorite and gypsum. Weathered surfaces are typically yellow stained from the weathering of pyrite and fresh surfaces are sugary and grey. Quartz-andalusite-pyrophyllite rock does not contain the coarse plagioclase that can be observed in PQSA.

Granodiorite-quartz monzonite weathers buff and is white to bluish on fresh surface. It is medium to coarse grained and equigranular. It consists of feldspar, quartz, hornblende and biotite with minor titanite. This intrusive rock is the footwall to the deposit and forms the southern limit to the deposit.

Copper-gold mineralization occurs in three areas, the Lower North, Upper North and 76 zones of the Empress deposit (Figure 3). These zones host a mineral resource of 10 004 000 tonnes grading 0.61 percent Cu and 0.789 grams per tonne Au, using a cut-off grade of 0.4 percent Cu (Osborne and Allen, 1995).

The age of mineralization was bracketed by K/Ar dating using biotite. Samples of granodiorite, the alteration zone and a post-mineral dike yielded dates of 86.7 ±2.6, 84.9 ±2.5 and 84.7 ±2.5 Ma respectively (McMillan, 1976). Chalcopyrite sometimes forms rims around corundum so it is probably older than 84.7 ±2.5 Ma.

Corundum-bearing Rocks and Assemblages

Corundum-bearing rocks were intersected in 16 drill holes. As indicated above, it is hosted within plagioclase-quartz-pyrophyllite-andalusite (PQSA) rocks as defined by Westpine Metals Ltd. geologists. However, detailed examination of corundum-bearing rocks indicates that this mineral typically is found adjacent to a light grey or pinkish, coarse-grained feldspathic rock comprised mainly of albite and strongly zoned orthoclase. This feldspar-rich rock is quartz-free and has been intersected over apparent thicknesses of a few centimetres to several metres. Typically, corundum comprises trace amounts to two percent of the rock over widths of generally 0.6 to 21 metres, with one intersection of 34 metres, most of it within andalusite-pyrophyllite-sericite rock. Usually, corundum occurs within andalusite but a few corundum grains are encased directly in feldspar. The corundum observed in drill core is dark to light blue in colour and the grains are commonly less than two millimetres in size. However, blue-black, euhedral crystals up to 3 centimetres in length with hexagonal prism or steep hexagonal dipyramidal forms (Plate [illegible]), approaching barrel-shaped crystals, occur in surface float overlying

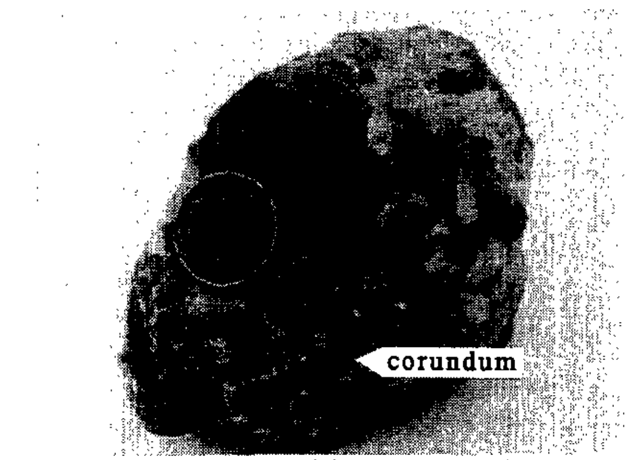

Plate 1. A rock fragment containing coarse, dark blue, doubly terminated corundum crystals, found in overburden above the 76 zone, Empress deposit area.

the 76 zone. A heavy mineral concentrate of overburden from the 76 zone contains dark-blue corundum and colorless corundum crystals that sometimes have light blue patches or blue, hexagonal cores. Petrographic examination of corundum from the host rock indicates that most of the fine-grained crystals are microfractured or contain inclusions of pyrophyllite or diaspore. Some of the coarser crystals have relatively fracture free zones several millimetres across that may be gem quality. Individual corundum crystals are separated from the host by pale grey halos, 2 to 5 millimetres wide, that consist mainly of coarse muscovite. Some corundum grains within copper-gold mineralized zones are rimmed by sulphides.

The corundum crystals are nearly pure Al_2O_3 but contain detectable concentrations of Fe, Ti and Cr (Table 1). Some crystals are chemically zoned. The zoning and observed textures such as coronas around corundum crystals clearly indicate that the Empress deposit system was not in equilibrium at the time of corundum formation. The stability field of corundum in the system $HCl-H_2O-(Al_2O_3)-K_2O-SiO_2$ at 0.5 kb and 400°C, in terms of the ratios of activity (a) of K^+ to H^+ and activity of SiO_2, is shown in Figure 4 (Bowers *et al.*, 1984). The figure may be an oversimplification, but it is useful in illustrating that pyrophillite is not in equilibrium with corundum. Muscovite coronas surrounding corundum and the relatively restricted occurrence of corundum within a large alteration zone may simply be the result of changing conditions, such as the activity of silica or potassium and hydrogen within the system. It is therefore possible that corundum is limited to a metasomatic halo genetically related to the coarse-grained albite-orthoclase

TABLE 1. MINERAL CHEMISTRY OF REPRESENTATIVE CORUNDUM CRYSTALS; EMPRESS DEPOSIT.

Sample	7	9	10
SiO_2	0.000	0.000	0.000
TiO_2	0.051	0.428	0.033
Al_2O_3	99.324	98.126	99.997
Cr_2O_3	0.037	0.002	0.104
FeO	1.116	2.233	0.596
MnO	0.008	0.000	0.001
MgO	0.000	0.01	0.000
CaO	0.000	0.000	0.000
Total	100.536	100.799	100.731
Si	0.0000	0.0000	0.0000
Al	1.9880	1.9713	1.9924
Ti	0.0007	0.0055	0.0004
Fe	0.0158	0.0318	0.0084
Cr	0.0005	0.0000	0.0014
Mg	0.0000	0.0003	0.0000
Mn	0.0001	0.0000	0.0000
Ca	0.0000	0.0000	0.0000
Total	2.0051	2.0089	2.0027

Note: Major oxides and cationic proportions calculated on a three oxygen basis.

TABLE 2. MINERAL CHEMISTRY OF REPRESENTATIVE ANDALUSITE CRYSTALS; EMPRESS DEPOSIT.

Sample	1	2	3	4
SiO_2	35.580	35.958	36.657	36.435
TiO_2	0.049	0.049	0.019	0.049
Al_2O_3	61.094	62.137	62.625	61.89
FeO	1.324	0.844	0.247	1.144
MnO	0.000	0.000	0.000	0.010
MgO	0.032	0.001	0.019	0.019
CaO	0.000	0.000	0.000	0.015
K_2O	0.012	0.022	0.012	0.011
Total	99.091	99.064	99.561	99.573
Si	1.0027	0.9843	0.9946	0.9934
Al	1.9739	2.0049	2.0028	1.9890
Fe	0.0304	0.0193	0.0056	0.0261
Mg	0.0013	0.0022	0.0000	0.0008
Ti	0.0010	0.0010	0.0004	0.0010
Mn	0.0000	0.0000	0.0000	0.0002
Ca	0.0000	0.0000	0.0000	0.0004
K	0.0004	0.0008	0.0004	0.0004
Total	3.0096	3.0126	3.0038	3.0113

Note: Major oxides and cationic proportions calculated on a five oxygen basis.

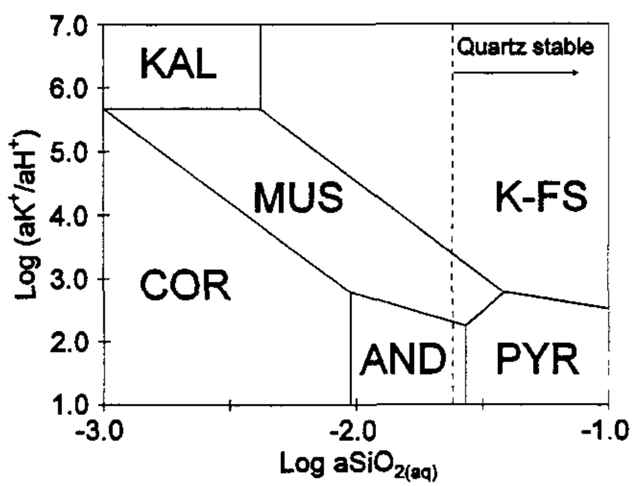

Figure 4. The system $HCl-H_2O-(Al_2O_3)-K_2O-SiO_2$, at 0.5 kb and 400°C. The vertical dotted line represents the saturation limit of quartz. Abreviations: COR - corundum, AND - andalusite, PYR - pyrophyllite, K-FS - Alkali Feldspar, KAL - Kalsilite (From Bowers *et al.*, 1984).

TABLE 3. MAJOR ELEMENT ANALYSES OF TYPICAL ANDALUSITE AND PYROPHYLLITE-BEARING ROCKS - EMPRESS DEPOSIT.

Rock type	Drill hole	Depth	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	Total
AR	W89-1	238-239	15.60	7.31	<0.01	5.61	0.05	0.10	0.02	0.11	0.15	55.80	0.51	7.95	93.20
KSA	W89-2	97-98	20.00	3.90	<0.01	4.37	4.38	0.17	0.06	3.37	0.50	57.00	0.56	3.55	97.90
PSA	W90-18	227-228.5	13.60	0.55	0.02	16.60	2.99	0.35	0.09	1.10	0.14	57.30	0.48	6.75	100.00
SAR	W89-1	171-172	18.00	0.43	0.01	7.14	1.37	4.84	0.05	0.58	0.17	59.50	0.61	6.60	99.30
QAS	W90-19	274-275	25.20	1.44	0.02	4.66	2.30	0.10	0.02	1.18	0.12	58.30	0.72	4.10	98.20
PQSA	W91-41	110	32.59	2.14	0.03	7.18	3.31	0.15	0.08	3.75	0.21	45.52	1.21	3.25	99.42
PQSA	W91-41	305	13.05	1.13	0.02	2.23	2.92	0.08	0.02	4.54	0.07	70.68	0.63	1.90	97.27
PQSA	W91-40	572	26.97	1.88	0.03	11.98	1.86	0.22	0.09	2.55	0.04	48.69	1.09	4.36	99.76
PQSA	W91-38	30	20.74	4.83	0.02	3.51	1.02	0.28	0.06	6.29	0.24	56.80	0.89	4.45	99.13
PQSA	W91-38	421	20.76	1.66	0.01	4.30	2.55	0.13	0.02	6.06	0.04	59.74	0.77	2.59	98.63
PQSA	W91-39	45	33.14	1.63	0.03	11.77	2.79	0.19	0.03	3.56	0.20	42.54	1.18	2.46	99.52
PQSA	W91-49	304	18.26	5.96	0.02	1.92	3.97	0.36	0.12	3.29	0.14	56.53	0.72	7.61	98.90
PQSA	W89-8	88	14.53	3.91	0.03	4.68	2.03	0.04	0.02	1.71	0.50	65.58	0.66	6.19	99.88
PQSA	W89-8	374	35.29	1.57	0.03	3.81	5.44	0.22	0.01	2.22	0.20	45.99	0.12	4.35	99.25
PQSA	W90-19	60	25.26	3.78	0.02	3.15	4.52	0.09	0.02	3.07	1.37	52.99	1.02	4.36	99.65
PQSA	W90-19	326	24.24	2.00	0.01	1.36	8.28	0.06	0.03	3.58	0.87	55.63	1.24	2.05	99.35
PQSA	W90-21	111	27.26	2.90	0.01	0.69	2.55	0.06	<0.01	4.19	0.10	56.88	0.53	3.74	98.91
PQSA	W90-20	128	14.57	1.35	0.02	7.68	5.76	0.10	0.07	2.12	0.26	63.53	0.56	3.02	99.04
PQSA	W90-23	65	32.72	1.14	0.03	4.71	5.55	0.27	0.06	1.66	0.43	47.28	1.24	4.25	99.34
PQSA	W90-23	304	7.31	1.41	0.04	14.86	1.43	0.17	0.03	1.00	0.30	70.41	0.72	2.32	100.00
PQSA	W90-27	171	28.30	0.93	0.04	1.68	2.88	0.07	<0.01	4.15	0.18	57.87	0.88	2.81	99.79
PQSA	W89-3	84	16.64	2.96	0.03	2.45	1.04	0.37	0.02	6.03	0.30	64.17	1.11	3.81	98.93
PQSA	W89-3	284	17.21	3.49	0.02	2.19	1.38	1.55	0.03	5.54	0.12	63.98	0.64	3.06	99.21
PQSA	W89-5	85	20.35	2.79	0.04	5.21	1.83	1.69	0.04	5.56	0.48	56.21	0.82	4.90	99.92
PQSA	W90-30	198	22.97	4.59	0.04	3.80	4.65	0.10	0.06	2.90	0.30	54.54	0.65	4.24	98.84
PQSA	W90-31	253	25.77	4.29	0.02	5.83	4.89	0.19	0.09	3.01	0.33	46.54	0.86	8.13	99.95
PQSA	W91-37	339	16.14	2.45	0.04	3.06	1.24	0.27	0.01	5.92	0.01	66.53	0.13	2.72	98.52
PQSA	W88-3	59	16.25	1.92	0.03	1.22	7.48	0.07	0.03	1.97	0.47	66.27	0.81	2.63	99.15
*	76WJ-37		16.99	0.05		0.28	0.075	0.03	<0.003	0.120	0.13	71.43	0.923		99.08
*	76WJ-42		17.50	0.04		0.67	0.034	0.02	0.003	0.082	0.40	74.11	0.876		97.61
average			21.53	2.66	0.02	5.27	3.23	0.44	0.04	3.25	0.29	57.24	0.76	4.22	
median			20.55	2.07	0.02	4.34	2.84	0.17	0.03	3.18	0.21	56.94	0.72	3.96	
standard deviation			7.02	1.68	0.01	4.06	2.02	0.95	0.03	1.79	0.28	7.54	0.29	1.81	
maximum			35.29	7.31	0.04	16.60	8.28	4.84	0.12	6.29	1.37	70.68	1.24	8.13	
minimum			7.31	0.43	0.01	0.69	0.05	0.04	0.01	0.11	0.01	42.54	0.12	1.90	

Key: PQSA: plagioclase-quartz-pyrophyllite-andalusite; AR: andalusite; KSA: K-feldspar-pyrophyllite-andalusite: PSA: plagioclase-pyrophyllite-andalusite: SAR: pyrophyllite-andalusite; QAS: quartz-andalusite-pyrophyllite; R: rock

Notes: Samples 76WJ-37 and 42 were collected by McMillan (1976) and are for comparison only Statistical analyses are for samples collected by Wespine Metals Ltd. (Madeisky, 1994).

TABLE 4. PYROPHYLLITE-BEARING MATERIALS WITH CURRENT INDUSTRIAL APPLICATIONS

Source	Product	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	LOI
USA	Refractory	75.0	19.3	0.8	0.1	0.1	0.2	0.1	–	3.9
	Whiteware	80.9	13.8	0.2	–	–	2.3	0.4	0.1	2.3
South Korea	Refractory	73-77	18-19	0.15-0.25	–	–	–	–	–	3.8-3.45
	Ceramic	76-80	15-19	0.15-0.30	–	–	–	–	–	3.3-3.3

(Sources: Ciullo and Thompson, 1994; Harben 1995) rock that may have a pegmatitic affinity. Work is in progress to better evaluate the potential of the 76 zone of the Empress deposit and overlying overburden as a source of sapphire and to explain the origin of the corundum.

Andalusite-pyrophyllite

The andalusite crystals from the Empress deposit have relatively low iron content (Table 2) and could satisfy current refractory specifications. However the andalusite-bearing rocks are generally too fine-grained to be processed into high-grade concentrates that could compete with South African material.

A large number of drill core samples were analyzed for metallic elements (Lambert, 1988, 1989, 1991a and b), but little major element data is available from the property. Table 3 shows the composition of andalusite-pyrophyllite-muscovite-bearing rocks compiled from Madeisky (1994). Unfortunately, these analyses are not supported by detailed petrographic or X-ray diffraction studies. The table indicates that these rocks are relatively rich in alumina, low in silica and that there are large variations in the concentrations of other major oxides. Typical properties of American and South Korean refractory and whiteware grade pyrophyllite are given in Table 4 for comparison. Most of the rocks from the Empress deposit appear to be high in Fe_2O_3, CaO, Na_2O and K_2O. Unfortunately, detailed sample and petrographic descriptions were not done, so it is not known if the high Fe_2O_3 content is due to the presence of sulphides and iron oxides or other sources. It is assumed that the relatively high CaO, Na_2O and K_2O contents are due to the presence of feldspar and mica. Although the andalusite-pyrophyllite bearing rocks from the Empress deposit do not meet current specifications for traditional North American refractory or ceramic applications, they may have industrial applications in domains with less stringent specifications. Two samples analysed by McMillan (1976) (Table 3) have similar compositions to andalusite-pyrophyllite products currently in the market place but are slightly high in TiO_2. Because pyrophyllite has a low unit value, $20.00 to $300.00 per tonne FOB depending on grade and degree of processing, it is important to consider transportation costs to markets.

Rare Earth Minerals

A rare reddish brown, rare earth element (REE) - bearing mineral, with brownish irradiation halos up to 0.5 centimetres in radius occurs within plagioclase-pyrophyllite-andalusite-bearing lithologies. Its distribution is erratic and it is present in trace amounts. This mineral was tentatively identified as bastnaesite ((Ca, La) CO_3F). A carbonate-phosphate-sulphide boulder, 30 by 30 by 25 centimetres was found by Westpine geologists near the corundum-bearing zone and probably contains rare earth elements. Furthermore, REE-bearing phosphate was described in concentrations of up to five percent with tennantite, energite, chalcopyrite and sphalerite in two main veins at the nearby Taylor-Windfall gold deposit (Price, 1986). These occurrences indicate that the area may have some exploration potential for REE's.

SUMMARY

The copper, gold and molybdenum potential of the Empress deposit was discussed by Osborne and Allen (1995). The non-metallic mineral potential of this deposit remains to be established. Corundum crystals from the Empress deposit are typically dark blue, subhedral to euhedral and a fraction of a millimetre to one centimetre in cross section. Some transparent, colourless crystals were found in overlying sediments. Coarse crystals contain numerous inclusions of pyrophyllite, but parts of them, up to several millimetres in size, are fracture and inclusion-free. The potential of this deposit as a source of corundum depends on the proportion and quality of coarse corundum crystals, their abundance and distribution either in residual soils, placers or primary host rock. Andalusite-pyrophyllite rocks may have industrial applications if produced as a by-product of metal mining, although the cost of transportation to markets may be prohibitive. Andalusite crystals within the Empress deposit area are too fine grained to be economically upgraded to compete with South African and French concentrates currently on the market. The area might also have Rare Earth element exploration potential.

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OKANAGAN AGGREGATE POTENTIAL PROJECT

By Alex Matheson, David MacDougall, Peter T. Bobrowsky and Nick Massey

KEYWORDS: Aggregate potential, Okanagan, sand and gravel.

INTRODUCTION

Aggregate is defined as a mass or body of rock particles, mineral grains, or a mixture of both. A working rule is that aggregate with a water absorption value of less that 2% will provide a good quality product, whereas that exceeding 4% may not (Collis & Fox, 1985). With this in mind, not all unconsolidated material can be used as good quality aggregate.

The future exploitation of sand and gravel in favourable deposits may be increasingly restricted as a result of growing public concern with environmental issues and expanding urbanization. Pits, once peripheral to populated areas, are now being incorporated into the ever encroaching development (Photo 1). There is a danger that much of this expansion may occur in areas overlying potential aggregate resources, thus sterilizing them (Photo 2). Paradoxically however, all development is dependent upon aggregate production since 95% is used in the construction industry. Of this amount about half goes into building construction and the other half into public works (R. Poulin *et al.*, 1993).

Production is on a demand basis as there is very little inventory accumulated. In anticipation of the burgeoning demand for aggregate and the well ordered production of sand and gravel, a documented inventory for the province is essential, with the intent of delineating landforms and their aggregate potential for future exploitation.

PREVIOUS STUDIES

Past work relevant to this study was reported by Nasmith (1962), Fulton (1965) and Hora (1988).

Studies undertaken by the Ministry of Energy, Mines and Petroleum Resources circa 1985, the Ministry of Environment, Lands and Parks circa 1984 and the Ministry of Transportation and Highways have been compiled into a series of unpublished maps (n.d.), by the Geotechnical and Materials Engineering Branch of the Province of British Columbia, Ministry of Transportation and Highways.

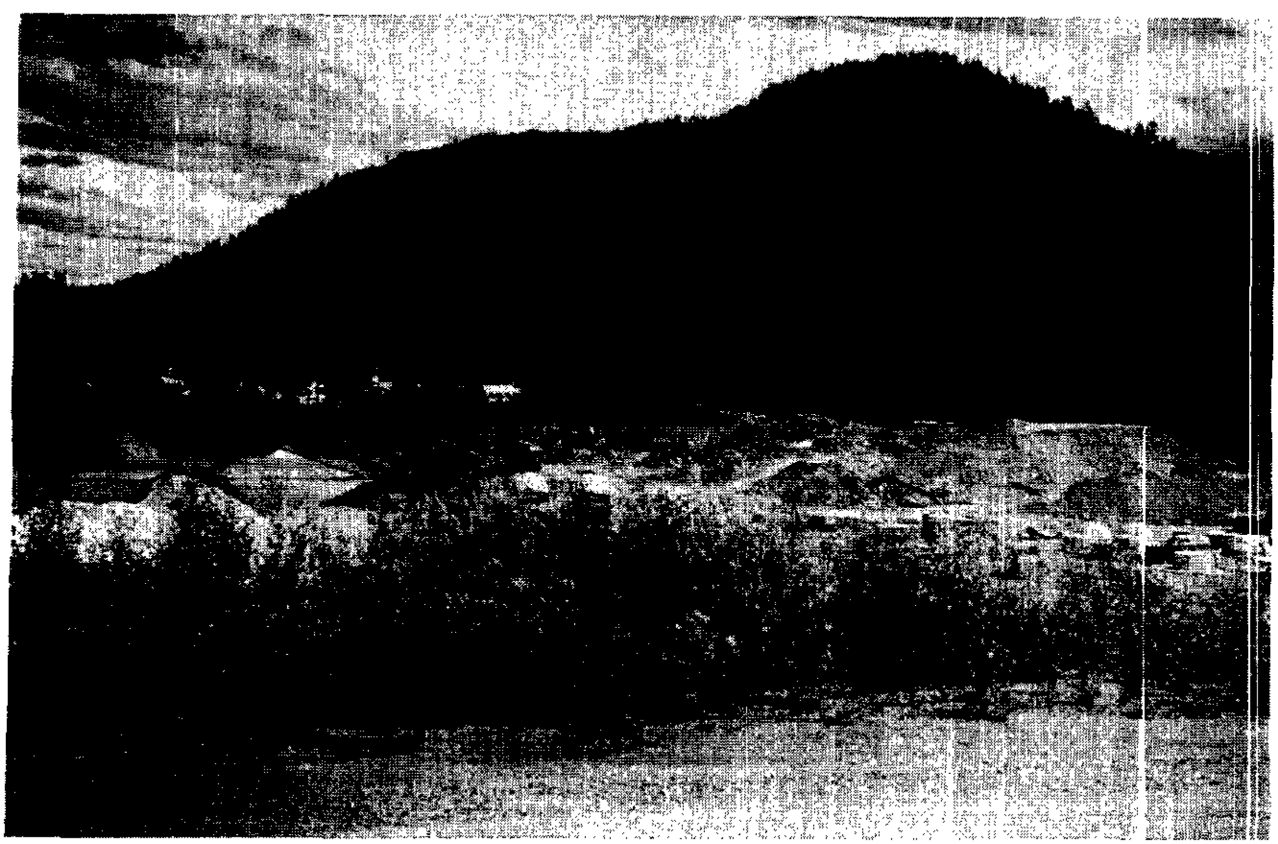

Photo 1. Urban enroachment onto pre-existing gravel operation.

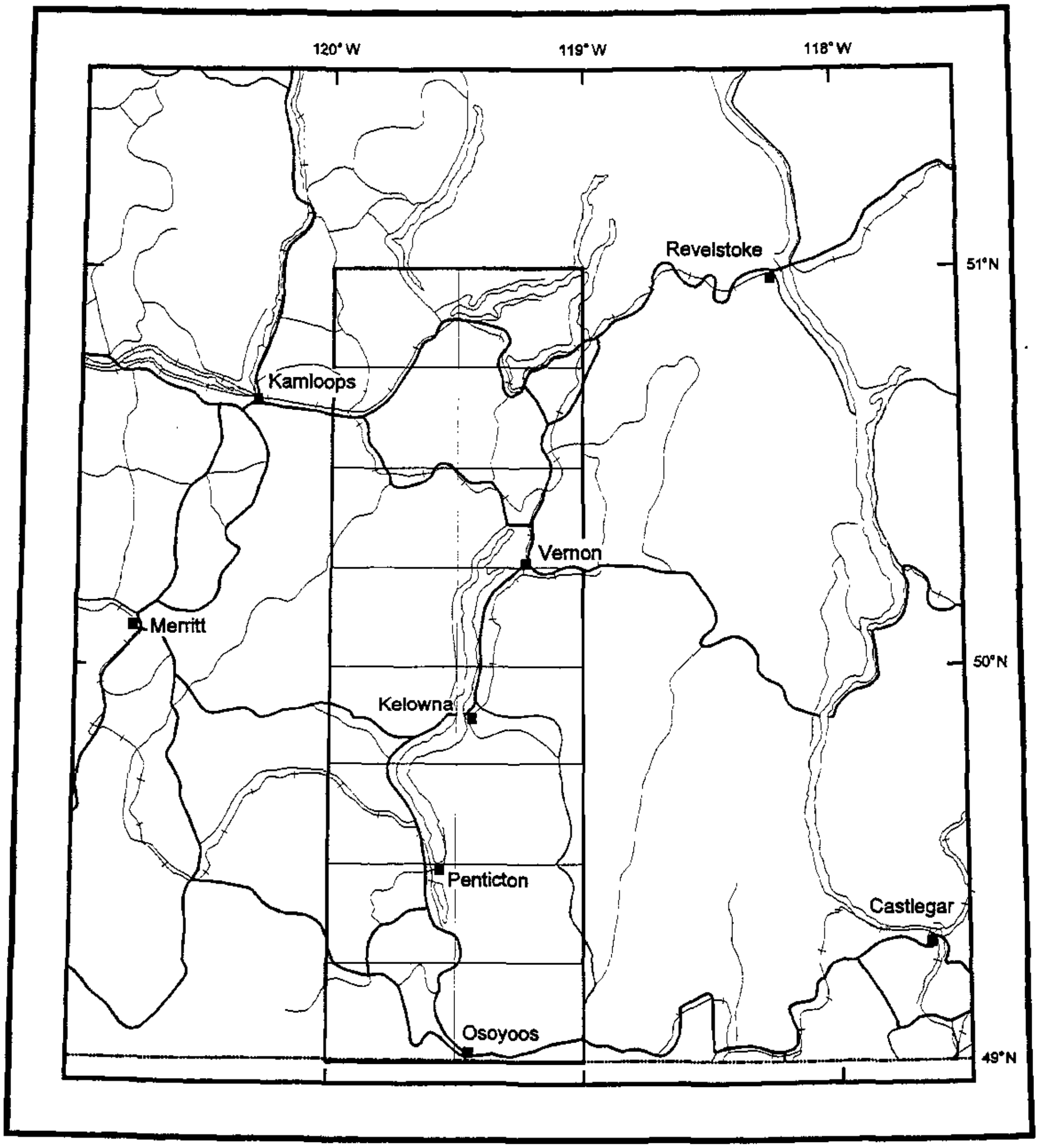

Figure 1. Location of study area in the southern interior of British Columbia.

PROJECT OBJECTIVES

The project objective was to examine existing resources and known occurrences and establish potential aggregate resources for the Shuswap and Okanagan Valley. This would be accomplished by compiling previous work, field observations, and air-photo mapping.

AGGREGATE POTENTIAL MAPS

The primary objective is to produce a series of aggregate potential maps for the study area. Pits that were previously located on topographic and aggregate inventory maps will be used together with new field data and polygons from soils and terrain maps to provide a database from which the potential maps will be produced at the 1:50 000 scale.

This information is in accordance with the aims identified at a workshop in 1995 (Bobrowsky *et al.*, 1996b). A case study example was completed last year for the Prince George area (Bobrowsky *et al.*, 1996a) and is now available.

METHODOLOGY

The project began, by documenting sites identified from license permits, Ministry of Transportation and Highways location maps, topographical maps, aggregate inventory maps for the Geological Survey Branch (*i.e.* Matheson *et al.*, 1996), and air-photos.

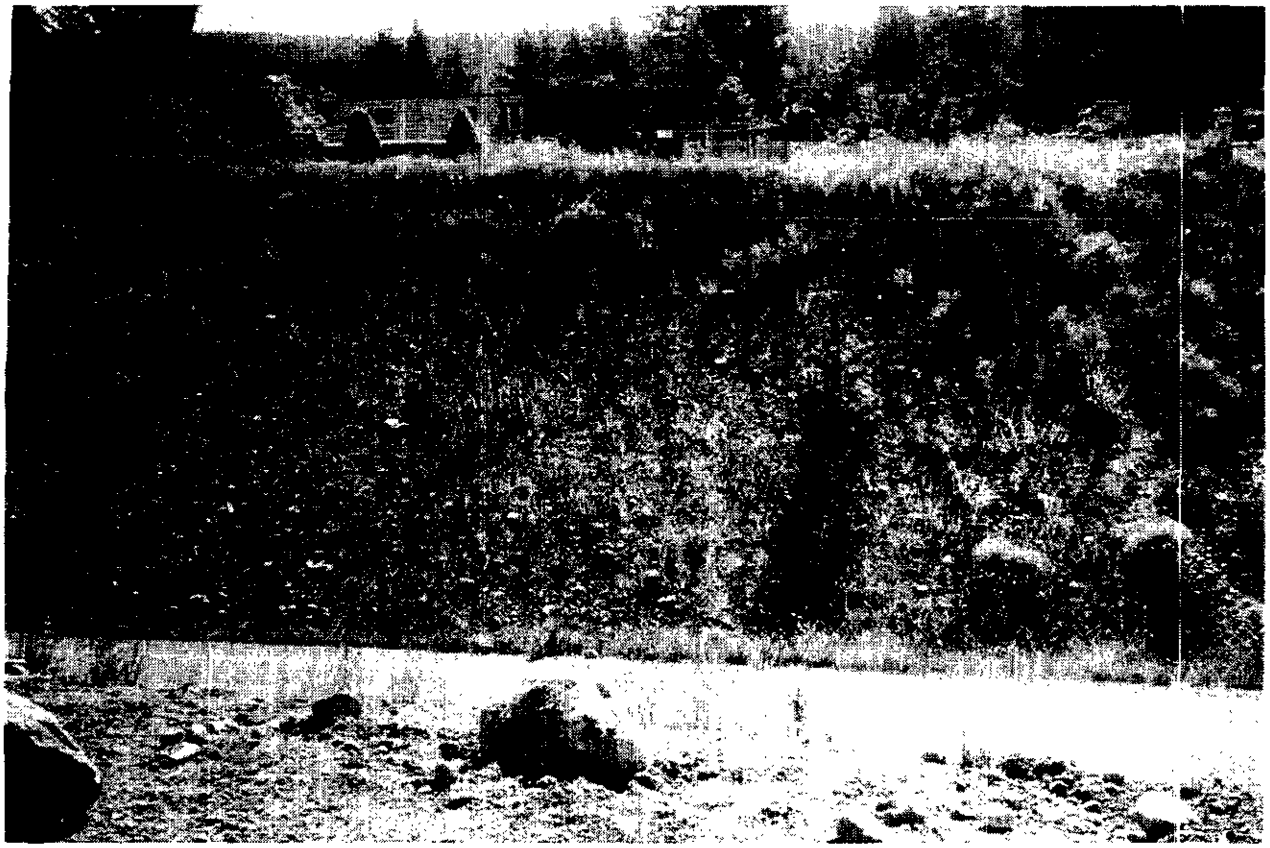

Photo 2. *Sterilization of aggregate resources.*

LOCATION OF STUDY AREA

In 1996, a survey was initiated in the Shuswap and Okanagan areas where population expansion has stressed present aggregate resources. This area lies within the southern interior physiographic region in southern British Columbia (Figure 1). Sixteen map sheets were covered; 82 E/3, 4, 5, 6, 11, 12, 13, 14, and 82 L/3, 4, 5, 6, 11, 12, 13, 14, forming a corridor 80 kilometres wide and 200 kilometres long from Shuswap Lake south to Osoyoos.

PHYSIOGRAPHY

The northeastern part is dissected by narrow, generally steep-sided glacial valleys, trending north-south and east-west, dominated by Shuswap Lake (Figure 2). The central and southern portion is traversed by a long narrow valley containing Okanagan Lake, Skaha Lake and Osoyoos Lake.

GLACIAL HISTORY

The south and central areas of B.C. were glaciated prior to and throughout the Wisconsinan (Ryder *et al.*, 1991). Glaciation in the southern Okanagan formed part of the Cordilleran Ice sheet that flowed southward along the Okanagan valley, a major physiographic depression in the region. Ice thickness reached up to 2000 metres in the valleys and hundreds of metres atop the intermontane plateaus. Thus the surface gradients of the ice sheet were very low and not related to the rugged terrain beneath the ice. The Fraser glaciation reached a maximum in the Late Wisconsinan at about 14 500 to 14 000 years BP (Ryder *et al.*, 1991). This was followed by deglaciation that began before 13 500 years BP and was virtually complete by 11 500 years BP.

Deglaciation formed a series of erosional landforms produced by downwasting of the ice sheet rather than a large recessing ice lobe front (Ryder *et al.*, 1991). The deglaciation was marked by an emergence of the uplands and isolation of large masses of stagnant and ablating ice in the valleys, resulting in the formation of glacial lake Penticton as drainage was stopped by ice damming to the south. Deglaciation was rapid with high sedimentation rates attributed to: (1) climate deterioration, (2) glacial and meltwater erosion, and (3) rapid reworking of sediments (Ryder *et al.*, 1991).

Glacial landforms were controlled mainly by the topography of the area. Drift accumulated in the low-lying areas and valleys. Conversely, the bedrock knobs and plateaus were coated with a thin veneer of till. Recessional landforms are found mainly in the low-lying parts of the plateaus and in the valleys. These include eskers, kame terraces, kettles, and moraines formed in a proglacial/ice-contact depositional environment.

Outwash consists of glaciofluvial (F^G), glaciolacustrine (L^G), and glaciomarine (W^G) sediments. Glaciofluvial sediments are composed mainly of sand and gravel that accumulated in subaerial and subaqueous environments.

FIELD WORK

Pits identified in the study area were photographed, and documented under the following notations: name of pit, unique identity number and license, licensee or operator, and development status. This included measuring pit dimensions and exposed sections that would allow facies interpretation, depositional history, and quarry type. A hand-held global positioning system and the N.T.S. maps were used to accurately define the pit location which was then plotted using UTM coordinates on the N.T.S maps and soil maps for the Okanagan Valley.

DATA COMPILATION

A database was compiled consisting of the licensing, field observations, air-photo interpretation, delineation and identification of landforms. The aggregate pits will be digitized as points on the sixteen map sheets. This information will later be combined with water well-logging and previous geotechnical reports to create attributes for each pit in ARC-info, the G.I.S. software used for plotting the data.

RESULTS/OBSERVATIONS

Field studies lasted over a five week period in June and July, 1996 and of the 308 known sites, 267 were examined. Due to time and financial constraints, the remaining 41 sites were evaluated by air-photo interpretation. The pits examined varied from borrow pits (Photo 3) that displayed 30% fines by volume, to large scale operating sand and gravel pits (Photo 4), and revegetated and reclaimed pits to housing developments in former pits (Photo 5).

DISTRIBUTION OF AGGREGATE RESOURCES

GEOGRAPHIC LOCATION

The demand for aggregate is greatest around the more densely populated areas where the need for sand and gravel reflects the active construction industry. Numerous pits in the Shuswap area and near settlements such as Salmon Arm (82 L/11), Vernon (82 L/6), Kelowna (82 E/14), Penticton (82 E/5), and Keremeos (82 E/4) form the majority of active aggregate extraction operations.

DEPOSIT, LANDFORM, AND SOIL TYPES

Aggregates were derived mainly from meltwater sediments that form in a proglacial environment. Fluvial sediments (i.e. fan, delta, and river deposits) form only thin deposits of unconsolidated material (Fulton, 1972) and represented less than 9% of the deposits with aggregate pits. Glaciofluvial deposits (meltwater sediments) account for 80% of the aggregate pits and are located mainly in and along the low-lying valleys. Of these glacial deposits,

Photo 3. Borrow pit with greater than 30% fines.

Photo 4. Large operating agggregate pit.

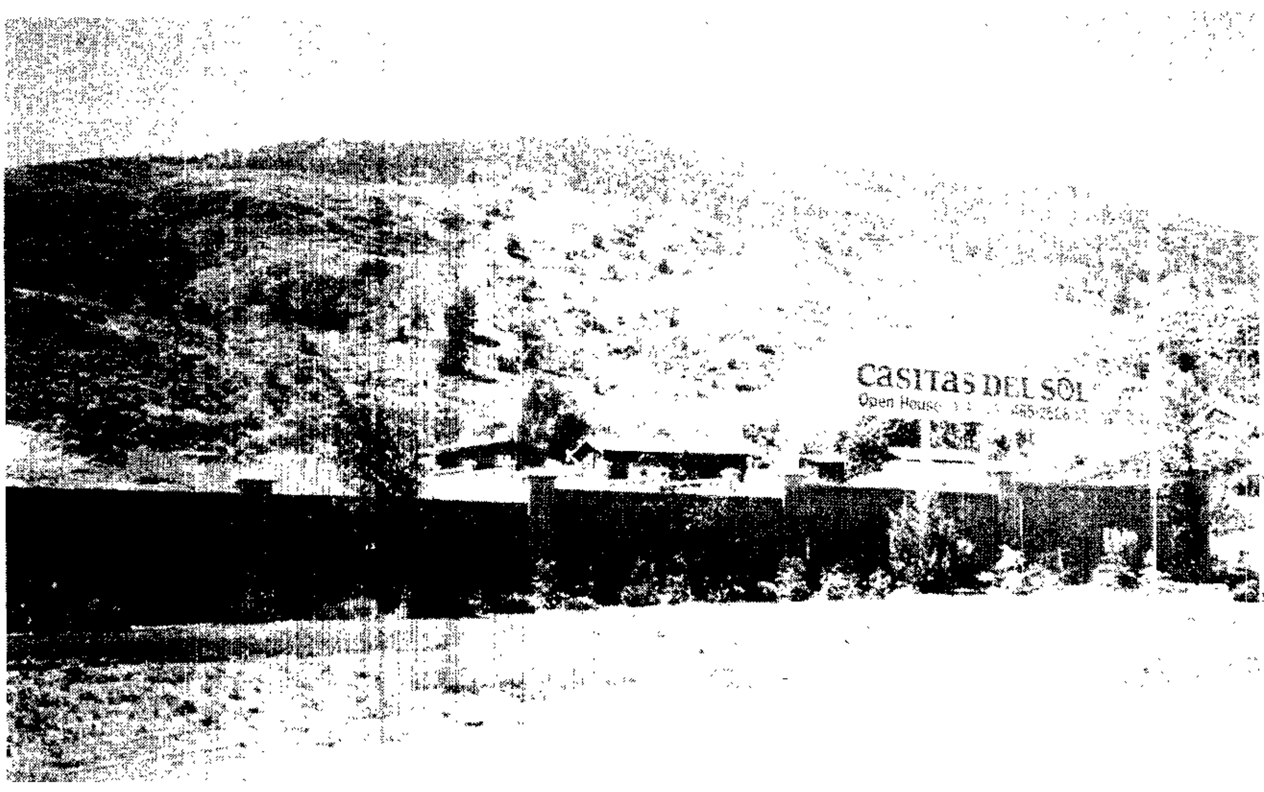

Photo 5. Subdivision in old pit location.

glaciofluvial fans, terraces, and kame terraces accounted for approximately 75% of the total pits under study. These sediments were most likely deposited during the deglaciation (Fulton, 1972) following the Fraser glaciation.

Landforms for each pit were derived from their location on Ministry of Environment soil maps for B.C. These correspond to deposit types identified at many of the pits. However, this is not always the case suggesting some ambiguity in the interpretation and boundaries of the labeled polygons.

Soil types have been correlated between soil maps using characteristics such as: vegetation, texture, landforms, soil drainage, moisture content, slope, elevation, bedrock, and soil taxonomy. Consistently, aggregate pits were found in coarse-grained glaciofluvial landforms with good drainage and moderate slopes throughout the Okanagan and Shuswap area.

CONCLUSIONS - DISCUSSION

LOCATING FUTURE DEPOSITS

Future deposits should be sought after in the low-lying areas where glaciofluvial deposits persist. When urban development and exploitation have limited the aggregate potential for these areas, smaller, but similar deposits located adjacent to the large valleys could be used in the future. These landforms will be located on the aggregate potential maps and with ground truthing and more detailed air-photo interpretation, will allow accurate identification of future aggregate resources.

VALUE OF AGGREGATE PROGRAM

There will always be a demand for aggregate and consequentially it is essential to have a well documented inventory for future use in general development planning, construction, and the resulting infrastructure of transportation networks. Thus, an inventory of aggregate resources in areas of British Columbia should be completed so that they may used in a most effective manner.

ACKNOWLEDGMENTS

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COALBED METHANE IN THE COMOX FORMATION

TSABLE RIVER AREA, VANCOUVER ISLAND

Barry D. Ryan

KEYWORDS: Coal, coalbed methane.

INTRODUCTION

There are two major coal basins on the east side of Vancouver Island, British Columbia (Figure 1). The Nanaimo basin is centered on the town of Nanaimo; between 1849 to about 1950 over 50 million tonnes of coal were extracted from seams in this basin. This basin is now considered to be largely mined out. At present companies are interested in the Comox coal basin, which extends from 20 kilometres north of Nanaimo to Campbell River and covers about 1230 square kilometres. Over 15 million tonnes have been mined from the Comox basin. Quinsam mine, the only operating coal mine on Vancouver Island, is located in the basin. The Comox basin coal resource, which is estimated to be over 300 million tonnes, is contained in the Late Cretaceous Comox Formation of the Nanaimo Group.

Virtually all mining on Vancouver Island has been underground, usually room and pillar, or an early form of long wall mining. Underground explosions caused by gassy coals were a problem and over the years killed many of the more than 930 people who lost their lives in the mines. The Quinsam coal mine is an underground room and pillar operation mining high-volatile bituminous coal. The maximum depth of mining is planned not to exceed 300 metres and this with the low rank of the coal limits the potential methane content of the coal. In fact measured coalbed methane (CBM) contents from depths ranging from 100 to 150 metresare up to 1.6 cubic metres/tonne on an ash-free basis (Ryan and Dawson, 1994a). These concentrations are low and are consistent with gas flows encountered at the mine. At Tsable River the rank of the coal is higher and coal resources are at depths exceeding 400 metres. Therefore CBM concentrations in the coal will be higher and preliminary tests of gas content will provide valuable data for any underground coal mining or CBM extraction plans.

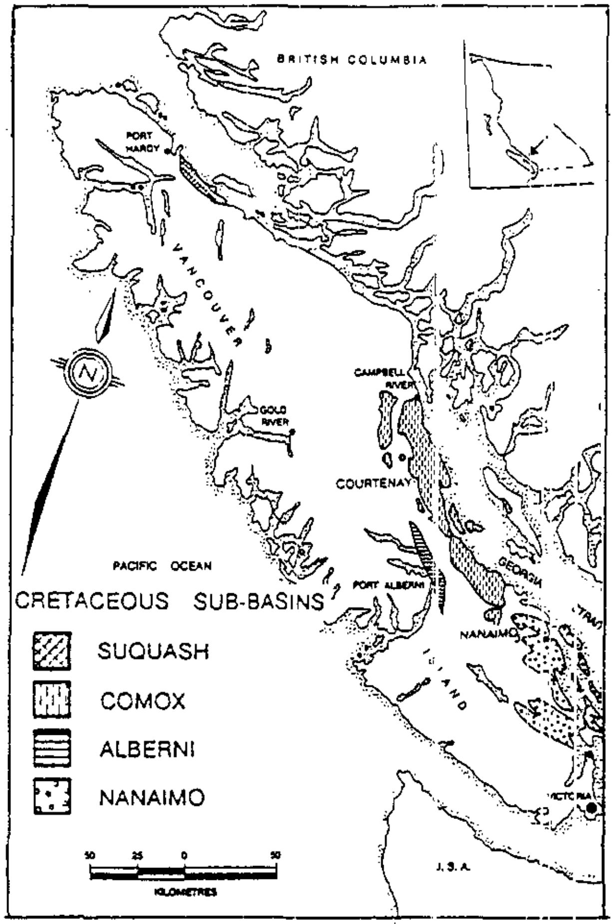

Figure 1: Major coal basins on Vancouver Island.

PREVIOUS WORK

The existence of coal on Vancouver Island was probably brought to the attention of the Hudson Bay fur traders in 1833. An Indian on seeing coal being used in a Hudson Bay Fort told Dr. Tolmie of its existence on Vancouver Island. The next year its presence was confirmed by Mr. Finlayson (Newsome, 1989). One of the earliest scientific reports of coal on Vancouver Island was by Hector (1861) who discussed the coal geology of some of the early mines of the Hudson Bay Company near Nanaimo. The earliest regional mapping of the coalfields of Vancouver Island was conducted by James Richardson in the period 1872 to 1878 (Richardson, 1878). He recognized the three main areas of coal deposition as the Nanaimo, Comox and Cowichan basins. MacKenzie, in the summers of 1921 and 1922, studied the stratigraphy of the Comox Formation (MacKenzie, 1922). Muller and Atchison (1970) published a summary of the geology of the coal basins on the Island. Gardner (1996) produced a report summarizing the history of coal exploration and mining activity on Vancouver Island and an appraising the coal resources.

REGIONAL GEOLOGY

The Nanaimo Group, which contains the coal measures of Vancouver Island, is Upper Cretaceous (Turonian to Maastrichtian) in age. It was deposited in the Late Mesozoic to Cenozoic sedimentary Georgia basin, which overlaps the Coast and Insular belts of the Cordillera. The deposition of the Nanaimo Group correlates with a period of rapid subsidence, which led to the accumulation of over 5 kilometres of sediments by the close of the Cretaceous (England and Bustin, 1995). Much of the Nanaimo Group in the Mount Washington area is in tectonic contact with the Triassic basement (Muller, 1989), which is often represented by the Karmutsen volcanics. In places the basement surface is intensely weathered and the resulting lateritic deposits are zones of localized shearing.

The Nanaimo Group was deformed by the Cowichan fold and thrust system, which is composed of a number of northwest-trending, southwest-verging thrusts, that account for a 20% to 30% shortening of the Nanaimo Group cover over the Wrangellian basement (England and Calon, 1991). This contraction is indirectly dated as Late Eocene.

There are at least three coal bearing formations within the Nanaimo Group (Table 1). The lower Comox Formation outcrops extensively in the Comox coal basin. It is overlain by marine sediments of the Haslam Formation in the Nanaimo basin or the Trent River Formation in the Comox. The second coal-bearing cyclotherm is marked by the deposition of the Extension and Protection formations, which host the coal seams and mines in the Nanaimo basin. Coal is reported in the Spray River Formation higher in the Nanaimo Group, but there are no significant deposits (Ward, 1978).

TABLE 1

STRATIGRAPHIC UNITS COMOX BASIN*			
STAGE	FORMATION	MEMBER	CYCLOTHERM
MAESTRICHTIAN	HORNBY		5
MAESTRICHTIAN	SPRAY		4
L CAMPANIAN	GEOFFREY		4
L CAMPANIAN	LAMBERT		4
L CAMPANIAN	DENMAN	Norman Point	3
		Graham	3
		Madigan	3
L CAMPANIAN	CEDAR DISTRICT		2
E CAMPANIAN	PROTECTION		2
E CAMPANIAN	TRENT RIVER	Willow Point	2
		Baynes Sound	2
		Royston	2
		Tsable	2
		Browns	2
		Puntledge	2
		Cowie	2
		Cougarsmith	2
SANTONIAN	COMOX	Dunsmuir	1
		Cumberland	1
		Benson	1

L late, E early. *After Muller and Jeletsky (1970), Cathyl-Bickford (1992) and Bickford *et al.* (1990)

The Comox Formation is divided into three members in the Comox basin. The lowest is the Benson member, which is overlain by the Cumberland and Dunsmuir members. In the Tsable River area, which marks the southern end of the Comox basin, the Benson member ranges in thickness from 0 to 220 metres and consists of conglomerate, minor red shale and siltstone (Cathyl-Bickford, 1992). It is overlain by the Cumberland member, which is composed of 30 to 90 metres of siltstone, shale, minor sandstone and coal. The uppermost Dunsmuir member is composed of 120 to 190 metres of sandstone, minor siltstone and coal. There are four, economically important seams in the Comox Formation. The lowermost No. 4 seam, which ranges in thickness from 1.2 to 4.5 metres (Cathyl-Bickford, 1991), is in the Cumberland member near its contact with the underlying Benson member. Near basement highs, where the Benson member thins, it grades into stony coal or coaly mudstone. The Cumberland member contains two other seams, including the No. 2 seam which is significant and ranges in thickness from 0.8 to 2.2 metres. The No. 1 seam is about 25 metres above the base of the Dunsmuir member and ranges in thickness from 0.9 to 2.4 metres. Figure 2, which is adapted from Bickford *et al.* (1990), is a schematic diagram illustrating seam stratigraphy in the Comox Formation. Recent exploration reports tend to number seams starting at 1 at the base of the succession as at Quinsam and Tsable River.

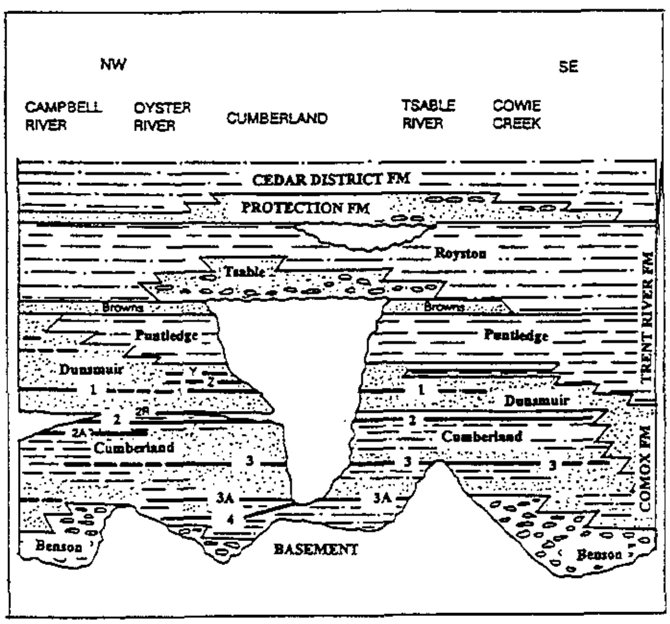

Figure 2: Seam stratigraphy in the Comox Coal Basin, modified from Bickford *et al.* (1990).

The Comox Formation in the Tsable River area is broken by three sets of faults (Cathyl-Bickford, 1992). The earliest set trends northwest with extensional or dextral strike slip movement. They are cut by near vertical, east or northeast-striking faults with sinstral offsets of up to 1000 metres. The third set of faults are of indeterminate relative age and consist of bedding plane shear zones. The coal seams often contain shear zones and low angle extension faults (Bickford *et al.*, 1990).

COAL MINING IN THE TSABLE RIVER AND CUMBERLAND AREAS

Coal development work started in the Tsable River area in 1869 when the Baynes Sound Colliery tried unsuccessfully to develop a mine. A short time later, in the Cumberland area, the Union Collieries opened the Number 3 tunnel, which was driven into the No. 1 seam. This was followed by construction of the Number 1 slope to develop the No 4 seam (slope is a coal term used to describe a tunnel that is constructed down the full dip of the coal seam). In 1888 the Union Collieries was bought by Robert Dunsmuir, who expanded the operations considerably and built a rail line connecting the mines to the wharf at Union Bay. The period 1890 to 1896 saw the construction of the Number 4 slope mine (1890), which accessed the No. 4 seam and the Number 5 shaft mine (1895), which penetrated the No. 1 seam.

A coking plant with 100 beehive coke ovens was built at Union Bay in 1896. The coke, which was made using fine washed coal, was shipped to metal smelters on Vancouver Island and south to the west coast of the United States. The ovens operated up until 1922. By 1900 the Cumberland mines were producing between 200 000 and 250 000 tonnes annually and production continued up to 1947 when the last mine, the Number 5 mine, closed. By this time 14.5 million tonnes had been extracted from the Cumberland mines. Most of the coal was extracted from the No. 1 seam although seams 2 and 4 were also mined. The mines were gassy and a number of explosions with loss of life occurred (Table 2). There were fewer fatalities in the Cumberland area than in mines in the Nanaimo basin possibly because the mines were smaller or not as deep.

Despite the fact that coal was prospected in the Tsable River area in 1869, it was not until 1945 that the Tsable River mine opened. It is located 20 kilometres south of Courtenay on Tsable River west of the area covered by Figure 3. Annual production in the later years was very low averaging about 50 000 tonnes and in the last year (1966) only 15 000 tonnes were mined. Over its life the mine produced 1.8 million tonnes. Slopes were driven north of the Tsable River; water from the roof, thick overburden of sand and gravel and faulting all caused problems. The coal was extracted from a seam 1.2 metres to 4.2 metres thick near the top of the Cumberland member, possibly the Comox No. 2 Seam (Cathyl-Bickford, 1992). This 2 Seam dips at about 15° to 20° to the northeast and ash content

TABLE 2

VANCOUVER ISLAND COAL MINE DISASTERS RELATED TO GAS EXPLOSIONS COMOX COAL BASIN

DATE	COLLIERY/MINE	FATALITIES	CAUSE
Feb15, 1901	COMOX NO. 6 SHAFT	64	EXPLOSION
Jul 15, 1903	COMOX NO. 6 MINE	16	EXPLOSION
Jun 3, 1917	COMOX NO. 6 MINE	4	EXPLOSION
Aug 30, 1922	COMOX NO. 4 MINE	18	EXPLOSION
Feb 8, 1925	COMOX NO. 4 MINE	33	EXPLOSION
SUMMARY TOTAL FATALIES (ALL CAUSES)			
IN THE COAL BASINS			
CUMBERLAND = 305 NANAIMO= 686 TOTAL= 991			

increases in areas where the thickness of the Benson member decreases. The coal is susceptible to spontaneous combustion because of its moderate to high sulphur content and rank (high-volatile A bituminous); fires were reported in two of the mining panels. The seam roof is composed of mudstone, which is often sheared and was difficult to support in the Tsable River mine (Bickford *et al.*, 1990).

LOCAL GEOLOGY TSABLE RIVER AREA

The most recent regional mapping of the Tsable River area was completed by Cathyl-Bickford (1992, Figure 3). In the 1990's there were exploration programs in the area, which outlined two seams of economic interest. The lower seam in the Cumberland member averages 1.92 metres thickness south of the Tsable River and 2.6 metres north of the river (Gardner, 1996). In the Dunsmuir member, about 50 metres above the lower seam, a second thinner seam outcrops, which averages 1.18 metres south of the river and 1.05 metres north of the river. Based on exploration in 1991 a potential resource of 26.2 million tonnes exists south of the river and 61.7 million tonnes to the north (Gardner, 1996). Prior to the 1996 exploration program only 11 million tonnes of this resource south of the river was considered to be well defined. These reserve and resource calculations consider only the lower seam. The 1996 exploration program was planned to better define faults and the reserves south of the river and prove up more reserves north of the river. Preliminary assessment of the 1996 exploration data indicates that there is an inplace proven reserve of over 35 million tonnes in an area that extends north and south of the Tsable River (personal communication, S. Gardner, 1996).

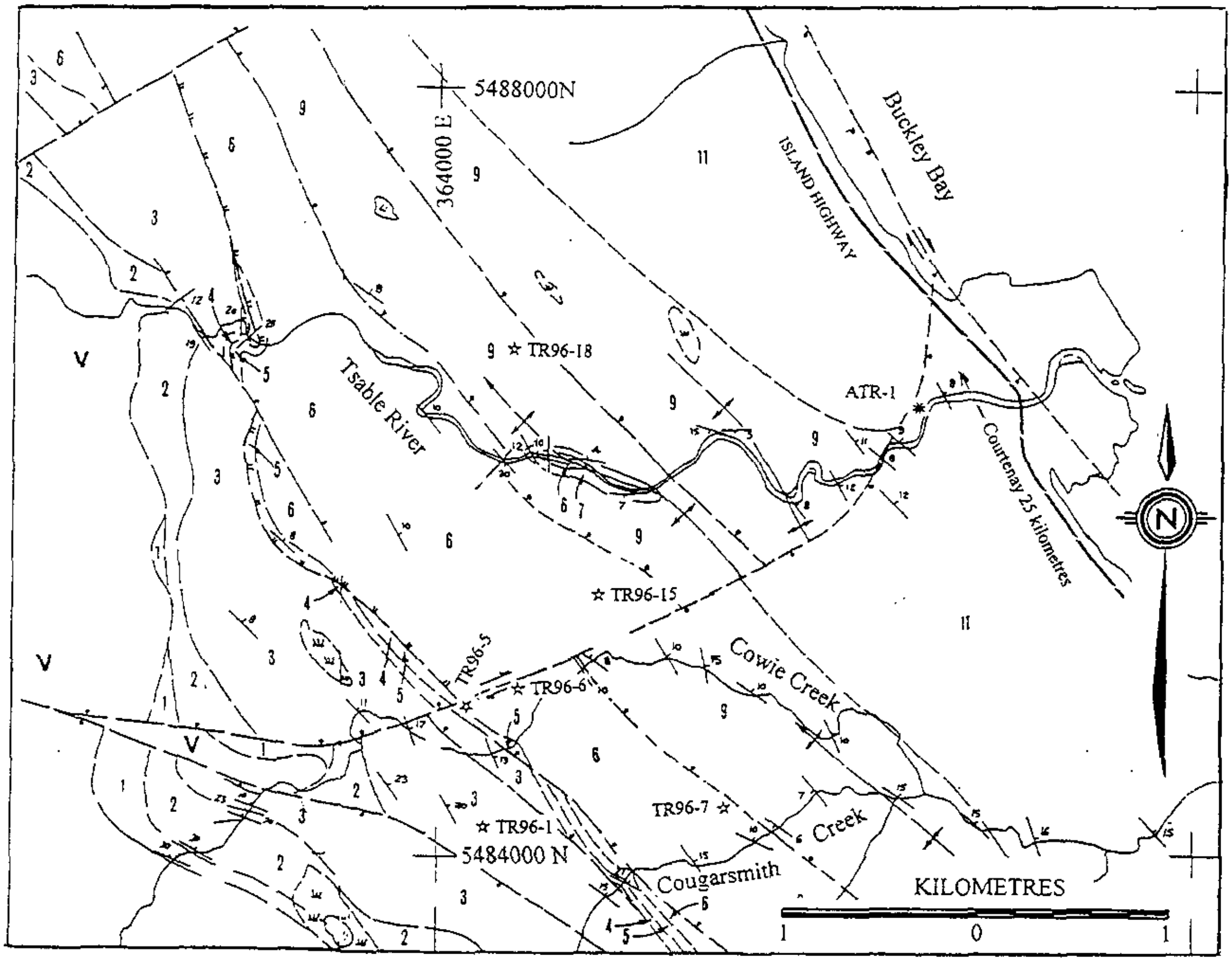

Figure 3: Regional geology Tsable River area from Cathyl-Bickford, (1992) showing location of selected drillholes.

LEGEND FOR FIGURE 3

FORMATION		MEMBER
TRENT RIVER	11	Willow Point
	10	Baynes Sound
	9	Royston
	8	Tsable
	7	Browns
	6	Puntledge
	5	Cowie
	4	Cougarsmith
COMOX	3	Dunsmuir
	2	Cumberland
	1	Benson
	V	Karmutsen

Contact
Fault with down dropped side
☆ TR96-18 Drillhole 1996
✱ ATR-1 Pre 1996 drillhole

COALBED METHANE DATA FROM VANCOUVER ISLAND

Coalbed methane was a major factor contributing to the many mine disasters in the Nanaimo and Comox coal basins. Despite this there is very little data, other than anecdotal, about methane contents of the coal. More recently interest in CBM as an energy resource has increased and Vancouver Island is seen as an interesting target because of its large resource of high-volatile bituminous coal occurring in a regional, moderately-deformed basin.

In the Nanaimo basin, as the mining got deeper, mines experienced difficulty with ventilation because of high gas contents and this is one reason for the closure of the last mines in the period 1947 to 1952 (Cathyl-Bickford, 1991). The mines worked the Douglas and Newcastle seams in the Pender Formation and the Wellington seam in the Extension Formation. Most of the coal was extracted from the Douglas seam, which averages 2.5 metres in thickness and is generally soft and sheared. The Newcastle seam is thin averaging only 1.2 metres thick and the underlying Wellington seam is 1.2

to 2.7 metres thick. Both these seams are hard, blocky and cleated, but they are not extensive. The Wellington seam does not extend eastwards of the outcrop of the Douglas seam.

The Douglas coal zone consists of four coal beds and includes the Newcastle seam. The total thickness of coal in the zone is about 6 metres. The petrography of the seams varies and the lowest seam has the highest inertinite content, though the zone as a whole is considered to be vitrinite rich ((Cathyl-Bickford, 1991). Generally, vitrinite is considered to adsorb more gas than inertinite but to desorb it more slowly. Desorption tests on coal from the Douglas seam collected from bore holes averaging 250 metres in depth and drilled near the Morden Colliery, south of Nanaimo, range from 6 to 12 cubic metres per tonne on an uncorrected basis (Cathyl-Bickford, 1991). The gas contains over 95% methane; the data probably comes from holes drilled by Novacorp in 1984. The gas contents indicate saturation or over saturation of the coal, based on the rank and depth of samples. This could be because the Douglas seam is within impermeable mudstones, which may tend to keep the gas in the seam (Cathyl-Bickford, 1991). Also shearing of the coal limits in-seam permeability and may have contributed to gas outbursts in the mines. The depth at which gas outbursts became prevalent decreased from 550 metres under Nanaimo Harbour to 240 metres at Cassidy, probably because of increased shearing in the Douglas seam to the south (Cathyl-Bickford *et al.*, 1991).

An equation for predicting CBM contents based on depth and reflectance (Ryan, 1989) has been used successfully to reproduce desorption results in Alberta (Dawson, 1994) and in this case it predicts a gas content of 3 to 3.5 cubic metres/tonne at a depth of 250 metres for 10% to 20% ash coal with a Rmmax of 0.68%.

Gas emission rates from mines can be used to estimate the gas content of the coal. The emission rates per tonne of coal mined are between 6 and 9 times greater than the desorption values per tonne of coal(Kissel *et al.*, 1973). Based on the data in Cathyl-Bickford (1991) the Douglas seam at 250 metres could contain up to 4 cubic metres per tonne, which is in agreement with the predicted capacities (Table 3), but lower than the desorption data.

The average mean maximum reflectance (Rmmax%) of coal from the Pender and Extension formations in the Nanaimo area of the Nanaimo basin is 0.68% (Kenyon and Bickford, 1989). They suggest that, because the Rmmax% values do not vary much from seam to seam and are not sensitive to the position of the seams in the stratigraphy, that coalification in this part of the basin post-dates deformation. Regionally the rank increases to the southwest and decreases to the northeast and over the whole basin England and Calon (1991) suggest that the rank was fixed during Late Eocene regional contraction, which defines the Cowichan fold and thrust belt. The Tsable River area is at the northern end of the Cowichan fold and thrust belt and in this area Kenyon and Bickford (1989) suggest that coalification predated deformation. This is important because, if correct, it means that rank does not increase to the northeast where Comox seams are more deeply buried and consequently their CBM content is influenced only by changes in depth. In the Comox basin the rank of the Comox Formation, as defined by Rmmax% values, increases to the south. It averages 0.73% in the Quinsam area but increases to 0.88% in the Tsable River area (Kenyon and Bickford, 1989).

There is some CBM emission data for mines from the Cumberland area (Cathyl-Bickford, 1991). Mine depths range from 200 to 300 metres and predicted gas contents range from 3 to 21 cubic metres/tonne (Table 3). The average values range from 7.8 to 11.7 cubic metre per tonne at depths that average 250 metres. The higher gas contents from coals of the Comox basin are in part supported by the higher Rmmax% values, which in the Cumberland/Tsable River area average 0.88% (Kenyon and Bickford, 1988). The higher gas content did not translate into more mine disasters in the Comox basin than in the Nanaimo basin. This is attributed to the mining method (generally longwall rather than the room and pillar method used in the Nanaimo basin Bickford, 1991) and the better permeability in the seams and roof rocks.

Gas has been reported in a few deep holes in the Tsable River area (Cathyl-Bickford, 1991). One hole drilled in 1914 intersected gassy coal at 350 metres and drilling was stopped because of excessive gas pressure. The hole is located about 4 kilometres northeast from the present drilling near the mouth of the Tsable River (ATR-1, Figure 3). The hole was capped and supplied gas to a local forestry camp until 1984 when the casing was sheared off by a landslide. Another hole drilled in 1945 in the Royston area, 12 kilometres north of Tsable River, intersected gas at 418 metres. After a fire was extinguished it was used as an unlicensed gas well by a local farmer.

TABLE 3

Existing coalbed methane desorption and emission data for the Nanaimo and Comox basins.

MINE	COAL FIELD	YEAR	SEAM	depth metres	emission m3/t	content m3/t
Reserve	Nanaimo	1918	Douglas Main	300	8.8	0.98
Morden	Nanaimo	1918	Douglas Main	250	23.8	2.64
Morden	Nanaimo	1990?	Douglas Main	?		12.00
No. 5	Comox	1918	Comox No. 1	200	17.2	1.91
No. 5	Comox	1935	Comox No. 2	300	128.1	14.23
No. 4	Comox	1918	Comox No. 4	250	64.5	7.17

COAL QUALITY

A limited amount of coal quality data was obtained as part of this study. Though it is not necessarily representative of the coal which may be mined, it does add to the small database of coal quality information available for the Tsable River. Some samples used for desorption were recombined with the rest of the seam after the desorption measurements and the seam analyzed as a whole. In these cases there is only an estimate of the raw ash available. For all the samples raw ash varies

TABLE 4

Coal quality data for four Tsable River samples.

type	yield	ADM%	Ash%	V.M%	F.C%	S%	MJ/Kg	F.S.I
			TRCBM10					
raw	100	0.92	34.46	28.4	37.14	0.4	20.99	3
1.6 float	58.8	0.75	14.86	32.58	52.55	0.53	29.8	7
			TRCBM11					
raw	100	1	29.96	28.62	41.42	0.67	24.1	5
1.6 float	66.6	0.58	16.79	32.65	50.56	0.71	29.22	7.5
			TRCBM12					
raw	100	0.86	23.27	31.87	44.86	0.8	26.81	6.5
1.6 float	87.2	0.66	18.79	34.61	46.6	0.75	28.57	7
			TRCBM13					
raw	100	1.11	14.64	32.58	52.78	0.73	30.04	7
1.6 float	91.8	0.72	11.26	35.75	52.99	0.68	31.35	7.5

TABLE 5

Vitrinite reflectance measurements.

Sample	depth m	rmmax%	Rmmin%	SD	Rmax%
TRCBM10	278.8	0.82	0.73	0.01	0.9
TRCBM11	296.8	0.83	0.77	0.01	0.89
TRCBM12	300.9	0.84	0.78	0.01	0.9
TRCBM13	376.2	0.84	0.79	0.01	0.88

from 15% to 55%. In four cases the desorption samples were analyzed separately and more extensive coal quality information is available. Based on the data in Table 4, Tsable River coal is a high calorific coal with excellent F.S.I values. Sulphur concentrations are moderate and it appears that it will be difficult to wash the below 0.6%. The coal washes with moderate ease and obviously contains some middlings material. Vitrinite reflectance values were also obtained for the four samples (Table 5). The Rmmax% values range from 0.82% to 0.84% and are therefore somewhat lower than previous measurements, which average 0.88%.

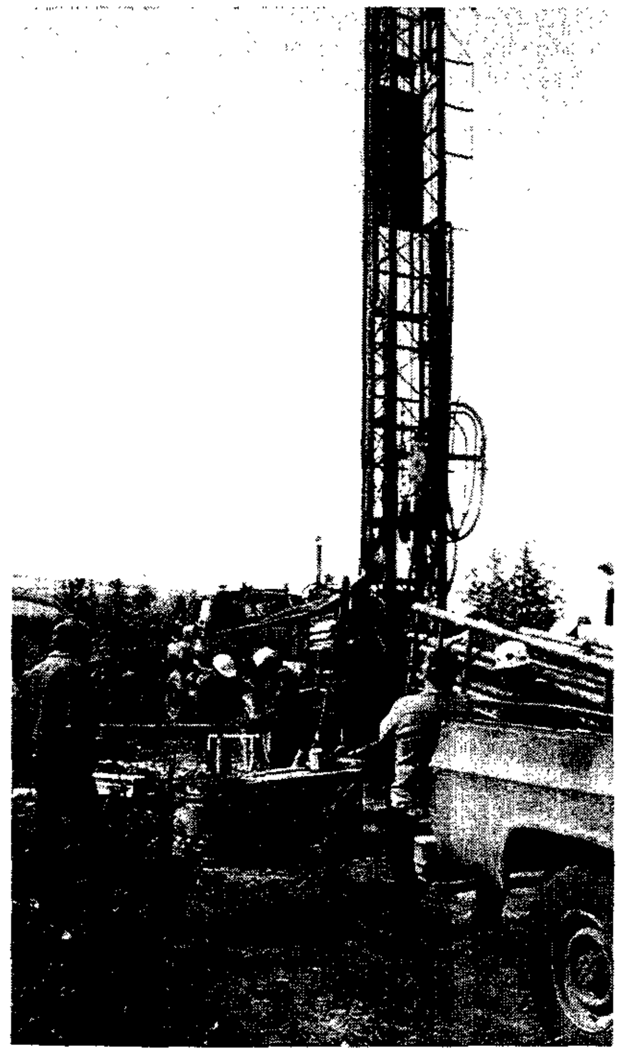

Photo 1: Drilling on the Tsable River property during the summer of 1996.

COALBED METHANE DESORPTION RESULTS

The 1996 drilling program employed a truck mounted rig (Photograph 1) to drill to the coal stratigraphy at which point a coring bit was attached and 8 cm core recovered through the coal section. Coring continued into the top of the Benson member to ensure that all the seams were penetrated. Sample collection techniques are similar to those described in Ryan and Dawson, (1994b). Samples for CBM desorption samples were collected from seams not being analyzed by the company to represent the largest possible range of depths. Generally thinner seams or single samples from larger seams were collected. The CBM canisters hold about 40 centimetres of core and were filled if possible. The diameter of the canisters is greater than 8 cm and coal was placed in a section of PVC pipe that acted as a sleeve for the sample and made it easier to insert the core sample into the canister, remembering that it is important not to get the O ring seals or valves of the canisters dirty. Most samples consisted of a number of lengths of core with some sheared coal (Photograph 2). A few of the samples were single lengths of core. Every effort was made to get the coal sealed into the canisters as quickly as possible, so as to minimize the lost time and the amount of gas escaping prior to the start of measurements. The time from starting to bring the core barrel to surface and sealing the coal in the canisters was less than 12 minutes. Once in the canister, as many desorption measurements as possible were made over the first few hours to provide good definition of the desorption curve and a good estimate of the lost gas component. Measurements are made by releasing the gas into a manometer and measuring the volume at existing atmospheric conditions.

Various ways of making lost gas corrections are discussed in Ryan and Dawson, (1994b) and in this study the method of Diamond and Levine (1981) is used. Lost gas corrections range up to 10% of the total gas content of the samples. A number of corrections, which are

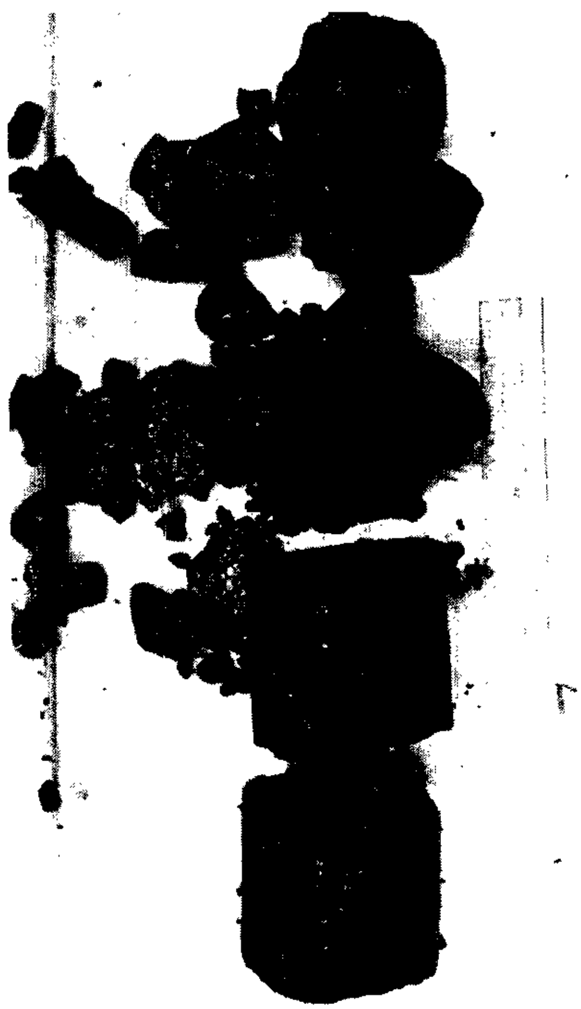

Photo 2: Typical coal sample used for desorption (sample TR96-11, scale is 15 centimetres long).

described in Ryan and Dawson (1994b) are made to the desorption data before a cumulative total desorbed gas amount can be calculated. During this study the pressure in the canister was calculated using the volume of gas desorbed at atmospheric conditions and the dead space in the canister. This is interesting because if the dead space is small and the desorption rate high then it is possible to build up a high pressure in the canister prior to releasing the gas into the manometer. Canisters were pressure checked to over two times atmospheric pressure and the measurement schedule was adjusted to ensure that pressure in the canisters did not exceed this value. Obviously for very gassy coal it is preferable to leave some dead space in the canister to safeguard against the build up of high pressures in the canister. It is therefore important to be able to make accurate dead space corrections.

A total of 13 samples were desorbed covering depths from 126 to 376 metres (Table 6) and obtained from 6 drill holes (Figure 3). Gas contents on an as-received basis range from 1.6 to 5.5 cubic metres per tonne.

GAS CONTENTS OF VANCOUVER ISLAND COALS

The gas content of the Tsable River samples (stars, Figure 4) increase consistently with depth but are less than would be predicted using either Ryan's equation (Ryan, 1992) or Kim's equation (Kim, 1977). In doing the calculations it was assumed that there was a normal geothermal gradient, a water table at 25 metres below surface and coal with 20% ash and a constant rank of Rmmax=0.83%. All available gas content data from the Nanaimo and Comox coal basin are plotted in Figure 4. The Quinsam samples (open diamonds) have lower rank (Rmmax=0.66%) and were collected from shallow depths. Their gas contents average less than 1 cubic metre per tonne. Two samples from the Comox basin (solid triangles) have higher gas contents than the two samples from the Nanaimo basin (solid diamonds).

A straight line fitted to the Tsable River desorption data (stars, Figure 4) predicts gas contents of 2.6 cubic metres per tonne at 200 metres increasing to 7.5 cubic metres per tonne at 600 metres on an as-received basis. This relationship is probably the best one to use to estimate the CBM resource potential of the southern part of the Comox basin and ventilation requirements of possible underground mines in the area. Diamond and Levine (1981) use the relationship:

$$Y = 220 \times X.$$

where Y is gas emission rates in cubic feet per ton and X is desorbed gas content in cubic metres per tonne to estimate the gas emission rates from coal in mature underground coal mines.

The shape of the desorption curve has been studied by Airey (1968) who developed an empirical equation, that predicts the shape of most desorption curves. Ryan and Dawson (1994b) illustrate a simple way of calculating Airey's constants which he designates as N

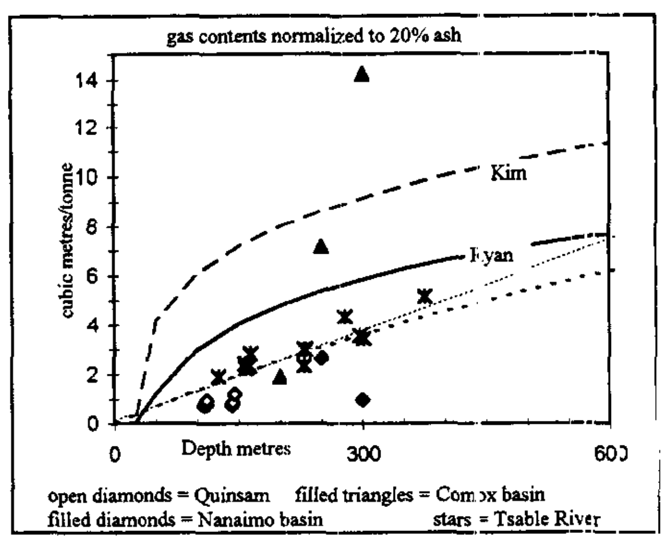

Figure 4: Gas *versus* Depth content for samples from the Tsable River area, Quinsam coal mine and Nanaimo and Comox basins. Curves illustrate predicted variation of gas content with depth using equations from Ryan (1992) and Kim (1977).

TABLE 6
Desorption data for Tsable River samples.

SAMPLE	CANISTER	SEAM	HOLE	FROM metres	TO metres	ASH	LENGTH cm	WEIGHT grams	DEAD SPACE cc	m³/tonne LOST GAS	DESORBED GAS	REMAINING GAS	TOTAL GAS	GAS ash free	HALF LIFE days	COMMENTS
TRCBM1	2	1	TR96-01	166.50	166.88	23.00	38.0	2156.5	1297	0.08	1.95	0.21	2.24	2.91	3.6	
TRCBM2	4	1	TR96-01	168.25	168.54	55.00	29.0	1965.0	1200	0.03	1.42	0.14	1.59	3.53	3	footwall coal
TRCBM3	1	2	TR96-05	127.40	127.80	20.00	35.0	2401.7	1002	0.06	1.59	0.25	1.90	2.38	1.6	
TRCBM4	5	1	TR96-05	158.60	159.00	23.40	37.0	2437.9	1149	0.07	1.95	0.30	2.32	3.03	1.4	hangingwall
TRCBM5	7	1	TR96-05	159.30	159.70	23.40	34.0	2131.0	1294	0.07	1.90	0.34	2.31	3.02	1.2	
TRCBM6	6	1	TR96-05	159.90	160.30	23.40	36.0	2174.6	1108	0.08	1.79	0.27	2.14	2.79	0.9	
TRCBM7	8	1	TR96-06	227.30	227.70	16.50	40.0	2598.3	1161	0.21	2.43	0.51	3.15	3.77	0.5	
TRCBM8	9	1	TR96-06	228.20	228.45	16.50	22.5	1521.9	1776	0.11	1.75	0.57	2.43	2.91	1.6	
TRCBM9	3	1	TR96-06	228.60	229.00	16.50	26.0	1696.0	1368	0.14	2.38	0.58	3.10	3.71	1.1	
TRCBM10	2	3	TR96-07	278.90	280.00	34.46	10.0	1100.1	2187	0.33	3.21	0.01	3.55	5.42	0.27	
TRCBM11	7	3	TR96-15	296.80	297.00	29.96	20.0	1688.5	1847.3	0.14	2.70	0.29	3.13	4.47	1.26	
TRCBM12	1	3	TR96-15	300.90	301.10	23.27	20.0	945.5	1939.7	0.12	2.85	0.34	3.31	4.31	2	
TRCBM13	2	4	TR96-18	376.20	376.54	14.64	32.0	1782.0	1789.9	0.33	5.14	0.04	5.51	6.46	0.6	full seam

and To. The value N was found not to correlate with any of the coal properties measured by him, but the constant To was found to be influenced by initial gas pressure in the sample and particle size. In this study To values from Tsable River data are inversely proportional to depth and gas content. It is difficult to separate the effects of depth and gas content, but in either case one can expect faster desorption of gas at greater depths. This is important and is not considered in the calculations by Diamond and Levine (1981). The To values for the Quinsam data do not correlate with gas content or depth and are therefore probably influenced by varying particle size. The half life of the desorption curve, which is the time taken for the first half of the gas to desorb, is easier to calculate than the value To. Half lives have a similar relationship to depth and gas content as To.

COALBED METHANE RESOURCES OF THE TSABLE RIVER AREA

In recent years a lot of attention has been paid to CBM as a resource, rather than a hazard in underground mining. There are published CBM resource assessments available for southeast British Columbia [Johnson and Smith (1991) over 300 billion cubic metres] and northwest British Columbia [Ryan and Dawson (1993) over 200 billion cubic metres]. The author estimates a resource of over 2900 billion cubic metres for northeast B.C, whereas on Vancouver Island the resource is estimated to be 17.1 billion cubic metres. To put these number is perspective it is interesting to note that at present about 21 billion cubic metres of natural gas are produced in British Columbia each year. The CBM resource numbers are large but as yet none of this resource has been recovered.

Technology for the extraction of CBM is improving but generally it is considered that there will be insufficient regional permeability to permit CBM extraction at depths greater than 1000 metres. As a first attempt at estimating the potential CBM resource to 1000 metres in the an area underlain by the Comox Formation in the Cumberland, Tsable River, Denman Island area, a potential resource area was outlined on Figure 5 which is modified from Bickford and Kenyon (1988). Coal extends at least to the western shore of Baynes Sound (Figure 3), where the coal is approximately 550 metres deep and the cover increases to 675 to 950 metres under Denman Island further to the east (Bickford, 1992).

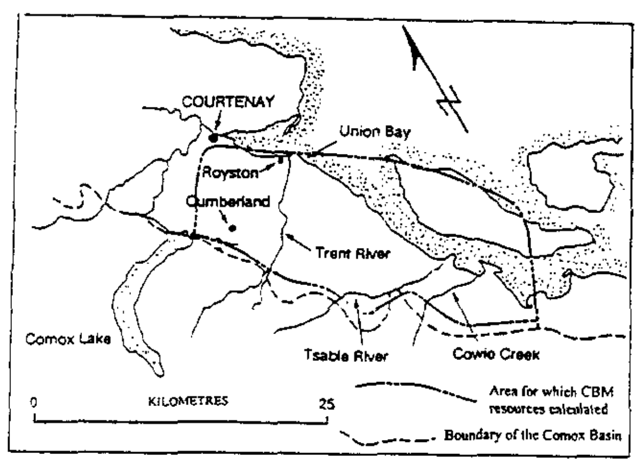

Figure 5: Regional map of the area underlain by the Comox Formation modified from Bickford and Kenyon (1988).

TABLE 7

Coalbed methane resource calculations for the southern end of the Comox basin (area outlined in Figure 5)

Resource calculation assuming linear or negative exponential increase in gas content with depth

ie curves A and B in Figure 4

Depth in metres $D=d1+(d2-d1)/L*X$ — Where L is surface expression of downdip length in metres extending northeast in Figure 6; d1 and d2 are the updip and down dip depths of the coal; X is the horizontal increment of L

(A) Gas content m^3/t $G=I+sl*D$ — Where D is depth in metres and I and sl are intercept and slope of line

(B) Gas content m3/t $G=C*(1-e^{(-lamda*D)})$ — Where C and lamda are constants defined in the input table

At depth d resource increment dr is given by

$dr=G*W*SG*T*dx$ — Where W is width of area, T is thickness of coal and SG is specific gravity

The variable G is replaced by D using equation A or B and the result integrated for values of X from 0 to L

the result is the total resource avialable

Input parameters			
L length in metres	10000	12500	2500
W width in kilometres	30		
T coal thickness metres	4		
SG specific gravity	1.2		
slope of gas content v D	0.012		
intercept of gas v depth line	0.12		
depth1 start depth d1	200		
depth2 finish depth d2	1000		
X length	10000	12500	
lamda	0.0012		
exp constant (C)	12		

Output data	linear		exponential	
Gas m^3/t at 1000m	12.12		9.3[illegible]	
X_1 to X_2	0-10000	2500-12500	0-12500	2500-12500
tonnes coal x 10^9	1.44	1.44	1.80	0.36
average m3/tonne	7.32	5.93	6.26	0.33
resource m^3 x 10^9	**10.54**	**8.54**	9.02	0.48

Seams 2 and 3 (Figure 2) range in thickness from 1.2 to 4.2 metres and 1 to 4.1 metres in the Tsable River, Cumberland areas (Cathyl-Bickford, 1992) indicating that an average of 4 metres of coal probably exists in the Cumberland member. It is assumed that the area outlined in Figure 5, which is about 300 square kilometres, is underlain by coal seams with a cumulative vertical thickness of 4 metres and that the resource is evenly distributed between depths of 200 and 1000 metres. Gas contents are predicted using the depth relationship derived from the desorption data (Figure 4). Two functions are fitted through the desorption data. The first, which is derived by fitting a line though the desorption data (curve A, Figure 4), probably over-estimates the gas content at a given depth so a second model (curve B, Figure 4) fits an exponential curve to the data. This curve probably under estimates gas contents. These curves are combined with a linear equation that relates depth of coal to horizontal projection of the down dip location and the result integrated to give the total CBM resource (Table 7). This was done using a computer spread sheet so that all parameters can be varied to illustrate the sensitivities of the resource estimate to the various parameters. The more conservative exponential model provides a resource estimate of 8.5 billion cubic metres billion cubic metres. This resource estimate cannot be converted easily into an estimate of recoverable reserves because there is no history of CBM extraction on Vancouver Island. Unlike natural gas, the percentage of a CBM resource that is economically recoverable is probably small.

CONCLUSIONS

Gas contents of coal from the Tsable River area vary from 1.6 to 5.5 cubic metres/tonne over a depth range of 127 to 376 metres. There is a consistent increase in gas content with depth and a linear extrapolation of the data indicates that gas contents at 600 and 1000 metres may be 6.2 and 8.4 cubic metres/tonne for 20% ash coal. These concentrations are high enough to make the area attractive for its CBM resource. A resource calculation for part of the southern end of the Comox basin outlines a potential resource of at least 8.5 billion cubic metres. The moderate gas contents indicate that care will have to be taken when mining the coal underground.

The Tsable River coal has a rank of high-volatile A bituminous based on four Rmmax% values that average 0.83%. A limited amount of coal quality data indicates that the coal is coking with F.S.I values that range from 7.0 to 7.5 at ash concentrations in the range of 10% to 20%. The washed coal has low to moderate concentrations of sulphur (0.5% to 0.8%) and excellent calorific value.

The Tsable River area has attractive CBM potential and may also be the site of the next coal mine on Vancouver Island. There is a strong international market for the type of thermal coal found at Tsable River. There is also an expanding market for soft coking coal which may be available from a Tsable River coal mine. There is continuing CBM exploration in Canada. The present natural gas prices may not be maintained and any increase in price will stimulate interest in potential CBM resources.

ACKNOWLEDGMENTS

Thanks are extended to the Quinsam Coal Corporation for letting me collect samples for this project. Collecting core samples for CBM desorption tests can be a time consuming and frustrating process, that requires a lot of waiting at the drill site for the seam to be intersected and the core to be recovered. The best one can hope for is good communication between the people involved in the program so that the waiting on site is kept to a minimum. In this case Steve Gardner, the consultant in charge of the program, was very helpful and provided all assistance possible. In the field Ron Swaren, the on-site geologist, remained remarkably sane through a long and far from smooth program. Finally the High-Rate Drilling Limited drilling crew helped in many ways and were rewarded with a certain amount of amusement as I tried to seal the maximum amount of coal in the minimum amount of time into various containers.

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COAL RANK VARIATIONS IN THE CABINET CREEK AREA, TELKWA COALFIELD, CENTRAL BRITISH COLUMBIA (93L/11)

Barry D. Ryan

KEYWORDS: Coal, Telkwa coalfield, coal rank, semi-anthracite, reflectance indicating surface, biaxial negative coals.

INTRODUCTION

The Telkwa coalfield is in central British Columbia, centered on the town of Smithers. It extends from north of Smithers to south of Telkwa along the Bulkley River for about 50 kilometres (Figure 1) and contains a potential coal resource of approximately 850 million tonnes (Ryan and Dawson, 1994). The Telkwa coal property, which occupies less than 10 percent of the whole field, is 15 kilometres south of Smithers and is centered on the confluence of the Telkwa River and Goathorn Creek. Coal on the property is generally high-volatile A bituminous and is considered to be an excellent thermal coal, however there is one area where the rank appears to be semi-anthracite. This report confirms the existence of this area of elevated coal rank in the Cabinet Creek area of the Telkwa coalfield and discusses some possible causes.

The geology of the Telkwa Coalfield is discussed in a number of papers (Koo, 1984, Palsgrove and Bustin, 1990) and is shown on regional geology maps of Tipper (1976), MacIntyre *et al.* (1989) and Ryan (1993). Coal-bearing rocks belong to the Skeena Group of Lower Cretaceous age and are assigned to the Red Rose Formation of Albian age and possibly also to the older Kitsun Creek Formation of Hauterivian age. Coal-bearing rocks outcrop north of Smithers, south of Smithers in the Bulkley River, north of the Telkwa River in the vicinity of Pine Creek, east and west of Goathorn Creek and at the headwaters of Tenas and Cabinet Creeks (Figure 1). Cretaceous rocks of Hauterivian age outcrop along the north east edge of the coalfield and contain only traces of coal.

EXPLORATION HISTORY

There is a long history of exploration and mining in the southern part of the Telkwa coalfield. In the Telkwa area coal seams were stripped in 1903 on Goathorn Creek, previously called Goat Creek (Dowling, 1915). In the Cabinet Creek area (previously Cabin Creek) from 1913 to 1915 the Transcontinental Exploration syndicate constructed 2 tunnels which intersected five seams of semi-anthracite (Dowling , 1915) and sank a shaft. Despite this intermittent activity there has been no mining in the area

In the period 1930 to 1970 six small underground mines and one surface mine operated in the Telkwa River-Goathorn Creek area and about 480 000 tonnes of coal were mined. A small tonnage of coal was mined in the Goathorn Creek area by Lloyd Gething during the 1970's and early 1980's.

Exploration activity at Telkwa is recorded in a number of geological assessment reports submitted to the B.C. Ministry of Energy Mines and Petroleum Resources (now part of the Ministry of Employment and Investment) and on file in Victoria (Handy and Cameron, 1982, 1983, 1984; McKinstry, 1990 and Ledda, 1992). The property was intensively explored in the period 1978 to 1989 by Crowsnest Resources Limited, when over 350 exploration holes were drilled and a large test pit excavated in the area east of Goathorn Creek. In 1989 Manalta Coal Limited acquired the property and since then has carried out a number of major programs which concentrated on the areas north of the Telkwa River, east of Goathorn Creek and east of Tenas Creek. Mineable coal reserves have now been outlined in all three areas. In 1996 as part of a major exploration program, a test pit was dug in the Tenas Creek area, which is now considered to contain the best mining potential on the property. The company is considering the possibility of developing an open pit thermal coal mine on the property. Drilling in 1995 intersected coal in the Cabinet Creek area but it appears that there are no mineable reserves in the area because coal intersections are thin and the structure appears to be complex.

STRATIGRAPHY

The Cretaceous stratigraphy on the Telkwa Coal property was divided into four units by Palsgrove and Bustin (1990). The lowest unit, which is 20 to 100 metres thick, rests unconformably on Lower Jurassic volcanic rocks of the Telkwa Formation, Hazelton Group. It is non-marine and is distinguished by an abundance of coarse clastics. It contains a single coal zone composed of up to six component seams, together referred to as Seam 1, which has a cumulative coal thickness averaging 7 metres in the Tenas Creek area (Figure 1).

Unit 2 is composed of from 60 to 170 metres of shallow marine mudstones and siltstones.

The major coal-bearing zone, comprising seams 2 to 10, is within unit 3 which averages 90 metres in thickness. The unit is composed of siltstones, mudstones and sandstones, which often overlie the seams with higher sulphur contents. The cumulative coal thickness in unit 3 ranges from 6 to 14 metres in areas considered

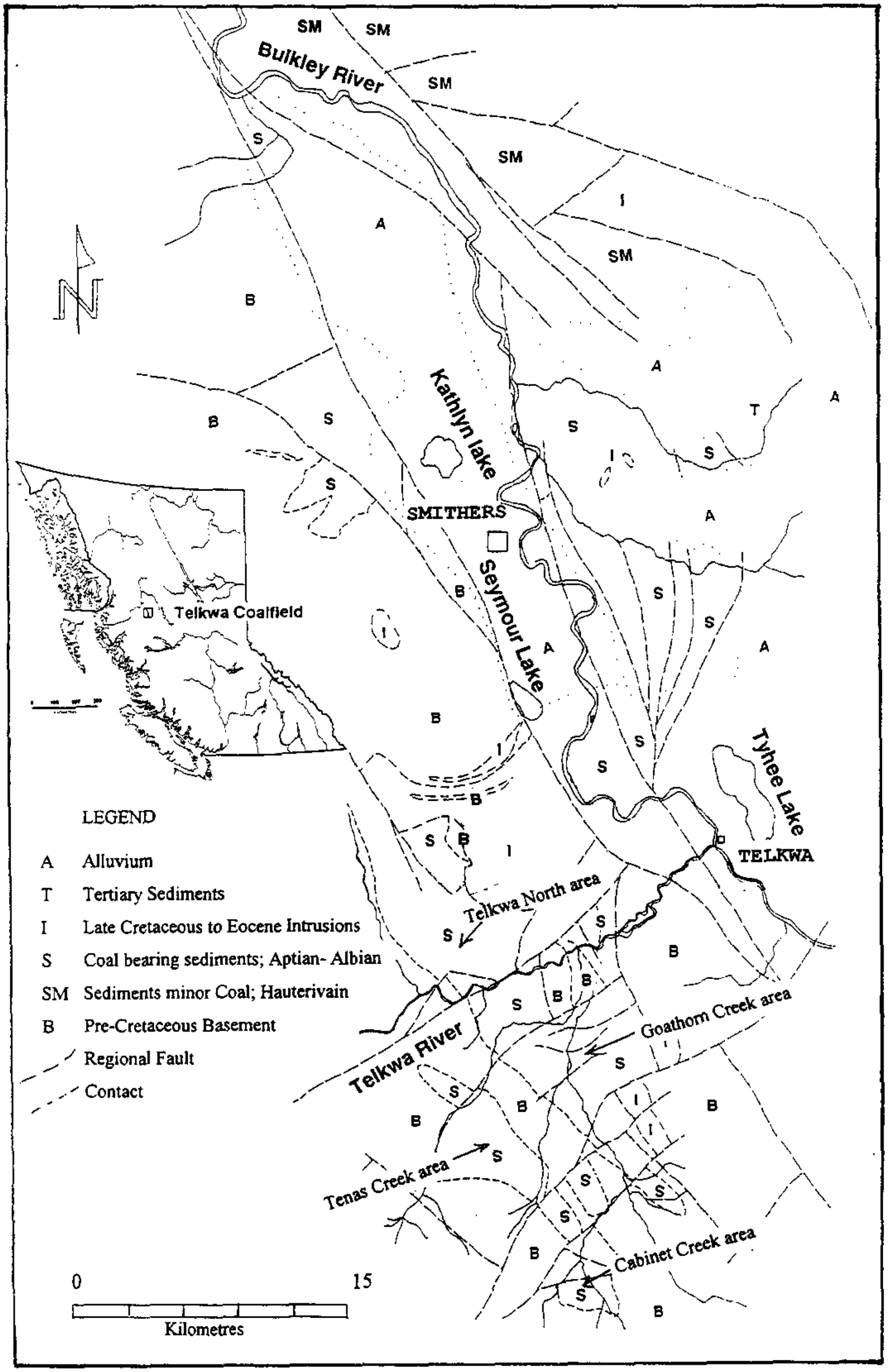

Figure 1: Geology of the Telkwa coalfield showing locations of Cabinet Creek, Telkwa North, Goathorn Creek and Tenas Creek areas.

for development. Unit 3 is overlain by the sandstone-rich unit 4 which is over 100 metres thick.

Outcrop on the Telkwa coal property is sparse. An understanding of the structural geology of the property has evolved as information from drilling and a number of geophysical surveys has became available. Bedding generally dips shallowly southeast or east and is disrupted by at least two generations of faulting. Early faults are east-dipping thrusts that offset the east dip of the sediments east of Goathorn Creek. Late steep-dipping faults trend northwest or northeast. Folding has produced open folds that trend northwest with shallow plunges.

TABLE 1

LOCATION OF REFLECTANCE DATA FROM CABINET CREEK

hole OC	Northing m	Easting m	Elev m	Dpth m	Rmax %	Rmmax %	Rint %	Rmin %
OC90-46	6047480	620980	900	0	2.2	2.2	2.04	1.74
OC90-47	6047480	620980	900	0	2.3	2.3	2.27	1.87
OC90-51	6047240	620960	920	0	2.33	2.32	2.28	1.83
OC90-52	6047160	620980	920	0	2.36	2.36	2.31	2.08
OC90-53	6047160	620980	920	0	2.44	2.44	2.34	2.04
T95R-52	6048400	620330	1005	117	1.72	1.6	1.57	1.43
T95R-56	6047210	620840	925	77	2.27	2.2	2.15	1.85
T95R-56	6047210	620840	925	119	2.3	2.21	2.15	1.9
T95R-56	6047210	620840	925	130	2.35	2.29	2.25	1.85
T95R-58	6046420	621170	990	24.5	2.75	2.61	2.55	2.15
T95R-59	6046470	620740	1005	103	2.75	2.58	2.5	2
T95D-1-1	6045540	621150	1105	61	3.3	3.03	3	2.4
T95D-1-2	6045330	621480	1115	61.2	3.35	3.1	3	2.55
T95D-1-3	6045007	621440	1125	52.1	3.3	3.32	3.2	2.7
R205*	6048353	620667	960	136		1.7		
R206*	6048779	620279	970	190		1.6		
R207*	6049330	620137	960	138		1.5		

* estimated from volatile matter

CABINET CREEK GEOLOGY

An outlier of the Telkwa coalfield outcrops in the Cabinet Creek area (Figure 1). A number of seams outcrop in the creeks and over the years there has been some prospecting and a number of holes have intersected coal.. Semi-anthracite is mentioned in the area by Dowling (1915), who describes an adit, probably located near Cabinet Creek, which intersected anthracite. Mean maximum reflectance measurements on vitrinite (Rmmax%) from drillhole and outcrop samples confirm a rank of low-volatile bituminous to anthracite (Ryan, 1992) (Table 1). The volatile content data from samples from three 3 rotary drill holes indicates a rank of at least low-volatile bituminous based on the relationship of volatile matter on a dry ash-free basis to Rmax% (Stach *et al.*, 1982). Two of these holes intersected 6 and 11 metres respectively of fine grained igneous rock in the sedimentary section (assessment report 1980). Two of the holes, 205 and 207 (Figure 2), intersected volcanic basement at depths of 167 and 173 metres giving some indication of the thickness of the sedimentary succession at Cabinet Creek. No intrusive rocks have been seen in outcrop in Cabinet or Webster Creeks, nor are any Tertiary plutons mapped in the area. They have not been encountered in any of the recent drilling in unit 1 in the Tenas Creek area and their presence in the Cabinet Creek area is unusual

The regional map (Ryan, 1993) shows a number of possible faults cutting the Cretaceous rocks in the Cabinet Creek area, which based in large part on air photo interpretation. They are shown on Figure 2 and appear to divide the reflectance data into a number of groups.

It is possible that the Cabinet Creek area represents a preserved block of the older Kitsun Creek sediments, Hauterivian to Albian in age, separated from younger middle Albian sediments to the north by a major fault. Generally the Kitsun Creek sediments outcrop near Smithers and are more sandy than the Albian sediments that host the coal in the Telkwa area (Tipper, 1976). Only traces of coal have been found in the Kitsun Creek sediments in the Smithers area by the author so this explanation is not considered likely and is not clearly supported by the palynological data. A single sample was analyzed for palynomorphs, but in part because of the high rank, the age determination was not very specific. The sample contained a Late Jurassic to Early Cretaceous assemblage of long-ranging gymnospermous taxa and a paralic to non-marine environment is suggested (Davies, 1991). This contrasts with 2 samples from Unit 1 in the Goathorn Creek area which provided ages ranging from Barremian to Albian and came from restricted marine environments.

Coal quality data (Table 2) from three 1982 rotary holes and outcrops indicate that the coal is characterized by moderate to low sulphur suggesting that it is probably not from the upper unit, which contains coal seams with higher sulphur contents. Seam thicknesses in outcrop range from 0.3 to 1.9 metres. There are over 7 metres cumulative coal outcropping in a section of a few hundred metres, which is located on Webster Creek above the confluence with Cabinet Creek (Figure 2).

TABLE 2

COAL QUALITY OUTCROP SAMPLES CABINET CREEK AREA

Sample	Type	Yield	ADM	VM%	Ash%	FC%	S%	Su%	Py%	O-%
OC90-5	raw	100	1.02	7.88	13.97	77.13	0.7	0.1	0	0.7
OC90-5	1.6 flt	91.2	1.01	9.01	9.79	80.19	0.5			
OC90-4	raw	100	0.82	10.08	11.7	77.4	1.3			
OC90-4	raw	100	0.77	9.23	22.64	67.36	0.7			
OC90-5	raw	100	1.5	10.58	25.93	61.99				
OC90-5	raw	100	1.34	8.29	17.15	73.22				
R205	raw	100	0.66	13.89	53.67	31.78				
R205	1.6 flt	15	0.61	13.7	19.26	66.43				
R206	raw	100	0.68	13.58	43.9	41.84				
R206	1.6 flt	35	0.72	14.44	23.57	61.27				
R207	raw	100	0.66	14	65.04	20.3				
R207	1.6 flt	9	0.48	19.76	11.3	68.46				

oxide analysis 90-52 1.6 float

SiO_2	Al_2O_3	TiO2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	B/A
56.51	29	1.33	5.63	2.14	0.65	0.6	0.9	1.3	0.6	0.1

ADM = air dried moisture Py = pyritic sulphur B/A = base acid ratio

Su = Sulphate sulphur Or = organic sulphur

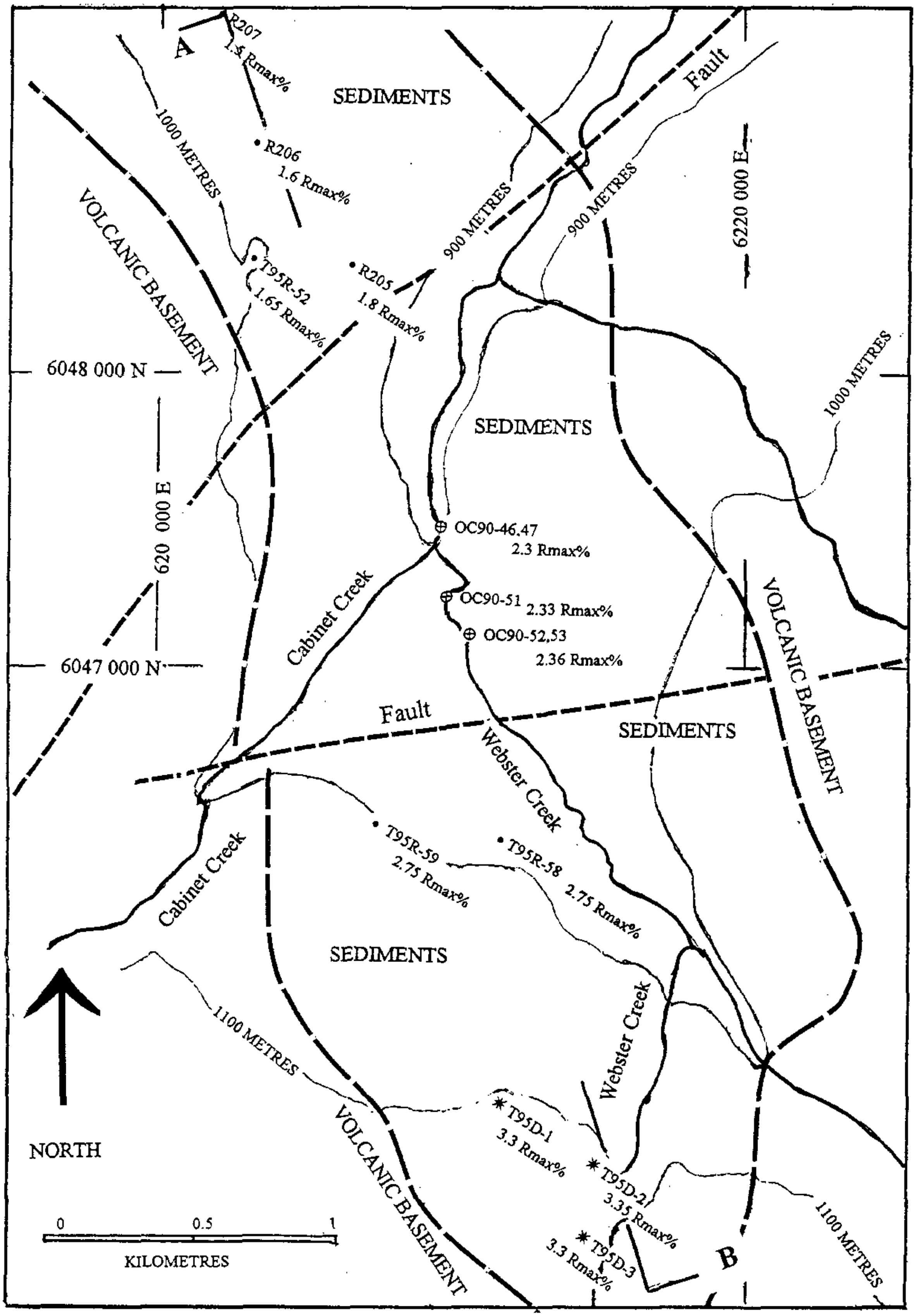

Figure 2: Geology of Cabinet Creek area showing location of Rmax% measurements.

VITRINITE REFLECTANCE MEASUREMENTS

Nine drill hole and 5 outcrop samples were analyzed. On each sample the reflectance of 50 vitrinite grains was measured using a procedure similar to that discussed by Kilby (1988), which allows the shape of the reflectance indicating surface to be described using samples composed of randomly oriented grains. The method allows the optical properties of the samples to be classified as uniaxial or biaxial positive or negative. Until recently it was assumed that most coal samples were uniaxial negative, in which case the maximum reflectance (Rmax%) of the reflectance indicating surface is equal to the intermediate reflectance (Rint%) and the value, mean maximum reflectance (Rmmax%), is a good measure of the actual maximum reflectance. When coal is biaxial negative most of the 50 maximum reflectance measurements will be less than the actual maximum of the indicatrix and only by using the technique discussed by Kilby (1988) can the actual Rmax% value be derived.

In this study each 10 reflectance measurements were bracketed by *the measurements of 2 standards.* Unfortunately neither standard has a reflectance higher than that of the Cabinet Creek samples. The data were corrected for drift and scale factors before being plotted into a reflectance *versus* bireflectance diagram and a histogram of vitrinite reflectance *versus* count (Figure 3). The shape of the reflectance indicating surface was illustrated using the R_{st} versus R_{am} plot introduced by Kilby (1988, Figure 4).

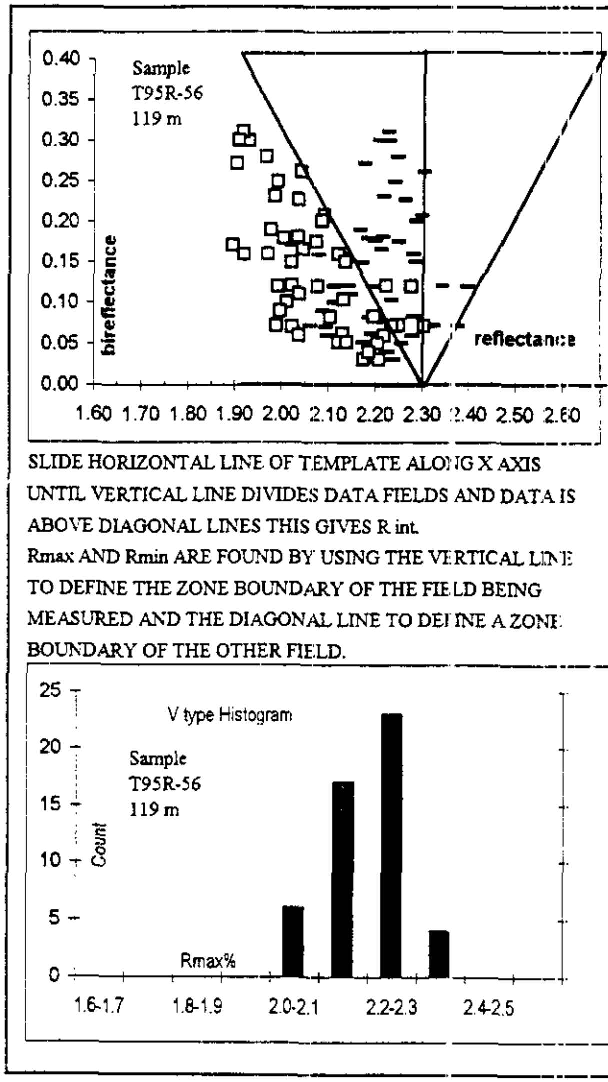

Figure 3: Example data from a Cabinet Creek sample. The bireflectance *versus* reflectance plot with template for determining Rmax% and histogram plot of V types

IMPLICATIONS OF THE DIFFERENCE BETWEEN RMMAX% AND RMAX%

The value Rmax% is greater than Rmmax% for biaxial coals and the relationship for Mist Mountain coals (Grieve, 1991) is given by:

Rmax%=Rmmax%*1.044.

Grieve suggests that the biaxiality is caused by a differential stress factor imposed upon the hydrostatic stress, which is responsible for the uniaxial component of the reflectance indicating surface. If this is the case then coals that experienced a simple burial history will have uniaxial reflectance indicating surfaces, Rmmax% will equal Rmax% and Rmmax% will be a true measure of rank. However for coals whose rank was established during folding, Rmmax% will be an underestimate of rank and the true rank will be indicated by Rmax%.

The maturity of vitrinite strongly influences the rheological properties of the coal. This is because reflectance correlates very well with the hydrogen content above a reflectance of about 1.0%. Coal with a reflectance of 0.6% to 1.0% is in the "oil window", meaning that the liptinites and vitrinites are generating oil, which may leave the coal or become trapped in the microporosity of the virtinite, which increases its reflectance and vastly improves its rheological properties. Above a reflectance of 1.0% the coal is in "the gas window" and the bitumen is broken down to gas, initially wet gas, and at a reflectance above about 1.3% to dry gas. The gas is partially adsorbed in the micro-porosity, which at this reflectance is becoming open again, and in part is lost by the coal to migrate and possibly become a natural gas resource. The evolution of coal maturity as a source for oil or natural gas is the mirror image of its evolution as a coking coal; one's loss is the others gain.

The possible under estimation of the rank of coals with biaxial negative reflectance indicating surfaces and the difference in internal structure for medium-volatile coals with biaxial or uniaxial optical properties have implications for the coking properties of coal.

It is possible that the rank of the Carboniferous high-vitrinite coals such as those from the Eastern U.S. was imposed during a simple burial history and they are uniaxial negative, whereas the more complicated maturation history of western Canadian coals ensured that they are predominantly biaxial negative. Bustin *et al.* (1986) heated and deformed samples of anthracite and was able to increase the reflectance as well as the biaxial

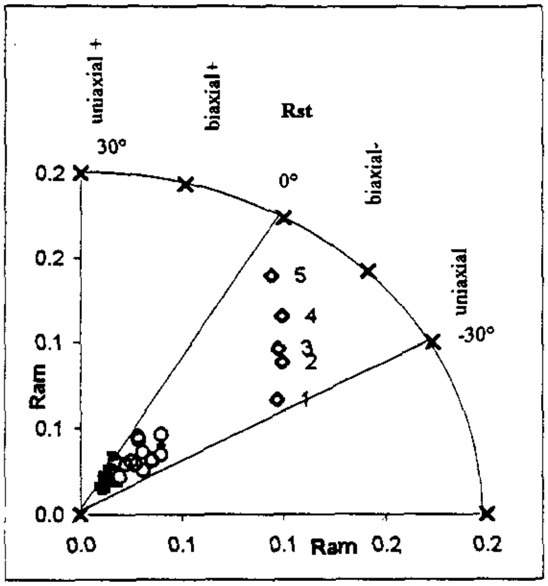

Figure 4: A R_{am} *versus* R_{st} plot illustrating the shape of the reflecting indicating surfaces for Cabinet Creek samples. Circles are Cabinet Creek data, diamonds are data from Bustin *et al.* (1986) and dashes are Seam 2 data from the rest of the Telkwa property.

negative component of the reflectance indicating surface (Figure 4). Clearly deformation does change a uniaxial negative reflectance indicating surfaces into a biaxial negative one possibly with higher Rmax% values.

Gransden *et al.* (1991) compare the chemical properties of vitrinites of identical Rmax% values from Western Canadian and Appalachian coals. Western Canadian vitrinites have approximately 2% less volatile matter and 0.1% less hydrogen than their Appalachian counterparts. But because of the probably biaxial negative nature of the western Canadian vitrinites their reflectances could have been under estimated by about 0.05%, which based on the hydrogen *versus* Rmmax% relationship in Stach *et al.* (1982) would account for about 0.06% hydrogen. If the true rank of the western Canadian vitrinites were used, then they would not appear to have a low hydrogen content.

It is difficult to relate coal molecular structure to its optical properties in the medium-volatile range because the material is still composed of large and somewhat disorganized molecules. It is possible that for two medium-volatile rank vitrinites with identical Rmax% values that the uniaxial negative vitrinite probably has a more uniform and ordered micro-porosity than the biaxial negative vitrinite. If Rmax% values are strongly correlated to hydrogen content, then both vitrinites will have the same amount of hydrogen (probably as bitumen) locked in the microporosity. One difference may well be that the biaxial negative vitrinite will soften at a higher temperature during coking making. It may be important to consider this when estimating the amount of fluidity in a coal blend required to make good coke.

The reflecting indicating surfaces of coals deformed during heating tend to be biaxial negative (Bustin, *et al.*, 1986). Compared to uniaxial negative surfaces, there is an increased spread of individual Rmax% values and the values may tend to be a bit higher. The spread in vitrinite reflectances is an important parameter in predicting Coke Stability Index in the method proposed by Schapiro and Gray (1964), which is still widely used. The method uses a number of graphs to derive constants from the maceral composition and vitrinite measurements of a coal sample. These constants are then used to provide a predicted Coke Stability Index called Coke Stability Factor. The method of Schapiro and Gray was examined in an attempt to see what the effect on Stability Factor would be of changing from a uniaxial negative to biaxial negative indicating reflecting surface. Results indicate that for coals with moderate to high inertinite contents there is little apparent increase or decrease in predicted stability index.

VITRINITE REFLECTANCES IN THE CABINET CREEK AREA

Fourteen Rmax% measurements exist for the Cabinet Creek area and in addition three Rmax% values are estimated using volatile measurements corrected to a dry ash free basis for samples from the three pre 1990 rotary holes (R205, R206 and R207, Figure 2). The data (Table 1) indicate a consistent trend of increasing rank to the south and along strike (based on a limited number of bedding measurements). There are no large intrusive bodies within 4 kilometres of the Cabinet Creek area and experience north of the Telkwa River indicates that the Late Cretaceous to Eocene quartz feldspar porphyries mapped in the area (MacIntyre *et al.*, 1989) have had little effect on coal rank. It appears that the pattern of Rmax% values is not caused by a local intrusion.

It is unlikely that the pattern of Rmax% values is caused by faults uplifting successively deeper sections of the sedimentary sequence to the south. The fault traces on Figure 2, which are copied from Ryan (1993) divide the data into three blocks and a third fault is hypothesized to separate the high reflectance measurements in the south. If the average Rmax% values in each block differ because of vertical fault displacement then if the Rmax%/100 metres gradient is known it is possible to estimate the displacement. The reflectance gradients for units 3 and 1 measured to the north (Ryan, 1992) are respectively 0.114% and 0.3 % per 100 metres. If the lower gradient is used then the average vertical displacement on the faults is approximately 490 metres and if the higher gradient is used the average displacement drops to about 185 metres. Even at a 185 metre displacement there would be considerable offset of the sedimentary/basement contact (assuming the contact is not vertical) across the faults. Except in one location there does not appear to be major offsets in the sediment/basement contact, except in one location, and consequently it seems to be unlikely that the pattern of Rmax% values is caused by faults.

If the Rmax% values are plotted against distance along traverse line A:B (Figure 2) there is a remarkably consistent trend apparent (Figure 5). The apparent

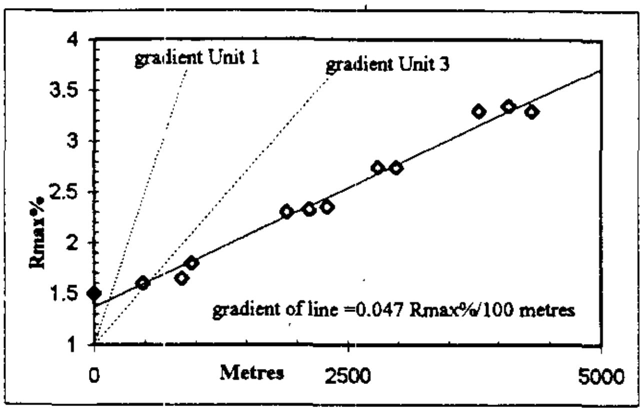

Figure 5: Plot of Rmax% data (Table 1) *versus* distance along or close to traverse line A:B (Figure 2).

gradient of Rmax%/100 metres is low and if the data represent a reflectance *versus* depth gradient then the present topographic surface intersects the iso-reflectance surfaces at a small angle. In the Cabinet Creek area the apparent reflectance gradient along A:B is 0.0471%/100 metres and if true gradients of 0.114% or 0.3% per 100 metres (Ryan, 1992)are used then this implies a dip to the north of the iso-reflectance surfaces of between 23° and 8°. Because the volcanic basement is within 200 metres of the surface to the north, it is unlikely that the iso reflectance surfaces parallel it. Therefore the high Rmax% values indicate that either the paleo heat flow from the basement was substantially greater to the south or there was substantial cover over the Cabinet Creek sediments to the south. Without any indication of the gradient no estimates of the post mid Cretaceous cover can be made.

The reflectance indicating surfaces for samples from the Cabinet Creek area are distinctly less biaxial and closer to being uniaxial negative than samples from the rest of the Telkwa property (Figure 4). Bustin *et al.* (1986) was able to increase the biaxiality of samples from uniaxial negative by straining them at high temperatures, as indicated in Figure 4 where his data are numbered in order of increasing applied strain and temperature. This suggests that coal rank at Cabinet Creek was established after the deformation whereas the coal rank of high-volatile bituminous in the rest of the Telkwa area was established prior to or during deformation.

CONCLUSIONS

The Cabinet Creek area has unusually high and variable rank compared to the rest of the Telkwa property. Indications are that the high rank relates to regional heat flow from the basement and thicker cover rather than local dikes or sills or nearby large intrusions. There is some evidence to suggest that the high rank was imposed on the coal in the Cabinet Creek area after the main deformation, which in the Telkwa area is considered to be mid Cretaceous (D. MacIntyre, personal communication 1996).

There is no clear evidence to suggest that the Cabinet creek sediments are older or different from the rest of the Skeena Group sediments in the Telkwa River area.

ACKNOWLEDGMENTS

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British Columbia Geological Survey
Geological Fieldwork 1996

COAL QUALITY VARIATIONS IN THE GETHING FORMATION

NORTHEAST BRITISH COLUMBIA

(93O,J,I)

Barry D. Ryan

INTRODUCTION

There are two major coal-bearing formations in northeast British Columbia, both of which outcrop extensively the length of the Peace River Coalfield (Figure 1). Coal seams of economic interest are generally contained in the younger Gates Formation in the southern part of the coalfield and in the Gething Formation in the northern part of the coalfield. The area where exploration interest switches formations is in the vicinity of Mount Spieker (Figure 2). Coal seams in the two formations have different coal quality characteristics. The quality and rank of coal in the Gates Formation does not reveal major variations either at the two mines or in the southern part of the Peace River coalfield. In contrast, the rank of coal in the Gething Formation ranges from high-volatile bituminous to semi-anthracite and there are significant changes in coal quality characteristics. Similar changes are present in other coal formations, such as the Mist Mountain Formation in southeast British Columbia. However they may be more extensive in the Gething Formation, and they are probably less understood because there are no mines in the formation.

TABLE 1
Jurassic and Cretaceous coal stratigraphy northeast and southeast British Columbia

NORTHEAST				SOUTHEAST	
Age	Group	Formation	Description	Formation	Group
Lower Cretaceous	Fort St. John	Hasler	Marine shale		
		Gates	Non marine sandstone, siltstone and coal.		
		Moosebar	Marine shale.		
	Bullhead	Gething	Siltstone, mudstone and coal.		Blairmo
		Cadomin	Conglomerate.	Cadomin	
Lower Cretaceous and Jurassic	Minnes		Non marine sandstone, siltstone and minor coal.	Elk	Kootenay
			Sltstone, mudstone and coal.	Mist Mountain	
	Fernie		Sandstone, siltstone and shale.	Morrisey	Fernie

This paper presents coal quality and rank information for the Gething Formation. It has been gathered from existing publications and from the coal assessment reports submitted by industry to the government. There is a lot of information in these reports that has now become public because many of the licenses covered by the reports have lapsed.

There is a long history of coal exploration in the Peace River Coalfield, and numerous informal property names have resulted. Figure 2 locates most of the major properties and identifies whether Gates or Gething coal is of more interest. At present there are two mines (Bullmoose and Quintette) extracting coal from the Gates Formation. In the last few years exploration and land acquisition have increased in areas underlain by the Gething Formation, especially in the area between the Sukunka and Pine rivers.

Resource and reserve calculations exist for most of the properties, usually based on exploration that took place in the late 1970's and early 1980's. No attempt is made here to reinterpret the geology of the various properties or to recalculate their reserves.

The Gething Formation, of Late Jurassic to Early Cretaceous age, overlies the Cadomin Formation (Table 1). Therefore it is slightly younger than the Mist Mountain Formation which underlies the Cadomin Formation in the southeast coalfields. The stratigraphy and sedimentology of the Gething Formation has been studied extensively by Gibson (Gibson, 1992). He describes the type section for the formation in the Peace River Canyon where it is 550 metres thick. It generally thins to the south and at the Saxon property at the southern end of the coalfield is only 7 metres thick. In the area of the Sukunka property (Figure 2) the economic coal seams are found in the upper and lower non-marine sections of the Gething Formation, which are separated by a marine tongue (Duff and Gilchrist, 1981 and Legun, 1987). The extent of the upper Gething coal-bearing zone is limited to the Sukunka River-Mt. Spieker area, but it has been suggested that there are other marine tongues in the Gething that wedge out to the south (Broatch, 1988).

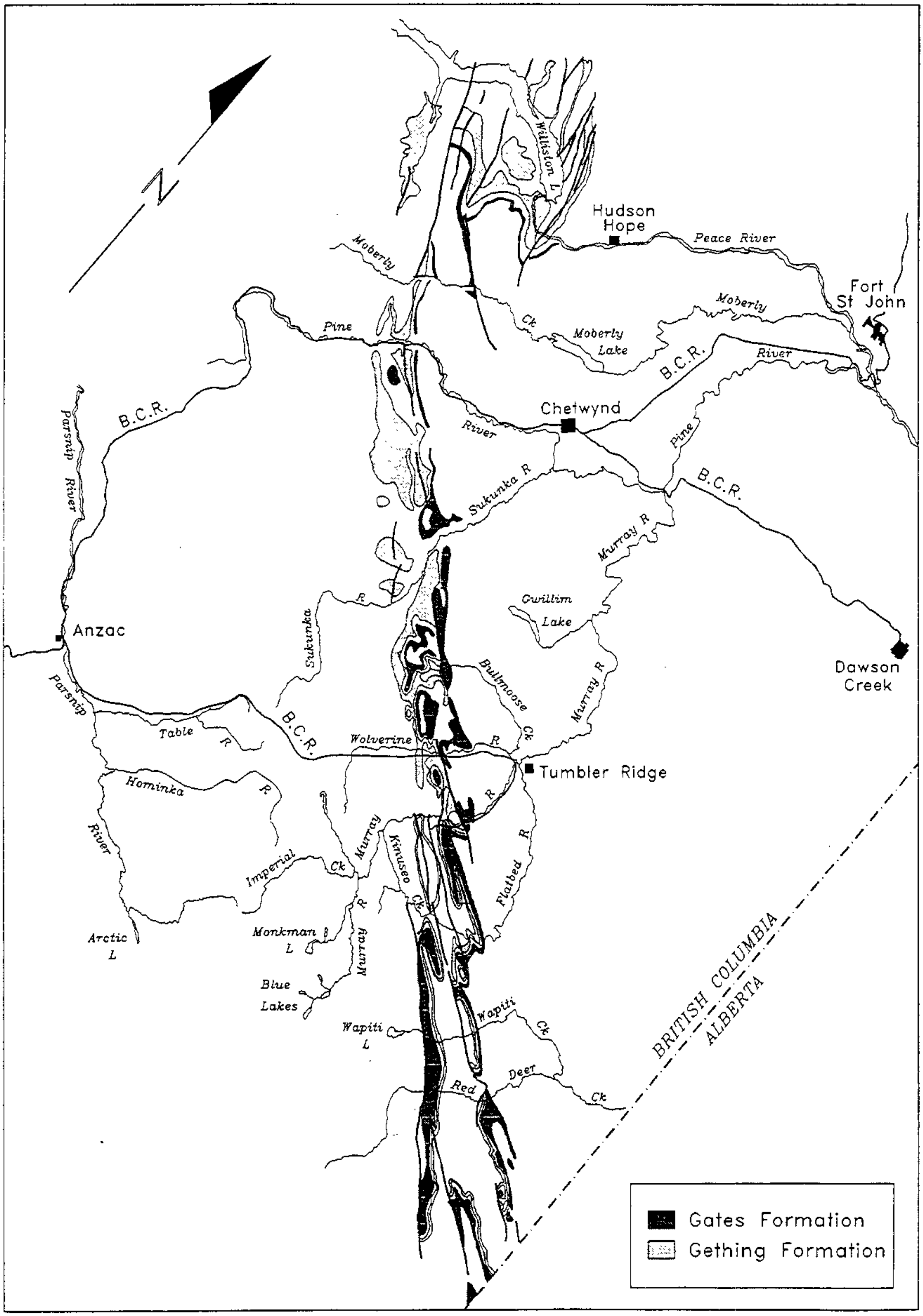


Figure 1: General outcrop pattern of the Gething and Gates formations in northeast British Columbia.

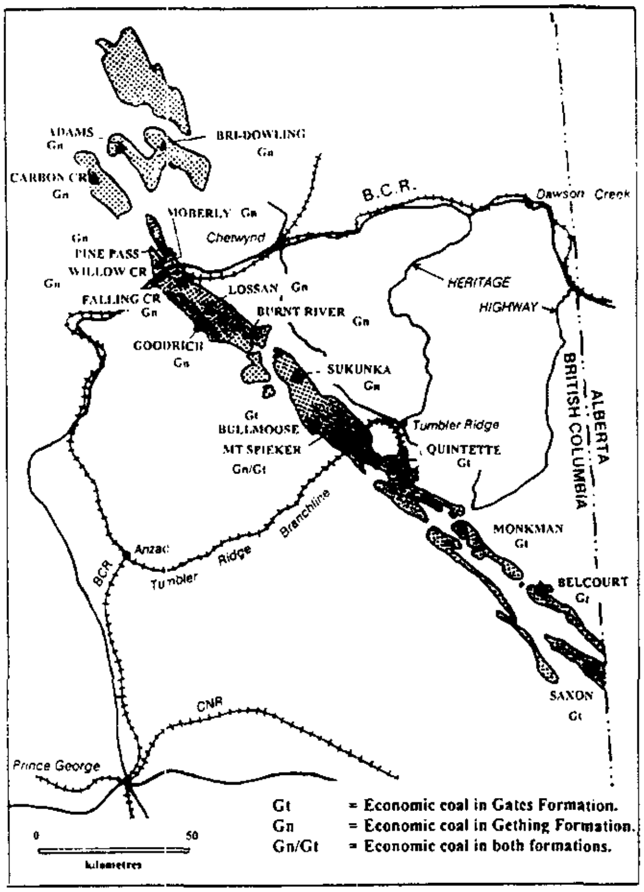


Figure 2: Coal properties in northeast British Columbia identifying them as Gething or Gates formations.

Photo 1: Macrinite in a groundmass of vitrinite B; Gething coal, Pine Pass property. Field of view 0.6 mm

COAL QUALITY AND PETROGRAPHIC CHARACTERISTICS OF THE GETHING FORMATION

One of the most conspicuous characteristics of coal seams from the Gething Formation is the ease with which they wash compared to many seams in the Gates and Mist Mountain formations. Often wash-ash contents of less than 5 percent can be achieved with high yields, as is noted in the discussions of coal quality data from the individual properties described in this paper. Another less welcome characteristic is that the free swelling index (FSI) values often appear to be suppressed and do not increase as much as expected as ash is removed. The explanation for these characteristics is found in the petrography of Gething Formation coal.

There is not a lot of data available on the petrography of the Gething Formation. Kalkreuth (1982) studied the rank and petrographic composition of a number of coals from western Canada but did not provide a lot of petrographic data for the Gething Formation. A number of other studies have concentrated on the Gates Formation (Marchioni and Kalkreuth, 1991 and Lamberson *et al.*, 1991). Some petrographic data are available from coal assessment reports and seven polished samples from the Pine Pass property were examined as part of this study.

Compared to the other major coal-bearing formations in British Columbia (Gates and Mist Mountain), Gething Formation coal has high and variable contents of inert coal macerals (inertinite). Inertinite contents can range from about 20 percent to 60 percent based on data from the Lossan property (Figure 2). This variation explains some of the range of FSI values for washed Gething coals because values will decrease as inertinite contents increase.

The varying concentrations of inertinite do not fully explain the washing characteristics of the coal. Samples from the Pine Pass property contain a lot of fragments composed of more than one maceral. A groundmass of vitrinite B or desmocollinite contains fragments of marcrinite and occasionally semifusinite and fusinite (Photo 1). Generally, compared to coals from the Mist Mountain Formation, there is much less semifusinite and fusinite (Photo 2). These macerals preserve the cell lumen which are the tunnel-shaped cavities in the

Photo 2: Macrinite and semifusinite in a groundmass of vitrinite B, Mist Mountain coal. Field of view 0.6 mm.

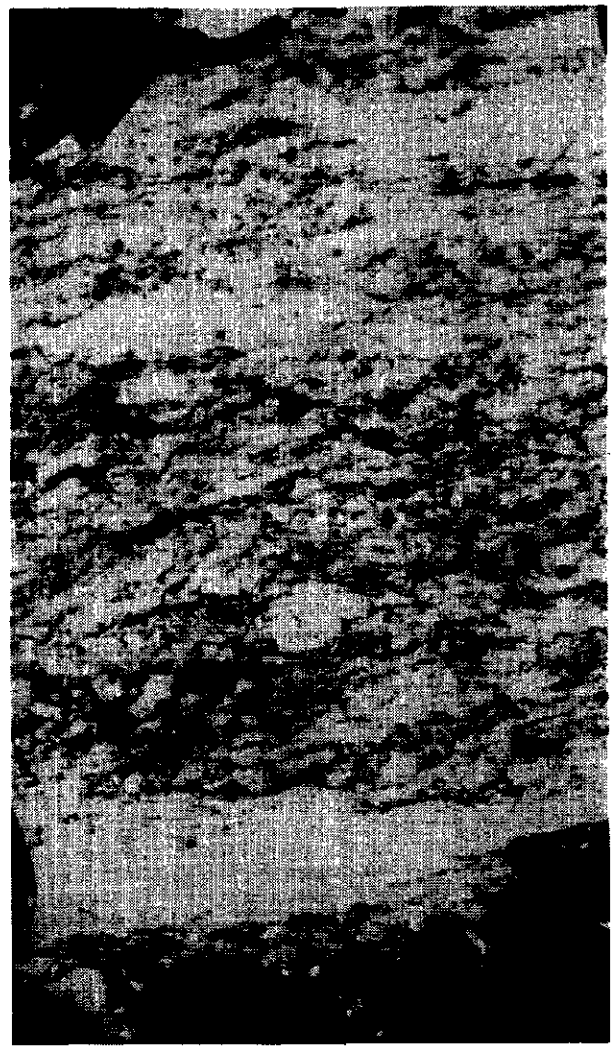


Photo 3: Finely dispersed mineral matter in vitrinite (Gelovitrinite?), Pine Pass property. field of view 0.6 mm.

original vegetation. The lumen provide ideal locations for the precipitation of syngenetic and diagenetic mineral matter, which is very difficult to liberate and remove by washing. Also there are very few dispersed mineral matter grains of extraneous origin dispersed in the vitrinite B, macrinite mixture. These grains will also be difficult to wash-out. Most of the finely dispersed mineral matter which is difficult to wash out is associated with vitrinite A or gelovitrinite (Photo 3).

Depositional Environment

Deissel (1992) describes how various coalification processes lead to the formation of the common macerals and a number of his figures are summarized in Figure 3. The high contents of inertinite found in Gething Formation coal indicate that vegetation experienced a moderate amount of humification in a low pH anaerobic environment, which softened or destroyed most cell structure, followed by periods of oxidation, fungal attack or burning in an aerobic environment. The initial period of humification must have been relatively long as most of the cell structure was destroyed and the inertinite formed was macrinite rather than semifusinite. The vegetal matter was then preserved by being submerged below the water table in an acid anaerobic environment. The term oxidation used to describe one of the processes that form inertinite is a bit misleading. The process is in part oxidation, but also involves removal of volatile constituents, such as hydrogen, with the end result being a decrease in the amount of biomass and an increase in the carbon content.

There does not appear to be much pyro-fusinite or oxy-semifusinite in the Gething coal samples from the Pine Pass property and any degrado-semifusinite that was formed was fragmented and incorporated in desmocollinite without the addition of extraneous mineral matter. A prime way that oxidized vegetation (later to form inertinite) is formed is by fungal alteration in aerobic conditions (Moore *et al.*, 1996). Often the upper part of raised mires, possibly towards the end of their development cycle, are above water and this part of the vegetation mat contains significantly more oxidized vegetation than that lower in the mire (Dehmer, 1993).

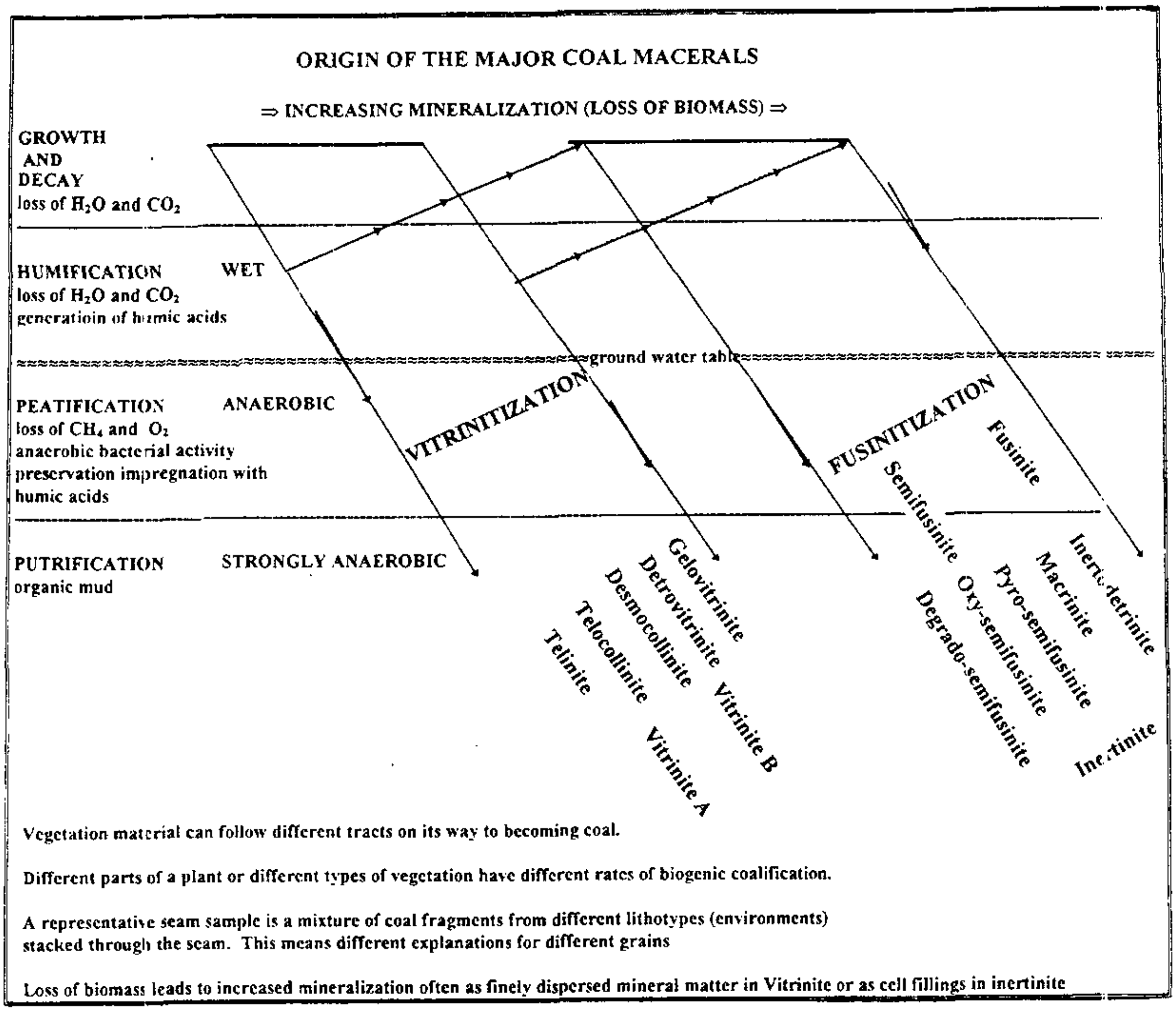


Figure 3: The relationship between various coalification processes and macerals; adapted from Deissel (1992). The vertical axis represents different environments and the horizontal axis the amount of biomass loss or time.

TABLE 2

Mineral Matter in plants and estimation of residual mineral matter in coal

plant	CaO	MgO	K_2O	Na_2O	Al_2O_3	SiO_2	Fe_2O_3	A LTA	Si/Al	B adjusted mm wt	C adjusted mm wt
cedar wood	15	4.2	12	2.8	0.4	3.8	0.3	0.47	9.50	0.03	0.03
cedar bark	22.2	1.7	4	0.7	0.4	2.8	0	10.29	7.00	0.43	0.53
myrtle wood	4.8	7.5	37.4	7.8	0.3	2	0.2	2.1	6.67	0.06	0.08
myrtle bark	10.8	6.5	13.2	3	0.3	2.3	0.1	6	7.67	0.21	0.25
myrle leaves	5.8	13.2	15.6	0.4	0.4	5.4	0.1	6	13.50	0.49	0.59
bay wood	33	8	21	7	3	0	0	2.55	0.00	0.00	0.00
bay leaves	10.1	5.4	13.2	0.3	0.4	2.2	0.1	6.62	5.50	0.22	0.27
grass	1	2.2	5.4	12.5	5.5	23	2.3	18.28	4.18	6.31	7.69
moss	3.5	17.6	1.7	30.3	3.8	15	1.5	12.01	3.95	2.70	3.30
litter	5.4	5.2	1.1	18	0.9	1	0.8	12.3	1.11	0.18	0.23
exc litter	11.8	7.4	13.7	7.2	1.6	6.3	0.51	7.59	3.94	0.72	0.88
AVERAGE	11.22	7.17	12.57	8.18	1.55	5.80	0.54	7.66	5.73	1.03	1.26

A = average mineral matter in plants. Mineral matter in coal is impoverished in Ca, Mg, K, Na with respect to plants

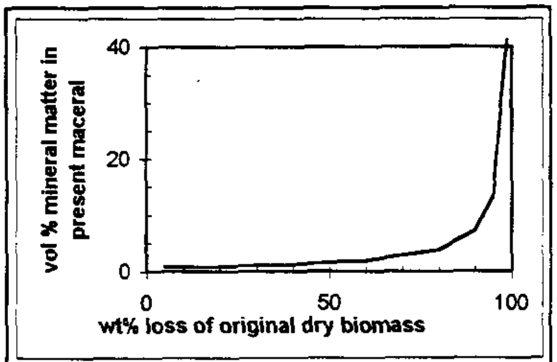
B = adjusted mineral matter calculated assuming a SiO_2/Al_2O_3 ratio of 2 i.e. 40% quartz and 60% kaolinite mixture

C = adjusted mineral matter calculated assuming only kaolinite survives with SiO_2/Al_2O_3 ratio of 1.2

		B	C
mm = mineral matter	adjusted mm in zero biomass loss sample	1.03	1.26
	effective percent after 20% evolatalization	1.29	1.58

99 % of original wt biomass must be removed to increase vol % mm to 43% LTA(low temperature ash) expressed on basis of dry sample

Dry sample devolatilizes by about 20% as rank increases from lignite to bituminuos rank



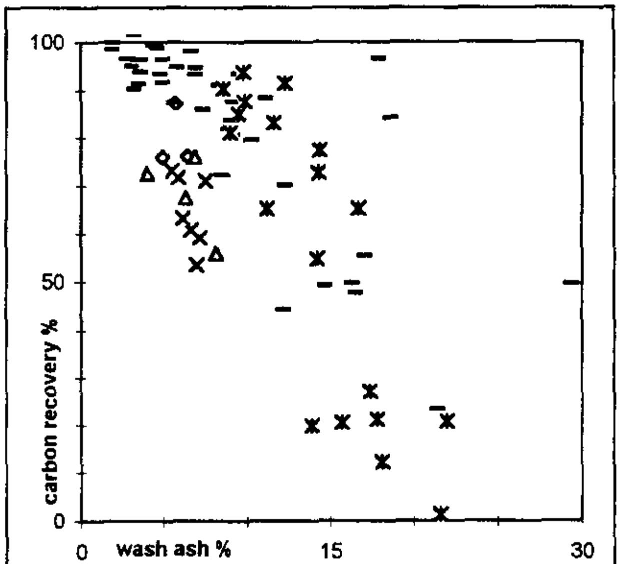
A	B	C	D	E	F
% wt loss bm	cor wt	% wt mm	% wt mm	% vol mm	% vol mm
5	4	2.04	1.67	0.99	0.81
20	16	2.41	1.98	1.18	0.96
40	32	3.19	2.62	1.56	1.28
60	48	4.71	3.88	2.33	1.91
80	64	8.99	7.46	4.54	3.74
90	72	16.49	13.89	8.69	7.21
95	76	28.32	24.39	16.00	13.46
99	79.2	66.39	61.72	48.78	43.74

A= weight loss of biomass
B = weight loss after 20% loss of volatile matter
C = new weight % of mineral matter calculated using B
D = new weight % of mineral matter calculated using A
E = C expressed as a volume percent
F = D expressed as a volume percent

Figure 4: Relationship between loss of biomass and volume percent mineral matter in the remaining coal.

This is probably one of the reasons why the upper parts of some Gething seams are inertinite rich.

The generation of desmocollinite and macrinite generally indicates a prolonged period of humification and destruction of biomass which is accompanied by an increase in the proportion of mineral matter in the remaining biomass. The amount of inherent mineral matter in vegetation varies, but Renton *et al.* (1979) provide an estimate of the average low-temperature ash content of about 8 percent for various plants from the Snuggedy Swamp (Table 2). The ash contains high concentrations of base oxides that are probably lost as the vegetation is dehydrated and coalified to bituminous coal rank. Two estimates of the mineral matter that remains, as an addition to bituminous coal, can be calculated by assuming either sufficient SiO_2 from the analyses is retained to make kaolinite or that sufficient SiO_2 is retained to make a mixture of 40 percent quartz and 60 percent kaolinite. These scenarios provide order of magnitude estimates of 1.6 percent and 2.2 percent weight mineral matter in bituminous coal after a 20 percent devolatalization caused by the increase in rank (Table 2). The relationship of the amount of biomass destroyed to the volume percent mineral matter in the resulting maceral (possibly desmocollinite or gelovitrinite) indicates that very large amounts of biomass must be destroyed to increase the volume of mineral matter (Figure 4). If the inherent ash is about 3 percent, then this implies an overall loss of biomass of about 40 percent. These numbers are only accurate to an order of magnitude because they are based on a small



dash	= Pine Pass	GETHING
Diamond	= Quintette	GATES
Star	= Coal mountain	MIST MOUNTAIN
Cross	= Elkview	MIST MOUNTAIN
Triangle	= Fording Coal	MIST MOUNTAIN

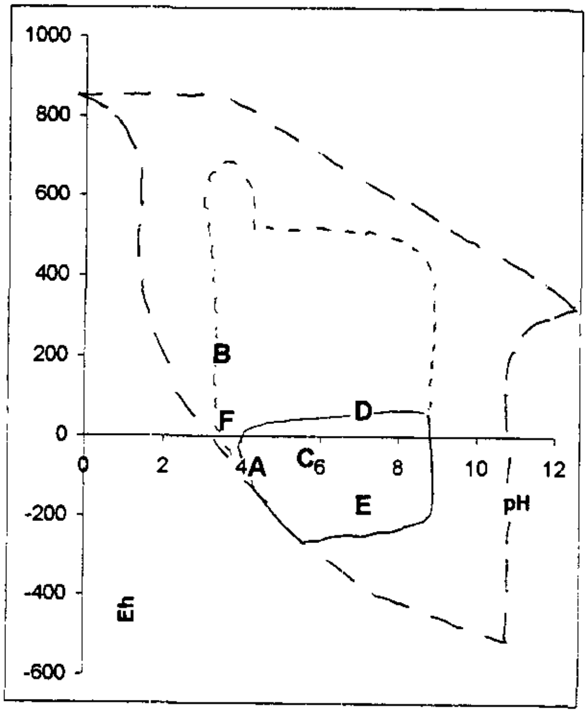
Carbon recovery = yld x (100- wash min matter)/(100 - raw min matter)

Figure 5: Relative ease of washing of some samples from Gething, Gates and Mist Mountain formations.

database, but they show that the main contribution to the amount of "difficult to remove" ash is probably extraneous mineral matter or syngenetic mineral matter deposited in lumen in semifusinite. It appears that in Gething coal neither of these sources is abundant and therefore the coal exhibits good washability. Gething coal appears to have been isolated from extraneous sources of mineral matter and to have experienced long periods of humification followed by periods of drying during which macrinite was formed.

Leckie and Kalkreuth (1990) have suggested that the Lower Cretaceous coals in northeast British Columbia formed in strandplain environments which were distant and protected from the shoreline and storm-tidal inundations. This does not specifically explain the low contents of extraneous ash or why the wash-ash contents of Gething coals are consistently lower than those of Gates coals. A plot of the relative washing characteristics of coals from the three formations (Figure 5) indicates that the Gething coal from the Pine pass property often washes to a lower wash ash with less loss of carbon than the other formations. Many of the poorer washing samples from the Pine Pass property are hangingwall and footwall samples with high raw ash contents.

Many post Carboniferous coals are enriched in inertinite with respect to Carboniferous coals. One explanation proposed by Taylor *et al.* (1989) is that the high inertinite content of Permian Gondwana coals is caused by cool climates with wet summers and dry cold winters, during which coal swamps dried out and vegetation was oxidized leading to the formation of inertinite. This environment might produce a fine



AREA	pyrite	Ash	REACT	Vit A	Vit B	INERT	Fus	Mac
A	L	L	H	H	L	L	A	A
B	L	A	L	L	H	H	L	H
C	H	A	A	L	H	A	H	L
D	A	H	L	L	H	H	H	L
E	H	L	H	H	L	L	A	A
F	L	L	L	L	H	H	L	H

CONCENTRATIONS DESIGNATED AS L=low H=high A=average
REACT=total reactives INERT= total inertinite
Vit A =vitrinite A Vit B=vitrinite B Fus=fusinites Mac=macrinite

Figure 6: A pH *versus* Eh plot showing the fields for various coal forming environments; derived from. Baas-Becking *et al.* (1960). Long dashes enclose all natural environments, short dashes enclose environments for coal formation and solid line encloses environment for pyrite formation. Gething coals probably formed in environments B and F.

layering of lithotypes similar to varves seen in clays. Possibly the cool climate and lack of ground-covering vegetation also allowed dust to blow into the swamps, which would explain the high contents of dispersed mineral matter found in some Gondwana coals. Hunt and Smyth (1989) suggest that the high inertinite/low ash Permian coals from Australian formed in cratonic basins in fresh water mires with low subsidence rates, allowing for extensive oxidation. Neither of these explanations can be used to explain the variable and sometimes high content of inertinite in Gething coals. However, it appears that conditions in Gething coal swamps were generally drier than those in Gates swamps.

It is possible to characterize Gething coals in terms of their formative swamp environment. To some extent, the contents of ash, pyrite, inerts and reactive macerals are the result of pH and Eh conditions in the swamp and the way these parameters changed over time before the onset of thermogenic coalification. All naturally occurring combinations of pH *versus* Eh are outlined in Figure 6 adapted from Baas-Becking (1960). The depositional pH and Eh conditions for various coals can be plotted and used to draw some conclusions as to their likely contents of ash, pyrite, inertinite and vitrinite. Pyrite is formed by bacterial reduction of sulphate to hydrogen sulphide in a pH environment ranging from slightly alkaline to 4 (Figure 6). The hydrogen sulphide then combines with iron to make pyrite. If this process occurs at higher pH values it will be accompanied by oxidation of biomass leading to a moderate increase in the contents of ash and inertinite. If it occurs at low pH, ash contents will be lower and vitrinite will probably predominate over inertinite. At very low, or high pH conditions pyrite concentrations will be low. High Eh values cause increased oxidation of biomass (increase in ash content) and influence the amount and type of inertinite formed. The exinite macerals are resistant to oxidation and their content may depend on how much biomass is removed, in which case high contents of exinite may be accompanied by high ash contents.

A number of possible pH, Eh environments are identified by letter in Figure 6 and possible characteristics of the coal summarized in the attached table. It is assumed that all environments have already experienced some humification. As in Figure 3, it is possible to use Figure 6 to illustrate that prior to the onset of thermogenic coalification, the biomass moves through a number of possible environments. The three peat environments discussed by Cecil *et al.* (1979) are represented by areas A, B and C in Figure 6. Roberts (1988) discusses the vitrinite and sulphur contents of Permian South African coals in which vitrinite correlates with sulphur content. He suggested that changes in Eh influence formation of inertinite and content of sulphur and the swamp environments he described can probably be represented by areas D and E in Figure 6. Renton *et al.* (1991) found a good correlation between the concentrations of sulphur and exinite in Pittsburgh coals, believed to represent an environment of pH>4.5 (area E, Figure 6). They also suggest that in very low pH environments pyrite does not form and the resultant coal may contain high proportions of bright vitrinite (area A, Figure 6).

Many Gething coals (with the exception of the Bird seam) have low concentrations of pyrite and ash and moderate to high inertinite contents. The inertinite has lost its cell structure and must have formed from biomass that had experienced extensive humification. Based on these characteristics Gething coals should plot within area F in Figure 6. Very low pH values inhibit the formation of pyrite and cause clays to flocculate at the margin of the peat swamp. They would also keep metals in solution and alter clay minerals to kaolinite which would result in coals with kaolinte-rich inherent mineral matter with low base/acid ratios.

The coal rank at the top and bottom of the Gething Formation has been estimated by Karst and White (1980) and Kalkreuth *et al.* (1989). The rank of the Gething coals was established prior to deformation and variations are related to changes in thickness of Gething plus post Gething sediments. The rank decreases to the southeast and northwest away from a central zone where the rank is semi-anthracite. This zone is situated to the east and parallel to the outcrop trend of the Gething Formation. The rank of Gething properties varies from high-volatile bituminous in the northern Peace River Coalfield to semi anthracite north of the Sukunka River.

TECHNIQUES FOR ENHANCING COAL QUALITY DATA INTERPRETATION

Coal quality characteristics of the Gething Formation are discussed below using information from coal assessment reports which are generally over 10 years old. Data available from most of the Gething Formation properties are compiled and attempts made to gain some understanding of overall trends in petrography, ash chemistry and rank. Over time the emphasis on various coal quality parameters has shifted and the challenge is to reinterpret older data in a way that is useful in terms of present day coal quality concerns. A number of approaches are discussed below that attempt to derive additional information from simple coal quality databases. Table 3 provides definitions and formulae for calculating some of the terms used in the following discussion.

Ash Basicity

The base acid ratio of coal is an important parameter used to assess the potential of a coal as a thermal or as a coking coal, yet this type of data are often not available in older coal quality data sets of. Estimates of the amount of non-combustible volatile matter derived from ash, using volatile matter *versus* ash plots and calorific value (CV) *versus* ash plots, provide some information on ash basicity. Ash basicity influences coke strength after reaction (CSR) and the fouling characteristics of ash in boilers. Generally an ash with low basicity is preferred for coking and thermal coals.

Useful information can be obtained from volatile matter (VM) data corrected to zero ash, using either the dry-ash-free calculation (VM daf) or the mineral matter-free basis (VM dmmf) calculation (Table 3). The mineral matter-free calculation attempts to correct for the

TABLE 3

Formulas used in calculating coal quality parameters.

VOLATILE MATTER (dmmf)
VM dmmf=100-FC dmmf
VM = volatile matter   dmmf = dry mineral matter free
FC dmmf=(FC-.15S)/ {(100-(m+1.08A+.55S)}*100
FC = fixed carbon   m = moisture
A = ash%   S = sulphur%
combine and simplify 1 and 2
VM dmmf=100*(VM-.08*A-0.4*S)/(100-M-1.08*A-0.55*S)
MINERAL MATTER TO ASH
Parr equation mm=1.08*A+0.55*S
mm = mineral matter

loss of weight when mineral matter is ashed and when pyrite (FeS_2) in the sample is oxidized to Fe_2O_3 and SO_2. The non-combustible components of the mineral matter that gassify when coal is heated, become part of the volatile matter measurement. If the dmmf correction is applied successfully, then a plot of VM dmmf *versus* ash will be a horizontal line. The daf method corrects only for the dilutant effect of ash and a plot of VM daf *versus* ash will provide a line with positive slope, that intersects the zero ash line at a good estimate of the VM daf at zero ash. The line has a positive slope because of the contribution of non-combustible volatile matter derived mainly from the decomposition of carbonates as the mineral matter is ashed. Magnesium carbonates lose the most weight on oxidation followed by calcium and finally iron carbonates. A simple experiment was conducted to quantify the decomposition of calcite into CaO and CO_2 when heated in an ash analysis. A coal sample was doped with 5 percent calcite and the results indicated that about half the calcite decomposed into CO_2 and CaO when the sample was ashed.

A point on a VM daf (y axis) *versus* ash (x axis) plot is moved to the left by an amount equal to the weight difference, mineral matter minus ash, because the X axis is plotted as ash not mineral matter. The point is raised by the same amount because this loss of weight is added to the volatile matter. Consequently the slope of the line is:(mineral matter - ash) / (ash)

This reduces to: (K-1)

where: K = (mineral matter)/ash.

The slope of the line increases as the amount of Ca, Mg and Fe carbonate material in the sample increases. Therefore, for seams low in pyrite it is a rough indication of the basicity of the ash.

The basicity of ash can also be estimated from plots of CV *versus* ash. When coal is combusted for a CV measurement there are various reactions that occur in the ash. These include endothermic break down of Ca, Fe and Mg carbonates to oxides of Ca, Mg and Fe and CO_2, and exothermic oxidation of pyrite to SO_2 and Fe_2O_3. The net amount of heat used when the mineral matter is transformed to ash is approximated by the projected ash concentration at zero CV. If the mineral matter was totally inert the ash value would be 100 percent at zero CV, but as the mineral matter looses weight and uses heat in the process, the ash value at zero CV is reduced to below 100 percent. Figure 7 illustrates the relationship between VM daf slope and ash at zero CV to ash basicity for a number of Gething properties, for which ash-oxide chemistry data are also available. Based on these relationships, if VM daf slope is high and ash at zero CV is low, then the ash base/oxide ratio is probably high.

The use of ash, VM and CV data to estimate ash basicity will not permit a quantitative determination of the ratio but the method discussed above will indicate trends and may be useful in the absence of more detailed information.

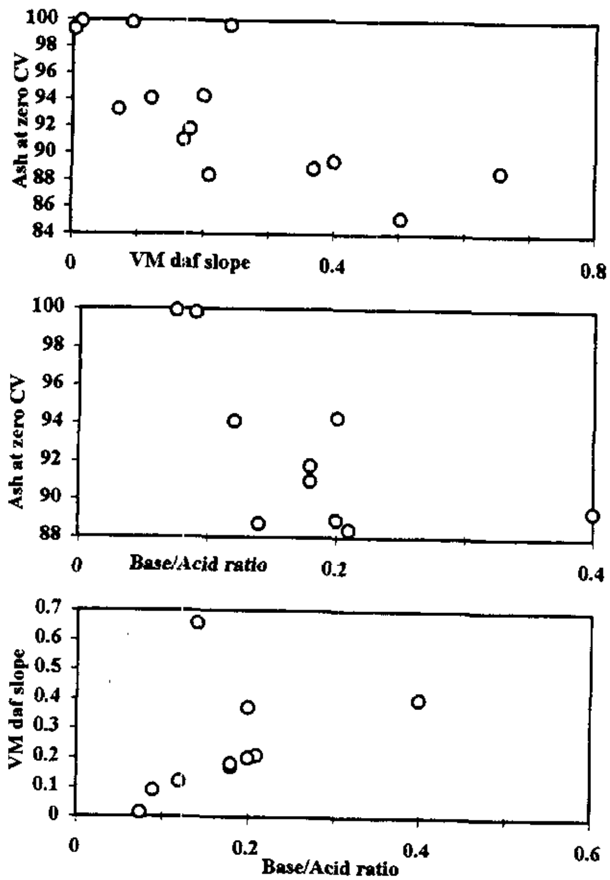
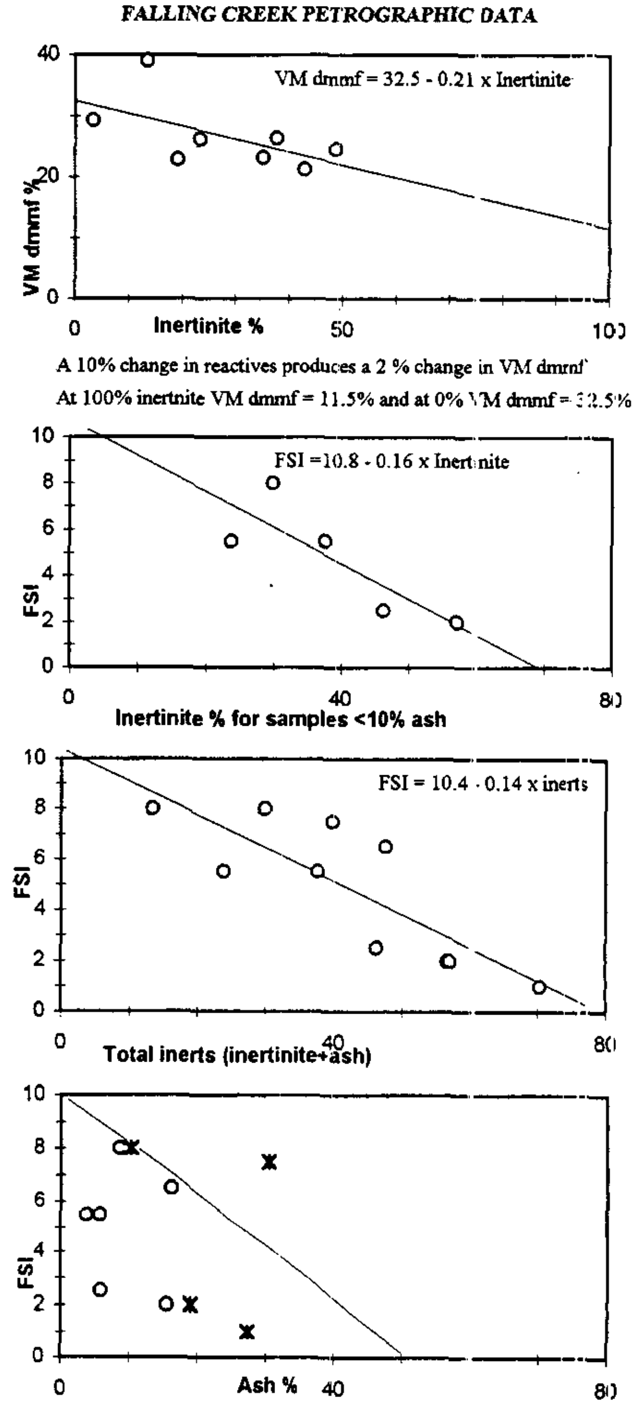


Figure 7: Relationship between slope of a VM daf *versus* ash plot and CV at zero ash to base/acid ratio.

Sulphur and oxide analyses

Plots of sulphur *versus* ash are provided for a number of properties. These are useful because they give a preliminary indication of whether the sulphur is in the coal or ash and how easy it may be to wash out. The same principle can be applied to ash-oxide analyses (Table 4). If oxides have a positive correlation with ash then they will be removed when the coal is washed and if they have a negative correlation then they will concentrate in the coal. A lot of information can be extracted from a correlation matrix of oxides and ash concentrations. For example a negative correlation of CaO and ash implies that there is calcite associated with the coal. A positive correlation of Fe_2O_3 with S indicates the presence of pyrite where as a negative or zero correlation may indicate the presence of organic sulphur and siderite.

A negative correlation of Fe_2O_3 with ash probably indicates the presence of siderite. If base-acid ratios have a negative correlation with ash then there are probably CaO, FeO or MgO carbonates associated with the coal which are difficult to remove.



star = high VM dmmf   diamond = low VM dmmf

2 points low FSI and high VM dmmf oxidized and removed from Vm dmmf versus inertinite plots

Figure 8: Relationship between VM dmmf, FSI and inertinite in coals from the Falling Creek property.

Free Swelling Index (FSI)

The free swelling index is a good preliminary measure of the agglomerating potential of a coal. It also has been used as an indicator of oxidation although it reflects more correctly variations in the content of inert

TABLE 4

PART OF A CORRELATION MATRIC FOR OXIDE AND ASH CONCENTRATION DATA FROM SOME GETHING PROPERTIES

		ash	S%	SiO_2	Al_2O_3	Fe_2O_3	TiO	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	B/A
Carbon Creek	ash	1.000	0.02	-0.20	0.31	-0.05	-0.22	0.04	-0.15	0.03	-0.59	0.15	-0.01	-0.08
	B/A	-0.08	0.66	-0.90	-0.74	0.99	-0.75	-0.39	0.48	0.90	-0.06	-0.39	0.67	1.00
Falling Creek	ash	1.00	0.58	0.67	-0.96	0.28	1.00	-1.00	-0.94	-0.69	-0.98	0.97	-0.91	-0.42
	B/A	-0.42	-0.98	-0.96	0.67	0.75	-0.38	0.34	0.71	0.95	0.59	-0.62	0.76	1.00
Goodrich	ash	1.00	-0.32	0.23	-0.50	0.21	ND	-0.42	-0.17	-0.08	-0.26	0.03	-0.25	0.06
	B/A	0.06	0.21	-0.84	-0.42	0.90	ND	-0.08	0.51	0.46	-0.05	-0.27	0.61	1.00
Willow Creek	ash	1.00	ND	0.43	-0.54	0.19	-0.51	-0.51	-0.43	-0.18	-0.69	0.14	-0.38	-0.15
	B/A	-0.15	ND	-0.93	-0.55	0.89	-0.33	0.09	0.71	0.97	0.39	-0.52	0.78	1.00
Sukunka	ash	1.00	-0.03	0.56	0.41	-0.18	0.16	0.32	-0.50	-0.67	-0.61	0.46	-0.75	-0.45
	B/A	-0.45	0.56	-0.84	-0.46	0.83	-0.64	-0.29	0.35	0.09	0.28	-0.56	0.41	1.00
Bri-Dowling	ash	1.00	0.12	0.01	0.06	-0.01	0.16	-0.20	-0.02	-0.10	-0.39	-0.03	-0.25	0.02
	B/A	0.02	0.55	-0.12	-0.71	0.88	-0.77	-0.09	0.56	0.69	-0.27	-0.28	0.56	1.00

material in coal, which includes ash, inertinite and oxidized vitrinite. Petrographic data from the Falling Creek property illustrates the relationship between inertinite content and FSI for medium-volatile coal (Figure 8). For samples with low and near constant ash contents the relationship between FSI and inertinite content is:

FSI =10.8 - 0.16 x inertinite

If the same plot is constructed using inertinite plus ash as the X ordinate a similar relationship is derived:

FSI = 10.4 - 0.14 x total inerts

indicating that petrographic inerts and mineral matter have the same effect on FSI. Both relationships indicate that if coal contains approximately 75 percent inert material then the FSI value will be zero and that approximately zero inert material is required to obtain an FSI value of 10. A similar relationship plotted by Price and Gransden (1989):

FSI = 15.9 - 0.29 x total inerts

predicts zero FSI at 55 percent total inerts and an FSI value of 10 at 20 percent total inerts.

A bounding line on the FSI *versus* ash plot (Figure 8) indicates that FSI is zero at 45 percent ash, which implies that the 45 percent ash sample with zero FSI has 75 percent -45 percent = 30 percent inertinite. When the equation of the bounding line on a FSI *versus* ash plot is not the same as that for the FSI *versus* inertinite plot then each FSI/ash point along the bounding line has a different inertinite content in the coal. Inertinite contents decrease to the top left of the latter plot. In fact it is possible to use the inertinite *versus* ash relationship to contour an FSI *versus* ash plot in terms of inertinite content in the coal (Figure 9). Points plotting to the left and below the bounding line are either enriched in inertinite or oxidized vitrinite. The relationship in Figure 9 is extremely schematic but probably gives some indication of the variations in petrography for the Gething Formation. The reactives/inerts ratio for Mist Mountain coals often increases as the ash decreases indicating that much of the finely disseminated ash is in the inertinite material, similar, but weaker relationships exist for the Gething Formation.

Inertinite content can be estimated from VM dmmf values because they increase as the inertinite percent decreases, as illustrated using data from the Falling Creek property (Figure 7) and Price and Gransden (1989,

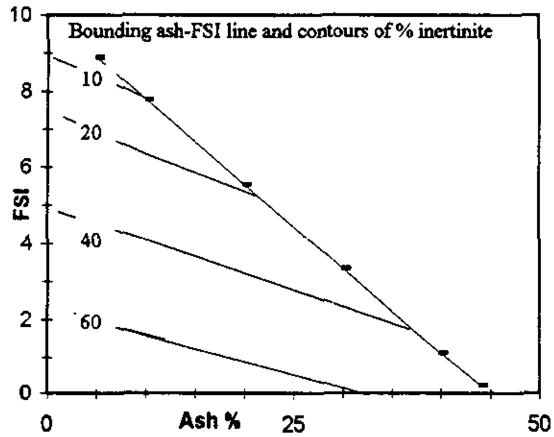


Figure 9: Schematic diagram illustrating variations of inertinite content within a FSI *versus* Ash plot.

Figure 10). Price and Gransden's data are from medium and low-volatile coals and VM dmmf values are 31.3 percent and 27.8 percent at 0 percent inertinite. The Falling Creek data from a medium-volatile coal predict a VM dmmf value of 32.5 percent at 0 percent inertinite. Unoxidized coal in which the FSI is suppressed by an increased inertinite content will have low VM dmmf values. A plot of FSI *versus* ash in which VM dmmf values are posted can be used to illustrate this effect (Figure 10). Data from unoxidized samples which plots in the lower left corner of FSI *versus* ash plots (Figure 10) will have low VM dmmf values (high inertinite contents) and data in the upper left of the plot will have higher VM dmmf values (lower inertinite contents).

Natural oxidation increases the volatile content and VM dmmf values of coals. This means that samples which plot in the lower left corner of an FSI *versus* ash plot and have markedly high VM dmmf values are oxidized, whereas if they have low VM dmmf values then they are enriched in inertinite. Data from Price and Gransden (1989) illustrates this effect (Figure 10) which may be a useful way of identifying oxidized samples using only proximate and FSI data. Oxidized samples are plotted with filled squares in Figure 10 and the VM dmmf values clearly identify 4 of the 5 oxidized samples.

Calorific value is decreased by oxidation but is not as sensitive to it as FSI. This is illustrated in a CV *versus* ash plot (Figure 10), in which the oxidized sample plots

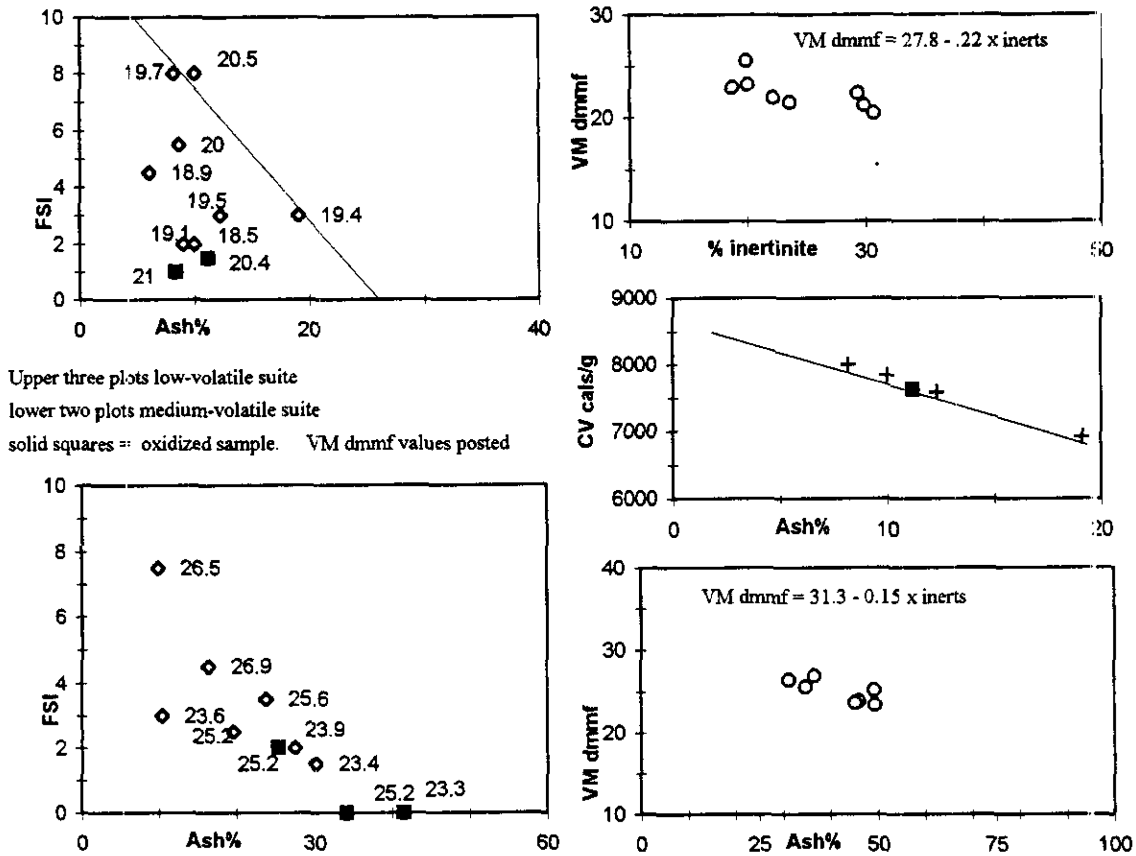


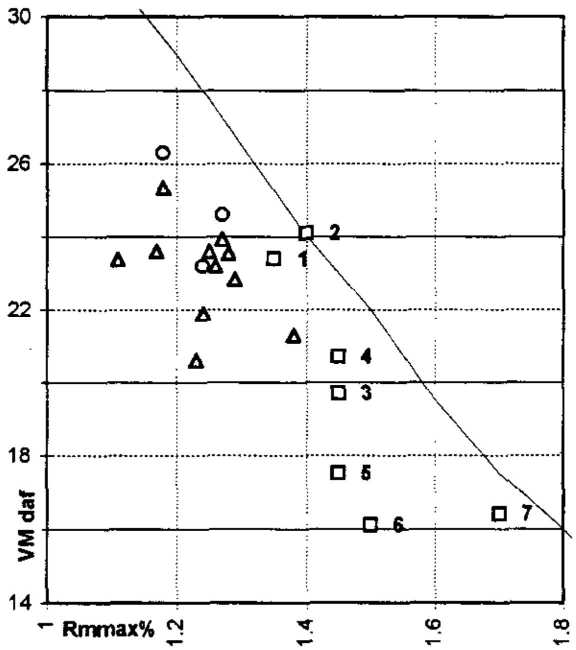
Figure 10: Use of VM dmmf values on an FSI *versus* ash plot to identify oxidation, data from Price and Gransden (1989).

slightly below the line. It is also important to realize that the heat content of pure carbon is about 8160 cals/g whereas that of methane is 12474 cals/g. Therefore, a reactive maceral composed of 32 percent volatile matter (from a medium-volatile bituminous rank coal) has a heat value about 8 percent greater than that of an inert maceral composed of 11 percent volatile matter. As a consequence, a sample with low FSI may plot below the best fit line through data on a CV *versus* ash plot because of high inertinite content. In fact a 20 percent increase in inertinite content can result in about a 150 calorie drop in heat value.

Estimation of Rank

Volatile-matter data (daf at zero ash basis) can be used to predict rank based on the assumption that coal samples are composed mostly of vitrinite. This is a valid assumption for most Carboniferous coals but not for Cretaceous coals. Stach *et al.* (1986, page 45) provides a table of ASTM criteria used to define coal rank. The equivalent mean maximum reflectance of vitrinite values (Rmmax percent) and VM daf values in the table provide a curve that can be used to predict the rank of typical eastern American coals, which contain over 80 percent reactive macerals (Figure 11). The use of VM daf values to predict rank will not work as well for Cretaceous coals because they have higher inertinite contents and lower VM daf values than Carboniferous coals of similar rank. Therefore rank estimates will generally be too high. At any rank, the volatile content of reactive macerals is higher than that of inert macerals and the volatile content of coal is a blend of these two values diluted by any ash present. If Rmmax percent and VM dmmf data are compared to a standard curve provided by Stach *et al.* (1986), then it is possible to estimate the relative degree of inertinite enrichment in the samples based on the distance points plot below the curve (Figure 11). Petrographic data (Falling Creek property, Figure 8) indicate that a 10 percent increase in inertinite content causes a 2 percent decrease in VM dmmf at constant Rmmax percent, which for the property is about 1.2 percent. A VM dmmf value of 32 percent (100 percent reactives) confirms the rank of Falling Creek coal as about 1.2 percent Rmmax, but most of the other data plot below the line implying inertinite enrichments of up to 40 percent. This result is in general agreement with the petrographic data available for the property.

The use of volatile matter to predict rank is complicated by evidence that the volatile content of vitrinite from western Canadian coals is lower than that of vitrinite from Carboniferous coals of the same rank from the eastern United States (Gransden *et al.*, 1991). It



Curve derived from Stach *et al*. (1986) VM daf versus Rmax%
Squares = Willow Creek data with seam number
Triangles = Pine Pass data Circles = Falling Creek data
A 2% change in VM equates to a 10% change in inertinite content

Figure 11: ASTM relationship of VM daf to Rmmax percent and estimation of inertinite content.

appears that vitrinites from British Columbia coals of the same reflectance as vitrinites from Appalachian coals have higher carbon and lower hydrogen contents (Price and Gransden, 1987), indicating that vitrinite reflectance may be in part controlled by the micro porosity of the maceral. In fact there is evidence that the reflectance of vitrinite is positively correlated with the amount of inertinite in a sample (Mastalerz *et al*., 1993 and Kalkreuth, 1982). This is apparent in a summary of petrographic data available for some Gething properties (Figure 12) in which there is a negative correlation of total reactives with Rmmax percent. Kalkreuth (1982) suggests that hydrogen compounds migrate from the liptinite macerals into vitrinite and that this lowers the Rmmax percent value of the vitrinite. He found a negative correlation of liptinite content with vitrinite reflectance. It is also possible that vitrinite in inertinite-rich coal suffers a degree of fusinization, which increases its reflectance and lowers its volatile content. This means that, even if a Cretaceous British Columbia coal sample has a high vitrinite content, the predicted rank may still be too high if it is derived using a VM daf value and data from Stach *et al*. (1986). Care should be taken when interpreting the fine detail of reflectance depth profiles; they may indicate more about petrography and swamp conditions than heat flow during coalification.

COAL QUALITY CHARACTERISTICS OF SOME GETHING FORMATION PROPERTIES

Pink Mountain property

Pink Mountain, which is about 160 kilometres northwest of Fort St. John in the Halfway River map area, is the most northerly property of economic interest. It has been prospected on a number of occasions since 1944 and was drilled in 1971 (Guardia, 1971). The Gething Formation is represented by 310 metres of non-marine sediments containing three coal bearing units. Coal seams up to 6.7 metres thick were found, but. there is evidence of structural thickening of seams. The coal is medium-volatile bituminous in rank based on a VM dmmf calculation of 24.6 percent from a drill core sample (Table 5). The coal has coking potential based on a single FSI measurement of 5.5. However it has high and variable sulphur contents (0.47 percent to 7.1 percent) with very high organic sulphur contents estimated to be up to 6 percent. It has been suggested that the sulphur comes from sour natural-gas leaking from an underlying Mississippian natural-gas reservoir. There is an extensive burn zone in the area which may have been sustained by the leak. It is not clear if sulphur in hydrogen sulphide from natural gas can become organically bound to the coal. However the gas may have increased the sulphur content of the coal after deposition. Coal with high organic sulphur cannot be used for coke making and has a decreased value as thermal coal. High organic sulphur contents have not been found in Gething coal to the south but much of the Gething Formation is underlain by natural-gas fields and the experience of Pink Mountain should be kept in mind.

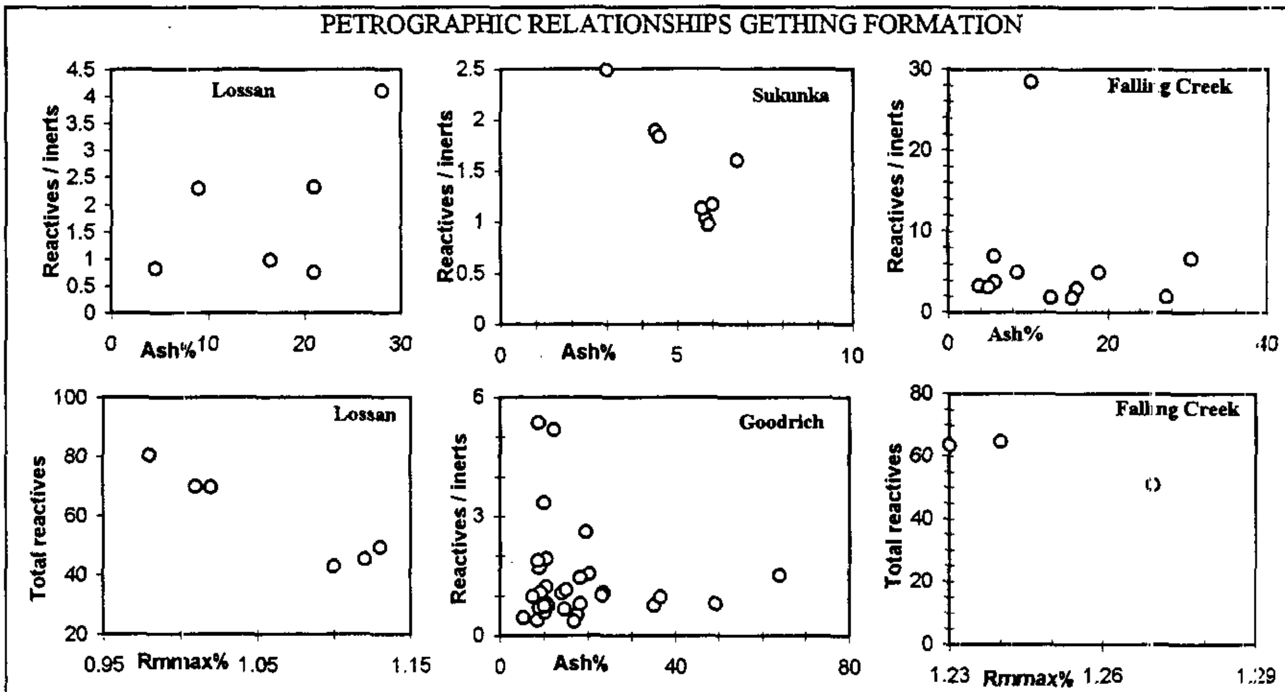
Bri-Dowling property

The Bri-Dowling property was explored extensively by Utah Mining in the 1970's (Duncan, 1980). It is in the Peace River Canyon area, possibly the first area prospected for coal in western Canada. McKenzie (1801) reported coal in the coalfield in 1793 and a number of small mines operated in the area in the early 1900's; though all have since closed.

TABLE 5

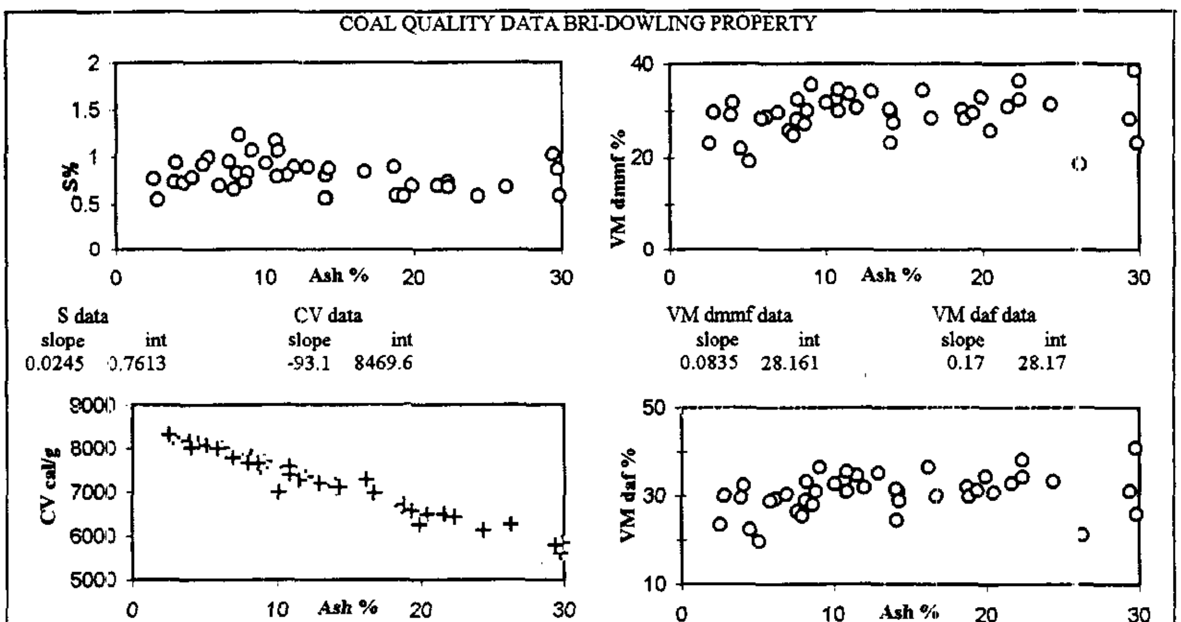
COAL QUALITY DATA PINK MOUNTAIN

				dry basis						VM
hole	seam	thick	H_2O ar	ASH	VM	FC	S	CV	FSI	mmf
trench	p1	6.7	11.02	9.97	34.5	55.5	5.2	5328		29.3
trench	p1		5.62	5.31	33.2	61.5	5.9	6153		28.7
trench	p2	1.07	12.8	11	35.4	53.6	0.8	4611		32.0
trench	p10	3.05	12.67	7.7	33.9	58.4	6.4	6802		28.6
trench	?	3.65	16.12	3.56	27.8	68.6	6	6094		24.0
trench	?	6.1	5.27	1.55	26.6	71.9	6.4	6923		23.0
drill	p1		0.48	5.35	29.4	65.2	7.1	8061	6	24.6



Property	Ash%	S%	Rmmax%	total Vit	Exinite	total semifus	total reactives	macrinite	fusinite	inerto-detrinite	mineral matter	total inerts
Goodrich	17.16	0.30	1.14	51.30	3.62	34.24	61.58	0.58	1.19	1.42	9.53	38.41
Sukunka	5.25	0.76	1.33	58.70	0.00	21.44	65.99	9.16	6.69			34.00
Lossan			1.06	49.85	3.77		59.52	0.35	1.08	2.43	11.67	44.72
Falling Ck	13.39		1.23	63.61	0.05	23.78	78.15		3.19			21.85

Figure 12: Some petrographic relations for the Goodrich, Sukunka, Lossan and Falling Creek properties



Intersection at zero CV =int/slope = 90.96 is less than 100% because of mineral matter/ash ratio and the heat stealing effect of the ash. A smaller value probably means a more basic ash. Predicted mineral matter/ash ratio is 100/90.6 = 1.099

Figure 13: Coal quality data from the Bri-Dowling property; data from Duncan (1980).

The Gething Formation is 425 metres thick and contains over 50 seams, but the majority are less than 1 metre thick. In the upper part of the formation there are four seams of economic interest, named Superior, Trojan, Titan and Falls, that can be correlated across the property. The Superior, Titan and Falls seams are medium-volatile bituminous and the Trojan seam is high-volatile bituminous. Some of the seams have coking properties, but generally the coal is a thermal or weak coking coal. Quality data (Figure 13) indicate that the coal has moderate sulphur. A plot of VM daf *versus* ash provides a line with a 0.175 slope suggesting a moderate base-acid ratio, confirmed by oxide analyses which provide an average base-acid ratio of 0.43.

The seams were tested for methane content to provide information for ventilation design as part of underground mine plans (Duncan, 1980). Gas contents of the Superior seam below 200 metres average 16.5 m^3/tonne and the Titan seam contains 19.5 m^3/tonne at 459 metres, these contents could make the seams interesting targets for CBM exploration. It should be noted that estimates of the residual gas component, which would not be recovered by a CBM well, have been added to these totals. The other two seams contained much less gas.

Adams property

The Adams property, which is located between the Bri-Dowling and Carbon Creek properties, was explored briefly in the 1980's (Ryan, 1982). No reflectance or petrographic data are available, but based on estimates of the VM daf value at zero ash (23.8 percent) a rank of medium-volatile bituminous is predicted for the property (Figure 14). Drilling intersected a number of seams with thicknesses ranging up to 1.6 metres.

The coal has moderate FSI values but one would expect values to be higher based on the rank and low ash concentrations. Based on posting high (star points) and low VM dmmf values (diamond points) into the FSI *versus* ash plot it appears that some of the samples are oxidized but others have high inertinite content. Sulphur is moderately high, averaging about 1 percent, and appears to be concentrated in the ash. No ash-oxide measurements are available for the property but the steep slope of the VM daf *versus* ash line implies a the high base/acid ratio.

Carbon Creek property

The Carbon Creek property was extensively explored for its potential as an underground thermal coal mine by Utah Mining Limited (Janes and Duncan, 1981). There may also be potential for weak coking coal on the property. Nine mineable seams have been identified in the Gething Formation, which is over 1000 metres thick (Gibson, 1985). Coal rank is medium-volatile bituminous with a VM daf value at zero ash of 27.2 percent (Figure 15). Despite favourable rank and low ash contents, seams have only intermediate FSI values, indicating that the coal contains high contents of inertinite. The two seams that average the highest sulphur contents also average the highest FSI values indicating that the sulphur is associated with higher vitrinite contents. Plots of CV *versus* ash and VM daf *versus* ash indicate moderate base/acid ratios.

Twelve Carbon Creek ash-oxide analyses (Figure 16) provide an average base-acid ratio of 0.2, which is acceptable for a thermal coal. No petrography or reflectance data are available but Karst and White (1979) indicate that a Rmmax percent value of 0.9 percent was measured for the top of the Gething. As for most Gething coals, seams wash easily to clean ash contents of less than 5 percent ash.

Falling Creek property

A Gething section of 450 metres, containing seven major seams, is present on the property (Mudry and Horgan, 1983). The thickest seam (Brenda seam) is 50 to 90 metres below the Moosebar and averages 6.5 metres of coal. Other seams range in thickness from 1 to 3.5 metres. Coal rank is medium-volatile bituminous based on Rmmax percent measurements of 1.26 percent to 1.46 percent. Rank calculated from VM daf values is higher and some values are less than 22 percent (Figure 17) predicting a rank of low-volatile bituminous (Stach *et al*., 1986, page 45). The coal has varying inertinite contents that range up to 50 percent (Figure 8) and some data indicate that the top parts of seams are often inertinite rich. There is a negative correlation of CaO with ash, probably indicating presence of calcite on cleats.

Pine Pass property

There are at least eleven seams in the Gething Formation on the Pine Pass property with thickness varying from 5 metres to less than 1 metre. Seam correlation is difficult because of complex structure. The most recent terminology identifies seams J at the top to A at the bottom of a coal succession that is about 200 metres thick (McKinstry, 1989). Previous reports used a different seam correlation (White and Fietz, 1984). Coal rank ranges from medium-volatile to low-volatile bituminous but resources of coking coal are limited. The coal washes easily and some seams have very low raw-ash concentrations. Sulphur content generally increases up section.

There is no evidence of oxidation in a CV *versus* ash plot. A plot of FSI *versus* ash coded by VM dmmf values (Figure 18) indicates that most of the samples with high VM dmmf values (stars) plot in the upper left and that most of the low FSI samples are characterized by low VM dmmf values (diamonds). This pattern indicates that the low FSI values are caused by high inertinite contents. There are however two samples which come from shallow depths in drill holes that have low FSI values and high VM dmmf values indicating possible oxidation. Organic sulphur is usually associated with reactive macerals so that if FSI values are varying because of changes in reactive content, then there should also be a correlation of FSI with sulphur (Figure 18). There is no evidence of oxidation in polished mounts of samples

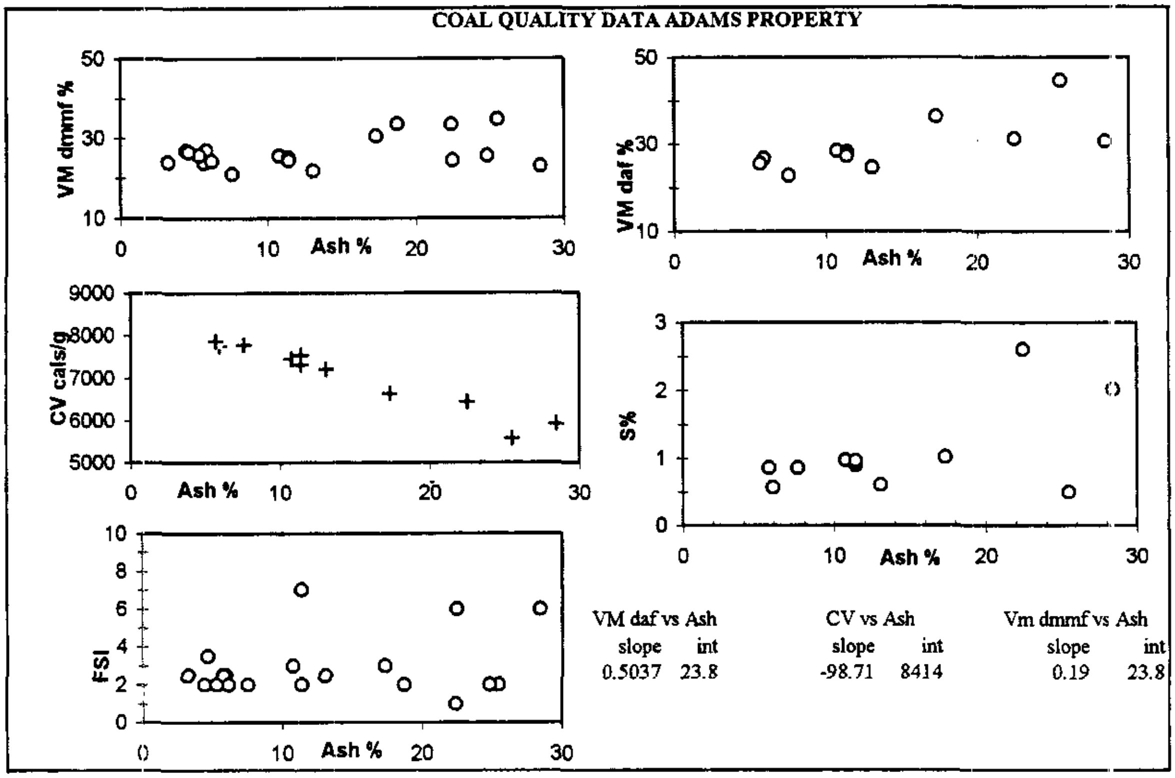


Figure 14: Coal quality data from the Adams property; data from Ryan (1982).

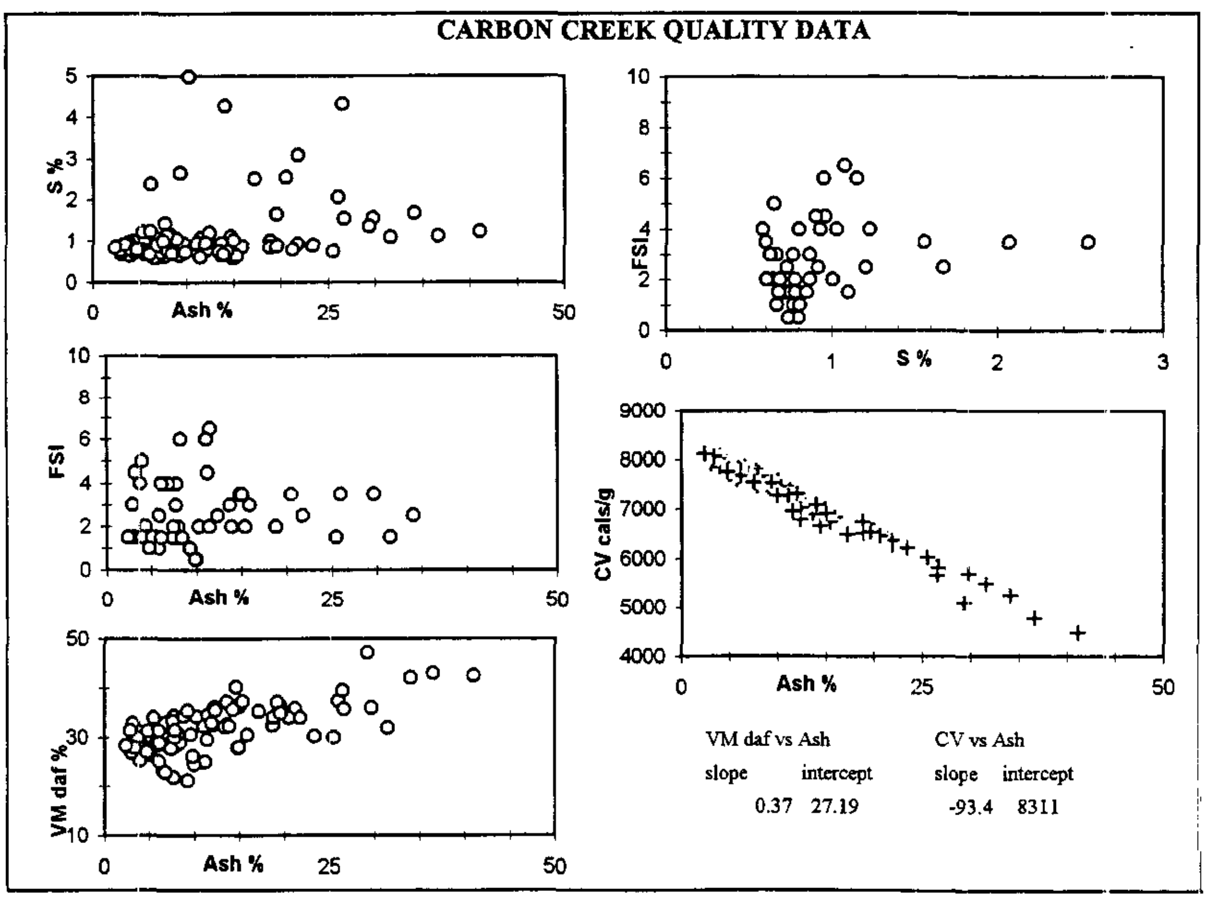


Figure 15: Coal quality data from the Carbon Creek property; data from Janes and Duncan (1981).

studied by the author. In one sample slit-eye vitrinite is present it has been equated with oxidation by some authors); but this is unlikely as the sample has an FSI of 6.5.

Reflectance measurements available for some samples range from 1.1 percent to 1.38 percent. They do not increase consistently with depth and appear to have a negative correlation with VM dmmf (Figure 18) and therefore probably have a positive correlation with inertinite content of the samples. An inverse relationship of vitrinite reflectance with the inert maceral

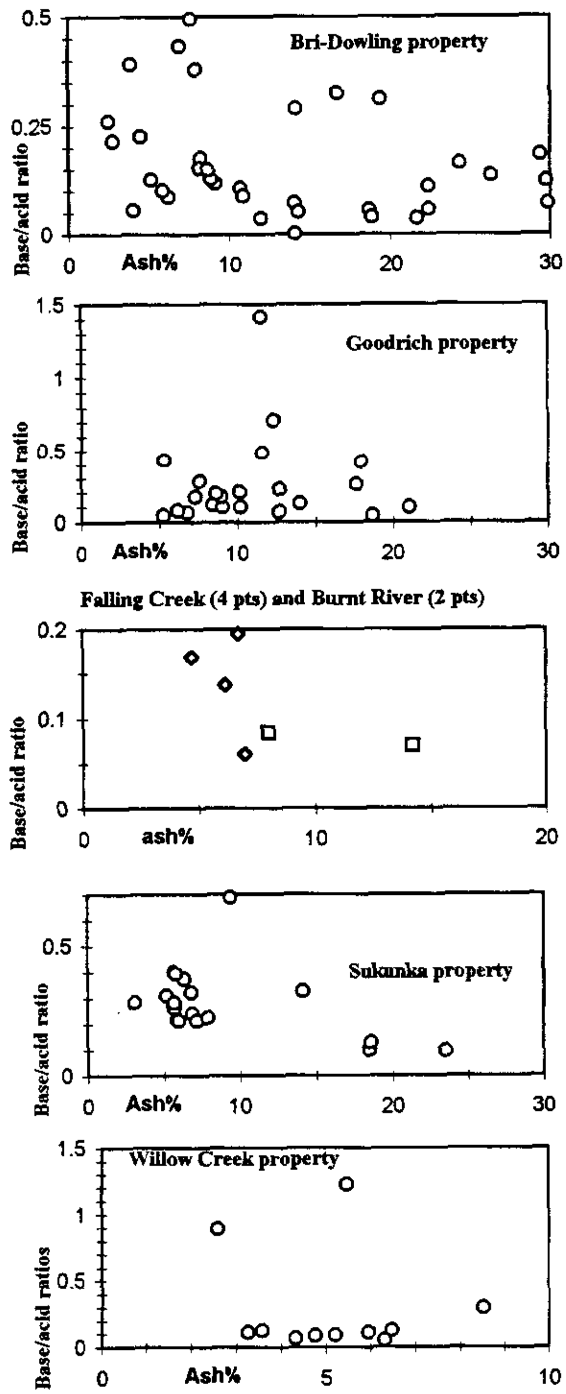
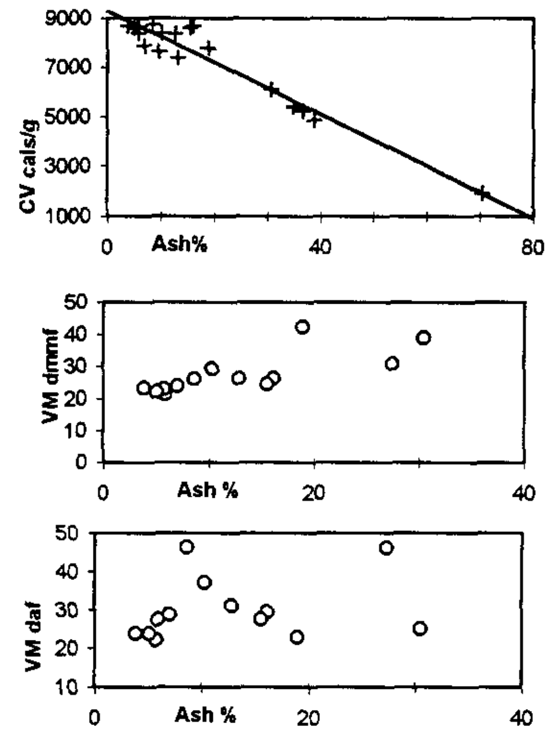


Figure 16: Base acid ratios for some Gething Formation properties.



Cals/g		Vmdaf	
slope	int	slope	int
-105	9312	0.73	23.39

Figure 17: Coal quality data from the Falling Creek property; data from Mudry and Hogan (1983).

content of samples is also apparent in samples from the Lossan and Falling Creek properties (Figure 12).

The Pine Pass samples are characterized by the association of low ash and high inertinite content and therefore have low FSI values which do not indicate oxidation. Finely dispersed mineral matter is associated with gelovitrinite and is probably the residue left after partial loss of biomass during humification. The lack of fusinite and semifusinite means that there are not many cell cavities available to provide sites for difficult to remove ash in the inertinite material, also mixtures of vitrinite B and macrinite are not associated with much finely dispersed extraneous mineral matter.

Moberly property

The Moberly property is west of the Pine Pass property on the north side of the Pine River. The Gething Formation is estimated to be over 350 metres thick and contains at least 7 mineable seams, two in the upper Gething are medium-volatile bituminous and the lower five in the lower part of the formation are low-volatile bituminous (Bienia, 1982). Number five seam contains over 5 metres of coal and is the best mining target. Even at low ash the seam has low FSI values and is therefore a thermal or weak coking coal, probably with a high inertinite content. Sulphur is approximately of 0.5 percent or lower and gross calorific value on an air dried basis ranges from 7000 to 8000 cals/g. A large

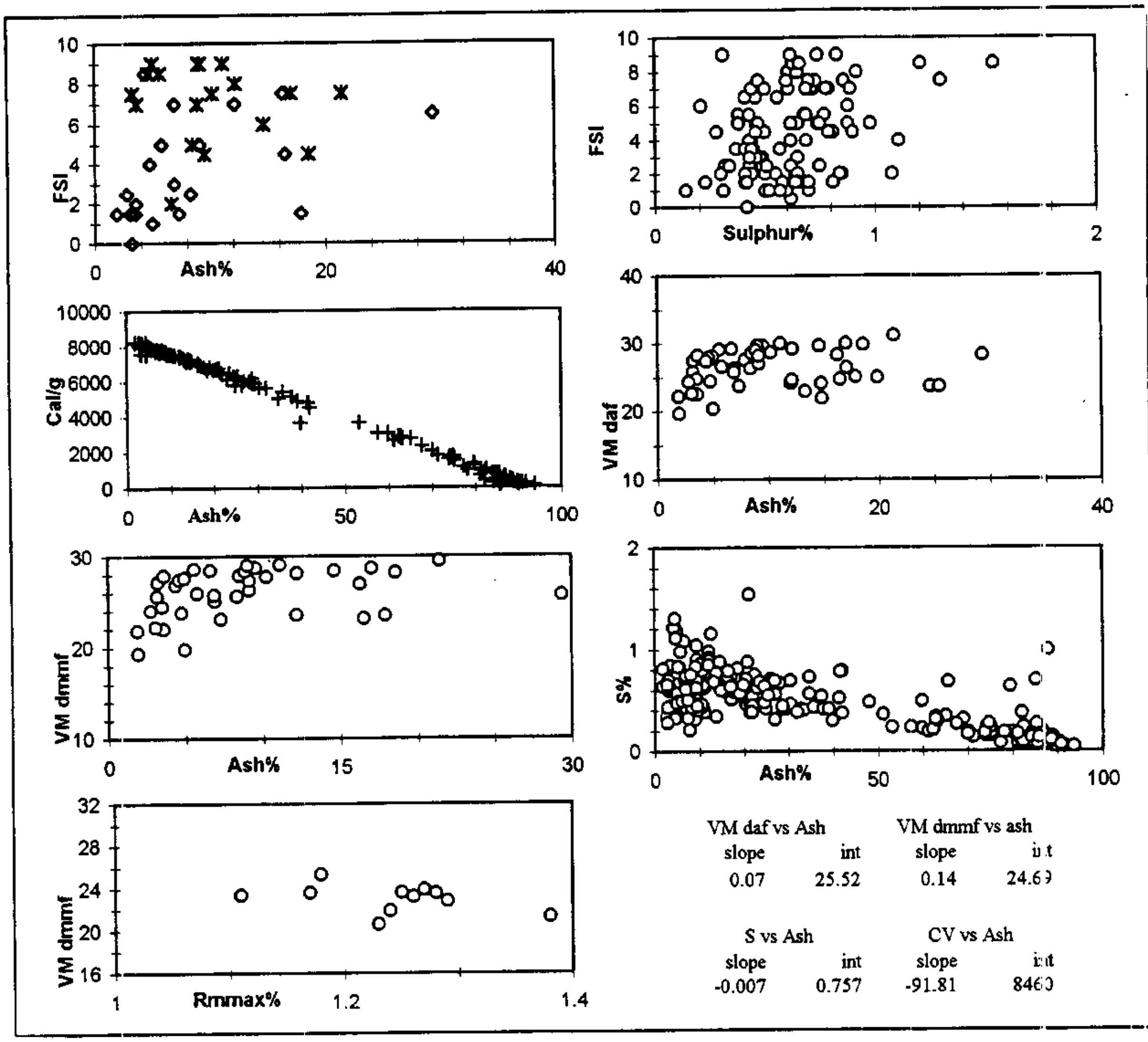


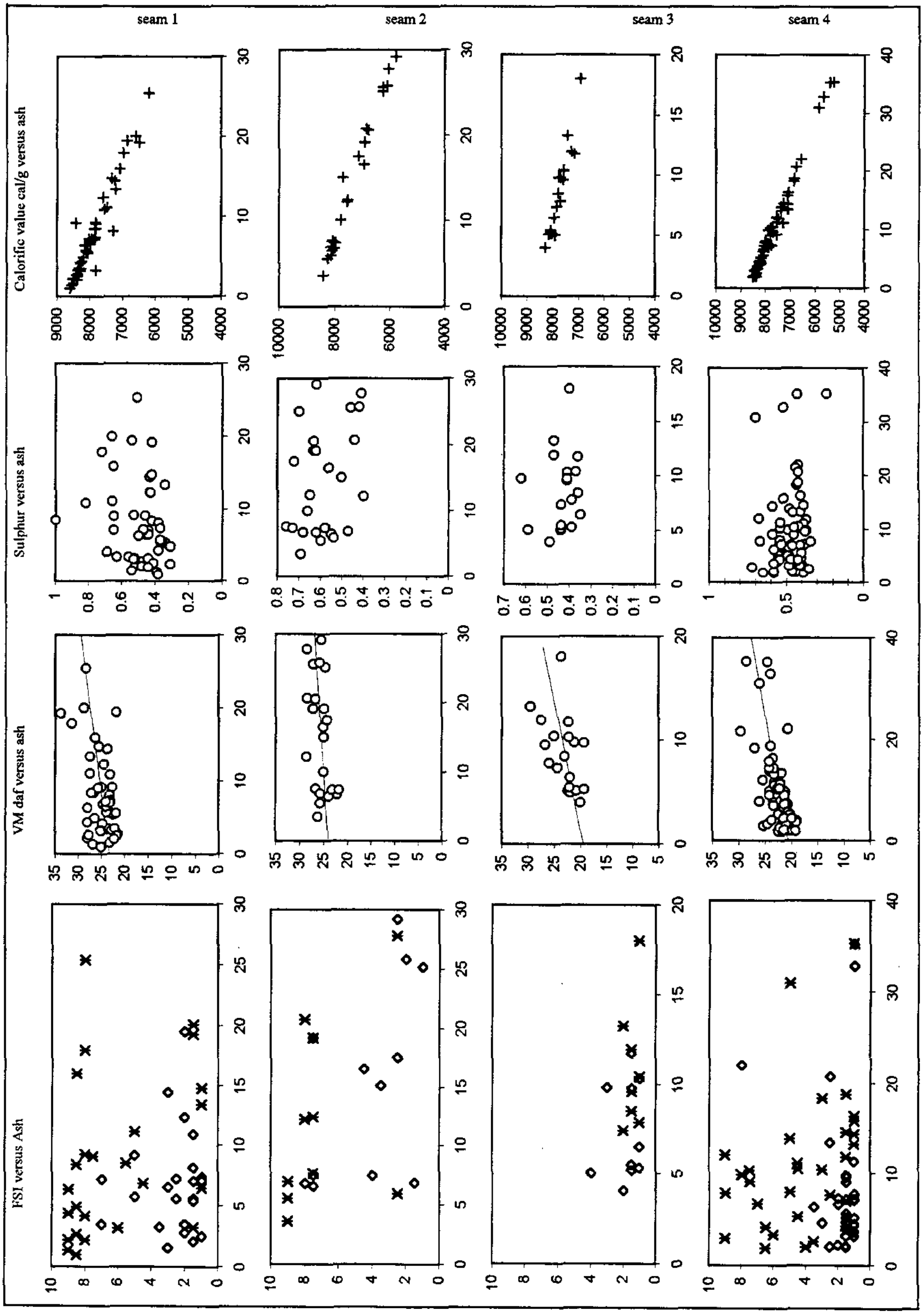
Figure 18: Coal quality data from the Pine Pass property; data from White and Fietz (1984) and McKinstry (1989).

resource has been calculated for the area but no attempt has been made to outline reserves.

Lossan property

Coal is found in the upper part of the Gething on the Lossan property, mostly in the uppermost number 1 seam which averages 8.6 metres in thickness. The total Gething section is 380 to 450 metres thick (Bienia, 1982) and contains five seams in the top 120 metres. Coal rank is medium-volatile bituminous with Rmmax percent values ranging from 0.98 percent to 1.12 percent for 1 seam and higher values up to 1.58 percent for seams lower in the section. Petrography on three samples of 1 seam indicates that the upper two-thirds of the seam is inertinite rich (averaging 54 percent) whereas the lower one-third of the seam averages 26.7 percent inertinite. Ash contents range from 25 percent to 5 percent and are uniform through the seam. The seam's high inertinite content explains the generally poor coking properties despite favorable rank and ash content. A metallurgical coal product with FSI of 4-8 and fluidity of 40-300 ddpm could be mined from the lower third of the seam. The combined seam could be sold as a weak coking or thermal coal.

It is interesting to note that there is a strong positive correlation of Rmmax percent with inertinite content (Figure 12). The higher content of inertinite in the upper part of the seam might indicate long term changes in climate that produced a trend towards drier conditions in the coal swamp prior to burial below the water table. Similar inertinite enrichment in the top of coal seams has been seen by Moore *et al.* (1993). The variable petrography has important implications on the marketability of the seam, as the result is to suppress the coking properties of the coal and to change it from a prime coking coal into a soft (low rank) or weak (higher rank) coking coal. An understanding of the extent of this high inertinite zone within seams is very important because of its implications for coking properties and value of the coal.


seam 1
seam 2
seam 3
seam 4
Calorific value cal/g versus ash
Sulphur versus ash
VM daf versus ash
FSI versus Ash

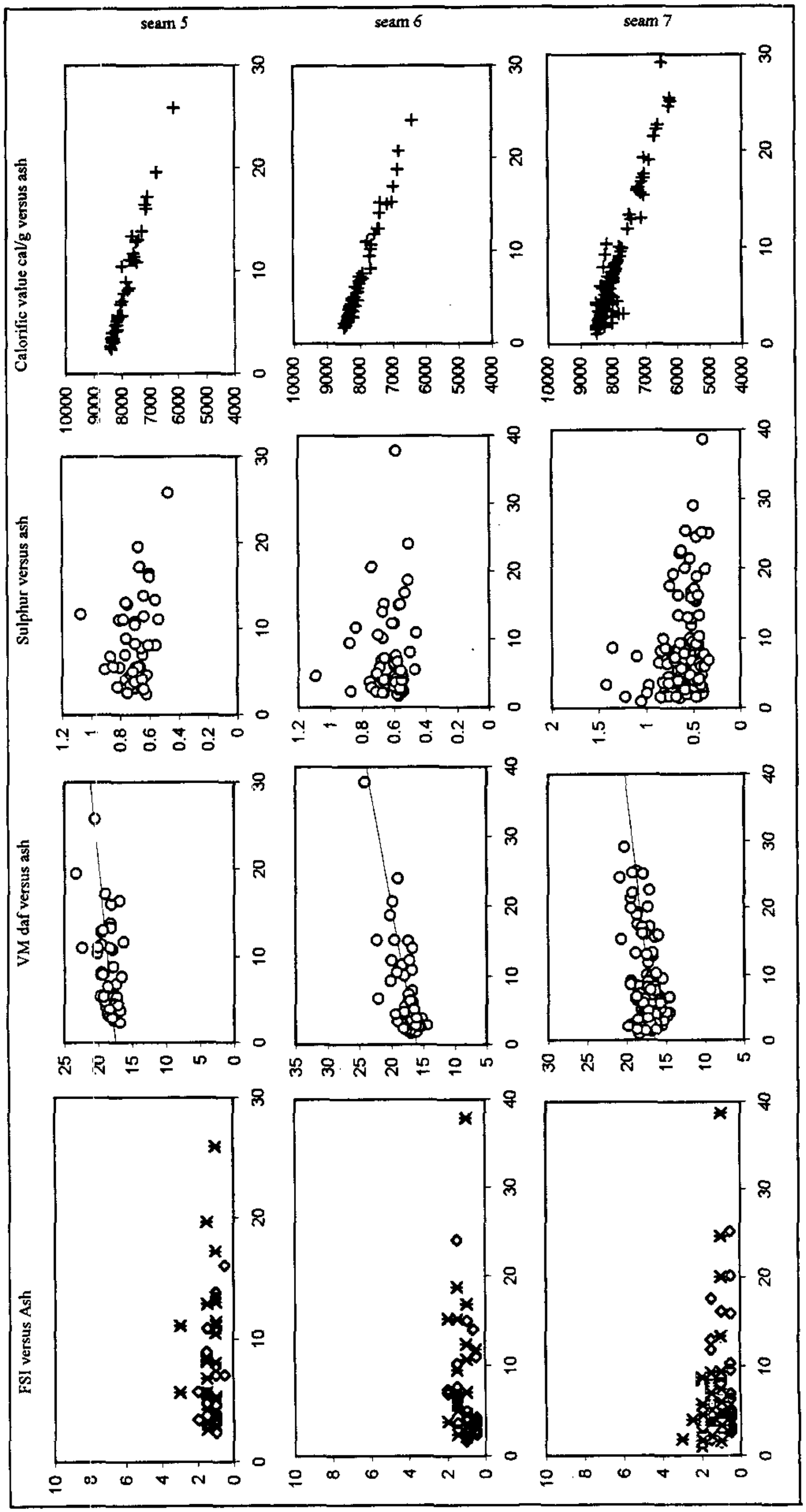
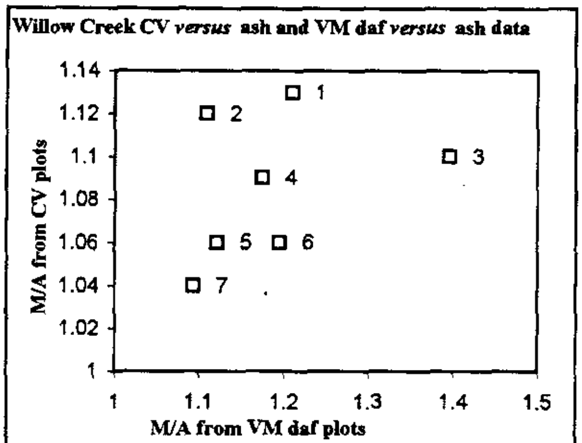


Figure 19: Coal quality data from the Willow Creek property; data from David Minerals (1982).



M/A (mineral matter/ash ratio) can be calculated from VM daf *versus* ash plots and CV *versus* ash plots

seam	M/A (VM)	M/A (CV)
1	1.21	1.13
2	1.11	1.12
3	1.396	1.1
4	1.175	1.09
5	1.122	1.06
6	1.196	1.06
7	1.094	1.04

Figure 20: Estimation of base acid ratio of Willow Creek seams using VM daf and CV data.

Willow Creek property

This property has a long history of exploration and is now being examined for its potential as a surface coal mine. Licenses cover parts of the old Pine Pass and Falling Creek properties as well as the original Willow Creek property. The Gething Formation is a least 300 metres thick and contains four seams in the upper part and 4 (possibly 5) seams in the lower part of the Formation separated by a 100 metre thick barren zone. Seams are numbered from 1 at the top of the formation to 8 at the bottom and 7 seam, which averages over 5 metres of coal, is the thickest. The upper seams are medium-volatile bituminous and may be marketable as coking or weak coking coal. The lower seams are low-volatile bituminous and could be sold as weak coking coal or specialty low-ash thermal coal.

A lot of proximate data are available (David Minerals, 1982) and it is possible to construct a number of plots for each seam (Figure 19). The rank of the seams varies from about 1.25 percent to 1.75 percent and combining these data with VM dmmf data provides estimates of the relative concentration of inertinite in the seams (Figure 11). The vertical distance that data plot below the Rmmax percent *versus* VM daf line in Figure 11 is proportional to the relative enrichment in inertinite in the samples and relative amounts can be estimated using the VM dmmf *versus* inertinite relationship for Falling Creek (Figure 8). Relative estimates of the inert maceral content for the Willow Creek seams agree with the general distribution of FSI values for the seams (Figure 19) and it appears that seams 3, 5, 6 and 7 are enriched in inertinite.

Data in ash *versus* FSI plots (Figure 19) are posted with different symbols depending on whether the VM dmmf values are above (star) or below (diamond) average. The plots indicate that most of the variation in FSI is caused by variation in inertinite content and not the result of oxidation.

The base-acid ratio of each seam is estimated using data from VM daf plots and CV values at zero ash (Figure 20). It appears that seams 1 to 4 in the upper part of the section have higher base-acid ratios than seams 5 to 8 in the lower part of the section. The upper seams have coking potential, therefore it is be important to determine the base-acid ratios because of their effect on coke strength after reaction (CSR) (Ryan and Price, 1993). Higher base-acid ratios lower CSR.

Burnt River property

Over 27 seams of low-volatile bituminous to semi-anthracite rank occur in the Lower Gething on the Burnt River property (McClymont, 1980). Six seams are thick and persistent enough to be considered mineable. The more important seams, which average from 2 to 4 metres in thickness are called the Upper, Lower and 60 seams (Figure 21). Average MV daf values at zero ash range from 18.1 percent to 13.4 percent (Figure 21) confirming a rank of low-volatile bituminous to semi-anthracite. If the seams are enriched in inertinite then the rank may be lower. The slopes of lines through the CV *versus* ash data indicate that the ash has low base-acid ratios, which agrees with two ash oxide analyses that provide an average base/acid ratio of 0.08. Sulphur in the seams is low, averaging 0.3 percent to 0.4 percent and is distributed in the ash and coal. The high rank may preclude the coal being used as a weak coking coal; it may be more suitable for PCI or as a specialty thermal coal.

Sukunka property

Three coal seams (Bird, Skeeter and Chamberlain) occur on the Sukunka property in the upper 60 metres of the Gething Formation, which contains a marine tongue 130 metres thick at this location. There are four thin seams in the lower Gething, below the marine tongue, but they are not considered for development. The uppermost Bird seam contains more sulphur than the Skeeter and Chamberlain seams and is not considered in mining plans, which concentrate on the Chamberlain seam (BP Exploration Canada Limited, 1979). The Chamberlain seam is 1.5 to 2.5 metres thick and has an average Rmmax percent of about 1.3 percent.

Data with above average (stars) and below average (diamonds) VM dmmf values are plotted on Figure 22 which shows that virtually all low FSI samples have below average VM dmmf values and therefore are probably not oxidized. Also there are not many samples with low ash concentrations and low FSI values indicating that there is not a large variation of inertinite content in the seams. This ensures that the coal all be of coking quality. Ash oxide analyses provide an average base/acid ratio of 0.25 (Figure 16) which is one of the

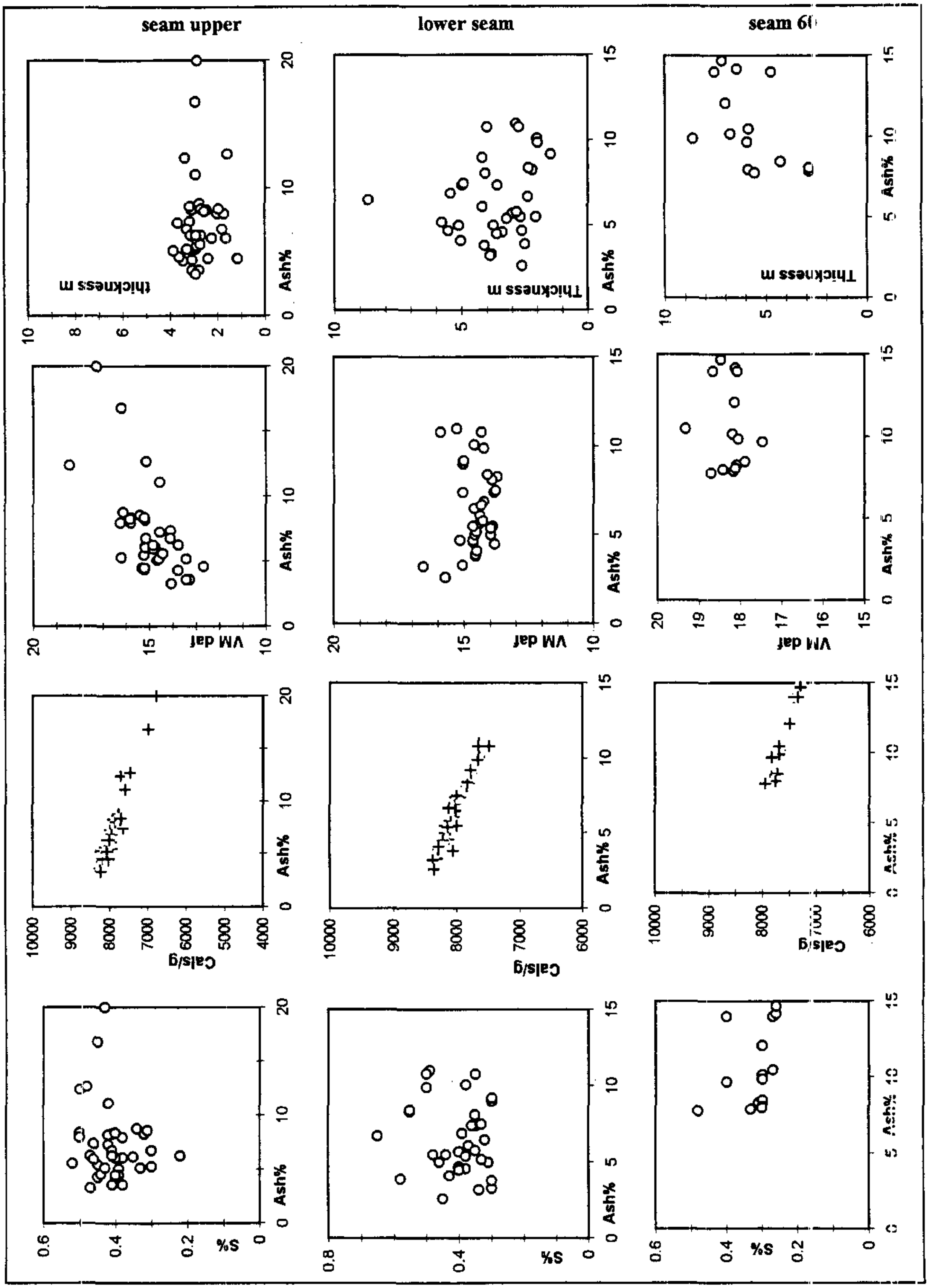


Figure 21: Coal Quality data from the Burnt River Property; data from McClymont (1980).

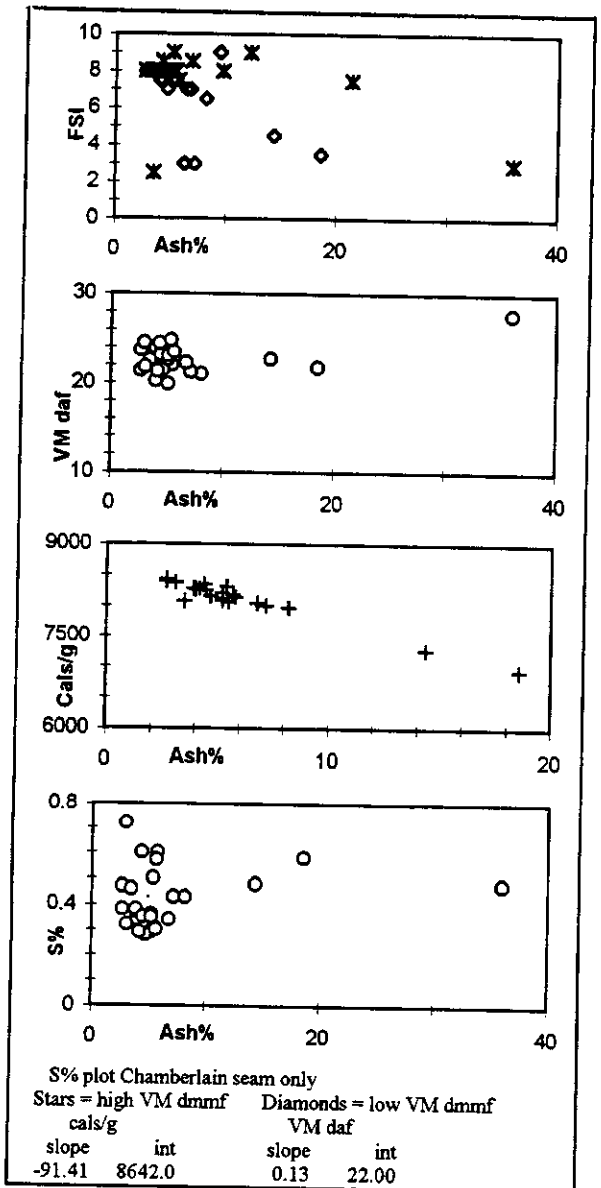


Figure 22: Coal quality data from the Sukunka property; data from British Petroleum Limited Canada (1979)

higher averages obtained for Gething coals and will lower CSR values. The ratio tends to increase as the ash content decreases. This implies that the base oxides effecting the base-acid ratio are associated with the coal part of the sample, probably in carbonates on cleats. It appears that coal above the marine tongue in the Gething may have been infiltrated by solutions that formed carbonate minerals on cleat surfaces. The cleat coating minerals can be removed with difficulty by crushing the coal to a finer size-consist and washing to a lower specific gravity, but if this also increases the base-acid ratio then the improvement in CSR might not be as great as expected.

The Sukunka property has about 190 million tonnes of in place underground mineable reserves. A study conducted in 1977 on nine samples classified three of the samples as highly gassy with methane. A more detailed study of gas content should be undertaken as part of any future mine planning.

Mount Spieker property

The Mount Spieker property is about 4 kilometres east of the Bullmoose wash plant and is the most southerly property in which multiple seams are found in the Gething (Brameda Resources, 1978) . Coal is also present in the overlying Gates Formation in which there are four potentially economic seams. The only important Gething seam is the Bird seam, which is present as a high sulphur 3.5 metres thick upper seam and a 1.75 metres thick lower Bird seam which is lower in sulphur. Other seams in the Upper Gething are not well developed and there has been very little exploration in the lower part of the formation which is 300 metres thick.

The Bird seam is medium to low-volatile bituminous based on a VM daf value of 21.6 percent. It has good FSI values and could be washed to less than 1 percent sulphur. The seam must have a moderate to high percentage of reactive macerals to maintain its rheology at the high rank. The moderate content of pyrite in the samples effects the VM daf *versus* ash relationship by depressing the slope of the line. This is because some of the FeS_2 is oxidized to $FeSO_4$ and SO_2 which effectively increases the weight of the ash. The slope of the line on the CV *versus* ash is decreased because of the exothermic reaction of FeS_2 to SO_2.

Other Gething properties

The Gething Formation is identified as far south as the Saxon property near the Alberta border, but it is thin and usually contains a single seam. While limited there is some coal potential in the Gething Formation in the southern Peace River coalfield. There is a possibility of renewed exploration on the Monkman property and the potential of the Gething coal to provide underground mineable reserves is being considered.

COAL MARKETS FOR SOFT AND WEAK COKING COALS

Coal markets are becoming more diverse and there are now many varieties of thermal and coking coal sold. Over the last few years markets have developed for marginal coking coals called either soft or weak coking coal. Gething coal may make an excellent weak coking coal product.

Soft coking coals are generally low rank and are on the low end of the coking coal window, which encompasses the medium-volatile bituminous coals. The weak coking coals, which are sometimes referred to as semi-soft coking coals, are higher rank and are at the high end of the coking coal range. Soft coking coals are characterized by high fluidity, high positive dilatation and good FSI and they contract in a sole heated oven. If coked on their own, they produce a coke with low stability index (+/- 45 percent) and will produce low pressure and good contraction in the coke oven. However they have a low coke yield because of the high volatile content. They make good bridging coals in a blend because of their high fluidities.

Weak coking coals are so called because high rank is

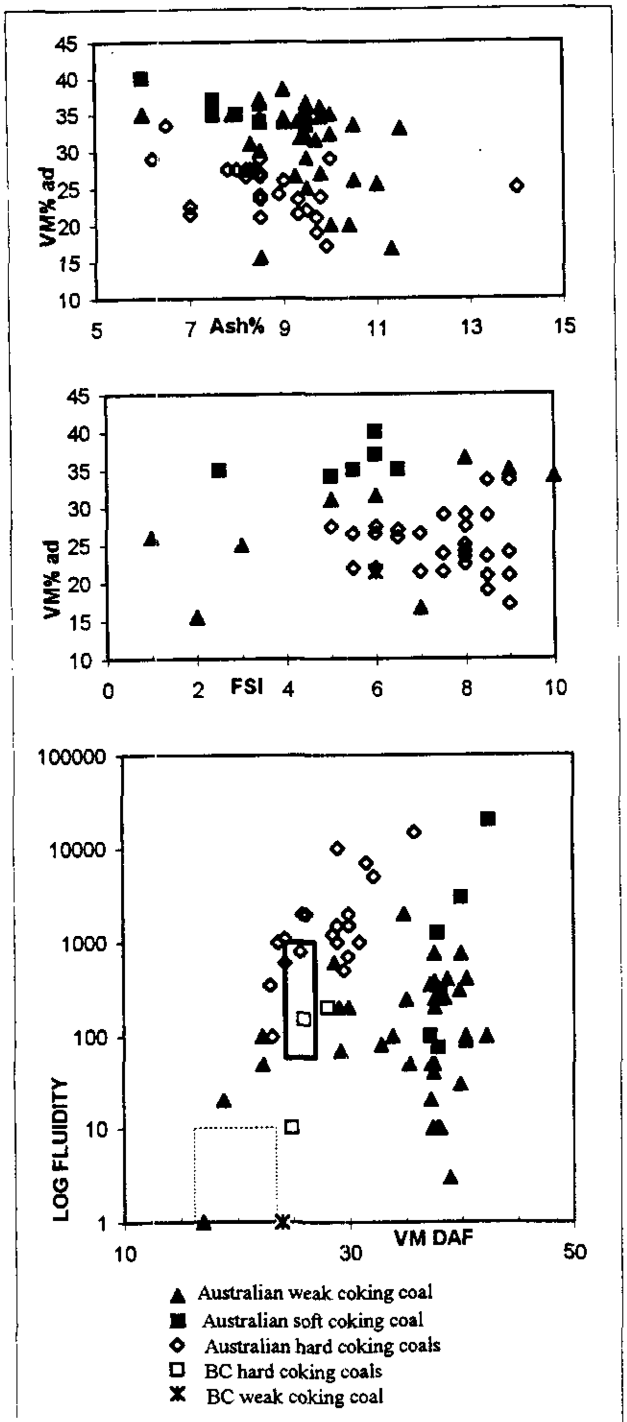


Figure 23: Plot of Australian and British Columbia soft and weak coking coals illustrating blending potential. The two boxes are the optimum blending box (thick line) and the field of some Gething coals (light outline) based on unreleased data.

beginning to destroy the agglomerating properties of the coal, especially if the inertinite content is high (>30 percent). These coals are characterized by low fluidity, low dilatation and moderate FSI. If they have high contents of inertinite, then they will produce cokes with stability indexes in the range of 50 percent. In the coke oven they have approximately zero contraction and produce moderate but acceptable oven pressures. At high rank (Rmmax>1.6 percent) the coal will probably expand in the coke oven and often exert unacceptable oven pressure if coked on its own. Coke stabilities may be in the 55 percent range. Weak coking coals have a higher coke yields than soft coking coals, but produce a lower volume of bi-products.

One of the major insights into coal blending for coke making over the last few years is that low fluidity vitrinites and semifusinite macerals in higher rank coals can soften and flow enough in the coke oven to ensure that a strong and coherent coke is produced. This means that coke oven operators can reduce the amount of low rank, high fluidity soft coking coals in their blends. There are a number of advantages of switching from soft to weak coking coals as long as the blend retains sufficient overall fluidity. Highly fluid coals are usually low rank and therefore produce weak cokes with low coke oven yields. Using less soft coking coal in the blend improves coke yield and makes a stronger coke. However higher rank coals may produce unacceptable coke oven pressures. This is not the case if the coals are high in inertinite which acts to reduce pressure in the coke oven. Therefore, a mixture of weak and hard coking coals produces a stronger coke with better coke oven yield. The mixture does not create much increase in coke oven pressure as long as the weak coking coal has high inertinite content. Ash content in the coke is also a concern. A high volatile coal (35 percent VM) with 10 percent ash will produce a coke with 15 percent ash where as a medium volatile coal (25 percent VM) will produce a coke with 13 percent ash.

Obviously there are advantages gained by switching to a weak coking coal as long as coke oven pressure is kept low and there is sufficient contraction for easy pushing of the coke. Gething coals with moderate to high rank, high inertinite content and low ash contents may be ideal for the expanding weak coking-coal market. A possible problem might be the base-acid ratios of Gething Formation coals, which are variable and sometimes higher than the ratios for other coking coals such as those found in the Gates and Mist Mountain formations.

Coal quality data for a number of Australian export coals are plotted on Figure 23. The data area available at "http://www.dpie.gov.au/resources.energy/coalmin/coalbook/spech.html" on the internet. Also plotted on the lowest plot in Figure 23 is the optimum blending box (heavy line) and a second box (light line) which includes many of the higher rank Gething coals. Individual Gething coals are not plotted, but coals from Willow Creek, Pine Pass and Lossan properties would plot in the box. It is apparent in the plots that the soft coking coals (solid squares) tend to be lower rank (higher VM) and there are not a lot of weak coking coals that are noticeably higher in rank. This has important implications for British Columbian coals, especially Gething coals. As can be seen from the lower plot in Figure 23 weak coking coals provide flexibility to ensure that blends with some Australian hard coking coals plot in the optimum blending box. A majority of the Australian hard coking coals plot to the upper right of the optimum blending box whereas British Columbia weak coking coals plot to the lower left of the box and a mixture of the two will plot in the box.

The shift from soft to weak coking coal and the decrease in the amount of hard coking coal in coke oven blends can be explained by coal and coke quality parameters. The coke maker is maintaining quality, improving yield and saving money. It is important to be aware of the fact that some weak coking coals, such as those from the Gething Formation, may be ideal for the expanding weak coking coal market. High rank, inertinite-rich coals, such as those from the Gething Formation, may not be common. Weak coking coal from the Gething Formation with its low ash, high rank and inertinite content, may be one of the few weak coking coals suitable for blending with Australian hard coking. Weak coking coals presently sell for about $4 to $8 less than hard coking coal. But if availability is limited this price difference might decrease.

CONCLUSIONS

Coal seams in the Gething Formation account for a large coal resource in the Peace River coalfield particularly in the northern part of the field. Smith (1989) estimates that the formation has over 300 million tonnes of measured resource. The raw-ash contents of Gething coal are often low and it washes easily to a low clean ash content. Middling ash seems to be restricted to the reactive macerals and this sometimes causes an enrichment of inertinite in the clean coal. The inverse relationship of ash content *versus* reactive maceral content also causes some low ash samples to have low FSI values. The absence of inherent ash in the inertinite is in part because of the low contents of fusinite and semifusinite macerals which have cell cavities occupied by inherent ash

Not all coal from the Gething Formation is hard coking coal, but much of the remainder is an excellent weak coking coal, which is in demand in today's market.

The maceral composition of seams vary and often the inertinite content of the seam increases towards the hangingwall. Although it might be possible to mine a coking coal product from the lower part of the seam and a thermal or weak coking coal product from the upper part, it is unlikely that this would be economic. Rank in the Gething Formation varies from property to property and because some properties have mineable seams through the full thickness of the formation the rank can vary considerably on a single property.

The existing proximate coal quality data available can be used to provide clues to some of the characteristics of the Gething coal quality in the absence of more detailed tests. It is possible to gain some information about rank, inertinite content, ash chemistry and degree of oxidation from the existing databases that often contain only proximate FSI, CV and sulphur analyses.

There are many aspects of coal quality that all play a part in defining the potential end use and marketability of the coal. Coal properties can only be developed with a clear understanding of the impact of coal quality parameters on the marketability of the clean coal.

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REGIONAL GEOCHEMICAL SURVEY PROGRAM: REVIEW OF 1996 ACTIVITIES

By Stephen Cook, Wayne Jackaman, Ray Lett and Steve Sibbick

KEYWORDS: Applied geochemistry, hydrogeochemistry, lake sediments, mineral deposits, mineral exploration, multi-element, stream sediments, reconnaissance geochemistry, Regional Geochemical Survey.

INTRODUCTION

Since 1976, the B.C. Regional Geochemical Survey (RGS) program has completed over forty reconnaissance-scale stream sediment and water surveys. At present, the RGS database contains analytical determinations, field observations and sample location information for 40 485 samples and covers 70 per cent of the province (Figure 1). Baseline geochemical data derived from the RGS program is used in the exploration and development of British Columbia's mineral resources. All components of sample collection, preparation and analysis are closely monitored to ensure consistency and conformance to standards set by the National Geochemical Reconnaissance Program.

The 1996 field season was one of the most active in the history of the RGS Program. Program activities included the release of new stream sediment and water geochemical data from the Cry Lake map area, the release of new stream sediment, stream water, spring water and spring sediment geochemical data from the Gataga Mountain region, and the completion of two reconnaissance-scale stream sediment and water surveys in north-central British Columbia. Additionally, two focused lake sediment surveys and a hydrogeochemical survey were conducted as part of multi-disciplinary mineral resource programs in the Babine, Gataga and Eagle Bay regions (Figure 1).

STREAM SEDIMENT SURVEYS

CRY LAKE RGS DATA RELEASE

A reconnaissance-scale RGS program was completed in the Cry Lake map area (NTS 104I) in September, 1995. Stream sediment samples, stream water samples and field observations were systematically collected from 1159 sites over a total area of 13 200 square kilometres. Survey results were released as Open File B.C. RGS 44 on July 4, 1996. Immediately following the release over 1400 claim units were staked by exploration companies and prospectors targeting the numerous base and precious metal anomalies identified in the data package (Jackaman, 1996).

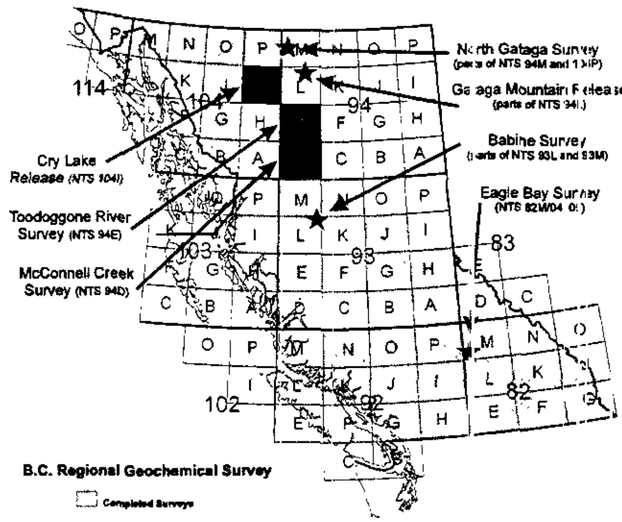

Figure 1. Location Map

GATAGA MOUNTAIN RELEASE

The Gataga Mountain stream sediment and water survey was conducted over seven 1:50 000 NTS map areas (NTS 94L/7, 8, 9, 10, 11, 14, 15) as part of a multi-disciplinary examination of the Kechika Basin (Ferri *et al.*, 1996). Samples were collected from 174 sites and covered an area of 1200 square kilometres In addition to the routine sediment and water analysis, water samples were also analyzed for trace and major elements by ICP-MS. Data from this survey (Jackaman *et al.*, 1996) plus results of detailed spring water and spring sediment geochemistry studies (Lett *et al.*, 1996) were released in August, 1996.

McCONNELL CREEK and TOODOGGONE RIVER SURVEYS

During July and August, a helicopter supported sample collection program was conducted in the McConnell Creek (NTS 94D) and Toodoggone River (NTS 94E) 1:250 000 map areas. Over the 18 500 square kilometre survey area stream sediment, stream water and field observations were collected from 1835 sample sites at an average density of 1 site every 10 square kilometres.

Samples were not collected in the Spatsizi and Tatlatui parks.

Stream sediment samples will be analyzed for precious and base metals, pathfinder and rare earth elements (Table 1). Water samples are being analyzed for pH, fluoride, uranium and sulphate. Survey results are scheduled to be released in July, 1997.

LAKE SEDIMENT SURVEYS

Two regional lake sediment and water geochemistry surveys were conducted in central and north-central B.C. during 1996, one in the Babine porphyry belt and a second in the North Gataga River area of the Kechika Trough. The surveys were undertaken in conjunction with Geological Survey Branch bedrock mapping projects and are a contribution to the ongoing Regional Geochemical Survey (RGS) lake sediment coverage of central British Columbia (Cook and Jackaman, 1994; Cook *et al.*, 1997). These surveys provide baseline geochemical data for mineral exploration and environmental studies. Complementary lake sediment geochemistry and bedrock mapping surveys have proven highly effective in stimulating mineral exploration in low-lying drift-covered regions of the northern Interior Plateau. For example, prior surveys in the Nechako River map area (NTS 93F) to the south were successful in delineating several areas of known mineralization (Cook *et al.*, 1995) and in revealing locations of new mineralized zones such as the Tsacha (MINFILE 093F 055) epithermal gold prospect. Mineral exploration in both the Babine and Gataga regions has been hindered by an extensive drift cover and poor bedrock exposure, and results of the survey are expected to provide useful new data to stimulate further exploration.

Lake sediments were analyzed for the standard RGS analytical suite of elements (Table 1). Unfiltered lake water were analyzed for the routine suite of pH, uranium, fluoride and sulphate. However, an expanded lake water analytical suite, initiated last year for the Pinchi Lake survey in the Fort Fraser map area (Cook *et al.*, 1997) was incorporated into the two 1996 surveys. An additional surface water sample was collected at approximately every second site and analyzed for trace and major elements by ICP-MS. Conductivity and total dissolved solids were also determined on RGS lake waters for the first time. In total, expanded water geochemistry data will be available for more than 400 sites over the two survey areas.

BABINE PORPHYRY BELT SURVEY

Conducted in June, 1996, the Babine regional lake sediment and water geochemistry survey covers all or part of six 1:50 000 NTS map areas (93L/9, 16; 93M/1, 2, 7, 8) in the Smithers and Hazelton map areas of central British Columbia. The survey is a contribution to the Nechako NATMAP Project, a joint project of the Geological Survey Branch, the Geological Survey of Canada, and university researchers (MacIntyre and Struik, 1997). Centred on northern Babine Lake, the survey area covers the entirety of the Babine porphyry belt and corresponds to areas of ongoing bedrock mapping (MacIntyre *et al.*, 1996, 1997) and surficial mapping and till geochemistry (Levson *et al.*, 1997; Huntley *et al.*, 1996). The survey area includes the former Bell (MINFILE 093M 001) and Granisle (MINFILE 093L 146) copper mines, and porphyry copper prospects such as Hearne Hill (MINFILE 093M 006), Nak (MINFILE 093M 010) and Trail Peak (MINFILE 093M 011) remain the primary exploration targets in the region.

Lake sediments and waters were collected from 332 sites. Additional water samples were obtained from 176 sites for supplementary ICP-MS analysis of trace and major elements.

TABLE 1. ROUTINE STREAM SEDIMENT and WATER ANALYTICAL SUITE

Element		Analytical Method	Detection Limit	Unit
Antimony	Sb	AAS-H/INAA	0.2/0.1	ppm
Arsenic	As	AAS-H/INAA	0.2/0.5	ppm
Barium	Ba	INAA	50	ppm
Bismuth	Bi	AAS-H	0.2	ppm
Bromine	Br	INAA	0.5	ppm
Cadmium	Cd	AAS	0.2	ppm
Cerium	Ce	INAA	3	ppm
Cesium	Cs	INAA	1	ppm
Chromium	Cr	INAA	5	ppm
Cobalt	Co	AAS/INAA	2/1	ppm
Copper	Cu	AAS	2	ppm
Fluorine	F	ION	40	ppm
Gold	Au	INAA	2	ppb
Hafnium	Hf	INAA	1	ppm
Iron	Fe	AAS/INAA	0.02/0.01	%
Lanthanum	La	INAA	0.5	ppm
Lead	Pb	AAS	2	ppm
Loss on Ignition	LOI	GRAV	0.1	%
Lutetium	Lu	INAA	0.05	ppm
Manganese	Mn	AAS	5	ppm
Mercury	Hg	AAS	10	ppb
Molybdenum	Mo	AAS/INAA	2/1	ppm
Nickel	Ni	AAS/INAA	2/20	ppm
Rubidium	Rb	INAA	5	ppm
Samarium	Sm	INAA	0.1	ppm
Scandium	Sc	INAA	0.1	ppm
Silver	Ag	AAS	0.2	ppm
Sodium	Na	INAA	0.01	%
Tantalum	Ta	INAA	0.5	ppm
Terbium	Tb	INAA	0.5	ppm
Thorium	Th	INAA	0.2	ppm
Tungsten	W	INAA	1	ppm
Uranium	U	INAA	0.5	ppm
Vanadium	V	AAS	5	ppm
Ytterbium	Yb	INAA	0.2	ppm
Zinc	Zn	AAS	2	ppm
pH (Waters)	pH	GCE	0.1	
Uranium (Waters)	UW	LIF	0.05	ppb
Fluoride (Waters)	FW	ION	20	ppb
Sulphate (Waters)	SO 4	TURB	1	ppm

NORTH GATAGA SURVEY

The North Gataga regional lake sediment and water geochemistry survey was conducted in July, 1996 in the Kechika Trough. It covers parts of several 1:50 000 map areas (94M/2, 3, 4, 5, 6, 12; 104P/8, 9, 10, 15, 16) in the Rabbit River and McBride map areas of north-central British Columbia. The survey was conducted jointly by the British Columbia Geological Survey Branch and the Geological Survey of Canada as part of the North Gataga Project, an interdisciplinary Geological Survey Branch bedrock mapping and geochemistry project.

The survey area is coincident with the 1996 bedrock mapping area of Ferri *et al.* (1997), and follows the previously-mapped distribution of Devonian-Mississippian Earn Group rocks within the Kechika Trough. The Earn Group is the most prospective unit in this belt for hosting sedimentary-exhalative (SEDEX) zinc-lead-barite deposits, the primary exploration target in the area.

The survey area is bounded in the southwest by the Rocky Mountain Trench and the Cassiar Mountains, and in the north by the British Columbia-Yukon border. The survey area also bridges the gap between two prior regional geochemical surveys to the north and south. To the south, the survey area is bounded by a Geological Survey Branch stream sediment and water geochemistry survey conducted in 1995 in the more mountainous terrain of the Gataga Mountain area (Jackaman *et al.*, 1996); to the north, it is bounded in the Yukon by the Geological Survey of Canada regional lake sediment survey of the Watson Lake map area (NTS 105A; Friske *et al.*, 1994). RGS stream sediment data for the McBride map area (NTS 104P) has been publicly available for a number of years, but is of limited use in the flat-lying Liard Plain which underlies much of the northwestern part of the North Gataga survey area.

Lake sediments and waters were collected from 444 sites. Additional water samples were obtained from 232 sites for ICP-MS analysis of trace and major elements in the Ottawa laboratories of the Geological Survey of Canada.

EAGLE BAY REGIONAL HYDROGEOCHEMICAL SURVEY

In the Adams Lake region, a regional hydrogeochemical survey was conducted on mapsheets 82M/04 and 05 as part of the Eagle Bay multi-disciplinary project. Details of this survey are reported in Sibbick *et al.*, (1997). The Eagle Bay project area hosts Devono-Mississippian age rocks of the Eagle Bay Assemblage which are highly similar to rocks hosting the Kuroko-type volcanogenic massive sulphide deposits (Kudz Ze Kayah and Wolverine) recently discovered in the Yukon. However, extensive overburden cover in the Eagle Bay area is an obstacle to new mineral discoveries. Detailed sampling of stream waters may detect subtle groundwater signatures of concealed mineralization. The Eagle Bay hydrogeochemical survey involved the collection of stream waters from primary and secondary drainages and the in-field measurement of the field parameters pH, redox potential, conductivity and temperature. Filtered and acidified water samples were analysed by ICP-MS for approximately 70 elements; sulphate was also determined on unfiltered sample splits. Results are currently being compiled for release in early 1997.

These activities were co-ordinated with 1:50 000 scale surficial mapping (Dixon-Warren *et al.*, 1997), a regional till geochemistry survey (Bobrowsky, *et al.*, 1997) and mineral deposit studies (Hoy, 1997) and geochemical orientation studies of several key mineral deposits in the area.. The project area corresponds to a region of previous Geological Survey Branch bedrock mapping (Schiarizza and Preto, 1987) covering NTS map sheets 82M/04, 05 and 12.

ACKNOWLEDGMENTS

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EAGLE BAY PROJECT: SURFICIAL GEOLOGY OF THE ADAMS PLATEAU (82M/4) AND NORTH BARRIERE LAKE (82M/5) MAP AREAS

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KEYWORDS: Quaternary, surficial geology, Adams Lake, Barriere Lakes, till, drift exploration, Eagle Bay

INTRODUCTION

Surficial geological mapping and drift exploration work was undertaken in 1996 by the BC Geological Survey Branch northeast of Kamloops in NTS map sheets 82M/4 (Adams Plateau) and 82M/5 (North Barriere Lake). The map area encompasses some 2000 square kilometres of rugged drift-covered terrain, overlying economically interesting Devono-Mississippian low-grade metamorphic rocks of the Eagle Bay Assemblage. Previous mining operations in volcanogenic sulphide-barite deposits such as Samatosum Mountain (MINFILE 082M 244) and Homestake (MINFILE 082M 025) confirm the high mineral potential of the region. Published detailed bedrock mapping of the area by Schiarizza and Preto (1987) and recent successful mineral discoveries in correlative rocks located in the Yukon (*i.e.* Kudz Ze Kayah and Wolverine) provided the primary impetus for renewed exploration activity in this area for VMS type mineralization. This exploration included mineral deposit studies (Höy, 1997), a stream water survey and geochemical orientation (Sibbick *et al.*, 1997), as well as 1:50 000 scale surficial mapping and drift exploration sampling. The latter two components provide vital information for mineral exploration in regions where unconsolidated sediments of variable thickness mask the underlying bedrock (Bobrowsky *et al.*, 1995).

The purpose of this paper is to describe surficial mapping methods and preliminary results focusing on the types of sediments observed, including their distribution and general character. Terrain maps showing the distribution of sediment type, estimated thickness and other terrain constraints are available at 1:50 000 scale as separate Open Files (Dixon-Warren *et al.*, 1997; Leboe *et al.*, 1997). Data pertaining to the drift exploration component of the Quaternary investigations, including till geochemistry and pebble lithology studies appear elsewhere (Bobrowsky *et al.*, 1997).

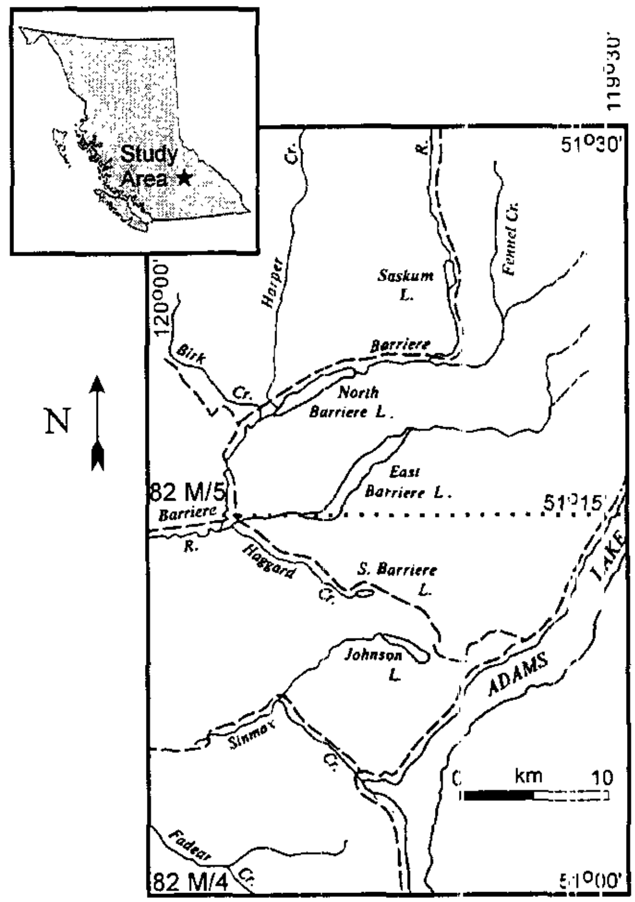

Figure 1. Location of the Adams Plateau (82M/4) and North Barriere Lake (82M/5) map areas.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Adams Plateau and North Barriere Lake map areas are located in south-central British Columbia, approximately eighty kilometres north-northeast of Kamloops (Figure 1). The study area lies within the Shuswap Highland, a region of broad forested mountains of moderate to high relief. Elevations in the two map areas range from about 450 m above sea level along the shores of Adams Lake in the south, to about 2630 m above sea level at Dunn Peak in the northwest. Topography is variable: in the north, several peaks which rise over 600 metres above tree-line punctuate the landscape, in contrast to the area in the southwest, where the Adams Plateau is a high (1680 m a.s.l.), flat and expansive topographic feature. Throughout the two map areas, several prominent valleys trending mainly southeast to southwest occur in the area, the largest represented by the Barriere River valley.

Vegetation

Vegetation is of the Southern Columbia and Interior Subalpine forest regions (Rowe, 1972). Valley bottoms are vegetated with black cottonwood, and have been cleared and planted to suit agricultural purposes. Hillsides and plateaus between valley bottoms (at elevations of approximately 1220 m), support a dense vegetation cover of western hemlock, red cedar, and Douglas fir. Upper valley slopes up to tree-line support a community of western white and Englemann spruce, and alpine fir. Above tree-line, slopes are either devoid of plant cover or sparsely vegetated with low-lying hardy shrubs. Alder and lodgepole pine are abundant in many disturbed areas.

Hydrologic system

Lakes are a conspicuous feature of the landscape. Excluding Adams Lake in the southwest, other moderately-sized water bodies include North, South and East Barriere lakes all located near the border of the two map sheets, Johnson Lake near the centre of 82 M/4, and Saskum Lake near the centre of 82 M/5. Sinmax Creek, and numerous minor creeks, drain southeastward into Adams Lake, whereas Harper, Fennel, Fadear and Haggard creeks drain via the Barriere River westward into the Thompson River.

Geologic setting

Underlain by rocks of the Kootenay Terrane, the region contains economically attractive lithologies represented by the Eagle Bay Assemblage and the Fennell Formation. These complexly deformed low-grade metamorphic rocks of Paleozoic age are flanked to the east by high-grade metamorphics of the Shuswap Complex and to the west by Intermontane rocks (Schiarizza and Preto, 1987). In the north, much of 82M/5 is underlain by a mid-Cretaceous granodiorite and quartz monzonite intrusion (Baldy Batholith). Known mineral occurrences are mainly associated with the Eagle Bay Assemblage and Fennell Formation. Massive sulphide deposits include SEDEX Pb-Zn-Ag and BESSHI Cu-Zn-Ag deposits, as well as polymetallic Cu-Pb-Zn deposits.

SURFICIAL MAPPING

The surficial geology component of the Quaternary geology program consisted of terrain mapping at a scale of 1:50 000 and Terrain Survey Intensity Level B (Resources Inventory Committee, 1996). Work first consisted of compiling and evaluating all existing terrain information available for the area. Soil and landscape maps produced by the Resource Analysis Branch of the British Columbia Ministry of Environment in 1975 provided background data on the type of materials likely to be encountered (Kowall, 1975a and b). Regional Quaternary mapping studies by the Geological Survey of Canada (e.g. Fulton *et al.*, 1983) contributed additional information on the types and distribution of sediments.

Air photographic interpretation and 'pretyping' followed the methodology of RIC (1996) and the terrain classification system of Howes and Kenk (1988). Air photos at a scale of 1:40 000 (approx.) (flight lines 15BCC-95014 and 15BCC-95009) were used in the map generation. Preliminary polygon interpretations were then verified through ground-truthing.

STRATIGRAPHY

Seventeen stratigraphic sections were examined and described in detail within the Adams Plateau map area. At each section, the following non-genetic observations were compiled: location, height of exposure, and description of units including sediment texture, clast size, angularity, and percentage, unit thickness, and the nature of contacts between units. Sketch diagrams were made, photographs were taken, and an initial genetic interpretation was made at each section. Sediments observed represented a variety of depositional environments ranging from glacigenic to lacustrine and fluvial. All of the deposits observed were correlative to the Late Wisconsinan and/or Holocene. Sediments older than the Late Wisconsinan were not encountered. Work by others indicates that this area was last glaciated sometime after 20 230 ± 270 years BP (Dyck *et al.*, 1965) and deglaciated sometime after about 11.3 ka.

SURFICIAL SEDIMENTS

Seven main types of deposits were observed including: basal till, ablation till, glaciofluvial, glaciolacustrine, fluvial, organic, and colluvial. The relative abundance and distribution of each, a reflection of preservation potential, is largely controlled by immediate topography and postglacial erosional processes. As a general observation, the plateaus and hills are mainly covered by combinations of till, colluvium, and glaciofluvial deposits, whereas fluvial, glaciofluvial and glaciolacustrine sediments are more common in valley settings. Colluvial deposits predominate on steeper slopes, whereas till and glaciofluvial sediments are more abundant on gentler slopes. Organic deposits occur locally in all types of terrain.

Basal Till

Throughout much of the region, bedrock is mantled by variable amounts of massive, very poorly sorted matrix-supported diamicton (Photo 1). Attributes of these diamictons suggest that they are most likely basal till accumulations (*cf.* Dreimanis 1988). Deposits of diamicton ranged in thickness from less than one metre (veneer) on steeper slopes and upland areas, to several tens of metres (blankets) on the low relief terrain and gentler slopes. The surface expression of these deposits ranges from gently rolling and hummocky to ridged and streamlined.

Two types of basal till were identified, essentially reflecting the type of bedrock from which they were derived. In the south, basal till deposits are primarily massive to poorly stratified with a sandy silt to silty clay texture, and a fissile matrix. Deposits are dense, compact, cohesive with irregular jointing patterns. Clast content ranges from 10-30%, usually averaging about 25%, and clasts range in size from granules to boulders averaging some 1-5 cm (small to medium pebble size). They are mainly subrounded to subangular in shape, and consist of both local and distantly derived lithologies. A number of clasts (mainly prolate in shape) have striated, faceted surfaces. Apparent pebble fabrics are interpreted to be well-defined and appear to be aligned parallel to paleo-ice flow. Colour is variable, and is often reflective of the underlying bedrock. The presence of gossan flecks within till matrix was noted on a number of occasions.

To the north, basal till in the vicinity of the Baldy Batholith is characteristically sandier in texture. In these areas, the till accumulations are highly consolidated, light to medium grey in colour, with a clayey sand matrix. All these attributes are indicative of the granitic and granodioritic bedrock source. The modal grain size of the fine fraction is about 0.25 to 0.50 cm (coincident with the size of crystals within granodiorite outcrops), but clasts range from granule to boulder in size. Clast content ranges from 5-30% and averages about 15%.

Ablation Till

Boulder fields and massive clast-supported diamicton mantle both bedrock and basal till deposits at several locations in the high plateaus in the central and northern parts (Photo 2). In contrast to the basal tills, these diamictons are generally less compact, dense and cohesive. The sandy matrix is poorly consolidated and usually deficient in silt and clay. Clast content is higher, ranging from 20-45%. As with the basal tills, the sediments are very poorly-sorted with clast size ranging from granule to boulder (latter often abundant), but mean clast size is generally larger (about 4 cm). Clast provenance is sometimes variable, but often deposits are almost entirely monolithologic in character (Baldy Batholith origin). However, mixed lithologies including Eagle Bay Assemblage rocks increase in abundance gradually to the south. These diamictons are interpreted as supraglacial or ablation till deposits, resulting from deposition by stagnating glacier ice (*cf.* Dreimanis, 1988).

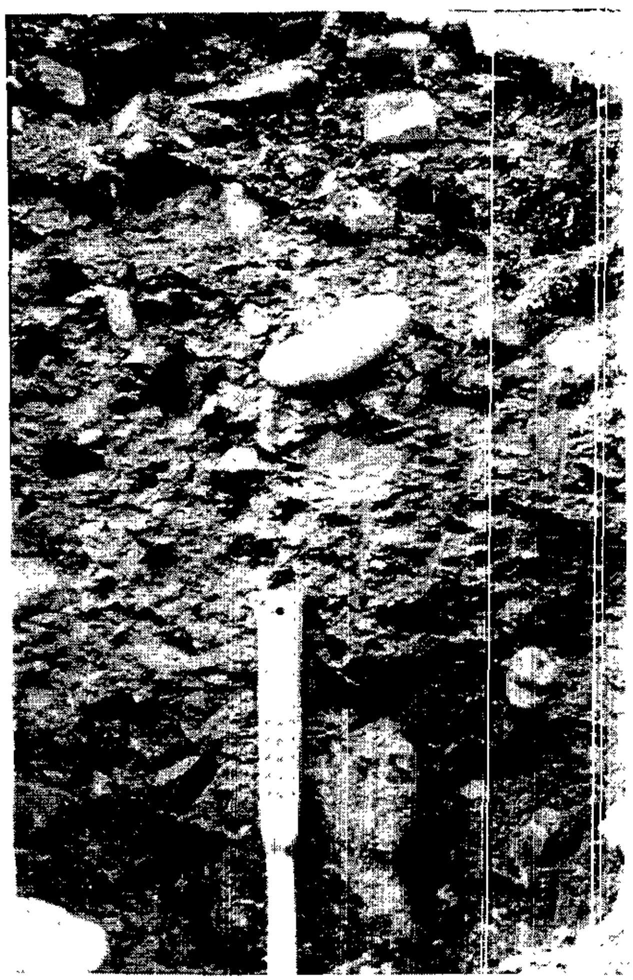

Photo 1: An exposure of basal till. Note massive nature of the matrix-supported diamicton.

Photo 2: Ablation till. Photo shows boulder field of granitic rocks. Typically observed on plateaus within the central and northern parts of the study area.

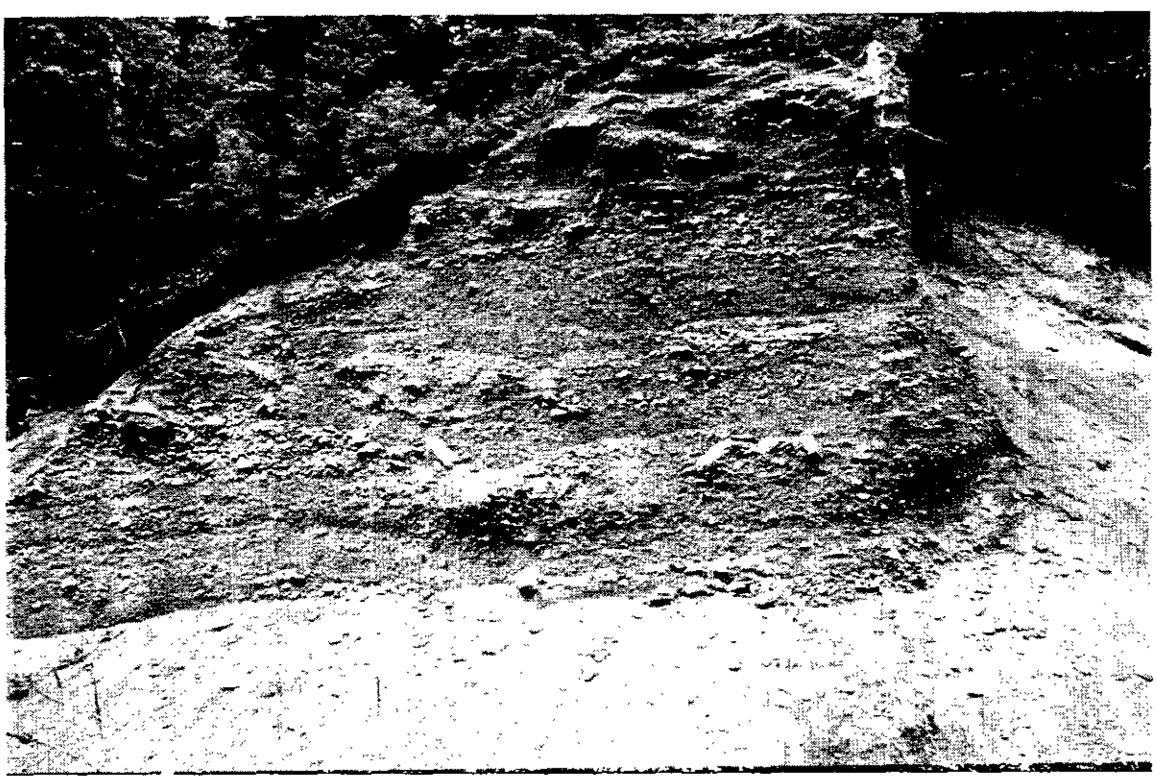

Photo 3. Well-stratified glaciofluvial gravel and sand observed several hundred metres above Adams Lake.

Glaciofluvial Sediments

Sequences of clast-supported gravel and interstratified beds of sand and silt occur in uplands and lower portions of valley slopes (Photo 3). The thickest accumulations are found along valley floors. Gravels are composed of poorly sorted, rounded clasts of variable lithologies, often ranging in size from pebbles to boulders. Deposit characteristics vary considerably from massive and crudely stratified to very well-stratified, and with normal, reverse or no grading. Open-work and matrix-filled beds were observed. Pebble imbrication and cross-stratification are present in many cases, providing indications of paleo-stream flow direction during deposition. The proportion of silty sand to coarse sand interbeds is also variable in the gravel deposits. The finer beds range from well to poorly sorted, often with cross-bedding structures and rarely with load features such as flame structures. In some cases, very coarse accumulations of sand and gravel are highly disrupted with steeply dipping, variably oriented, strongly faulted features. In other cases, deposits are well-stratified, horizontally bedded and moderately well-sorted consisting of alternating layers of sand and gravel. This range in characteristics is interpreted to reflect differences in proximity to ice during deposition, from ice-proximal to ice-distal. The deposits are all interpreted to represent glaciofluvial environments (*cf.* Miall, 1977; Collinson, 1978).

Glaciolacustrine Sediments

Along certain sections of the valley bottoms of Cicero Creek and Barriere River, and parts of the shorelines of Adams Lake, outcrops of rhythmically laminated silts are common (Photo 4). Flat, tabular horizontally stratified laminations are the most common, but ripple drift laminated beds, and ball and pillow structures also occur. Individual beds and laminations generally show sharp basal contacts, and vary in thickness from a few millimetres to several tens of centimetres. Massive, normally and reversely graded beds are present. Convolutions, rip-up clasts and load structures are occasionally present. Texturally, deposits range from sandy silt with isolated stones to clay and clayey silt with few particles coarser than sand. Penetrative structures underlying many isolated clasts indicate they are dropstones. These sediments are interpreted as being

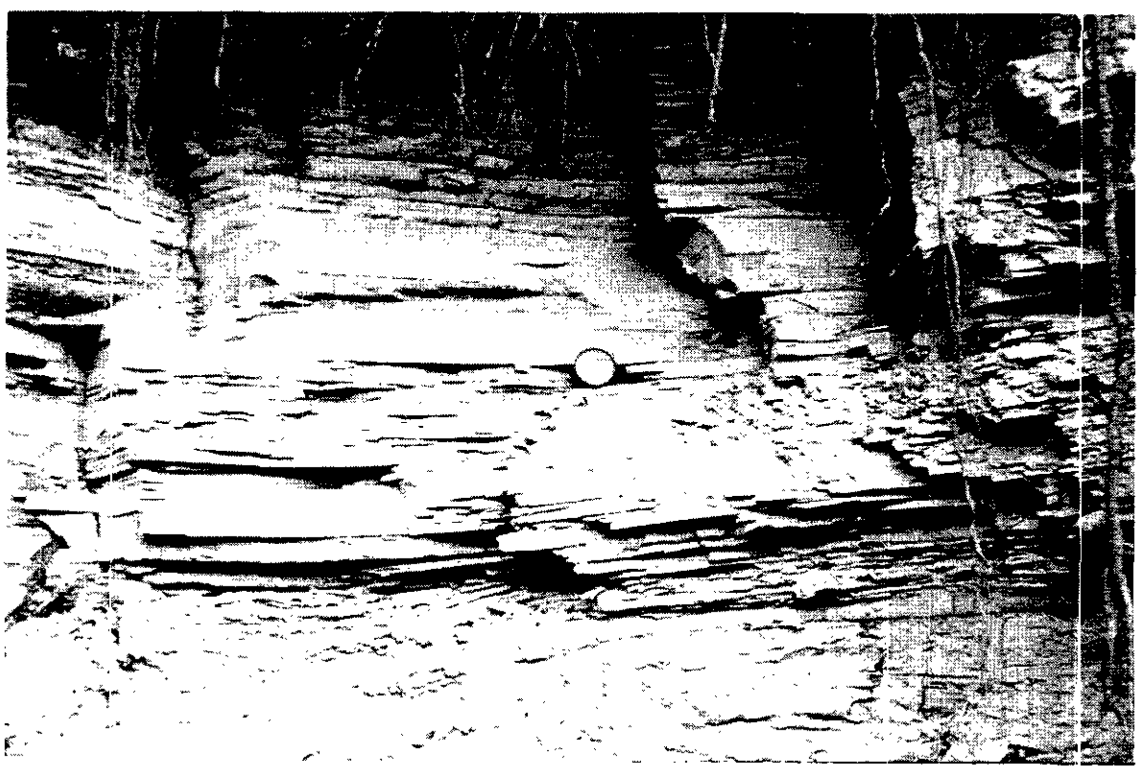

Photo 4. Bedded and laminated glaciolacustrine clayey silt.

deposited in a glaciolacustrine environment (*cf.* Shaw 1975; Catto, 1987). Variations in deposit characteristics indicate differing proximity to glacial ice sources during deposition.

Fluvial Sediments

Throughout the region, streams have incised channels and gullies into bedrock or older drift deposits. Within these areas, accumulations of clean, well-sorted and stratified sand and gravel can be observed. Clasts are generally well-rounded and reflect variable provenance. Restricted to the lower elevations of the study, fluvial deposits appear as small terraced landforms or discontinuous sediment veneers over other types of deposits preserved within the modern floodplains.

Colluvium

The high relief topography in the region accelerates the development and accumulation of colluvial debris. Deposits of colluvium vary in thickness from a few centimetres to a few metres and have been observed to overlie all other types of sediments and bedrock. Colluvial sediments accumulate as a result of gravity-induced downslope movement of fractured bedrock or other unconsolidated sediment such as till, outwash or fluvial sediments. The material contributing to the development of the colluvium strongly influences the character of the final deposit. As a result, colluvium varies from massive to crudely stratified, poorly-sorted to moderately sorted, matrix to clast-supported, monolithic to polylithic. Clast size ranges from granule to boulder and shape can include very angular to well-rounded rocks. Usually, colluvial deposits are thin, dominated by local lithologies and clasts are mainly angular in shape. Bedrock and glacial deposits on steep slopes are commonly covered by colluvium. Given the importance of relief, colluvium dominates the central and northern portions of the North Barriere Lake map area.

Organic Deposits

Extensive organic deposits are located along major meltwater channels, where well-developed streams are not present and drainage is poor. Organic deposits are also established on level upland plateaus where underlying deposits or bedrock also inhibit quick drainage.

CONCLUSION

The contemporary landscape of the Adams Plateau-North Barriere Lake region is the product of a well-documented glacial and postglacial geological history. Although the area has been subjected to several glaciations, it is the effects of the final glaciation during the Late Wisconsinan, coupled with extensive modification during the Holocene that has had the most pronounced impact on the type and distribution of surficial sediments in this area. Much of the area, except the highest peaks in the northwest where bedrock exposures are abundant, is covered by some form of glacigenic material, often a veneer or blanket of basal till, but in some cases also a supraglacial till. The next most ubiquitous type of deposit consists of various types of colluvium usually in the form of veneers less than a metre in thickness which overlie either bedrock or other types of unconsolidated sediment. Stratified outwash deposits are found in valley bottoms often at higher elevations, whereas postglacial fluvial deposits are more common at lower elevations. Although more abundant in surrounding areas beyond the limit of mapping, glaciolacustrine sediments are also found in low-lying depressions and at elevations correlative to regional postglacial lake levels. Finally, in flat areas of poor drainage, organic deposits are commonly found.

Knowledge regarding the type, character, thickness and distribution of unconsolidated sediments covering bedrock is an important element in any regional and local exploration program. Because bedrock is often masked by a cover of overburden, the proper genetic interpretation of these deposits is essential in recognizing and delimiting potential areas of mineralization. Knowledge of paleo-flow direction, responsible for erosion and sediment deposition (both glacigenic and non-glacigenic) is equally critical in any program relying on a drift exploration approach. The surficial sediment information presented here should be integrated with the till geochemistry focus presented elsewhere (Bobrowsky *et al.*, 1996) to ensure success in a regional drift prospecting initiative in this region.

ACKNOWLEDGMENTS

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EAGLE BAY PROJECT: TILL GEOCHEMISTRY OF THE ADAMS PLATEAU (82M/4) AND NORTH BARRIERE LAKE (82M/5) MAP AREAS

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KEYWORDS: drift exploration, till geochemistry, exploration, Quaternary, Eagle Bay, Adams Lake, Barriere, prospecting, VMS

INTRODUCTION

Drift exploration studies were undertaken in the summer of 1996 as part of an integrated regional exploration program centred on Devono-Mississippian rocks of the Eagle Bay Assemblage. Volcanogenic sulphide-barite deposits in the area including Rea Gold (MINFILE 082M 191) and Homestake (MINFILE 082M 025) suggest the region has considerable mineral potential. The drift exploration component of the study involved 1:50 0000 scale surficial geology mapping (Dixon-Warren *et al.*, 1997a) and till geochemistry sampling on NTS map sheets 82M/4 (Adams Plateau) and 82M/5 (North Barriere Lake) directly northeast of Kamloops (Figure 1). Related studies included mineral deposits research (Höy, 1997), and a stream water survey and geochemical orientation (Sibbick *et al.*, 1997). Recent and successful exploration activity in correlative rocks in the Yukon at properties such as Kudz Ze Kayah and Wolverine provided the impetus for work in the Eagle Bay Assemblage.

The purpose of the drift exploration program was to document the surficial geology of the area and to provide results of a reconnaissance level till geochemistry sampling initiative. The goal of the surficial geology research was to map approximately 2000 square kilometres of rugged, moderately high relief, glaciated terrain by documenting the type and distribution of Quaternary sediments present. Discussion and greater detail is provided in Dixon-Warren *et al.* (1997a), whereas the surficial maps for both sheets are available in Leboe *et al.* (1997) and Dixon-Warren *et al.* (1997b).

The objectives of the till geochemistry project were:

- to define new anomalies which may be used in the discovery of mineralization targets;
- to stimulate new exploration and economic activity;
- to provide information that will be of use in all areas where mineral exploration has been hampered by thick glacial drift cover, and where traditional prospecting and exploration techniques have proven unsuccessful despite indications of high mineral potential.

The purpose of this paper is to summarize the till geochemistry activities of the 1996 summer field season. We review the setting, sampling techniques and methods of analysis and preliminary results of the research. Brief discussion of the paleo-ice flow history and Quaternary stratigraphy is provided to supplement the analytical results presented elsewhere.

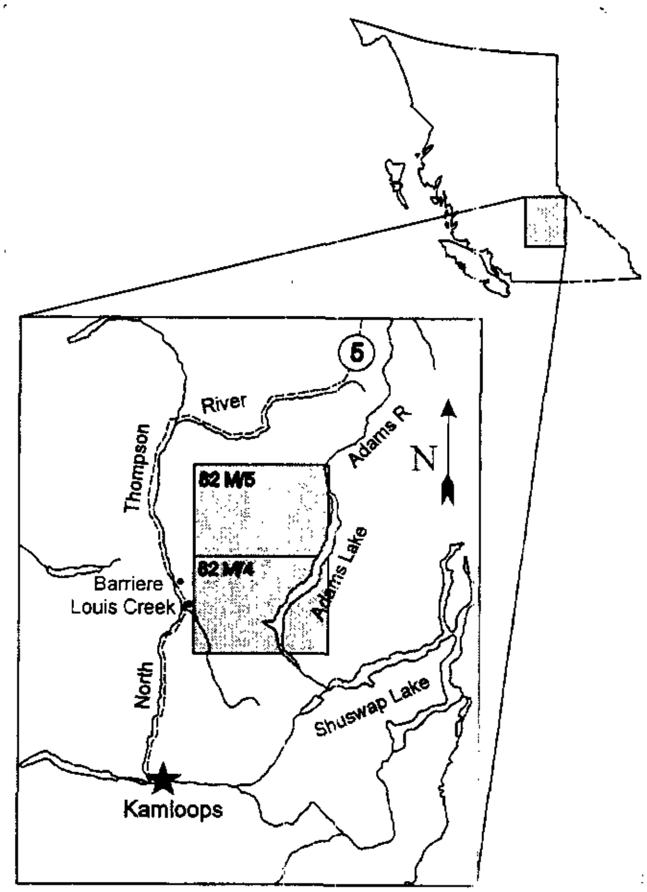

Figure 1. Location of Eagle Bay drift exploration project study area in south-central British Columbia.

BACKGROUND

Located in south-central British Columbia, the Adams Plateau and North Barriere Lake map area lies in the southern part of the Shuswap Highland, within the Interior Plateau (Holland, 1976). This region is characterized by moderate to high relief, glaciated, and fluvially dissected topography. Elevations range from 450 to 2630 m above sea level (Photo 1). Most of the area is covered by drift of mixed genesis and of variable thickness rarely exceeding a few tens of metres. Ground moraine (various facies of till) dominates the landscape, followed in turn by colluvial, glaciofluvial and fluvial sediments. As such, the area is very amenable to a till geochemistry survey.

In terms of the bedrock geology, the area lies within the Kootenay Terrane, supporting economically attractive suites including Paleozoic metasedimentary and metavolcanic rocks of the Eagle Bay Assemblage and Fennell Formation. As mapped in detail by the BC Geological Survey Branch (Schiarizza and Preto, 1987), both the Eagle Bay and Fennell transect significant parts of both map sheets. Schiarrizza and Preto (1987) assigned ages of Early Cambrian to Late Mississippian to rocks of the Eagle Bay Assemblage. These consisted of quartzites, quartzose schists, and limestones overlain by calcareous phyllite, calc-silicate schist and skarn or mafic metavolcanics, which in turn are overlain by felsic metavolcanic rocks, intermediate locally alkalic metavolcanics and clastic metasediments. The Fennell Formation comprises oceanic rocks consisting of bedded cherts, gabbro, diabase, pillowed basalt, sandstone, quartz-feldspar-porphyry and conglomerate.

Rocks of the Intermontane Belt border the west, whereas high-grade metamorphic rocks of the Shuswap Complex lie to the east.

The Devono-Mississippian felsic to intermediate metavolcanic rocks of the Eagle Bay Assemblage host polymetallic precious and base metal massive sulphide occurrences; most notably Rea Gold, Samatosum (MINFILE 082M 244) and Homestake mines (Figure 2). There are 79 mineral occurrences in total, 42 of them are on NTS 82M/4 and 37 of them on NTS 82M/5. All "past producer" occurrences (6) and "developed prospects" (3) include Pb, Zn, Ag, and Cu. Seven of these occurrences include Au.

METHODS

Fieldwork was based out of two camps: one near Tod Mountain for work in NTS 82M/4 and a second at the west end of East Barriere Lake for work in NTS 82M/5. Access to the lower two-thirds of the area is excellent. An extensive network of logging roads intersects most moderate slopes and all plateaus. There is, however, a lack of road access to the very steep slopes on the eastern shore of Adams Lake adjacent to the Adams Plateau, and the extreme southwestern margin of the Adams Plateau map area. The northern reaches of the study area are at

Photo 1. View to northwest along Sinmax Creek, with Homestake in centre of photo. Note high relief, plateau topography.

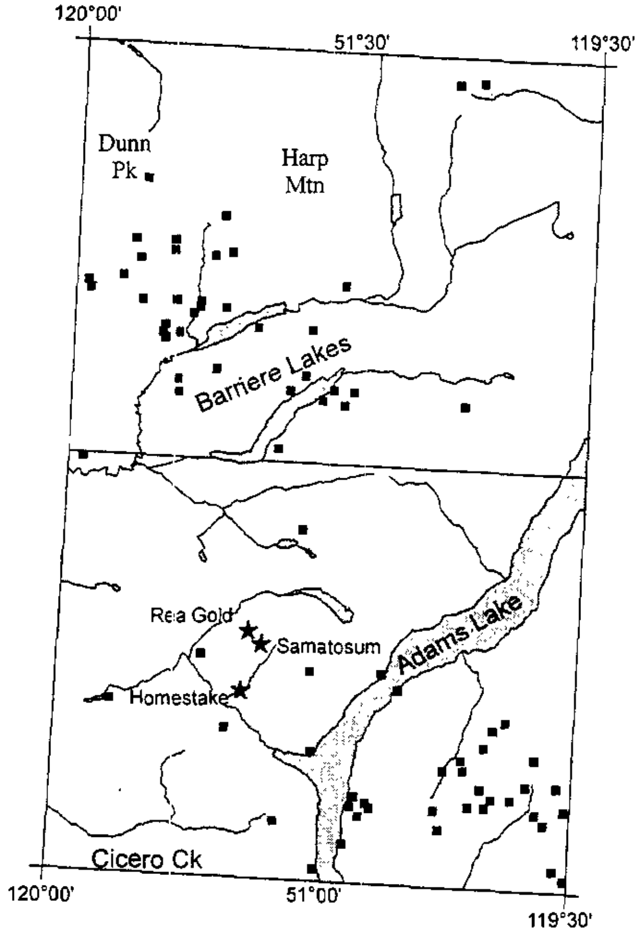

Figure 2. Mineral occurrence locations for NTS 82M/4 and 5 from MINFILE database.

Photo 2. Example of striated bullet-shaped boulder lying on till surface.

increasingly higher elevation, and close to treeline; consequently, logging roads are infrequent, and access is restricted, especially in the northwest corner near Dunn Peak and Harp Mountain.

The majority of fieldwork was conducted with a 4-wheel drive vehicle along secondary roads and trails of varying condition. Where road or 4-wheel drive track access was blocked or non-existent, traverses were completed on foot.

Initial work consisted of compiling and evaluating all existing terrain information available for the area. Soil and landscape maps produced by the Resource Analysis Branch of the British Columbia Ministry of Environment (Kowall, 1975a, 1975b) provided background data on the type of materials likely to be encountered. Regional Quaternary mapping studies completed by the Geological Survey of Canada (*e.g.* Fulton *et al.*, 1986) contributed further information on the types and distribution of sediments which may occur in the region. Regional ice flow was determined from Fulton *et al.* (1986) using their 1:250 000 surficial geology map of the Seymour Arm. Airphoto analysis contributed to paleo-ice-flow determinations from the identification of rare drumlinoid features and lineations on plateaus. Detailed local ice-flow directions were obtained by measuring the orientation of striations or grooves on bedrock surfaces, and apparent till fabric was determined from the orientation of bullet-shaped boulders (Photo 2).

Air photographic interpretation and 'pretyping' followed the methodology of RIC (1996) and the terrain classification system of Howes and Kenk (1988). Air photos at a scale of 1:40 000 (approx.) (flight lines 15BCC-95009, 95014 and 95017) were used in the map generation. Final terrain maps were produced at a scale of 1:50 000. Preliminary polygon interpretations were verified through ground-truthing. About half of the polygons were evaluated on the ground, thereby corresponding to a Terrain Survey Intensity Level B (Resources Inventory Committee, 1996).

At each ground-truthing field station some or all of the following observations were made: GPS-verified UTM location, identifying geographic features (*i.e.* creek, cliff, ridge), type of bedrock exposure if present, unconsolidated surface material and expression (terrain polygon unit), general slope, orientation of striations/grooves on bedrock or of bullet-shaped boulders.

Bulk sediment samples (1-5 kg in size) were collected for geochemical analysis over much of the study area. Emphasis was placed on collecting basal till deposits (first derivative products according to Shilts, 1993), although ablation till, colluviated till and colluvium was also collected under certain circumstances. Natural exposures and hand excavation were used to obtain samples from undisturbed, unweathered C horizon (parent material) deposits. At each sample site, the following information was recorded: type of exposure (gully, roadcut, etc.), depth to sample from top of soil, thickness of A and B soil horizons, clast percentage, matrix or clast-supported diamicton, consolidation, matrix texture, presence or absence of structures, bedding, clast angularity (average and range), clast size (average and range), clast lithologies, and colour. The sample was evaluated as being derived from one of five categories; basal till derived from the Eagle Bay Assemblage, basal till derived from the Baldy Batholith, colluviated/reworked basal till, ablation till, or colluvium. Sediment samples were submitted to Eco Tech Laboratories in Kamloops for processing. This involved air drying, splitting, and sieving to <63μm. The pulps, <63μm sample and unsieved split were subsequently returned to the BCGS. The <63μm fraction of each sample was further divided into 10 and 30 gram portions. The smaller portion was sent to Acme Analytical Laboratory, Vancouver, where samples were subjected to aqua regia digestion and analysis for 30 elements by ICP (inductively coupled plasma emission spectroscopy) and for major oxides by $LiBO_2$ fusion - ICP (11 oxides, loss on ignition and 7 minor elements). The larger portion was sent to Activation Laboratories, Ancaster, Ontario, for INA (thermal neutron activation analysis) analysis for 35 elements (Table 1).

TABLE 1: ANALYTICAL METHODS EMPLOYED AND ELEMENTS ANALYZED FOR TILL GEOCHEMISTRY SURVEY.

ANALYSIS	ELEMENTS
Whole Rock	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, MnO, TiO_2, P_2O_5, Cr_2O_3, LOI, Ba, Ni, Nb, Sr, Sc, Y, Zr
INA	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, Lu
ICP	Mo, Cu, Pb, Zn, Ag, Ni, Co, Mn, Fe, As, U, Au, Th, Sr, Cd, Sb, Bi, V, Ca, P, La, Cr, Mg, Ba, Ti, B, Al, Na, K, W

Pebble samples were collected at a number of till sample stations for lithologic provenance studies. Between 105 and 110 clasts were collected at each station from within the trench dug for diamicton sampling. (A higher number than 100 clasts was collected to anticipate miscounts, non-identification and specimen destruction). Pebbles were returned to camp daily, split and are now stored in the Department of Earth Sciences, Simon Fraser University pending future identification. Sampling focused on the Adams Plateau map area and the southern margin of the North Barriere Lake map, in order to limit data collected to tills representative of the Eagle Bay Assemblage.

RESULTS

A total of 660 field stations were examined for ground truthing over the total area during the course of this survey. The resultant field checking density based on full map sheets is one station per 2.5 km^2 for NTS 82M/4 and one station per 3.6 km^2 for NTS 82M/5. Excluding inaccessible areas, field checking density increases to one station per 2.0 km^2 and one station per 2.3 km^2 for NTS 82M/4 and M/5, respectively.

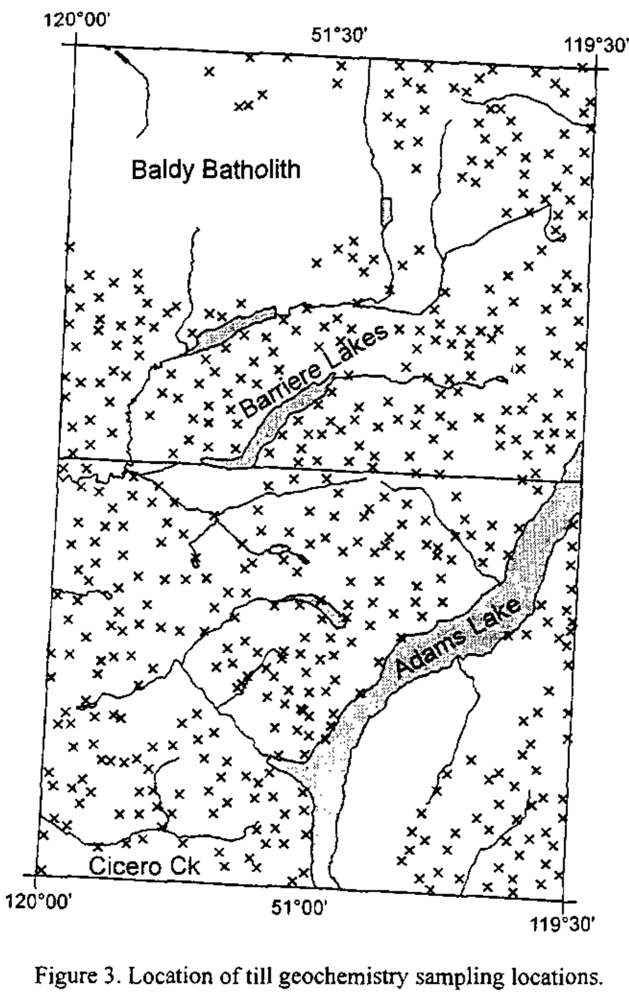

Figure 3. Location of till geochemistry sampling locations.

A total of 96 pebble lithology stations were eventually sampled for provenance during this survey. Sampling density averaged one per 11 km^2, although not equally distributed, since a higher concentration of stations occur in the southwest part of NTS 82M/4. Excluding inaccessible areas, pebble sampling density is about one per 9 km^2. Results of the identification are pending, but will be used to calculate transport distances and infer paleo-ice dynamics (*cf.* Bobrowsky, 1995).

A total of 535 bulk sediment samples were initially collected for the till geochemistry study (Figure 3). Of these, 526 samples were considered acceptable for the objectives of this survey. Samples were collected at an average depth of 1.9 m below soil surface. Till sample density averaged one per 3.8 km^2 for the total survey area. *Excluding inaccessible regions, sampling density* averages one per 2.6 km^2. This level of sampling provides a high level of reconnaissance information for the region.

Most of the samples taken for geochemical analysis were representative of basal till, most likely lodgement till (Photo 3). Of the 526 samples, 413 or 79% represented this sediment type (Table 2). Two types of basal till were recognized, one reflecting an origin predominantly seated in Eagle Bay Assemblage rocks (M1), and the other derived from Baldy Batholith rocks (M3). Basal till which has undergone slight downslope movement was classed as colluviated till (CM). Samples taken from this type of deposit accounted for 76 or 14% of the total. Together, these three groups (93%) represent the highest quality media to sample for drift exploration. Also valid, but more difficult to interpret were the remaining 37 or 7% of the samples which were collected from ablation till (M2) *and colluvium* (C).

TABLE 2: FREQUENCY, PERCENT AND DISTRIBUTION OF SEDIMENT TYPE SAMPLED FOR TILL GEOCHEMISTRY SURVEY.

UNIT	DESCRIPTION	#	%
M1	Lodgement till derived from Eagle Bay Assemblage	340	65%
M3	Lodgement till derived from Baldy Batholith	73	14%
M2	Ablation till, generally derived from Baldy Batholith	17	3%
CM	Colluviated/reworked till	76	14%
C	Colluvium	20	4%
Total		526	100%

Results and interpretation of the till geochemistry survey for this study appear elsewhere (Bobrowsky *et al.*, 1997).

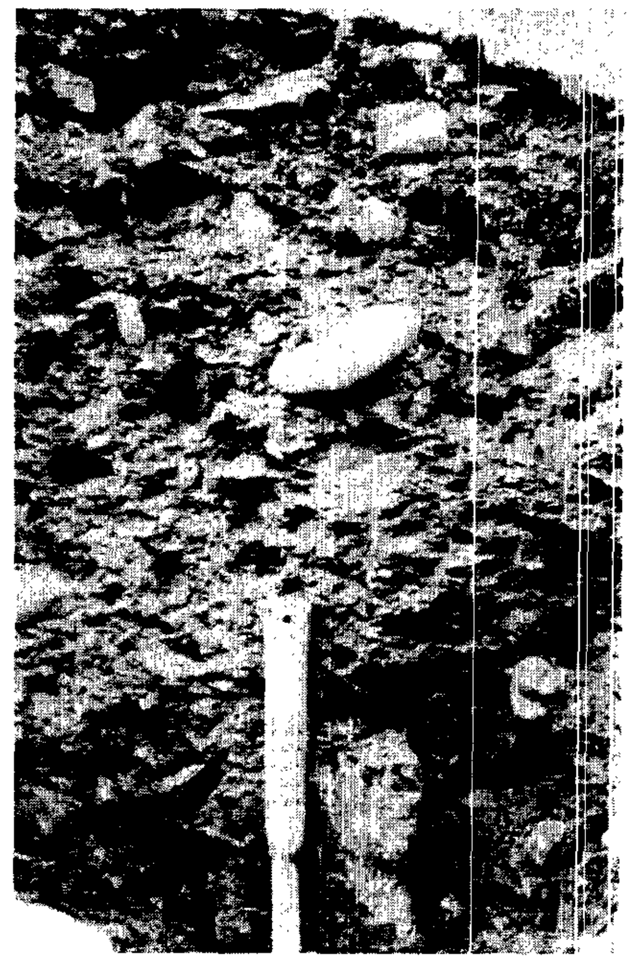

Photo 3. Example of basal till deposit representative of commonly sampled materials during Eagle Bay drift exploration project.

Previous geochemical studies provide an indication as to the style of mineralization, configuration of anomaly plumes and regional dispersal patterns one can expect for this area. Three examples of property scale geochemical sampling from two separate occurrences are presented here as analogues to the expected regional dispersal patterns.

At the Silver 1 property, located directly south of the confluence of Homestake and Sinmax creeks, B Horizon soil samples illustrate two forms of geochemical anomaly patterns (Richards, 1989). The cobalt plume shows a fan-shaped down-ice dispersal pattern with a sharp apex and broader fan tail extending about 500 m in length from the northwest to the southeast. The direction of this anomaly parallels the regional ice flow pattern and reflects strong clastic dispersion in the basal till media (Figure 4). At the same property, arsenic displays a less distinct dispersal pattern. In this case, although the long axis of the plume

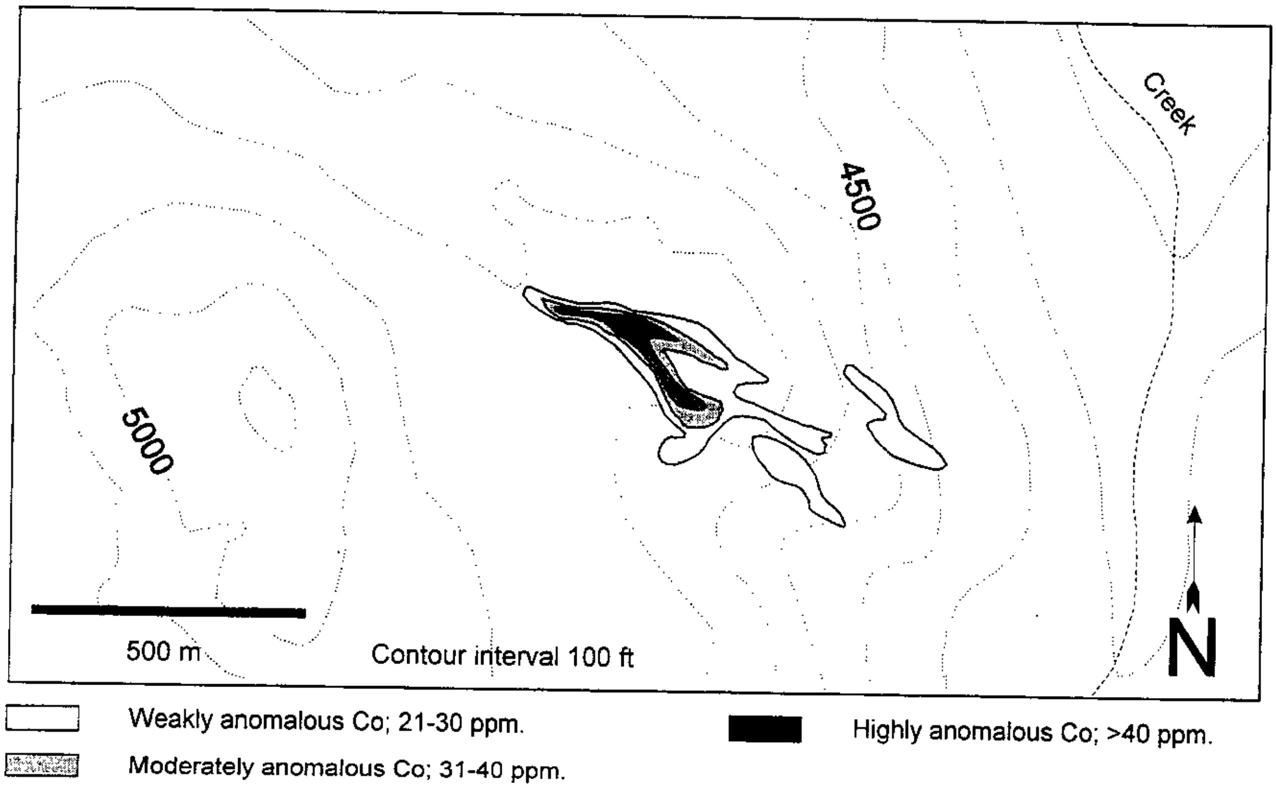

Figure 4. Cobalt soil anomaly for the Silver 1 property. Modified after Richards, 1986.

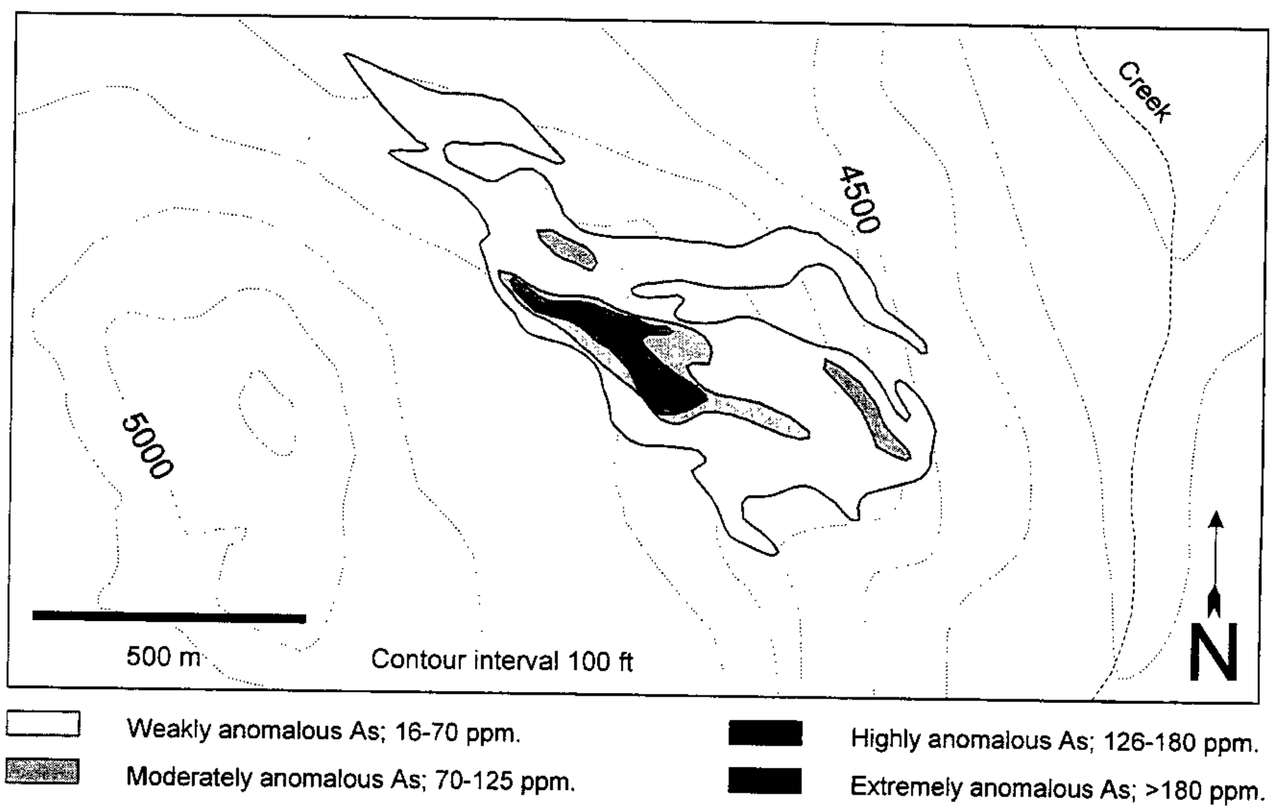

Figure 5. Arsenic soil anomaly for the Silver 1 property. Modified after Richards, 1986

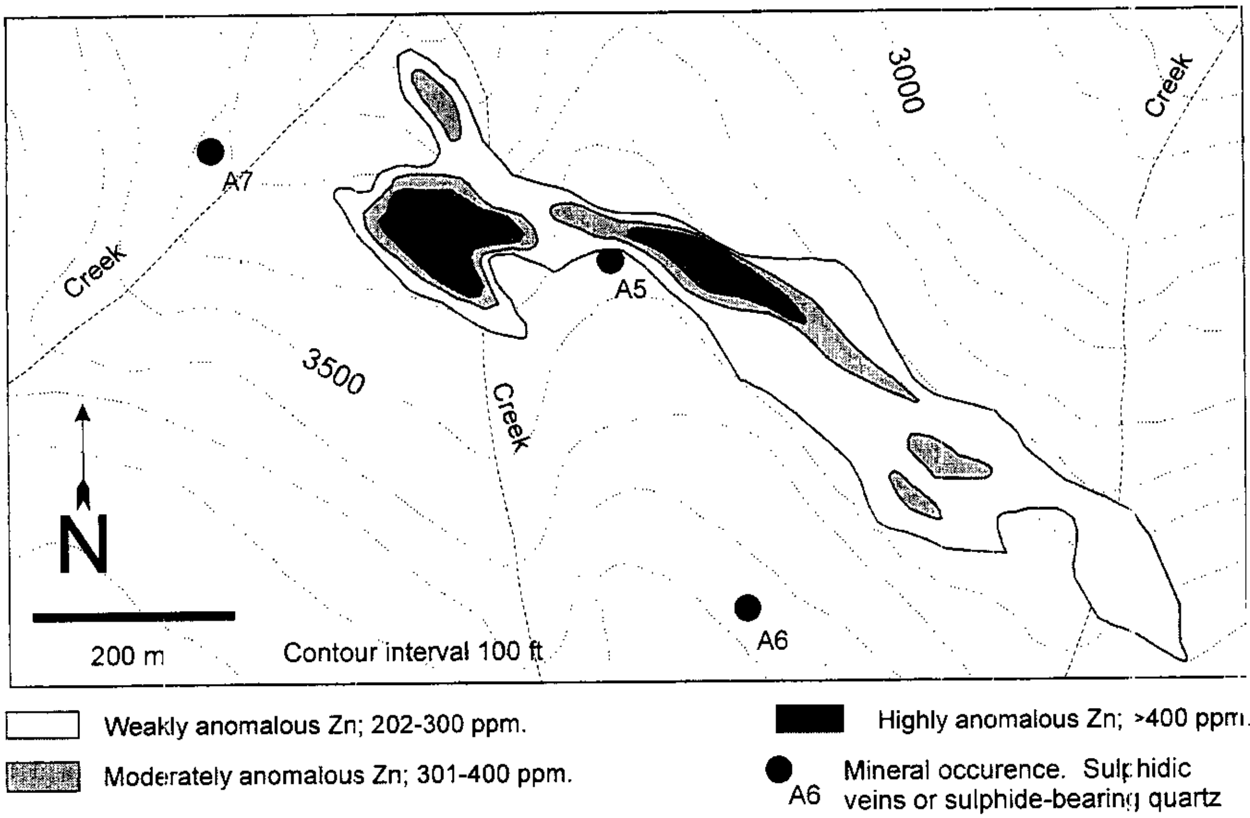

Figure 6. Zinc soil anomaly for the Kamad 3 property. Modified after Marr, 1989.

parallels regional ice flow from northwest to southeast and thus reflects typical clastic dispersal, a secondary downslope northeasterly component has been overprinted on the initial shape. Here, hydromorphic dispersion may have modified the original shape creating an anomaly over one km long and 500 m wide (Figure 5). Cobalt illustrates a single vector (ice-parallel) configuration, whereas arsenic illustrates a compound two vector configuration consisting of ice parallel plus downslope directions.

At the Kamad 3 property, also near the confluence of Homestake and Sinmax creeks, but about two kilometres north of Silver 1, a zinc anomaly shows a classic cigar-shaped dispersal plume (Marr, 1989). As in the previous cases, the form parallels regional ice flow to the southeast (Figure 6). This particular anomaly is about one kilometre long and 200 m wide. Although the anomaly crosses a slope and follows the contours of the land, there is no secondary downslope dispersion as in the case of arsenic in the previous example. A possible minor hydromorphic extension to the dispersal plume may be present at the head of the anomaly where it crosses a small creek.

GLACIAL HISTORY

The success of the regional drift exploration program requires the proper integration of consistent C horizon till geochemical data within the framework of a well-defined Quaternary geologic history.

According to Fulton and others (Fulton and Smith, 1978; Ryder *et al.* 1991), the present-day landscape of south-central British Columbia is the result of two cycles of glaciation, one interglacial and intensive early Holocene erosion and sedimentation. Although not necessarily present in the study area, the following lithologic units and their correlative geologic climate units have been identified in south-central British Columbia. The oldest deposits in the region, thus far identified at only two locations some 60 and 100 km to the south, are the interglacial Westwold Sediments. These deposits consist of cross-stratified gravely sand, capped by marl, sand, silt and clay all of which are equivalent in age to the Highbury Non-glacial Interval in the Fraser Lowland (Sangamonian).

Next in age are Okanagan Centre Drift deposits, consisting of coarse, poorly stratified gravel, laminated silt and till, presently recognized at Heffley Creek, (20 km to the south of the study area) and elsewhere farther south. These sediments were deposited during the Okanagan Centre Glaciation, equivalent to the Semiahmoo Glaciation in the Fraser Lowland (Early Wisconsinan).

Middle Wisconsinan, Olympia Non-Glacial Interval Bessette Sediments overlie the Okanagan Drift deposits. They consist of nonglacial silt, sand and gravel with some organic material and in some cases up to two tephras.

The Kamloops Lake Drift overlies the Bessette Sediments, and underlies the present-day surface cover of postglacial deposits. This unit consists of silt, sand, gravel and till deposited during the Fraser Glaciation (Late Wisconsinan).

The surface and near-surface sediments mapped in the Adams Plateau and Barriere Lakes areas directly result from the last cycle of glaciation and deglaciation (Fraser Glaciation), and ensuing postglacial activity. Regional ice flow, as determined from Fulton *et al.* (1986) ranges from south to southeast. This regional flow direction was observed in several locations in both map areas. Ice flow was also diverted locally in several of the valleys. For example, along the Barriere River valley at the boundary of NTS maps 82 M/4 and 82 M/5, striations on a bullet shaped boulder embedded in till indicate that ice flowed to the east, parallel to the valley orientation. Similar down-valley deflection of ice flow is recorded on bullet-shaped boulders within the Fadear Creek valley, and western Sinmax valley, where regional southeast flow was deflected eastward (Photo 2).

Existing radiocarbon dates provide a tentative chronology for glaciation and deglaciation of the Adams Plateau region. Late Wisconsinan ice first covered the area sometime after 20230 ± 270 years BP. Dates of 11.3 ka and 10.1 ka indicate that deglaciation began shortly before this time in the lowland areas of this region (Dyck *et al.*, 1965).

DRIFT EXPLORATION IMPLICATIONS

The moderately high relief and clearly defined valley systems contribute to a well suited landscape for drift exploration. Excluding exposed bedrock peaks, much of the non-lowland areas are mantled by colluvium often less than a metre thick or, more commonly, locally derived basal till. Basal till deposits are often less than several metres thick and commonly directly overlie bedrock. Moreover, till observed in both map sheets appears to be representative of the last glaciation to have affected the region. Sediments older than Late Wisconsinan were not observed.

The above characteristics are positive signs for both reconnaissance and property scale drift prospecting work. Basal till is clearly recognized as the most ideal sediment sampling media for drift prospecting (Shilts, 1993) and in this study area it represents the dominant sediment type. Thin deposits of basal till usually reflect a more proximal source area for the sediment. If the surficial sediments are all Late Wisconsinan or postglacial in age, then there are no complications of multiple ice flow directions to interpret. Finally, the ice flow direction is generally south to southeast over highland and mid-slope areas or vary south to east within confined valley settings.

Existing geochemical anomalies from known mineral occurrences indicate that the dispersal plumes conform to classic down-ice shapes, usually proximal to the source bedrock. This implies that the anomalous values detected through this reconnaissance survey will be very useful for future exploration activity. Moreover, clastic dispersal patterns associated with these anomalies will most likely strongly parallel ice flow, they may possibly be imprinted with only minor hydromorphic downslope effects and they will probably occur within tens of metres of the source rock.

SUMMARY

A drift exploration project was initiated and completed during the summer of 1996 focusing on surficial geology mapping and till geochemistry surveying over rocks of the Eagle Bay Assemblage northeast of Kamloops. Two 1: 50 000 scale terrain geology maps have been completed for the area, showing the type and distribution of surficial sediments present. A total of 526 samples were collected for the till geochemistry survey and subjected to ICP, INA and whole rock analysis.

The results of this research indicates that the local terrain is highly favourable for drift exploration studies. Dispersal plumes of known geochemical anomalies conform to traditional down-ice, cigar-shaped configurations. Drift cover, although extensive, consists primarily of thin basal till deposits. Local and regional ice flow patterns range from south to southeast and are easily determined in the field at the site level. Integration of the surficial geology maps and reconnaissance till geochemistry results should now be pursued at the property scale of exploration to locate potential mineral deposits now obscured by surficial sediments.

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EAGLE BAY PROJECT: REGIONAL HYDROGEOCHEMICAL SURVEY AND GEOCHEMICAL ORIENTATION STUDIES (82M/4 AND 5)

By S.J. Sibbick, J.L. Runnells and R.E.W. Lett

KEYWORDS: Adams Plateau, Eagle Bay, Exploration Geochemistry, Hydrogeochemical Survey, Massive Sulphide, Orientation Survey, Regional Geochemical Survey, RGS.

INTRODUCTION

Geological Survey Branch staff conducted two exploration geochemistry programs as part of the Eagle Bay project (Figure 1). These included a regional stream water geochemistry (hydrogeochemical) survey and a detailed soil and biogeochemical orientation study of the significant mineral deposit types in the region. These activities were co-ordinated with 1:50 000 scale surficial mapping (Dixon-Warren *et al.*, 1997), a regional till geochemistry survey (Bobrowsky, *et al.*, 1997) and mineral deposit studies (Hoy, 1997). The project area corresponds to a region of previous Geological Survey Branch bedrock mapping (Schiarizza and Preto, 1987) covering NTS map sheets 82M/04, 05 and 12 (Figure 2).

The Eagle Bay project area hosts Devono-Mississippian age rocks of the Eagle Bay Assemblage which are identical in many respects to rocks hosting the Kuroko-type volcanogenic massive sulphide deposits (Kudz Ze Kayah and Wolverine) recently discovered in the Yukon. The known deposits in the survey area, including the Homestake (MINFILE 82M 025), Twin Mountain (MINFILE 82M 020) and Rea Gold (MINFILE 82M 191) deposits, are highly similar to these Yukon examples and provide excellent targets for exploration. In addition, Cambrian-age Eagle Bay Assemblage rocks in the south-east corner of the project area host several significant SEDEX Pb-Zn-Ag and Besshi Cu-Zn-Ag deposits. Details of these deposits are reported in Schiarizza and Preto (1987).

However, the extensive overburden cover and the relatively small size of the target deposits are obstacles to new mineral discoveries. This suggests that geochemical exploration techniques can play a significant role in detecting new mineralization.

The goals of the Eagle Bay Exploration Geochemistry program are to:

- Produce regional stream water geochemistry maps of major and minor elements.
- Determine critical exploration geochemistry parameters for massive sulphide exploration in overburden covered areas.

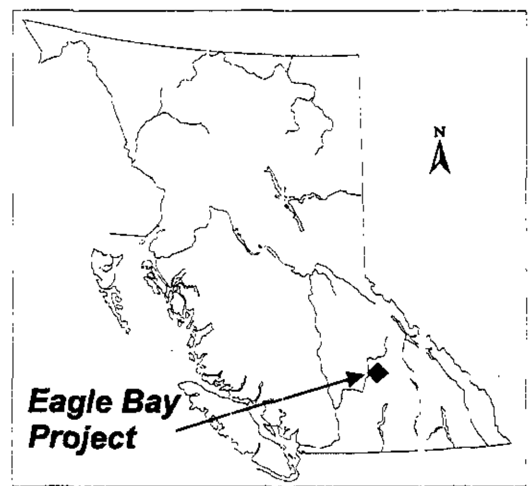

Figure 1. Location of the Eagle Bay Project

HYDROGEOCHEMICAL SURVEY

Stream water surveys offer the advantage of detecting subtle anomalies derived from groundwater sources. The sources may be from concealed or buried mineralization. Critical to the success of a hydrogeochemical survey is the use of an analytical method that provides a low detection limit for the elements of interest. The declining cost of inductively coupled plasma mass spectrometry (ICP-MS) has provided an analytical technique that can provide detection limits in the parts per trillion (ppt) range. To date, few regional stream water geochemical surveys have been conducted in British Columbia. Recently, the Geological Survey Branch released Regional Geochemical Survey (RGS) data on the Gataga area that included ICP-MS data on waters collected during the survey (Jackaman, *et al.*, 1996). In a related study, Lett et al. (1996) released data on spring water chemistry from mineralized and non-mineralized seepages in the Gataga area.

The Eagle Bay hydrogeochemical survey is a pilot project to test the applicability of regional stream water geochemistry as an exploration tool in British Columbia. Data from this survey can also be utilized as a baseline database for environmental assessments and reclamation activities.

METHODOLOGY

SAMPLE COLLECTION

Sample collection was carried out from late-June to late August of 1996. A total of 257 stream water samples were systematically collected from 218 sites (Figure 2). Considerable effort was taken to collect all samples upstream of known anthropogenic disturbances such as bridges or culverts on logging roads. Streams of 1 to 2 kilometres in length were the preferred target. However, in some cases streams of greater or lesser length were sampled. Field duplicate samples were routinely collected in each analytical block of twenty samples.

Collected surface water samples were stored in two 250 millilitre polyethylene bottles. Each bottle was rinsed thoroughly with stream water before sample collection. Precautions were taken to exclude suspended solids when possible. One bottle of each pair was immediately refrigerated after collection to retard any chemical changes. Field measurements of pH, Eh, conductivity and temperature were taken at each site. Field observations regarding sample media, sample site and local terrain were also recorded. An aluminum tag inscribed with the sample identification number was fixed to a permanent object at each sample site.

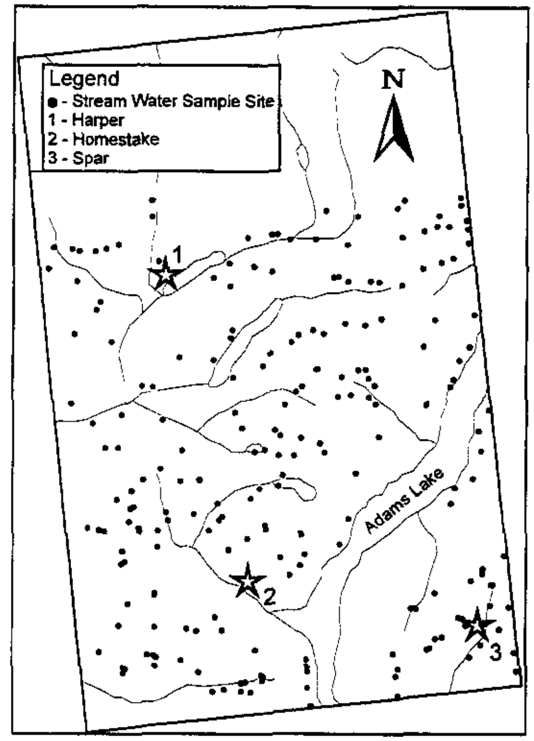

Figure 2. Regional hydrochemistry sample sites and orientation study locations.

SAMPLE PREPARATION AND ANALYSIS

At the field camp, a 100 ml portion of each refrigerated 250 ml surface water sample was filtered through a 0.45-micron cellulose nitrate filter paper into an I-Chem certified™ high-density polyethylene sample bottle. The filtered sample was then acidified to pH 2 to 3 with 50% ultra-pure nitric acid. The remaining 150 millilitres was retained for sulphate and fluoride analysis. At the Ministry laboratory, quality control reference standards and analytical blanks were inserted into each analytical block of 20 water samples.

Filtered and acidified water samples were analysed for trace and major elements by inductively coupled plasma mass spectrometer (ICP-MS) for 66 elements by Activation Laboratories (Ancaster, Ontario) using a Perkin Elmer Elan 6000 inductively coupled plasma mass spectrometer and an Perkin Elmer AS91 autosampler. Reported detection limits for each element and measured parameters are listed in Table 1.

Sulphate in waters was determined by a turbidimetric method. A 20 ml aliquot of the sample was mixed with barium chloride and an isopropyl alcohol - hydrochloric acid - sodium chloride reagent. The turbidity of the resulting barium sulphate suspension was measured with a spectrophotometer at 420 nanometres. The determination of fluoride in waters involved mixing an aliquot of the sample with an equal volume of total ionic strength adjustment buffer (TISAB II solution). The fluoride was measured using a Corning 101 meter with an Orion fluoride electrode.

Temperature, pH, Eh and conductivity were measured in the field using hand-held digital meters. pH measures the hydrogen ion activity of the sample; Eh is an estimate of the reduction-oxidation potential and is measured in millivolts (mv). Conductivity is an indication of the total dissolved load of ions within the streamwater and is measured in milliSiemens per second (µS/S). The pH, Eh and conductivity meters were placed in large mouth 250 ml polyethylene bottles rinsed clean and filled with stream water. Ambient temperature was maintained by placing each bottle out of direct sunlight and/or keeping the bottle within the stream flow. Readings were allowed to stabilize over approximately thirty seconds to one minute. Temperature was measured directly from the stream. All instruments were calibrated every 10-12 samples.

CATCHMENT BASINS

In accord with the methodology employed by the Regional Geochemical Survey program, catchment basins will be used to present the results of this survey. Catchment basins are defined by the topographic height of land that separates one stream from surrounding streams. These polygons are assumed to represent the metal determination of a sample collected at the catchment basin outlet. Catchment basins provide the most effective method for integrating stream geochemical data with other spatial databases.

GEOCHEMICAL ORIENTATION

Detailed geochemical orientation studies were conducted at three mineral occurrences in the Eagle Bay project area (Figure 2). These were selected as representative of the two common mineral deposit types for the region and included the Harper, Homestake, and Spar deposits. Summary details of each deposit are listed in Table 2.

The objective of the orientation study was to determine the effectiveness of various sample media in the detection of massive sulphide mineralization and to highlight critical pathfinder elements. Soil pits or profiles were excavated on lines that traversed the deposits. Samples were collected of the representative soil horizons, humus and forest litter. In addition, samples of common vegetation types were also collected. This included tree bark from Lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga glauca*), twigs from Subalpine fir (*Abies lasiocarpa*), and leaves from the shrubs of Sitka alder (*Alnus viridis*), Falsebox (*Paxistima myrsinites*), Saskatoon (*Amelanchier alnifolia*) and White-flowered Rhododendron (*Rhododendron albiflorum*).

TABLE 2
ORIENTATION STUDY SITES

Name	MINFILE	Type	Commodities
Harper	082M060	Kuroko	Cu, Pb, Zn
Homestake	082M025	Kuroko	Ag, Pb, Zn, Au, Cu, Ba
Spar	082M017	Sedex	Pb, Zn, Ag

Soil samples (-63 micron fraction) were analysed for 50 trace elements including Au, As, Ba, Co, Cu, Mo, Ni, Hg and Zn by thermal neutron activation and by aqua regia digestion-inductively coupled plasma emission spectroscopy (ICP). The soil samples were also analysed for 11 major oxides, loss on ignition (LOI), Ba, Ni, Sr, Zr, Y, Nb and Sc by lithium metaborate fusion-ICP. Dried humus, forest litter, tree bark, leaf and twig samples were macerated and part of the sample compressed into a briquette. A second portion of the macerated material was ashed at 480°C and the ash analysed for 30 trace elements by aqua regia digestion-ICP.

TABLE 1. STREAM WATER ANALYSIS

Element		Analytical Method	Detection Limit	Unit
pH	pH		0.1	pH
Eh	Eh		1	mv
Conductivity	Cond		10	µS/S
Temperature	T		0.1	C°
Sulphate	SO4	TURB	1	ppm
Fluoride	FW	ION	20	ppb
Lithium	*Li*	*ICPMS*	*0.1*	*ppb*
Sodium	Na	ICPMS	0.1	ppb
Magnesium	Mg	ICPMS	0.1	ppb
Aluminium	Al	ICPMS	0.1	ppb
Silicon	Si	ICPMS	1	ppb
Calcium	Ca	ICPMS	1	ppb
Scandium	*Sc*	*ICPMS*	*0.01*	*ppb*
Titanium	Ti	ICPMS	0.01	ppb
Vanadium	V	ICPMS	0.01	ppb
Chromium	Cr	ICPMS	0.1	ppb
Manganese	Mn	ICPMS	0.01	ppb
Iron	Fe	ICPMS	0.1	ppb
Cobalt	*Co*	*ICPMS*	*0.001*	ppb
Nickel	Ni	ICPMS	0.001	ppb
Copper	Cu	ICPMS	0.001	ppb
Zinc	Zn	ICPMS	0.001	ppb
Gallium	Ga	ICPMS	0.001	ppb
Arsenic	As	ICPMS	0.01	ppb
Selenium	Se	ICPMS	0.01	ppb
Bromine	Br	ICPMS	1	ppb
Rubidium	Rb	ICPMS	0.001	ppb
Strontium	Sr	ICPMS	0.001	ppb
Yttrium	Y	ICPMS	0.001	ppb
Zirconium	Zr	ICPMS	0.001	ppb
Niobium	Nb	ICPMS	0.001	ppb
Molybdenum	Mo	ICPMS	0.01	ppb
Ruthenium	Ru	ICPMS	0.01	ppb
Palladium	Pd	ICPMS	0.01	ppb
Silver	Ag	ICPMS	0.001	ppb
Cadmium	Cd	ICPMS	0.001	ppb
Indium	In	ICPMS	0.001	ppb
Tin	Sn	ICPMS	0.001	ppb
Antimony	Sb	ICPMS	0.01	ppb
Tellurium	Te	ICPMS	0.01	ppb
Iodine	I	ICPMS	0.02	ppb
Cesium	Cs	ICPMS	0.001	ppb
Barium	Ba	ICPMS	0.001	ppb
Lanthanum	La	ICPMS	0.001	ppb
Cerium	Ce	ICPMS	0.001	ppb
Praeseodymium	Pr	ICPMS	0.00	ppb
Neodymium	Nd	ICPMS	0.00	ppb
Samarium	Sm	ICPMS	0.00	ppb
Europium	Er	ICPMS	0.00	ppb
Gadolinium	Gd	ICPMS	0.00	ppb
Terbium	Tb	ICPMS	0.00	ppb
Dysprosium	Dy	ICPMS	0.00	ppb
Holmium	Ho	ICPMS	0.00	ppb
Erbium	Er	ICPMS	0.00	ppb
Thulium	Tm	ICPMS	0.00	ppb
Ytterbium	Yb	ICPMS	0.00	ppb
Hafnium	Hf	ICPMS	0.001	ppb
Tantalum	Ta	ICPMS	0.001	ppb
Tungsten	W	ICPMS	0.001	ppb
Rhenium	Re	ICPMS	0.001	ppb
Osmium	Os	ICPMS	0.001	ppb
Platinum	Pt	ICPMS	0.001	ppb
Gold	Au	ICPMS	0.001	ppb
Mercury	Hg	ICPMS	0.01	ppb
Thallium	Tl	ICPMS	0.001	ppb
Lead	Pb	ICPMS	0.01	ppb
Bismuth	Bi	ICPMS	0.001	ppb
Thorium	Th	ICPMS	0.001	ppb
Uranium	U	ICPMS	0.001	ppb

CONCLUSIONS

Results from these two geochemistry programs will be released to the public in early 1997. Data from the hydrogeochemical survey can be utilized in the exploration for new mineralization in the Eagle Bay Assemblage. The data will also provide a reliable environmental baseline database for any reclamation activities in the area. Information from the orientation studies can be applied to refining geochemical exploration models and techniques for VMS and SEDEX mineralization in the region.

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QUATERNARY GEOLOGY AND ICE FLOW HISTORY OF THE BABINE COPPER PORPHYRY BELT, BRITISH COLUMBIA (NTS 93 L/NE, M/SE)

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KEYWORDS: Surficial geology, Quaternary stratigraphy, ice-flow history, glaciation

INTRODUCTION

This paper provides an overview of surficial geology, Quaternary stratigraphy and ice flow history studies conducted in the Babine porphyry belt and surrounding regions by the British Columbia Geological Survey. The studies were conducted in conjunction with regional till geochemistry (Levson *et al.*, 1997), lake sediment geochemistry (Cook *et al.*, 1997) and bedrock geology mapping (MacIntyre *et al.*, 1997) components. These studies are part of the Nechako National Mapping (NATMAP) Project, coordinated by the Geological Survey of Canada and the British Columbia Geological Survey. The components of the NATMAP project discussed in this paper were also performed in collaboration with researchers from the Ministry of Forests.

Time-stratigraphic, 1:50 000, surficial geology mapping, incorporating local and regional ice flow history data, was completed on the Nakinilerak Lake map sheet (NTS 93 M/8) in 1996 (Figure 1). This work extends 1995 mapping on the Fulton Lake - Old Fort Mountain map sheets (93L/16 and M/1, respectively Huntley *et al.*, 1996) and will provide a complete overview of the surficial geology of the Babine copper porphyry belt. The main objectives of the surficial geology mapping are to understand and map the distribution of Quaternary deposits, decipher the glacial history and ice-flow patterns and locate areas most suitable for conducting drift exploration programs. Stratigraphic and sedimentologic studies of Quaternary deposits were conducted in order to define the glacial history and aid in interpreting till geochemical data.

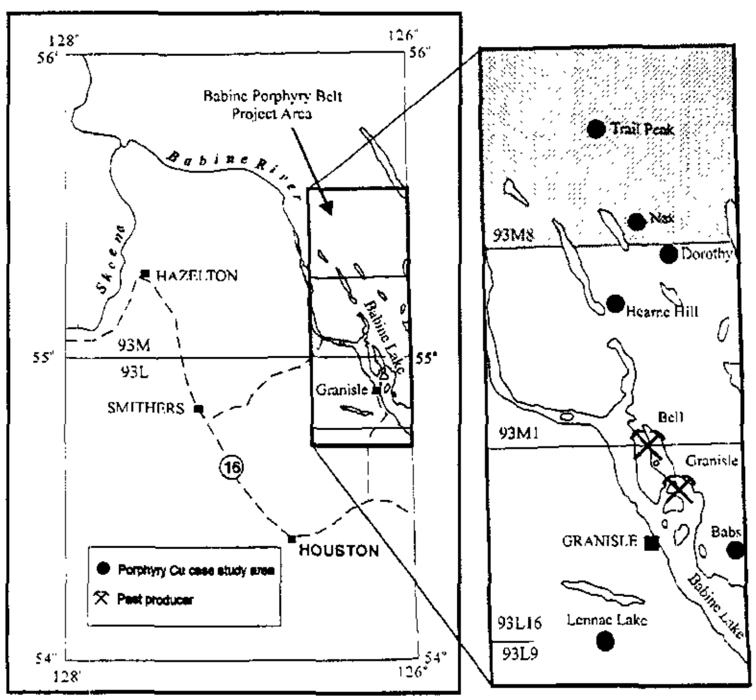

Figure 1. Location map of the study region showing major copper porphyry prospects investigated in this study.

PREVIOUS QUATERNARY STUDIES

Reconnaissance (1:250 000-scale) mapping of Quaternary deposits in the Nechako Plateau was conducted by Tipper (1971). Wittneben (1981) completed 1:50 000 scale terrain mapping in parts of the Nechako map sheet (NTS 93 M/NW, NE, SW). Most recently, Plouffe (1994a, b) completed 1:100 000-scale surficial geology mapping in the central part of the Nechako Plateau, east and southeast of the Babine porphyry belt. Levson and Giles (in press) discussed the Quaternary geology of the Nechako Plateau and the surficial geology of the southern part of the Babine region was described by Huntley *et al.* (1996).

PHYSIOGRAPHY AND LANDFORMS

The Babine porphyry belt occurs in the northernmost part of the Nechako Plateau physiographic region (Holland, 1976). The Nechako Plateau is an area of low relief compared to the Hazelton Mountains to the west and the Skeena Mountains to the north. The Bait Range, at the southern end of the Skeena Mountains, occurs in the north central part of the 1996 map area (Figure 2). Surface elevations range from about 700 to 1000 metres in the plateau and the highest mountain in the map area is Frypan Peak at 1932 metres (6337 ft). The Bait Range and the topographically high area to the southeast, create a major drainage divide. Beaverdale, Dust and Sinta creeks flow southeasterly from this area towards the Northwest Arm of Takla Lake and Tahlo Creek flows into Morison Lake in the southwest corner of the map area (Figure 2). Low lying areas in the southwest and northeast parts of the map sheet are poorly drained and occupied by numerous lakes and marshes.

During Late Wisconsinan glaciation, ice moved into the Nechako Plateau from the Coast Mountains to the west and southwest and from the Skeena Mountains to the northwest, before flowing easterly and northeasterly towards the Rocky Mountains (Tipper, 1971). Well developed flutings and drumlinoid ridges, oriented parallel to the regional ice-flow direction, are dominant features on the plateaus. During deglaciation, stagnant ice topography, large esker complexes, glaciofluvial deposits and meltwater channels, developed in many areas. Much of the variation in topography and surficial geology in the plateau areas is due to these features. In low-lying regions, such as the valleys now occupied by Babine and Takla lakes, large glacial lakes formed and deposited extensive belts of glaciolacustrine sediments, generally below 950 metres elevation. Topography in these areas is subdued and older glacial landforms are often difficult to recognize.

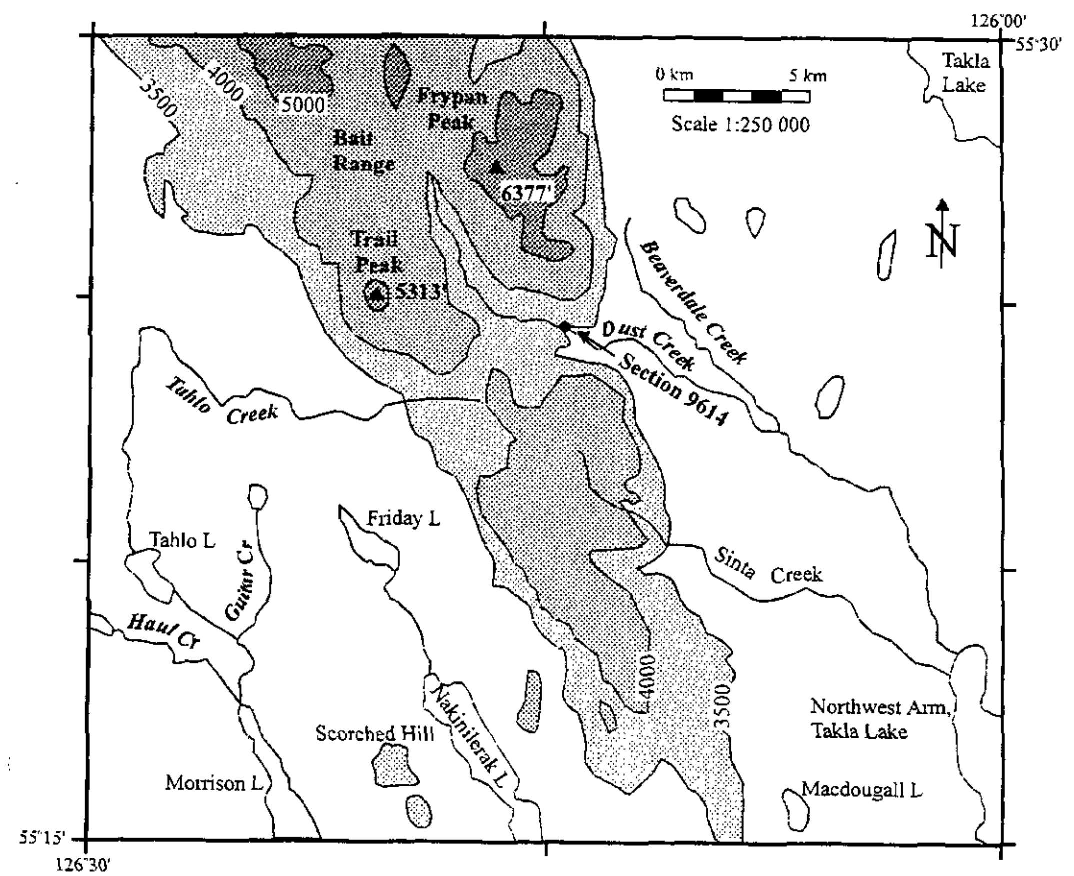

Figure 2. Generalized topography and place names in the 1996 map area (NTS 93 M/8).

FIELD PROCEDURES

Surficial geology mapping was completed by compilation of existing terrain-mapping data, interpretation of air photographs, field checking and stratigraphic and sedimentologic investigations of Quaternary exposures in the study areas. Ice-flow history was largely deciphered from the measurement of the orientation of crag-and-tail features, flutings, drumlins and striae (Photo 1).

Logging road access to the 1996 map area was limited to the westernmost and easternmost sides of the map sheet. Other parts of the map area were accessed by all-terrain vehicle, motor boat, canoe and helicopter.

Sedimentologic data were collected at all sample sites in order to distinguish till from glacigenic debris flow, colluvium, glaciofluvial or glaciolacustrine sediments. Sedimentologic data collected at each sample site included descriptions of sediment type, primary and secondary structures, matrix texture, presence of fissility, compactness, total percentage and modal size of clasts, rounding of clasts, presence of striated clasts, pebble lithologies, and sediment genesis and thickness. Further information was noted on soil horizons, local slope, bedrock striae, bedrock lithology, clast provenance and abundance and type of mineralized clasts. Field sites include natural river cuts, wave-cut benches on lake shorelines and anthropogenetic exposures (roadcuts, borrow pits, soil pits and trenches).

QUATERNARY STRATIGRAPHY AND SURFICIAL GEOLOGY

LATE WISCONSINAN GLACIAL DEPOSITS AND OLDER SEDIMENTS

Morainal sediments in the Nechako Plateau region were assigned by Tipper (1971) to the Fraser glaciation which is dated in several parts of British Columbia as Late Wisconsinan (Ryder and Clague, 1989). A Late Wisconsinan age for the last glaciation in the region is also indicated by radiocarbon dates on wood and mammoth bones recovered from lacustrine deposits under till at the Bell Copper mine (NTS 93 L/16) on Babine Lake. Single fragments of spruce (*Picea* sp.) and fir (*Abies* sp.), yielding dates of 42 900±1860 years B.P. (GSC-1657) and 43 800±1830 years B.P. (GSC-1687), and a date of 34 000±690 years B.P. (GSC-1754) on mammoth bone collagen from the interglacial sediments (Harington *et al.*, 1974), indicate that the overlying till was deposited during the Late Wisconsinan glaciation. Palynological data from interglacial lake sediments are indicative of a shrub tundra vegetation.

The Quaternary stratigraphy of the northern Nechako Plateau has been reconstructed from a number of exposures in the region. Quaternary sediments underlying till are rarely exposed in the survey areas. The most complete stratigraphic sections encountered in the region mainly occur in the vicinity of the Nechako Reservoir (Levson and Giles, in press). The stratigraphic record of pre-Late Wisconsinan events elsewhere in the area was largely removed during the last glaciation.

A representative stratigraphic section from the Babine porphyry belt is provided in Figure 3. Exposures at this site, located on Dust Creek reveal a thick sequence of advance-phase glaciolacustrine and glaciofluvial deposits (Photo 2) overlain by till deposited during the last glaciation and finally by post-glacial gravels and sands. The lowest exposed unit (Figure 3) overlies bedrock and consists of well stratified, very dense sands, silts and clays. These sediments are interpreted as proximal glaciolacustrine deposits. Their stratigraphic position indicates that they probably were deposited during the advance phase of the last glaciation in the region. Their presence in the Dust Creek valley indicates that glaciers in the Late Wisconsinan occupied the Takla Lake valley before the southern Bait Ranges were completely ice covered. The resulting ice-damming of the Dust Creek drainage resulted in the development of a glacial lake in that valley.

A thick sequence of gravels and sands (Figure 3; Photo 2) that overlie the glaciolacustrine deposits are interpreted as a prograding deltaic sequence that was deposited by water flowing out from the Bait Range. Large-scale, steeply dipping, planar cross-beds in this unit are interpreted to be forset beds deposited in this prograding delta. Paleoflow directions are highly variable but generally southerly. The forset gravels are erosionally overlain by a trough and planar cross-bedded unit of coarse gravels interpreted as channelized topset beds. A locally present, overlying unit of bedded fine sands also may be delta top sediments that were deposited when the main gravelly feeder channels shifted to another part of the delta. The entire sand and gravel sequence is sharply overlain by a massive, matrix supported, dense, silty diamicton, interpreted as a till. The upper part of the diamicton is less dense, has a gravelly-sand matrix and locally is crudely bedded. This unit probably was deposited as a series of debris flows during deglaciation. The capping gravels and sands at the site are interpreted to be glaciofluvial sediments deposited prior to incision of the modern Dust Creek valley, probably beginning in the early Holocene.

Glacial deposits form a cover of variable thickness across much of the Nechako Plateau and occur mainly as fluted, drumlinized or relatively flat topography. Hummocky or kettled topography also occurs in some areas but is relatively uncommon in the Babine region. Morainal sediments include dense, matrix-supported, silty diamictons interpreted as lodgement and melt-out tills. Compressive deformation structures, such as shear planes, occur near the base of the till, and overturned folds and thrust faults, interpreted as glaciotectonic structures, are locally present in the upper part of the underlying glaciofluvial sediments. Loose, massive to stratified, sandy diamictons of inferred debris-flow origin often commonly occur at the surface. These diamictons are

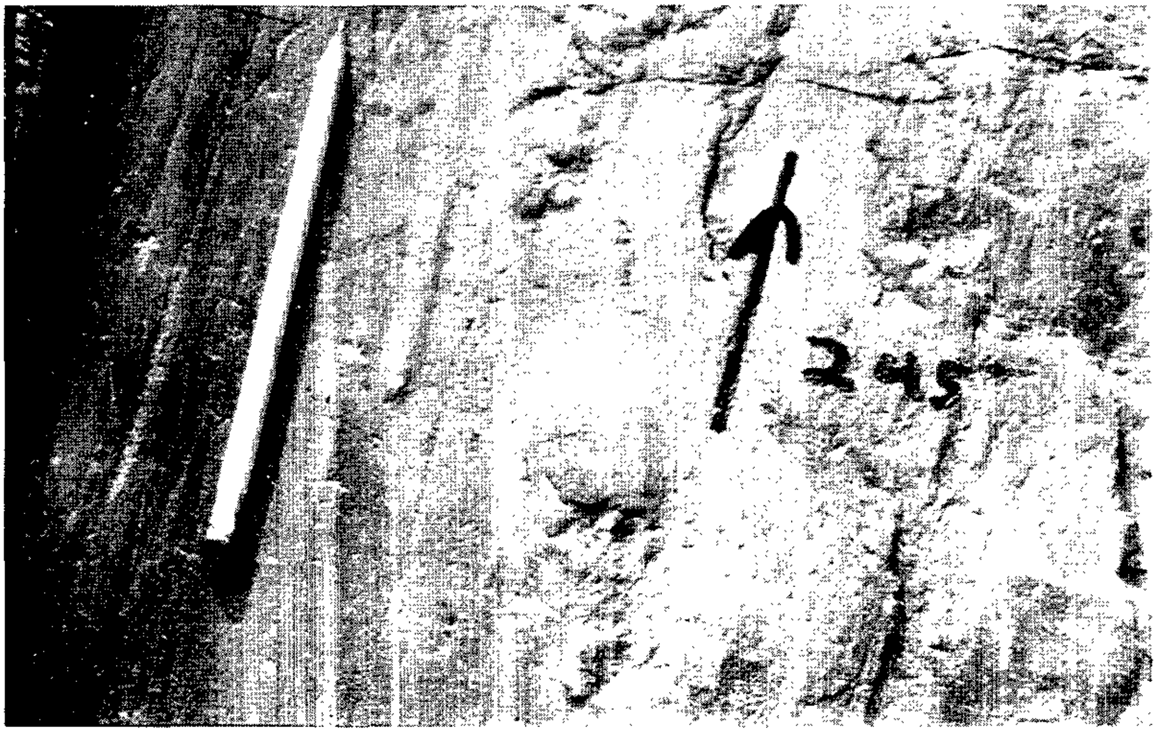

Photo 1. Striae with directional indicators on bedrock in the southern Babine Mountains.

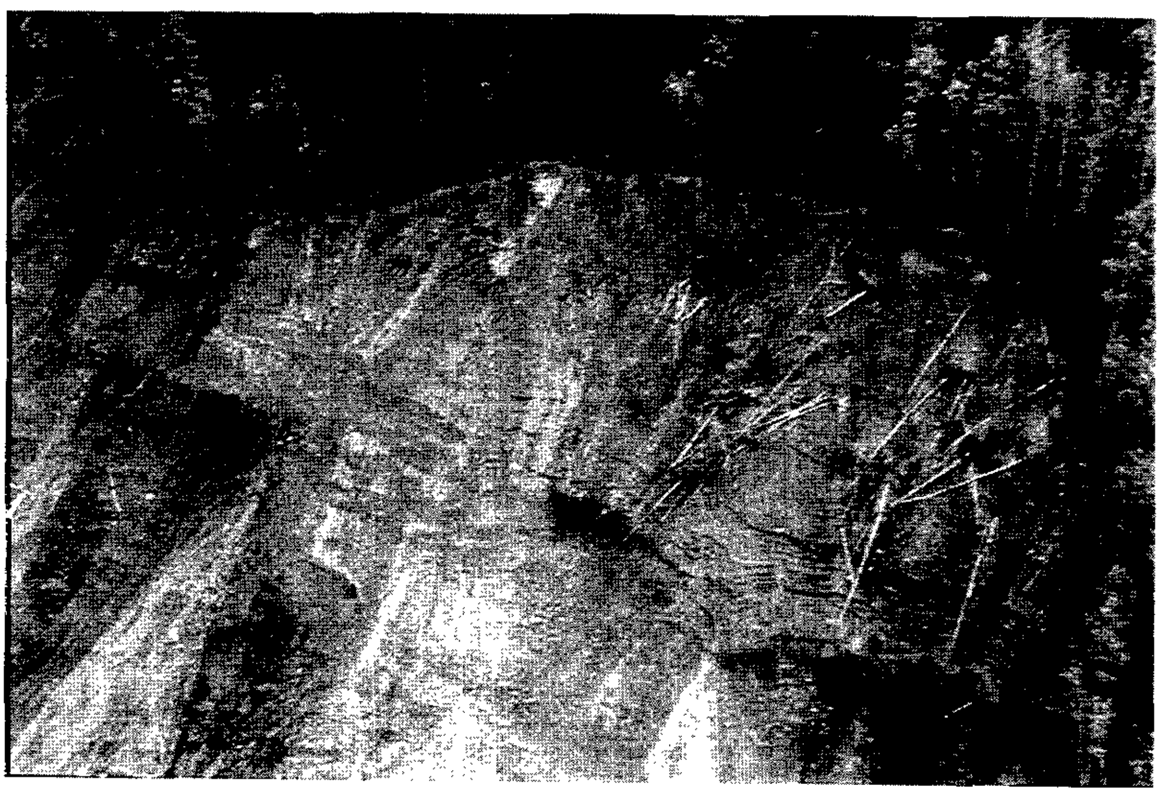

Photo 2. Upper part of glaciofluvial deltaic complex exposed along Dust Creek in the southeastern part of the Bait Range.

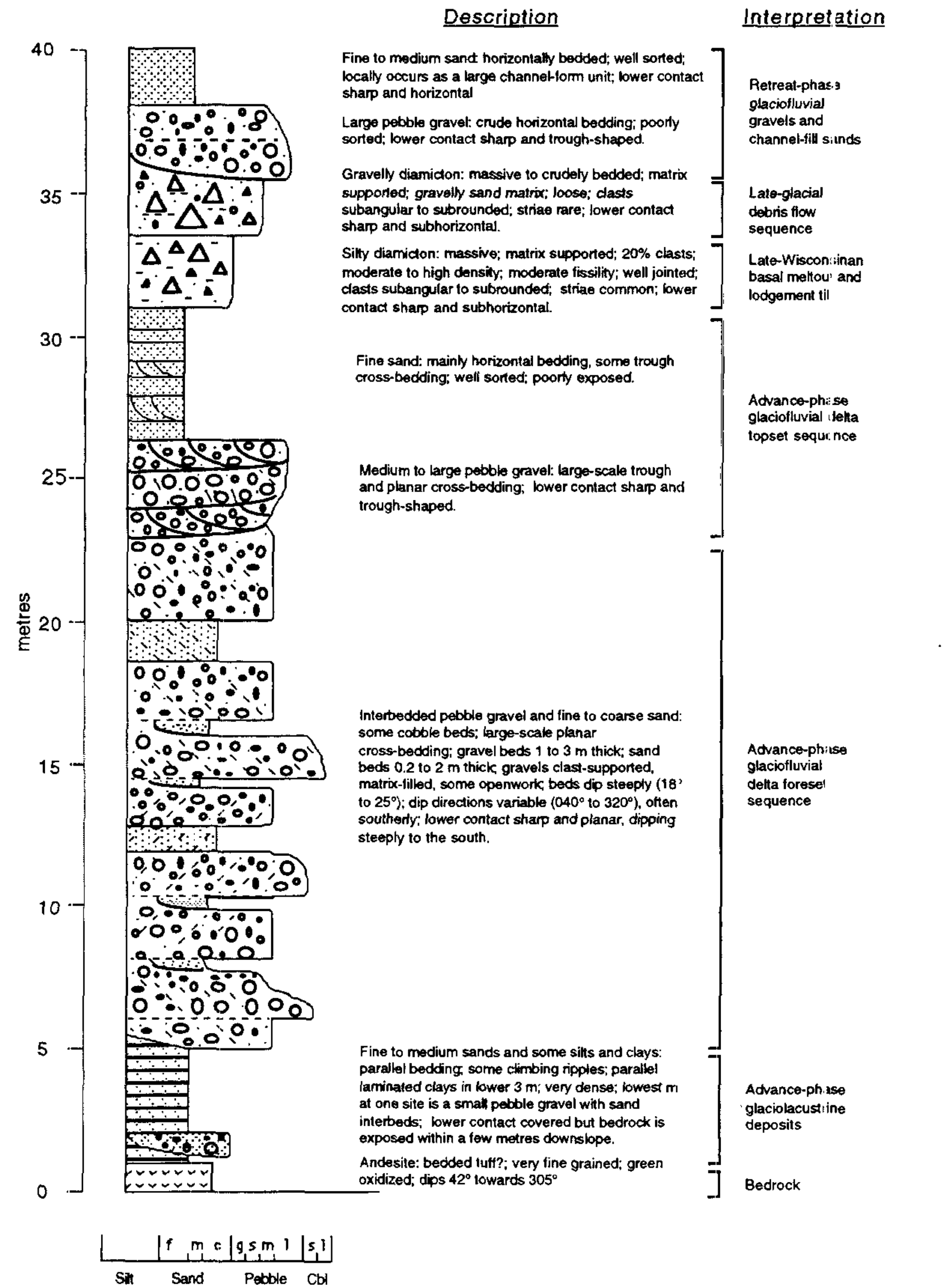

Figure 3. Stratigraphy of Quaternary sediments exposed at the Dust Creek section (Section VLE-9614; see Figure 2 for location).

often interbedded with gravels and sands or fine sediments.

Basal tills usually unconformably overlie bedrock or, more rarely, older deposits. They often are overlain by glacigenic debris-flow deposits, glaciofluvial deposits or, on slopes, by diamicton of colluvial origin. Till thickness varies from less than a metre along bedrock ridges and steep slopes to several tens of metres in main valleys and in the lee (down-ice) of bedrock highs. Thick exposures of till (>10 m) also occur locally in narrow valleys oriented at high angles to the regional ice-flow direction. In many areas within valley bottoms, morainal sediments are largely buried by glaciofluvial, fluvial and organic sediments.

LATE WISCONSINAN DEGLACIAL DEPOSITS

Deposits formed during deglaciation include both glaciofluvial and glaciolacustrine sediments. Glaciofluvial deposits in the 1996 map area occur as outwash plains, eskers, kames, terraces and fans in valley bottoms and along valley flanks. They consist mainly of poorly to well sorted, stratified, pebble and cobble gravels and sands of variable thickness. Eskers and esker complexes are locally present. They are characterized by sinuous, gravel ridges (Photo 3) that formed in subglacial tunnels. A well developed esker complex (Photo 3) is present in the region northwest Tahlo Lake. The eskers trend southeasterly and straddle the boundary between the Nakinilerak (NTS 93 M/8) and Netalzul Mountain (93 M/7) map sheets. They are composed mainly of stratified gravels and sands and some diamicton.

Hummocky topography, consisting of ridges and knobs of sand and gravel with large kettles, locally indicates the presence of ice blocks within gravelly sediments during deposition of glaciofluvial outwash. Hummocky topography is present mainly in the Macdougall Lake area and in the region a few to several kilometres north of Tahlo Lake. Large kame deposits are uncommon but locally developed along the margins of the stagnating ice and in association with eskers.

Glaciofluvial gravels and sands deposited in front and along the margins of retreating glaciers are widespread in the region. They are especially common within the Dust Creek and Sinta Creek valleys (Figure 2). Deposition of these sediments likely occurred as ice retreated into the Bait Range and glaciofluvial drainage extended down the Dust and Sinta creek valleys into the Northwest Arm of Takla Lake. A large glaciofluvial system extending north of lower Dust Creek towards Takla Lake in the northeast corner of the map area (Figure 2) may have developed either in front of ice retreating up the Takla Lake valley or along the west margin of the Takla Lake glacier.

Exposures of glaciolacustrine sediments occur mainly in low-lying areas, often near modern lakes. Lake levels were at least locally controlled by ice dams. Maximum lake levels in large valleys in the region such as the Babine and Takla Lake valleys are recorded by the upper elevation of deltaic deposits at about 760 metres above sea level. Exposures in these raised deltas reveal well stratified, sands and gravels, commonly with normal faults that formed when the deltas partially collapsed as lake levels dropped (Photo 4). Isolated glaciolacustrine and glaciofluvial deltaic deposits occurring at higher elevations reflect more localized ice damming in smaller tributary valleys (Photo 2).

HOLOCENE FLUVIAL, COLLUVIAL AND ORGANIC DEPOSITS

The most dominant Holocene deposits in the region are extensive areas of organic deposits (Photo 5). Low lying areas in the relatively low relief regions west and east of the Bait Range are characterized by numerous marshes and shallow lakes filled with organic sediment consisting of decayed marsh vegetation with minor sand, silt and clay. Holocene fluvial sediments in the region are dominated by floodplain silts, fine sands and organics and channel gravels.

Colluvial deposits are most common in the Bait Range and in the high relief areas west and east of Nakinilerak Lake and west of the Northwest Arm of Takla Lake. Steep slopes commonly have a thin veneer of weathered and broken bedrock clasts in a loose sandy matrix. These deposits grade downhill into a thicker cover of colluvial diamicton derived from both local bedrock and till remobilized by gravity after deposition. Colluvial veneers commonly overlie thin tills on steep slopes. Thick accumulations of talus are relatively uncommon due to the overall subdued topography, but they do occur below steep rocky cliffs that are locally present in the more mountainous parts of the Bait Range (Photo 6).

A number of large postglacial alluvial fans and fan deltas occur in the map area, especially along the margins of large lakes such as Morison and Nakinilerak lakes and the Northwest Arm of Takla Lake. Extensive areas of fluvial silts and sands also occur along the southeast-trending valleys that lie northwest of each of these lakes. These fluvial sediments are locally underlain by glaciofluvial gravels and in flat-lying areas they are commonly overlain by organic deposits.

ICE-FLOW HISTORY

Study of ice-flow history, glacial dispersal patterns and transportation distances are required to locate the bedrock sources of mineralized float or geochemically anomalous soil samples. Results of ice-flow studies in the Babine porphyry belt indicate that the dominant flow direction during the last part of the Late Wisconsinan glaciation was southeasterly (about 145°). Crag-and-tail features, drumlins and glacial flutings are present throughout the region and reflect this regional trends (Photo 7). Many of these features have formed by subglacial water as well as ice erosion but they generally parallel regional dispersal patterns (Levson and Giles, in press). This is because subglacial meltwater flows under active ice respond to the driving potential created by the surface slope of the glacier and therefore are generally parallel to ice-flow direction (Kor *et al.*, 1991).

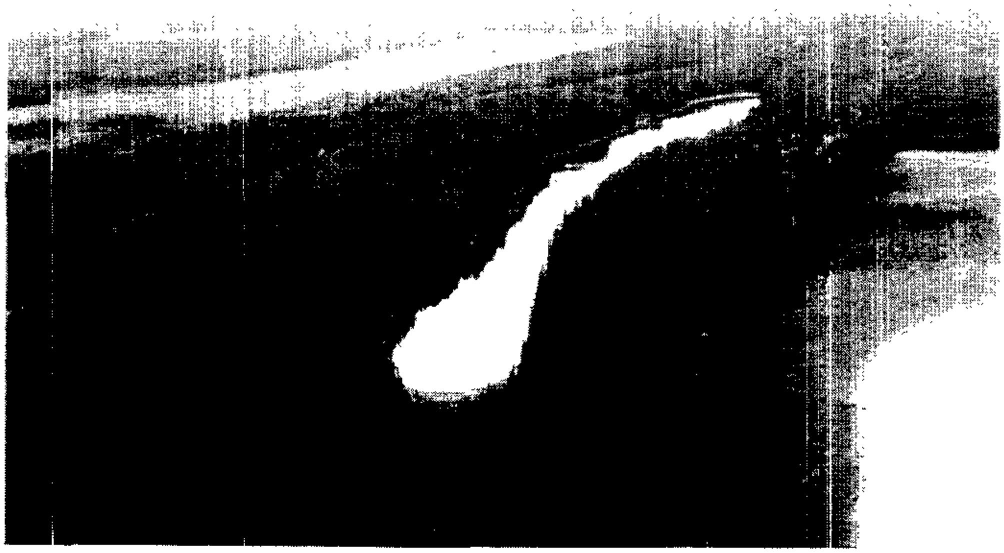

Photo 3. Esker ridges north of Tahlo Lake on the boundary of NTS map sheets 93M/7 and M/8 (Figure 1).

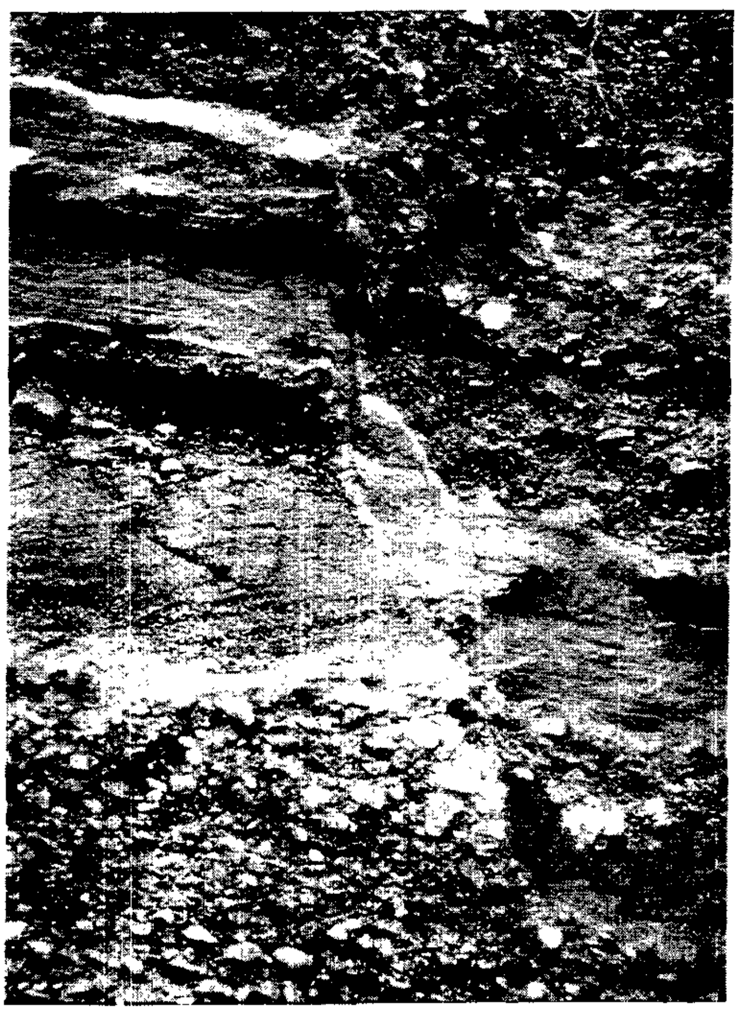

Photo 4. Small-scale normal faulting in sands and gravels in a raised glaciofluvial delta deposit near Babine Lake. Normal faults of varying size are abundant in the deposit and indicate collapse toward the valley centre, probably as a result of lowering of Glacial Lake Babine in the late Pleistocene.

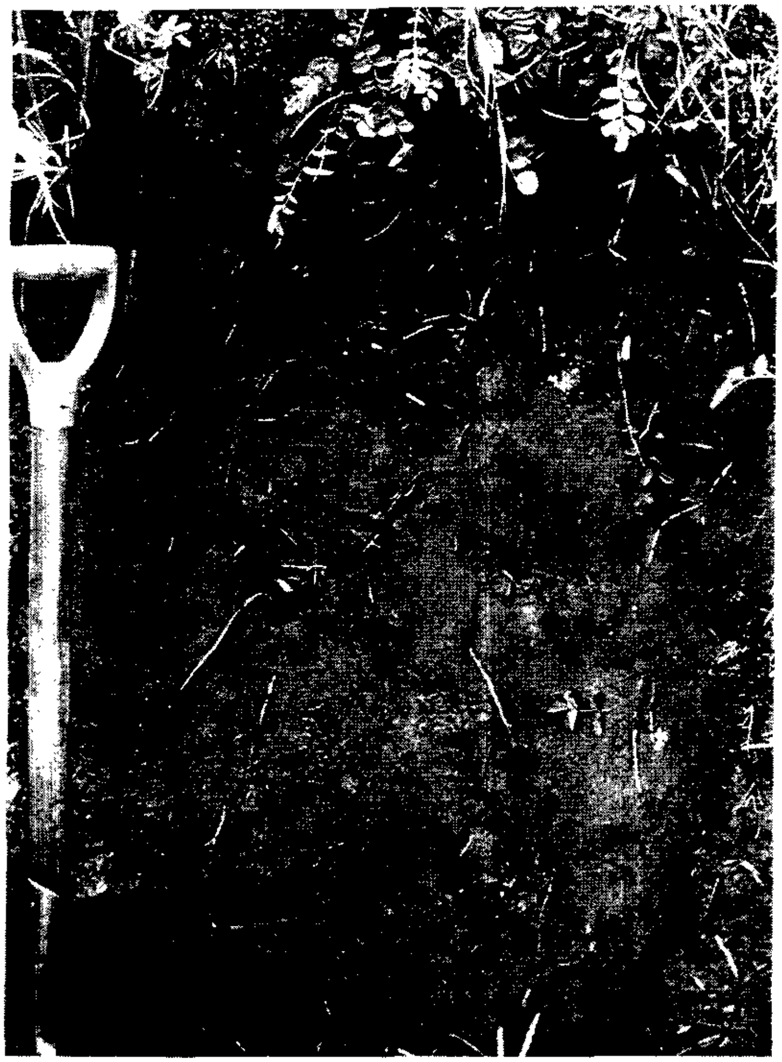

Photo 5. Organic soil and peat, more than 1 metre thick, exposed along a creek channel cutting through a small bog near Trail Peak

Photo 6. Talus slopes on the south side of a cirque at the headwaters of Frypan Creek in the Bait Range.

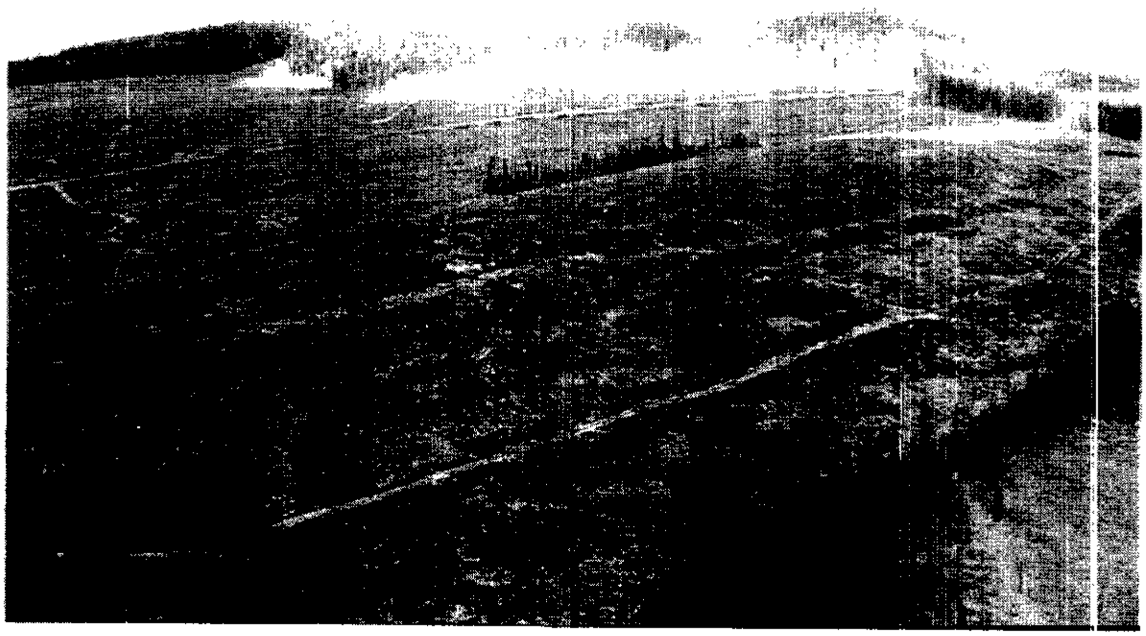

Photo 7. Well developed fluted and drumlinized topography exposed in a clear-cut north of Babine Lake. Ice-flow direction is from the right to the left (southeasterly).

At the Late Wisconsinan glacial maximum, ice covered all but the highest peaks in the region and movement appears to have been relatively unaffected by topography. In the Bait Range, the ice surface was in excess of 1950 metres as indicated by glacial erratics and regionally trending striae and flutings on top of Frypan Peak (elevation 1931 m). A lateral moraine on the south flank of a high mountain in the northern part of the 1996 map area (Photo 8), indicates that an active ice margin stabilized in this region at an elevation of approximately 1600 metres. Topographic control of ice flow during the latter phases is most apparent in the Bait Range where relief is high. Topographically influenced ice flow in this area is also clearly indicated by the presence of well developed cirque basins on the north and east facing sides of large mountains (Photo 6). During deglaciation, ice flow was increasingly controlled by topography as the glaciers thinned. Cirque glacier activity dominated during the later phases of the last glaciation and may have extended into the Holocene.

In the southern Babine Mountains, anomalous westerly ice-flow indicators are present. These include well developed roche-moutonnée (Photo 9) that locally indicate upslope ice-flow toward the west over the southern end of the Babine Range. Similar westerly ice-flow indicators have also been discovered to the southeast as far as the Maxan and Goosly lakes area. Westerly ice-flow patterns in the northern Nechako Plateau were previously reported by Tipper (1995). However, this study has extended their distribution further to the south and east and new evidence on the timing of this event has important implications for the Quaternary history of the region.

Westerly ice flow in this region appears to have occurred at a late stage in the last glaciation as indicated by stratigraphic, lithologic and geomorphic criteria. This includes the presence of westerly ice-flow indicators at the surface in areas where preservation from later ice erosion would not likely occur (*e.g.* in stoss-side positions). For example, westerly ice-flow indicators in the Dome Mountain area are preserved on the top of the mountain as well as on the east side at relatively low elevations. During the last glaciation, ice flowed along the east side of the mountain from the Babine Lake area and clearly would have eroded or at least partially obscured the exposed features on the east side of the mountain. In addition, investigations of glacial dispersal in surface tills in these areas indicate westerly dispersal. Tracing of erratics with distinctive lithologies and known source areas in the Dome Mountain region, for example, has

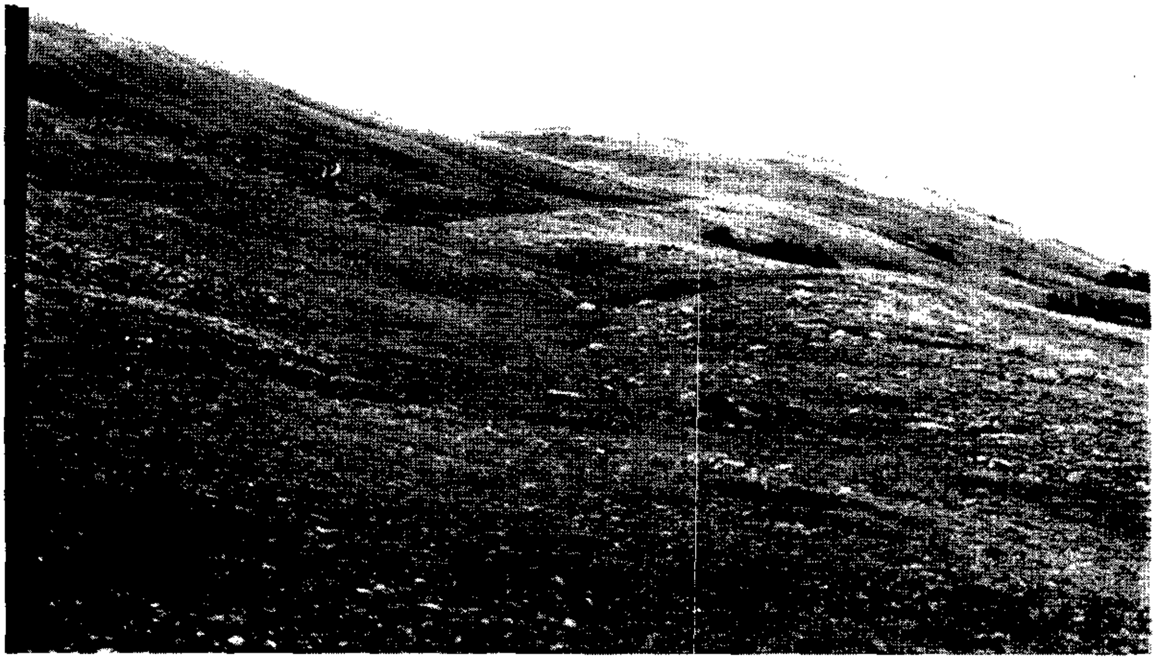

Photo 8. Lateral moraine on the south flank of an unnamed mountain northwest of Frypan Peak. The moraine is unusally well preserved and extends for a few kilometres along the side of the mountain. It marks the location of a significant late-glacial ice margin in the region at an elevation of about 1600 metres. Note the large number of erratics in places on the moraine surface. The person (at left) is standing on bedrock outcropping above the moraine.

Photo 9. Roche moutonée on the east side of Dome Mountain in the southern Babine Mountains. Paleoflow indicators are westerly at the site (see text for discussion).

shown substantial westerly and upslope transport of the erratics from their source areas.

Derivation of westerly ice-flow features during the later part of the Late Wisconsinan glaciation differs with the previous interpretation of Tipper (1994) who postulated that the westerly ice flow patterns represented a relict flow pattern from an earlier glaciation or possibly from the maximum phase of the last glaciation when movement of ice towards the Coast Mountains occurred as the result of the development of ice dome in the central part of the Interior Plateau. We suggest, however, that since westerly ice-flow indicators occur only locally and developed late in the last glaciation, they probably reflect a more local phenomena. We suggest that rapid calving of tidewater glaciers in large valleys on the west side of the Coast Mountains, such as the Skeena River valley, may have resulted in a draw-down of ice in that area. Rapid calving and significant lowering of the ice surface in these valleys, may have resulted in the eastern migration of local ice divides, the 'capture' of glacial ice from east of the Coast Mountains and the local reversal of ice flow into valleys such the Skeena and some of its tributary valleys. This hypothesis is consistent with the development of westerly ice flow indicators late in the last glaciation and with their relatively limited extent. The full extent, timing and duration of this westerly ice flow event and its influence on glacial dispersal has not yet been determined but is the subject of ongoing research.

SUMMARY

Late Wisconsinan glaciers first advanced into the Babine region along major valleys such as the Babine and Takla valleys. Damming of tributary drainage and the development of proglacial lakes occurred in some valleys such as the Dust Creek valley in the Bait Range. Meltwater streams flowing from the advancing ice, deposited coarse-grained proglacial outwash plains in the valley bottoms and glaciofluvial deltas developed where the streams entered the proglacial lakes. Debris-flow sediments were deposited with the outwash and proglacial lake sediments. Lodgement and meltout tills were eventually deposited by the glaciers as they advanced southeasterly over the entire region. Drumlins, crag-and-tails, flutings and striae in many areas crosscut major topographic highs, and indicate that the ice was thick enough to be relatively unaffected by topography during full-glacial times.

Results of ice-flow studies indicate that in most areas in the Babine porphyry belt, the dominant flow-direction was southeasterly. Glacial dispersal patterns appear to be dominated by this regional ice-flow direction. In many areas, the regional ice-flow was modified by topographic control during both early and late stages of glaciation but effects of these modifications on glacial dispersal patterns are restricted mainly to areas of relatively high relief. For example, glaciers in the Bait Range resulted in well developed cirque basins on the north and east facing sides of large mountains there.

In the southern Babine Mountains and further to the south and east, a late glacial, westerly ice-flow event occurred, the full extent of which is currently being investigated. This event apparently did not influence glacial dispersal in the Babine porphyry belt but it probably did have an effect further south. Westerly ice flow in this part of the Nechako Plateau is regionally anomalous and may have occurred when a late-glacial ice divide in the Coast Mountains locally migrated into the interior. A postulated driving mechanism is the rapid calving of tide-water glaciers, such as the Skeena River valley glacier, which may have allowed for significant lowering of glaciers in those valleys relative to ice in the interior and the subsequent capture of glacial ice from drainage areas to the east.

Morainal sediments deposited during the last glaciation are widespread in the Interior Plateau and form a cover, varying in average thickness from a few to several metres in low-lying areas, to less than a metre in upland regions. During deglaciation, loose, sandy gravelly diamictons were deposited on top of the tills by debris flows. Stagnant ice masses locally resulted in the development of large esker complexes and dammed meltwater to create glacial lakes and associated glaciofluvial deltas. Gravelly outwash plains covered the main valley bottoms as large volumes of sediment and water were removed from the ice margin. Glaciofluvial sediments consist mainly of poorly to well sorted, stratified, pebble and cobble gravels and sands. Glaciolacustrine sediments are common in large valleys, generally at elevations below 950 metres, often near modern lakes.

During postglacial times, the surficial geology of the area was modified mainly by fluvial activity and the local development of alluvial fans in the valley bottoms, as well as by colluvial reworking of glacial deposits along the valley sides.

ACKNOWLEDGMENTS

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EVALUATING THE USE OF TILL GEOCHEMISTRY TO DEFINE BURIED MINERAL TARGETS: A CASE STUDY FROM THE BELL MINE PROPERTY (NTS 93L/16, 93 M/1), WEST-CENTRAL BRITISH COLUMBIA

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KEYWORDS: Bell mine, drift exploration, geochemistry, porphyry copper mineralization, surficial geology, Quaternary history, Babine Lake

INTRODUCTION

Mineral exploration programs conducted in the Interior Plateau of British Columbia have typically been hampered by the presence of thick glacial till mantling bedrock. In these areas, trenching, rotary drilling and soil sampling can be used to obtain a better understanding of the underlying geology. Unfortunately the use of these techniques are often limited by an inadequate understanding of the Quaternary geology and regional glacial history.

In support of mineral exploration, regional surficial geology studies were undertaken in central British Columbia, by the Geological Survey of Canada and the British Columbia Geological Survey. This joint-governmental study was part of the much larger Nechako NATMAP Project. Two main objectives of this study are, to determine changes in the regional ice flow directions, during the Pleistocene in central British Columbia and also to examine the use of till geochemistry in mineral exploration. In the summer of 1995 and 1996, regional till geochemistry surveys were conducted by the British Columbia Geological Survey, in the Babine Lake area; encompassing the Fulton Lake (93 L/16), Old Fort Mountain (93 M/01) and Nakinilerak (93 M/08) map areas (Figure 1).

The Bell mine, a porphyry copper deposit was chosen as a model for this study because of its well defined zone of mineralization and the occurrence of an extensive blanket of glacial till. In this report the effectiveness of till sampling for the delineation of buried mineralization is examined by a comparison of till geochemistry with the known ore-body at Bell mine. The study will contribute to the development of a model of glacial dispersal, which can be used in future exploration programs in the region and in other glaciated areas.

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Bell Mine study area is located in the central part of the Babine Lake basin, approximately 10 km northeast of the town of Granisle (Figures 1, 2). It is situated on the

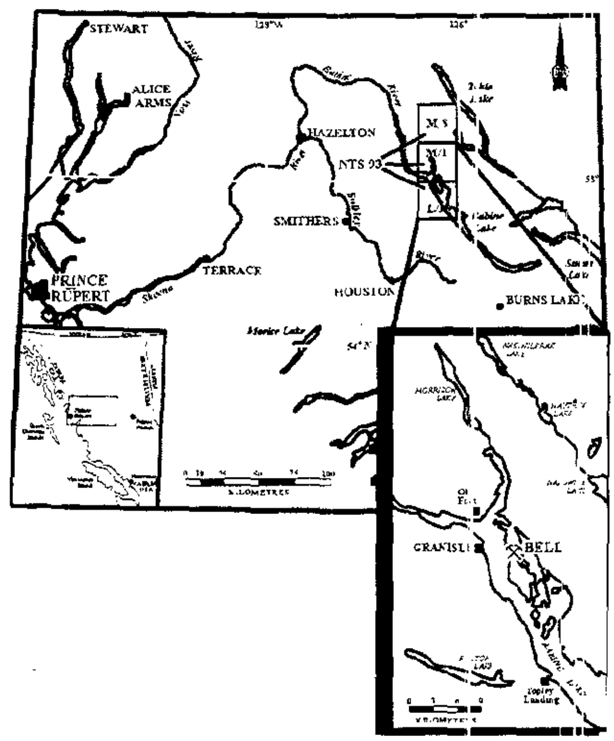

Figure 1 - Location of study area in British Columbia.

Newman Peninsula which straddles the Fulton Lake (93 L/16) and Old Fort Mountain (93 M/01) NTS map sheets. The mine property can be accessed by the Hagan Forest Service Road, via the Northwoods barge from Mitchell Bay or by private barge operated by Noranda Mines Limited

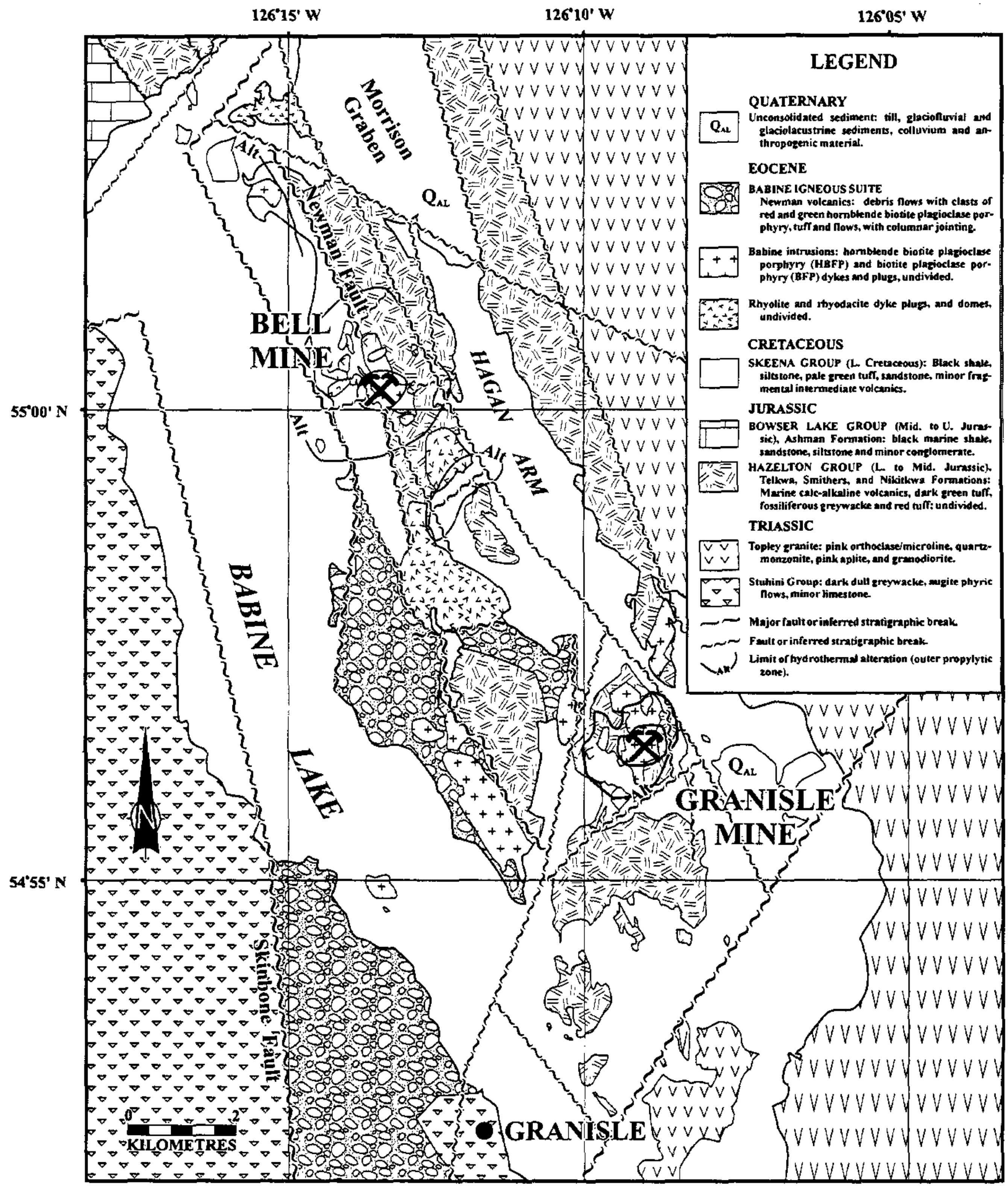

Figure 2 - Bedrock geology of the northern Babine Lake area, including the Newman Peninsula (after Dirom *et al.*, 1995)

from the mine to a gravel road 8 km north of Granisle.

Much of the property has a subdued topography, with elevations ranging from 715 to 850 metres. Locally, some bedrock knobs occur at elevations over 900 metres. To the west and east of Babine Lake lie a series of parallel, northwest-southeast trending bedrock ridges reaching a maximum elevation of 1200 metres. Drainage from the property enters Babine Lake at approximately 712 metres (2350 feet). Babine Lake drains into the west-draining Babine and Skeena rivers.

BEDROCK GEOLOGY AND MINERALIZATION

The study area lies within the Stikinia Terrane of the Intermontane Tectonic Belt of west-central British Columbia (Wheeler and McFeely, 1991; McMillan and Struik, 1996). Bedrock geology in the Babine Lake area was mapped by Carter (1973), Tipper and Richards (1976), MacIntyre *et al.* (1996b) and Richards (*in press*). Regional geology consists of uplifted, tilted and folded fault blocks of rocks ranging in age from the pre-Permian to the Eocene (MacIntyre *et al.*, 1996a). The oldest strata are comprised of shallow-water carbonates and island-arc volcanic and volcaniclastic rocks of the Stikine assemblage (Monger, 1977).

As Stikinia evolved in the Middle Jurassic to Early Cretaceous, molasse-type marine and non-marine sedimentary rocks accumulated in the Bowser and Nechako successor basins. These rocks are correlative to the Bowser Lake and Skeena Group units found in the Bell Mine study area (Richards, 1988). Subduction of oceanic crust under the North American plate in the Middle Cretaceous led to intense magmatic activity during the Late Cretaceous and Early Tertiary. Andean-type volcanic piles were constructed on uplifted and eroded blocks of Stikinia (Dirom *et al.*, 1995). Products of the associated dikes and plugs of this magmatism include the Middle to Late Cretaceous Bulkley and Eocene Babine intrusions. These intrusive rocks are host to the major mineral deposits found in the area (Carter, 1976).

The Newman Peninsula is dissected by a number of northwest-southeast trending fault systems (Figure 2). Here, intrusions of Eocene Babine Igneous Suite rocks; rhyolite, rhyodacite and biotite feldspar porphyry (BFP) were emplaced across the trace of the Newman Fault at sites of transcurrent faulting (Dirom *et al.*, 1995). These rocks intrude Lower to Middle Jurassic Hazelton Group volcanics and Skeena Group sedimentary rocks (MacIntyre *et al.*, 1996a).

The ore-body at the Bell mine is a classic high-level, symmetrically zoned porphyry copper-gold deposit. Zones of biotite-magnetite and propylitic alteration are associated with multiple-phase subvolcanic intrusions of the Babine Igneous Suite (Carter, 1981; Dirom *et al.*, 1995). These intrusions are overprinted by pervasive quartz-sericite alteration (Carson *et al.*, 1976).

Copper-gold mineralization at the Bell mine occurs predominantly in the Eocene-age quartz-sericite altered rhyodacite and biotite-feldspar porphyry, with a maximum grade of 0.47% copper. Lesser amounts of copper mineralization are present in disseminated sulphides and stockworks in Hazelton rocks (Dirom *et al.*, 1995). Pyrite and chalcopyrite occur in disseminations, fracture fillings and as coatings in the main stockwork, and across the propylitic/biotite-magnetite alteration zones. Trace molybdenite and bornite also occur within the biotite-altered biotite-feldspar porphyry (Carson *et al.*, 1976). Other minerals present include silver, chalcocite, sphalerite and galena.

REGIONAL GLACIAL HISTORY

The Babine Lake area has undergone a complex history of multiple glacial and interglacial cycles throughout the Quaternary. Broad U-shaped valleys, streamlined and scoured bedrock surfaces and the presence of thick deposits of till, glaciofluvial and glaciolacustrine sediments are remnant features of the Late Wisconsinan glaciation.

Pre-late Wisconsinan fluvial and lacustrine sediments are rarely exposed in the Babine area. Lacustrine sediments uncovered at the Bell mine contain mammoth skeletal remains and charred plant material which have returned an Olympia nonglacial age ranging between *ca.* 43800±1860 to 34000±690 BP (Harrington *et al.*, 1974). Possible advance stage glaciofluvial sediments, underlying Fraser Glaciation till, are exposed along the Hagan Road (Huntley *et al.*, 1996a).

The onset of Late Wisconsinan Fraser Glaciation (approximately 25 ka; Clague, 1981), was marked by ice accumulation in the southern Skeena and Babine Mountains, located to the north and north-west of the study area. Glaciers from these sources flowed south-east along the Babine, Fulton and Takla lake valleys (Figure 3).

Basal till lies unconformably over glaciolacustrine sediments, suggesting a glacial lake was ponded in the Babine valley during ice advance. Advance phase glacial lake sediments were deposited to a maximum elevation of 790 metres (2600 feet), before being overridden by Fraser Glaciation ice (Huntley *et al.*, 1996a).

At the glacial maximum, south-east flowing glaciers coalesced to form part of the Cordilleran Ice Sheet. This ice sheet probably overtopped many mountain peaks in the Babine area with elevations of less than 1818 metres (6000 feet), as indicated by the presence of striated and polished bedrock, exposed at approximately 1727 metres (5700 feet) on the peak of Dome Mountain (Figure 3). Along the southern part of the Babine Lake area, this ice mass coalesced with ice originating from the Coast Mountains and moved northeastward into the Stuart Lake basin (Plouffe, 1991, 1995, 1996; Tipper, 1994).

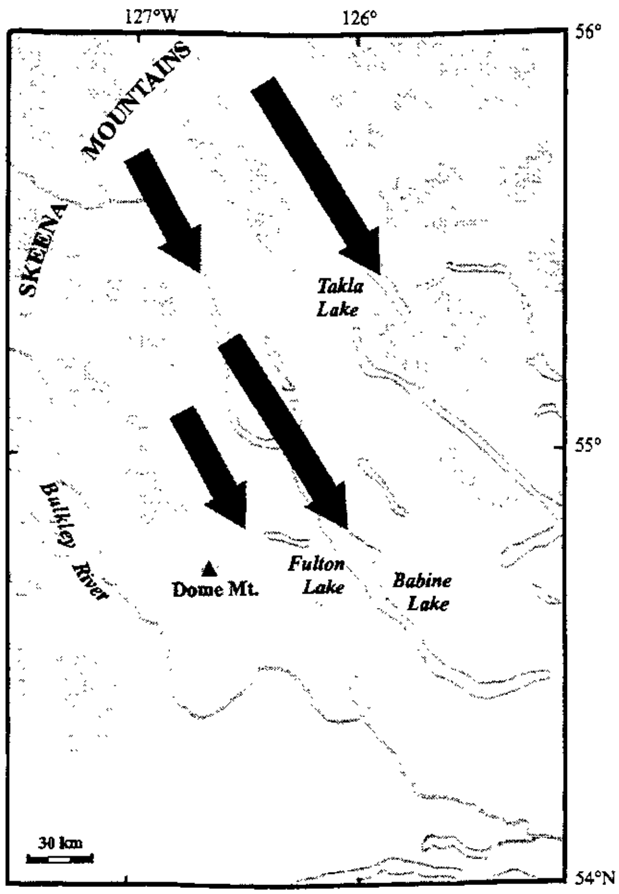

Figure 3 - Ice flow patterns in central British Columbia during the advance phase of the Late Wisconsinan, Fraser Glaciation (after Plouffe, 1996).

Multiple ice flow directions, indicated by the orientation of streamlined landforms and glacial erosional features, are recorded throughout the Babine Lake area and are evidence of a complex glacial history in this area of west-central British Columbia (Levson *et al.*, 1997b). Of these ice flow directions, the south-east movement deposited the majority of the till composing most of ground moraine in the area as indicated by surficial mapping (Stumpf *et al.*, 1996b; Huntley *et al.*, 1996b). Streamlined and striated bedrock surfaces also indicate a regionally dominant south-southeast ice flow direction, with striae and landforms oriented between 130° and 180° (Figures 4a, b). Cross-cutting striae in the Babine Lake area are suggestive of topographically-controlled ice flow which took place after the culmination of glaciation.

Following climate amelioration, glaciers retreated stepwise from the highlands into Babine and Fulton lake valleys (Huntley *et al.*, 1996a). Stagnant ice confined to valleys, deposited a veneer of supraglacial and glaciofluvial sediments. During the later stages of ice retreat, glacial lakes were dammed by moraines and/or ice in these valleys, depositing glaciolacustrine silt and clays at elevations from 760 metres (2500 feet) to 830 metres (2750 feet). A similar range of lake base-levels has been documented by Plouffe (1996) and Clague (1988), in the "glacial lake Fraser" basin, suggesting that "glacial lake Babine" was likely part of a much larger lake system in central British Columbia (Huntley *et al.*, 1996a).

SURFICIAL SEDIMENTS AT THE BELL MINE PROPERTY

The surficial geology of the Fulton Lake (93L/16) and Old Fort Mountain (93 M/01) NTS sheets was mapped by the British Columbia Geological Survey, in 1995 at a 1:50,000 scale (See Huntley *et al.*, 1996b; Stumpf *et al.*, 1996b). At the Bell mine, the surficial geology was mapped (Figure 4a, b), to provide a database of surficial materials which may be encountered during mine reclamation at the property. A variety of surficial materials are present at the Bell mine property. Basal lodgement till is the most abundant and aerially extensive surficial deposit, with lesser amounts of ablation moraine, colluvium, glaciolacustrine, glaciofluvial, lacustrine and anthropogenic sediments.

Pre-Late Wisconsinan silt and clay are exposed in drainage and pit cuts along the eastern and southern walls of the open pit excavation at Bell mine. These sediments are finely laminated, highly deformed and contain dropstones which increase in abundance towards the base of the unit. Locally, on the eastern wall these sediments overlie a gravelly, stony diamicton, which in turn overlies striated bedrock.

Throughout the study area, basal till occurs as a blanket (1m thick) or veneer (<1m thick) over glacially-streamlined bedrock surfaces. It is massive, dense, varies in colour from dark-brown to maroon, and is highly jointed and fissile. The till matrix varies from a silty sand to a clayey silt and contains an abundance of dark-coloured sedimentary rock fragments, derived from distal bedrock source units. Locally, the till contains clasts of weathered mineralized bedrock, especially down-ice of the Bell ore-body (Figure 5). A unit of winnowed basal till locally occurs as a veneer over lodgement till or bedrock (Stumpf *et al.*, 1996a). It has similar characteristics of lodgement till, but is less compact and much sandier in texture. When overlying clay-rich lodgement till, winnowed basal till often fines downwards to a silty sand. It may also occur beneath glaciofluvial or glaciolacustrine sediments.

Glaciolacustrine silt and clay occur below 790 metres (2600 feet) in low-lying areas along Babine Lake. These sediments occur as both a veneer and blankets (up to several metres thick), commonly overlying morainal deposits. Subordinate glaciofluvial sediments are exposed along modern channel cuts and small ice-contact ridges to the north-east of the Newman Peninsula. Anthropogenic

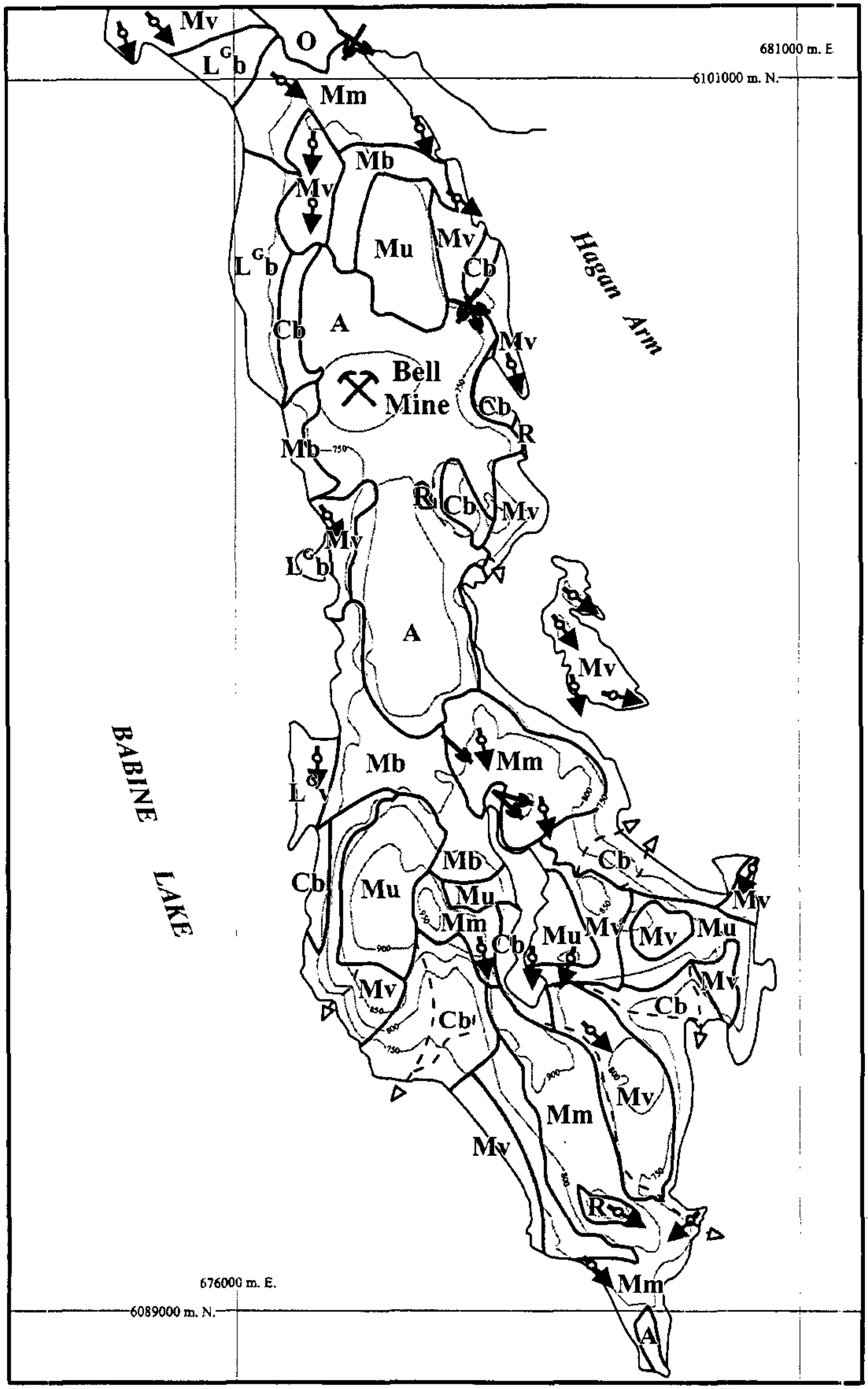

Figure 4a - Surficial Geology of the Newman Peninsula, Babine Lake, British Columbia. See figure 4b for legend.

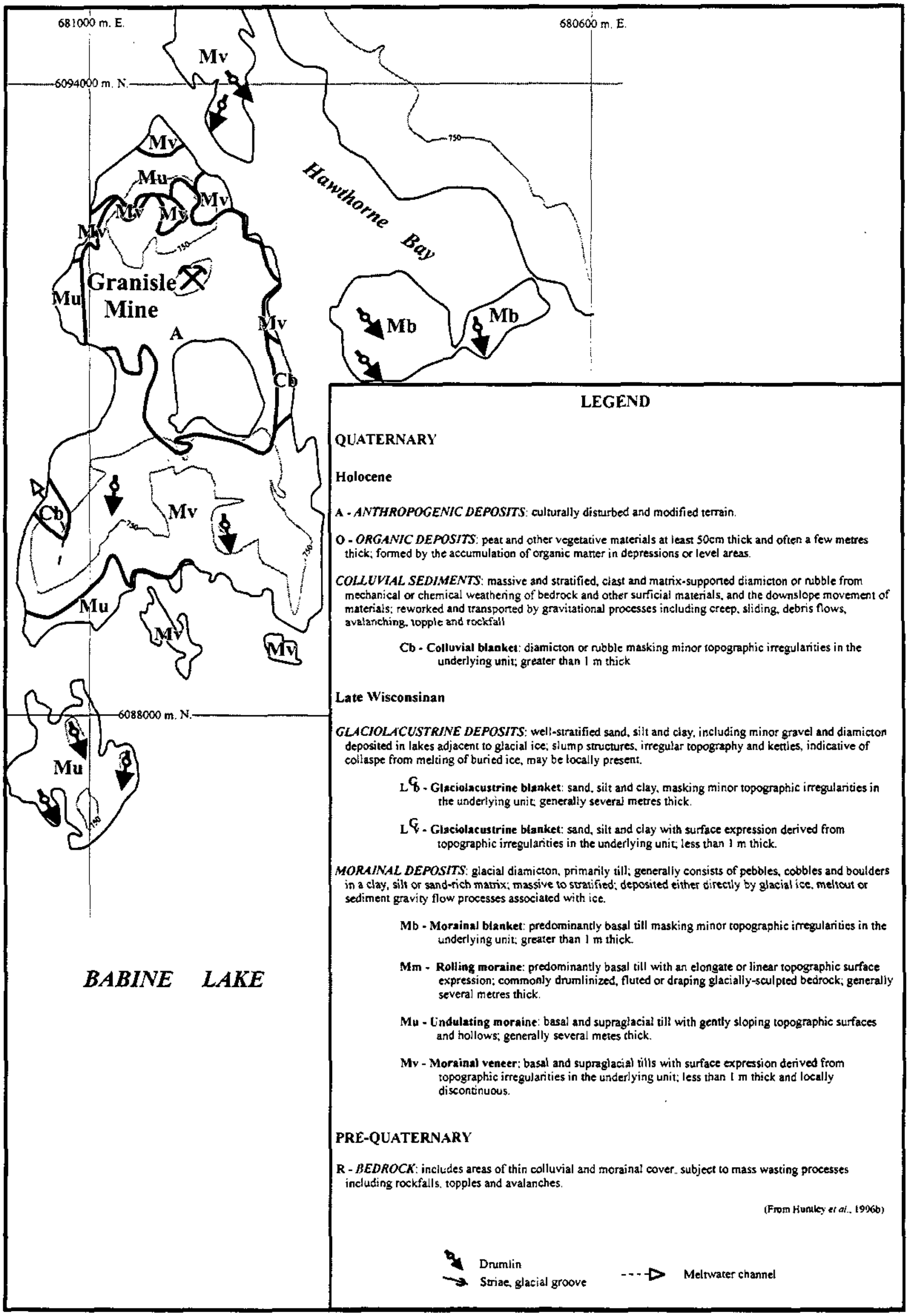

Figure 4b - Surficial Geology of McDonald Island, Babine Lake, British Columbia.

Figure 5 - Deformed weathered rhyodacite boulder in basal lodgement till. Photo taken at sample site 3180, north-east of the Bell mine.

deposits occur throughout the property, mainly in the vicinity of the open pit and tailings piles. Extensive mining and overburden extraction has greatly altered the original topography. Thus, it is often difficult from surface characteristics alone to determine the original, *in situ* materials from those which were culturally modified. Particular caution was taken when describing these features and collecting till samples for analysis.

SAMPLING METHODS

Sixty-four samples of glacial drift were collected on the Bell mine property (Figure 6), with a sample spacing of 300 to 500 metres. Samples were collected from hand-dug pits, road cuts and open pit exposures, from the C-soil horizon, at a minimum depth of 75 cm below the surface. Vertical profile samples were collected around the Bell open pit where till exposures exceeded 3 metres in thickness, in order to investigate geochemical variability (samples 95-1177 and 95-1178; 95-2309 to 95-2315 in Table 1). To compare the geochemistry of variable sediment types, multiple samples were collected from

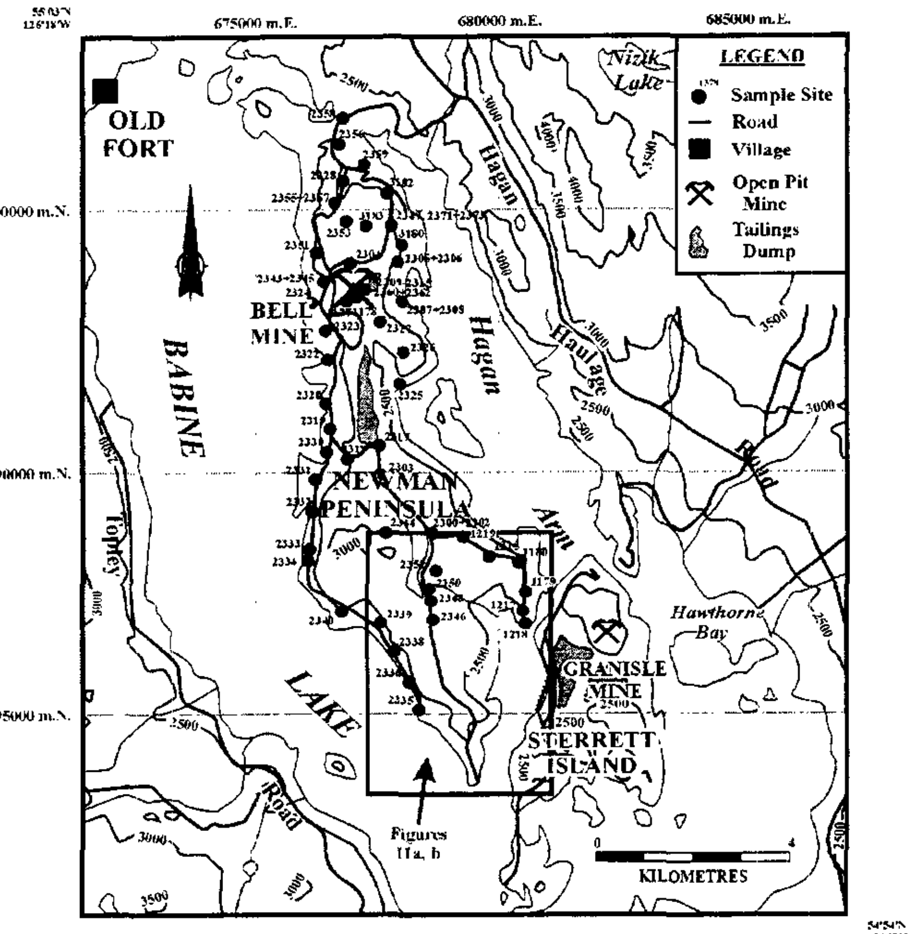

Figure 6 - Sample locations at the Bell mine property. Note, the box outlines the area shown in figure 11.

TABLE 1: ANALYTICAL RESULTS FROM TILL SAMPLES COLLECTED AT NEWMAN PENINSULA

Sample ID.	UTM Eastings	UTM Northings	Map Unit	Mo ppm	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	Fe %	As ppm	Sr ppm	Cd ppm	Bi ppm	V ppm	Ca %	P %	La ppm	Cr ppm	Mg %	Ba ppm	Ti %	Al %	Na %	K %	Hg ppb	W ppm
95-1177	677538	6098300	Cb	1	45	11	98	< .3	42	14	723	3.81	14	175	0.5	< 2	42	1.07	0.064	8	27	0.59	254	0.02	1.64	0.02	0.11	130	< 2
95-1178	677600	6098350	Mb	1	48	11	112	0.3	40	15	944	4.29	16	117	0.7	< 2	47	1.61	0.064	8	28	0.65	284	0.02	1.91	0.02	0.13	135	< 2
95-1179	680585	6092893	Mb	1	64	21	131	< .3	52	16	1823	5.07	24	59	0.8	< 2	57	0.71	0.065	23	27	0.62	318	0.04	2.16	0.03	0.11	140	< 2
95-1180	680427	6093327	Mb	1	58	13	118	< .3	42	17	1011	4.73	16	79	0.4	3	57	0.79	0.066	14	29	0.65	358	0.02	2.33	0.03	0.11	135	< 2
95-1215	679929	6093472	Mv	3	25	9	60	< .3	17	7	393	2.00	3	47	< .2	2	36	0.42	0.040	13	15	0.40	131	0.05	1.44	0.03	0.08	40	< 2
95-1217	680663	6092393	Mb	1	49	14	90	< .3	34	11	668	4.18	15	56	0.4	4	55	0.56	0.050	14	27	0.56	262	0.03	2.05	0.02	0.09	105	< 2
95-1218	680740	6092209	Mb	1	37	5	74	< .3	29	10	462	3.62	11	41	< .2	< 2	50	0.38	0.057	11	24	0.51	141	0.03	1.69	0.02	0.07	95	< 2
95-1219	679418	6093850	Mb	1	20	6	133	< .3	28	9	333	3.03	4	30	< .2	< 2	48	0.27	0.049	8	19	0.45	202	0.06	2.45	0.02	0.13	40	< 2
95-2300	678652	6094104	Mb	1	47	15	124	0.3	31	17	885	4.28	13	68	0.2	< 2	56	1.85	0.066	13	25	0.70	284	0.02	1.90	0.03	0.12	140	< 2
95-2302	678652	6094104	Mb	2	51	18	126	0.4	34	18	963	4.56	16	61	0.5	2	61	0.65	0.070	15	27	0.71	251	0.03	1.99	0.03	0.13	155	< 2
95-2303	678056	6094686	Mb	1	47	20	116	0.3	38	22	1183	3.99	11	77	0.3	2	50	1.81	0.060	11	22	0.69	293	0.02	1.82	0.03	0.13	185	< 2
95-2304	677150	6098850	Mb	1	47	13	103	0.3	37	15	888	4.33	13	69	< .2	< 2	53	0.49	0.054	11	26	0.58	480	0.01	1.90	0.03	0.12	175	< 2
95-2305	677950	6098900	Mb	3	96	11	97	0.3	33	17	791	3.98	13	80	< .2	< 2	46	0.87	0.054	8	23	0.70	275	0.01	1.59	0.03	0.13	130	< 2
95-2306	677950	6098900	Mb	4	133	13	107	< .3	37	19	823	4.24	15	96	0.2	< 2	49	1.09	0.056	9	25	0.66	288	0.01	1.70	0.03	0.14	150	< 2
95-2307	678150	6098150	Cv	2	58	19	123	< .3	24	10	371	3.40	13	31	< .2	< 2	42	0.29	0.043	12	19	0.37	122	0.05	1.12	0.01	0.06	70	< 2
95-2308	678150	6098150	Mb	2	74	13	128	< .3	31	15	675	4.51	20	37	< .2	< 2	53	0.34	0.042	14	25	0.48	186	0.02	1.83	0.02	0.09	170	< 2
95-2309	677600	6098450	Mb	2	67	15	104	0.4	46	16	666	4.33	14	77	< .2	2	51	0.51	0.052	11	29	0.60	315	0.01	1.97	0.03	0.14	155	< 2
95-2310	677600	6098450	Mb	1	41	10	96	0.3	30	14	664	3.77	12	96	< .2	< 2	47	1.50	0.053	9	22	0.65	255	0.02	1.67	0.03	0.12	185	< 2
95-2311	677600	6098450	Mb	2	65	10	104	0.3	36	16	652	3.95	7	112	0.6	< 2	48	0.99	0.055	9	24	0.68	272	0.01	1.70	0.02	0.14	180	< 2
95-2312	677600	6098450	Mb	1	43	11	105	0.3	36	17	723	4.05	13	116	< .2	< 2	48	1.03	0.056	9	25	0.71	278	0.02	1.69	0.02	0.13	130	< 2
95-2313	677600	6098450	Mb	3	82	14	110	0.3	38	19	838	4.19	18	126	0.7	< 2	48	1.02	0.059	9	24	0.74	277	0.02	1.59	0.02	0.13	120	< 2
95-2314	677600	6098450	Mb	4	68	15	116	< .3	41	20	852	4.38	20	129	0.3	< 2	48	0.86	0.059	9	24	0.71	270	0.02	1.60	0.02	0.13	125	< 2
95-2315	677600	6098450	Mb	1	44	13	102	0.4	38	17	676	3.94	9	118	< .2	< 2	49	0.95	0.056	9	25	0.75	283	0.02	1.69	0.02	0.13	125	< 2
95-2317	677892	6095569	Mb	2	74	19	107	< .3	30	13	585	4.67	18	45	< .2	< 2	55	0.39	0.044	16	26	0.61	267	0.02	2.10	0.02	0.12	195	< 2
95-2318	677410	6095150	Mb	1	41	11	92	< .3	27	15	665	3.50	11	109	0.3	< 2	46	1.82	0.072	11	20	0.70	235	0.04	1.37	0.04	0.10	115	< 2
95-2319	677025	6095666	Mb	1	48	13	98	0.3	32	16	756	4.16	13	74	0.2	< 2	51	0.68	0.054	12	24	0.55	433	0.02	1.82	0.03	0.12	115	< 2
95-2320	676848	6096253	Mb	2	57	13	74	< .3	24	11	437	3.43	13	32	< .2	< 2	44	0.22	0.031	8	19	0.53	128	0.04	1.42	0.01	0.07	80	< 2
95-2322	676891	6096754	Mb	2	65	19	122	0.4	37	20	1234	4.60	21	46	0.6	< 2	53	0.55	0.058	12	24	0.55	459	0.02	1.82	0.02	0.12	125	< 2
95-2323	676740	6097296	Mb	2	366	14	112	< .3	29	11	419	3.37	13	47	0.4	< 2	41	0.35	0.048	10	19	0.40	314	0.03	1.27	0.01	0.09	170	< 2
95-2324	676490	6097642	Mb	2	105	20	176	< .3	40	19	953	4.95	34	65	0.5	< 2	56	0.46	0.067	13	27	0.59	377	0.02	1.88	0.03	0.13	140	2
95-2325	678200	6096600	Mb	2	83	21	107	< .3	35	19	816	4.87	22	37	< .2	2	51	0.39	0.055	13	23	0.47	193	0.02	1.68	0.02	0.08	180	< 2
95-2326	678092	6097275	Mv	2	63	14	95	< .3	35	12	423	4.67	15	48	0.2	2	56	0.40	0.053	13	30	0.54	277	0.01	2.18	0.02	0.12	175	< 2
95-2327	677600	6097492	Mb	2	105	20	104	1.4	38	21	1011	4.58	18	45	< .2	< 2	52	0.51	0.043	14	25	0.47	556	0.02	1.69	0.02	0.18	145	2
95-2328	677050	6100600	Mb	1	52	11	108	< .3	48	23	1245	4.02	20	77	0.7	3	47	3.00	0.080	9	25	0.60	269	0.02	1.78	0.02	0.10	165	2
95-2330	676921	6095422	Mb	1	34	15	73	< .3	26	8	302	4.13	12	36	< .2	< 2	51	0.16	0.031	7	26	0.54	145	0.01	1.94	0.02	0.11	130	< 2
95-2331	676814	6094779	Mv	1	37	14	71	< .3	23	9	483	3.53	9	58	0.2	< 2	46	0.43	0.045	12	21	0.53	168	0.03	1.59	0.02	0.09	125	< 2
95-2332	676727	6094225	Mb	1	44	14	79	< .3	26	11	638	4.08	12	57	< .2	< 2	53	0.45	0.060	15	21	0.51	146	0.04	1.41	0.03	0.10	135	< 2
95-2333	676699	6093494	Lgv	1	30	10	60	< .3	27	9	389	3.02	8	42	< .2	< 2	40	0.30	0.021	11	20	0.42	203	0.04	1.26	0.01	0.08	100	< 2

TABLE 1: ANALYTICAL RESULTS FROM TILL SAMPLES COLLECTED AT NEWMAN PENINSULA

Sample ID.	UTM Eastings	UTM Northings	Map Unit	Mo ppm	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	Fe %	As ppm	Sr ppm	Cd ppm	Bi ppm	V ppm	Ca %	P %	La ppm	Cr ppm	Mg %	Ba ppm	Ti %	Al %	Na %	K %	Hg ppb	W ppm
95-2334	676697	6093493	Mb	1	41	13	74	< .3	26	13	680	3.88	15	59	< .2	< 2	53	0.47	0.060	16	23	0.45	254	0.03	1.73	0.02	0.11	115	< 2
95-2335	678764	6090579	Lgb	1	25	11	72	< .3	26	10	453	3.44	9	44	< .2	3	46	0.33	0.045	8	23	0.60	151	0.03	1.73	0.02	0.14	75	< 2
95-2336	678649	6090915	Cb	< 1	28	5	37	< .3	9	5	238	2.15	< 2	68	< .2	< 2	45	0.74	0.124	21	7	0.58	62	0.06	0.99	0.05	0.09	35	< 2
95-2338	678428	6091420	Mb	1	41	9	67	< .3	21	10	519	3.24	6	76	< .2	< 2	51	0.63	0.080	14	20	0.77	142	0.06	1.36	0.05	0.11	45	< 2
95-2339	678123	6092110	Mb	1	39	9	58	< .3	22	8	334	3.77	11	55	0.3	< 2	50	0.39	0.038	11	23	0.54	193	0.03	1.83	0.03	0.10	130	< 2
95-2340	677560	6092309	Mb	1	20	10	55	< .3	21	9	392	2.98	7	51	< .2	< 2	45	0.37	0.028	11	20	0.48	116	0.06	1.30	0.02	0.11	165	< 2
95-2343	676760	6098526	Mb	1	46	12	99	< .3	36	13	734	4.14	14	48	0.2	< 2	48	0.37	0.045	11	26	0.50	227	0.02	1.68	0.02	0.11	240	< 2
95-2344	678101	6093996	Mb	1	30	10	71	< .3	26	10	487	3.45	9	41	0.2	< 2	45	0.29	0.037	11	23	0.51	162	0.04	1.54	0.02	0.11	105	< 2
95-2345	676760	6098526	Mh	1	16	5	53	< .3	23	6	243	2.41	5	27	< .2	< 2	31	0.21	0.030	8	19	0.37	120	0.03	1.02	0.01	0.07	155	< 2
95-2346	678819	6092327	Mv	< 1	28	5	59	0.3	17	10	509	3.02	3	57	< .2	< 2	62	0.61	0.094	16	25	0.97	102	0.09	1.42	0.06	0.07	75	< 2
95-2347	677736	6099596	Mb	1	47	16	205	< .3	26	11	636	3.62	11	38	0.4	< 2	45	0.29	0.039	9	23	0.43	231	0.03	1.48	0.01	0.10	160	< 2
95-2348	678927	6092563	Mv	1	42	15	89	< .3	26	12	711	3.96	14	44	0.3	< 2	53	0.47	0.043	16	26	0.64	187	0.03	1.83	0.02	0.10	125	< 2
95-2350	678657	6093077	Mv	1	36	12	78	< .3	22	9	456	3.88	13	47	< .2	< 2	51	0.48	0.057	15	24	0.59	184	0.03	1.88	0.03	0.09	80	< 2
95-2351	676571	6098998	Mb	2	32	12	83	< .3	29	10	286	3.70	12	23	< .2	< 2	45	0.18	0.036	8	23	0.52	96	0.06	1.30	0.01	0.14	140	< 2
95-2352	678841	6093251	Mv	1	42	13	84	< .3	28	11	581	4.00	12	54	< .2	< 2	53	0.49	0.049	15	26	0.56	234	0.03	1.97	0.02	0.12	190	< 2
95-2353	676720	6099646	Mb	1	44	12	98	< .3	43	11	725	4.08	14	52	0.4	< 2	48	0.35	0.041	14	31	0.55	360	0.01	1.81	0.02	0.12	200	< 2
95-2355	676691	6099880	Mb	1	39	11	86	< .3	33	12	625	3.91	12	35	0.4	< 2	44	0.25	0.033	9	26	0.48	157	0.02	1.53	0.02	0.11	300	< 2
95-2356	676692	6100986	Mb	1	29	14	59	< .3	27	8	300	3.16	8	35	0.2	< 2	40	0.20	0.027	9	23	0.47	164	0.02	1.41	0.02	0.09	150	< 2
95-2357	676691	6099880	Mh	1	19	7	56	< .3	25	7	282	2.68	7	28	< .2	< 2	34	0.21	0.033	7	20	0.38	84	0.04	1.00	0.01	0.06	140	2
95-2358	676748	6101509	Mb	1	40	10	88	< .3	36	13	814	3.95	14	58	0.3	< 2	47	0.46	0.052	10	26	0.50	271	0.01	1.51	0.02	0.09	210	< 2
95-2359	677171	6100591	Mb	1	35	11	76	< .3	29	10	450	3.53	10	44	0.4	3	43	0.27	0.035	10	25	0.48	162	0.02	1.44	0.02	0.09	155	< 2
95-2360	678650	6094100	Lgb	1	55	13	103	< .3	37	16	660	4.20	11	101	0.4	< 2	52	0.72	0.039	7	27	0.85	624	0.01	2.25	0.03	0.19	165	< 2
95-3180	677900	6099250	Mb	1	1550	14	434	0.5	47	17	1004	4.35	15	56	2.0	2	56	0.45	0.070	17	28	0.61	460	0.02	2.01	0.02	0.10	180	< 2
95-3182	677750	6100225	Mb	1	44	9	60	< .3	33	10	485	4.13	11	40	<.2	< 2	55	0.36	0.030	9	26	0.57	209	0.01	2.06	0.02	0.10	380	< 2
95-3183	677425	6099950	Mb	1	57	48	101	0.3	37	14	808	4.43	13	53	0.4	< 2	53	0.43	0.050	12	26	0.52	347	0.02	1.92	0.02	0.09	206	4
		max.		4	366	21	176	1	52	23	1823	5.07	34	175	0.8	4	61	3.00	0.080	23	30	0.75	556	0.06	2.45	0.04	0.18	195	2
		min.		< 1	0	0	0	< .3	0	0	0	0.00	< 2	0	< .2	< 2	0	0.00	0.000	0	0	0.00	0	0.00	0.00	0.00	0.00	0	< 2
		mean		1.2	63.1	11.7	90.0	0.2	29.0	11.9	594.1	3.60	11.5	56.6	0.4	2.1	46.1	0.57	0.049	11.0	22.5	0.54	219.6	0.03	1.57	0.02	0.10	133.2	1.2
95-2371	677736	6099600	b/r	1	55	129	2347	0.5	12	17	3005	4.65	23	23	7.8	< 2	100	1.03	0.185	11	18	2.09	38	0.02	2.62	0.04	0.17	11	15
95-2373	677736	6099610	b/r	< 1	12	8	540	0.3	17	17	3255	5.46	38	9	1.1	< 2	110	0.53	0.191	12	23	2.29	43	0.01	2.74	0.01	0.19	20	16
		Detection Limit		1	1	3	1	0.3	1	1	2	0.01	2	1	0.2	2	1	0.01	0.001	1	1	0.01	1	0.01	0.01	0.01	0.01	10	2

Note: Map units; M-morainal, C-colluvium, Lg-glaciolacustrine sediments, b/r-bedrock (assay); terrain modifiers: b=blanket, h=hummocky, v=veneer.

Analytical method: Aqua regia-ICP, analysis by ACME Analytical vertical exposures from a few sites of undisturbed till where basal lodgement till was overlain by winnowed basal till or colluvium.

Each sample weighing between 1 to 3 kg, was stored in 8-mil plastic bags, air dried (at 25-30°C), split, disaggregated, and sieved to < 63μm, i.e. the silt plus clay sized-fraction. Representative splits were analyzed for 47 different elements by aqua regia inductively coupled plasma emission spectroscopy (ICP-ES) and instrumental neutron activation (INA).

In addition to studying the matrix component of till, the lithology of clasts in till were examined to identify source bedrock units of the till and to determine the length of glacial dispersal in the area. At selected sites, 25 pebbles were collected from undisturbed till and their lithologies recorded. In this study the mineralized and sedimentary rock fractions of the total clast counts are plotted to measure the length of dispersal, down-ice of bedrock contacts (Figure 7).

PREVIOUS WORK

In 1981, Noranda Inc. conducted B-horizon soil sampling across the southern part of the Newman Peninsula, to locate new zones of mineralization. Glacial overburden profile sampling was conducted at the Bell mine property in the 1970's (Okon, 1974; Levinson and Carter, 1979), in order to study the vertical distribution of base metal concentrations within overburden overlying mineralized and non-mineralized bedrock. Results from these studies indicate higher copper and molybdenum concentrations in till over mineralized bedrock. In contrast, zinc concentrations in till are often elevated over non-mineralized bedrock. Levinson and Carter (1979) suggest these high zinc values reflect sulphide mineralization in peripheral areas (pyrite halo) rimming the porphyry copper deposit.

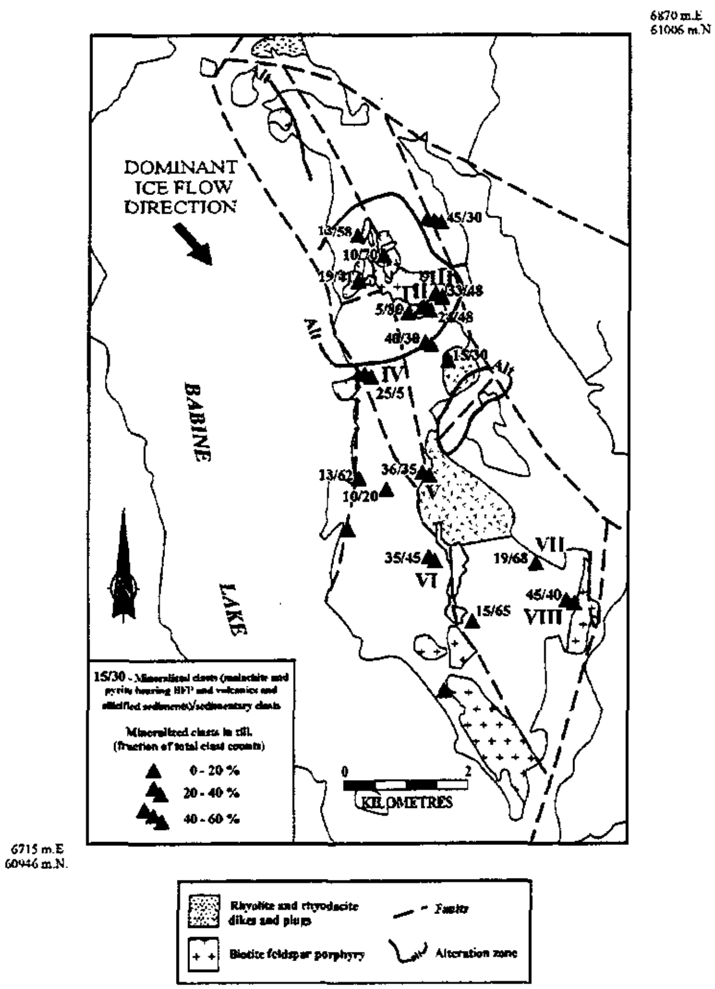

Figure 7 - Distribution of mineralized and sedimentary clasts in till at the Newman Peninsula.

RESULTS

Of the 47 elements analyzed for this study, the distribution of 7 elements (silver, cadmium, copper, mercury, molybdenum, nickel, and zinc), will be discussed here. However, the complete data set for the ICP-ES analysis is presented in Table 1. Elemental concentrations of copper, molybdenum, zinc, silver, mercury, cadmium and nickel in till are plotted on maps using symbols proportional to concentration (Figures 8a, b; 9a, b, c, 10a, b). Statistical analysis of the data identified background and anomalous levels of the geochemical data. In this study, mean till geochemical concentrations measured in a regional till survey from 93 L/16 represent background threshold values, whereas the data above the 95th percentile are considered to be anomalous (Table 2).

Re-contoured plots of Noranda's soil geochemical data show several distinct zones of anomalous copper values, area, higher than background concentrations of these elements occur along major faults and along bedrock contacts (*e.g.* zinc - Figure 9a).

Significant variations in the geochemistry occur in vertical profiles of glacial drift sampled at several sites (Table 3). At locations A and B, where winnowed basal till overlies basal lodgment till, geochemical concentrations in lodgement till are 1.5 to 3 times higher. Lower variability in geochemistry was observed at location C where colluvium overlies lodgement till.

The distribution of mineralized and sedimentary clasts in till recorded at selected sample sites across the Bell mine area reflect the sample's relative location to up-ice bedrock units. For example, an abundance of sedimentary clasts (maximum of 80%) are found in the upper part of the till unit at site I (Figure 7). Less than 100 metes north-east of I at site II and III (Figure 7), the sedimentary clast concentrations decrease to about 50 percent. Site I is

Table 2: Cumulative Frequencies of Selected Geochemical Data

Percentile	Cu (ppm)	Mo (ppm)	Zn (ppm)	Ag (ppm)	Hg (ppb)	Cd (ppm)	Ni (ppm)
REG	44	1	88	0.2	88	0.3	24
50%	44	1	92	0.2	135	0.2	30
75%	57	2	108	0.2	170	0.4	36
90%	83	2	128	0.3	199	0.7	41
95%	98	3	150	0.4	222	0.7	45

(REG - mean of regional till geochemistry data from 93 L/16)

oriented parallel to the main ice flow direction (Figures 11a, b). Additional copper and molybdenum anomalies occur in the area, associated with Babine intrusions or occurring along major faults. In this study, tills sampled in the southern third of the peninsula contain much lower concentrations of copper and molybdenum than the soil. Concentrations in till range from slightly below to slightly above background levels in the soil (Table 1; Figures 8a, b). A single molybdenum anomaly in till located along fault-bounded Babine intrusive rocks on the eastern-most part of the Newman Peninsula (Site B, Figure 8b), is coincident with elevated copper values in soil in the area (Figure 11a).

The majority of the till anomalies identified in this study are located within or along the boundary of alteration encircling the Bell mine ore-body. Here, maximum concentrations in till are observed for copper (1550 ppm), molybdenum (4 ppm), zinc (434 ppm), silver (1.4 ppm), cadmium (2.0 ppm) (Site A, Figures 8a, b; 9a; 10a; Site E, Figure 9b). The highest mercury concentration in till (380 ppb), occurs slightly to the north-east of the zone of alteration (Site F, Figure 9c). Throughout the entire study

located down-ice of Skeena Group sediments whereas sites II and III occur down-ice of Skeena sediments and Hazelton volcanics.

DISCUSSION

Differences between soil and till geochemistry in the southern part of the Newman Peninsula could be an artifact of differences in the origin of the sampling media in the soil survey. A large part of the area where the soil sampling program was conducted is covered by a blanket of colluvium (Cb) or a veneer of basal till (Mv) (Figure 4a) These sediments have a simple genesis and their matrix and clast components have been transported over relatively short distances. Therefore, their geochemical composition may reflect the geochemistry of mineralized bedrock in the area. Till collected from the same area was typically sampled in morainal exposures with thicknesses greater than 1 metre. Thicker till units typically contain a greater percentage of more distally derived material. Therefore, the geochemistry of the till will reflect the mineralogy of

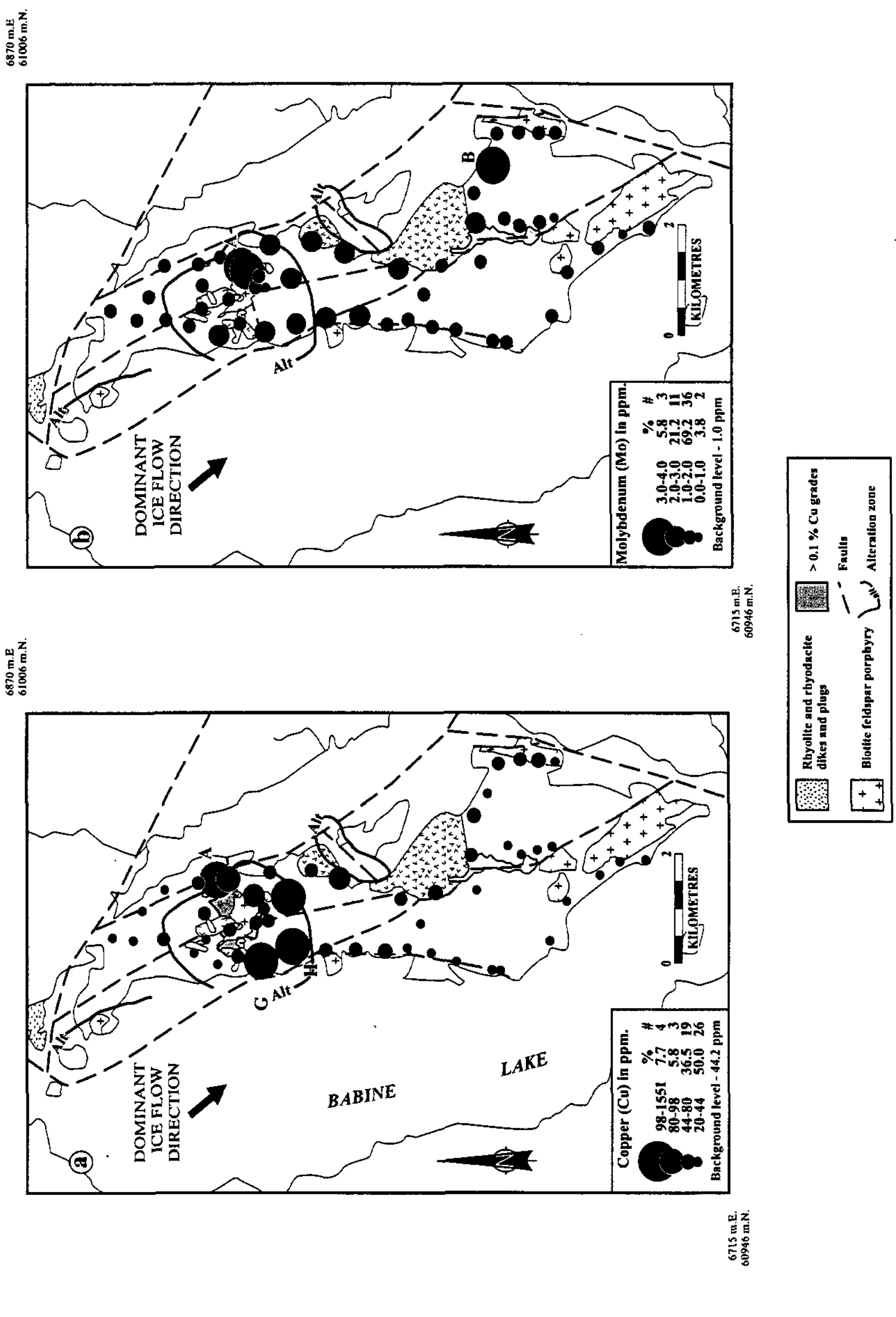

Figure 8 - Copper (a) and molybdenum (b) concentrations in till from the Newman Peninsula.

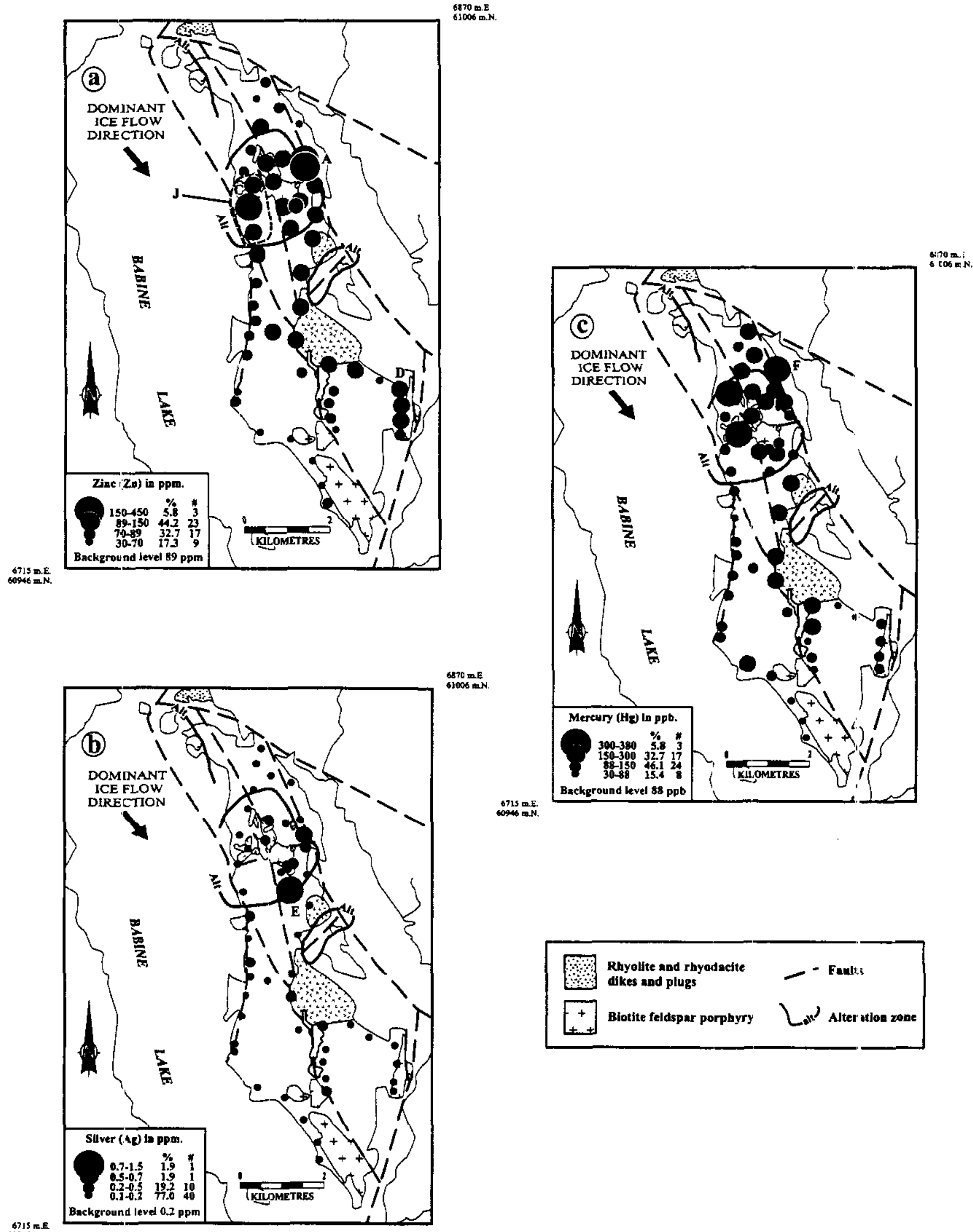

Figure 9 - Zinc (a), silver (b) and mercury (c) concentrations in till from the Newman Peninsula.

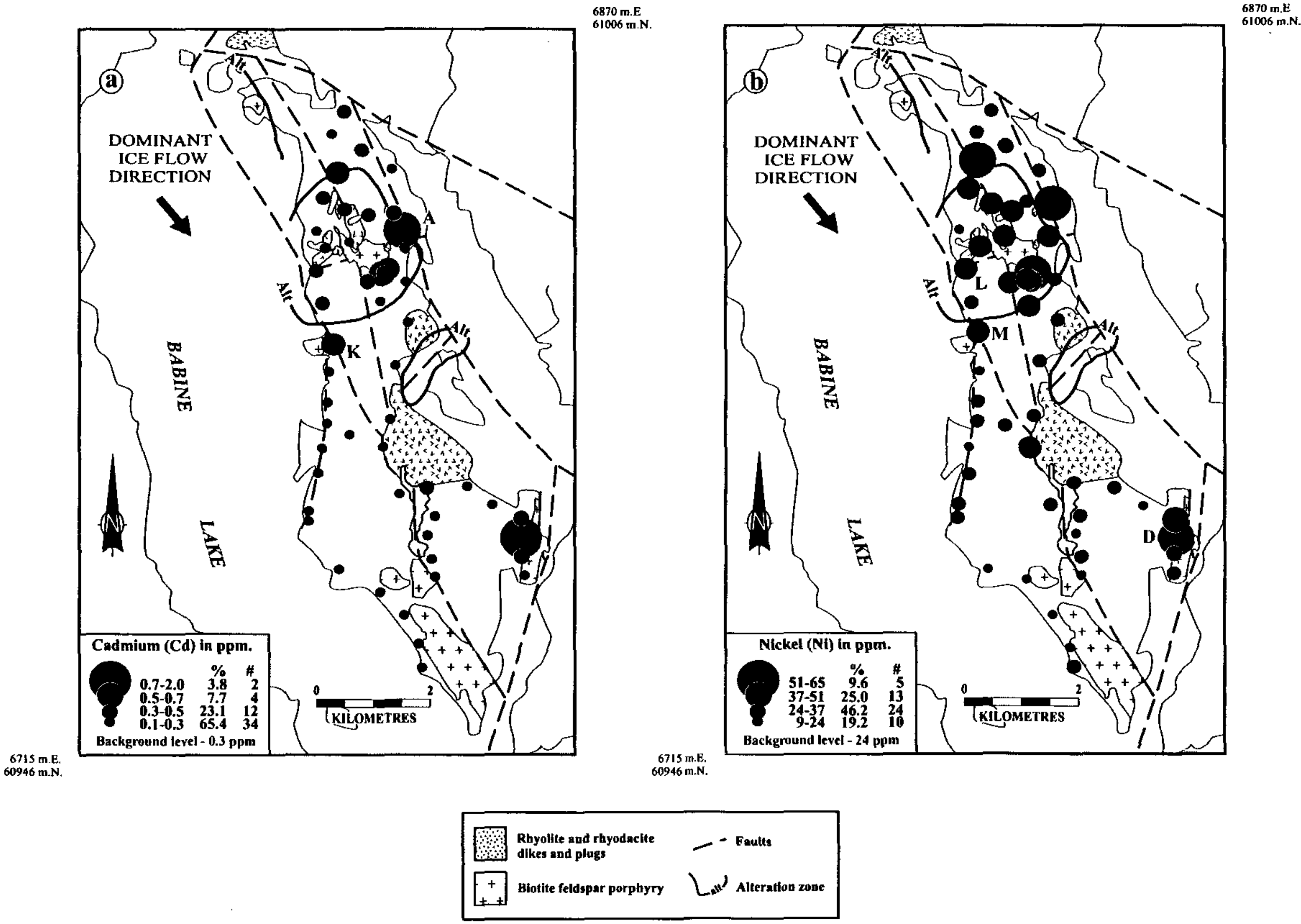

Figure 10 - Cadmium (a) and nickel (b) concentrations in till from the Newman Peninsula.

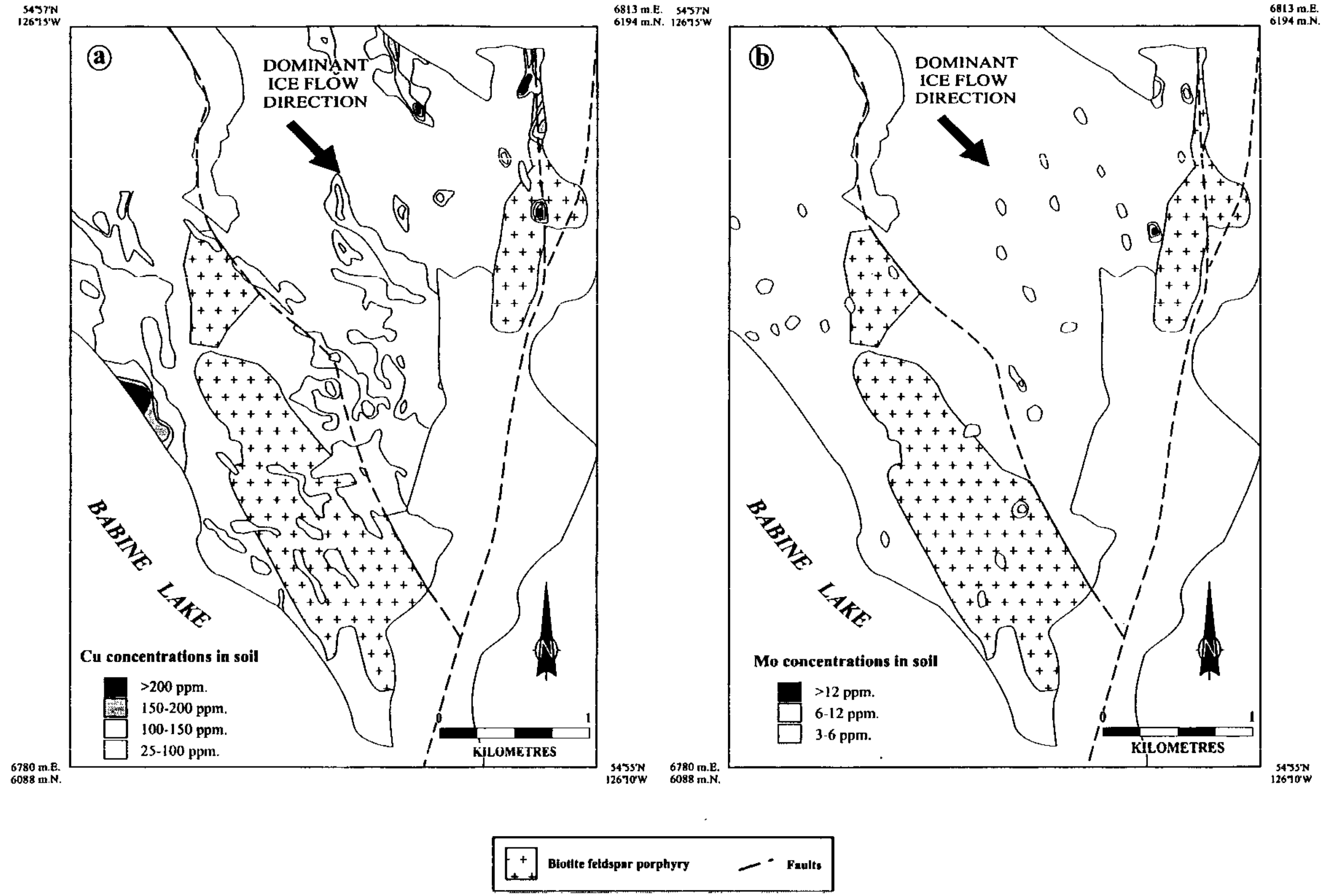

Figure 11 - Copper (a) and molybdenum (b) concentrations in soil, southern part of Newman Peninsula.

Table 3: ICP and INA Data from Selected Vertical Profile Sites											
Profile Site	**Sample #**	**Al (%)**	**As (ppm)**	**Ba (ppm)**	**Cu (ppm)**	**Fe (%)**	**Hg (ppb)**	**Mn (ppm)**	**Sm (ppm)**	**Yb (ppm)**	**Zn (ppm)**
A	95-2345	1.02	11	670	16	2.41	155	243	4.0	2.6	53
	95-2343	1.66	20	840	46	4.14	240	734	5.7	3.6	99
B	95-2357	1.00	9.9	560	19	2.68	140	282	3.5	2.5	56
	95-2355	1.53	20	820	39	3.91	300	625	4.8	3.4	86
C	95-2307	1.12	18	620	58	3.40	70	371	4.6	2.6	123
	95-2308	1.83	23	770	74	4.51	170	675	5.2	2.9	128

Note: Samples at each profile site lie in stratigraphic order (top to bottom).

bedrock from over a much larger area.

Numerous geochemical anomalies in till (Table 1; Figures 8a, b), occur south and east of the Bell mine site. The intensity of these anomalies and their location with respect to regional ice flow and the limits of alteration outlined by Carter *et al.* (1976); Figures 8a, b), suggest dispersal from mineralized intrusive bodies within the alteration zone. For example, anomalous copper values in till at site A (Figure 8a), indicate that this till may overlie mineralized bedrock (*cf.* Levinson and Carter, 1979). Alternatively, the till at site A may contain material eroded from unknown mineralized intrusive bodies located to the north of the mapped alteration zone.

Above background concentrations (mean regional concentrations) for copper (Sites G and H, Figure 8a), zinc (Area J, Figure 9a), cadmium (Site K, Figure 10a) and nickel (Sites L and M, Figure 10b) in till occur to the south and west of the Bell deposit. Significant copper anomalies along the western edge of the Newman Peninsula (Sites G and H, Figure 8a), suggest dispersal from unknown mineralized bodies located to the north-west, possibly lying beneath Babine Lake

In the southern part of the Newman Peninsula ice flow shifts slightly from a south-east direction towards the east (Figure 4a). Over the south-east half of the peninsula (Figures 8a, b; 9a; 10a, b), geochemical concentrations in till occur above background values for copper, molybdenum, zinc, cadmium and nickel. Mineralized material could be carried in a large dispersal train extending south and eastward of the Bell ore-body. The detectable length of dispersal for the matrix component of till may be up to 5 kilometres down-ice of Babine intrusive bodies.

The distance over which clasts of eroded bedrock material are transported down-ice of source bedrock units are a function of their lithology, the size and relief of the outcrop area and the glacial dynamics (Clark, 1987). High concentrations of mineralized clasts are recorded in till at sample sites along the central and southeastern portions of the Newman Peninsula (Sites IV, V, VI, VII and VIII, Figure 7). The Bell ore-body, and mineralized bodies located within its alteration zone are sources for mineralized clasts at sites IV, V and VI. At sites VII and VIII, mineralized clasts in till may also derived from the Bell deposit. Alternatively, these clasts could be eroded from unknown mineralized bodies within Babine intrusive rocks located approximately 1 kilometre to the north-west. In either case, glacial dispersal of mineralized clasts may extend for over 4 kilometres down-ice of source bedrock units.

For the analysis of till geochemistry data it is essential to understand how changes in depth to bedrock will effect the composition of till. Typically, where thin till cover overlies bedrock, the clast and matrix components of the till are dominated by material derived from relatively local sources. In addition, the lithological and matrix concentrations of till may vary dramatically within vertical profiles (Broster, 1986). The upper part of the till profile usually contains a higher percentage of distally-transported material than compared to the lower part which generally contains a high concentration of material eroded from the underlying units.

In this study, till samples collected from a nine metre exposure along the Bell mine open pit (Site A, Figure 8b), show very little variability in their geochemistry with increasing depth. Moderately high copper, molybdenum and cadmium concentrations occur only within the lowest part of the till profile overlying bedrock (samples 95-2313 and 95-2314 for molybdenum; sample 95-2313 for copper and cadmium, in Table 1). Otherwise, the concentrations of elements discussed in this study show no correlation with an increase in depth (samples 95-2309 to 95-2312 and 95-2315, in Table 1). Similar results of this study were obtained from vertical profile samples at the NAK property (Levson *et al.*, 1997a, this volume). The concentration of mineralized and sedimentary clasts also show no significant variation with depth. Mineralized clast concentrations vary from 24 to 33 % over the whole nine metre profile (Figure 7, sites II and III).

CONCLUSIONS

Till geochemistry can be used to locate mineral deposits in areas of thick glacial drift. In this study, anomalous till geochemistry is only confined to the alteration zone around the Bell mine. Occurrences of copper, zinc, and cadmium anomalies in till to the north-east of the Bell deposit, along the margin of Bell's alteration zone suggest these anomalies may be derived from unknown sources of mineralization at the periphery of the alteration zone. Alternatively, these anomalies could have their source from unknown mineralized bodies located farther to the north-west. Above background concentrations of copper, zinc, cadmium and nickel in till occurring to the south and west of the Bell deposit may have sources to the north-west beneath Babine Lake.

Glacial dispersal of material occurs down-ice of source bedrock units. Till containing above background values for copper, molybdenum, zinc and mercury concentrations extends for up to 5 kilometres southeastward of Babine intrusions. Dispersal trains containing mineralized clasts extend for over 4 kilometres down-ice of bedrock source units. Dispersal trains of both matrix and lithological components of till from the Bell deposit may extend southeastward into the Hagan Arm.

Geochemical concentrations in basal lodgement till collected from a vertical profile at Bell mine show very little variability with depth. Slightly elevated concentrations of copper, molybdenum and cadmium occur in the lowest part of the till overlying bedrock, but throughout the profile there exists no distinct correlation in geochemistry with increasing depth.

Winnowed basal till and lodgement till collected from vertical sections produced significant geochemical variability. Geochemical concentrations in lodgement till are several times higher than concentrations in the winnowed basal till. Therefore, it is essential to distinguish between these types of sediments encountered in a sampling program in order to accurately interpret geochemical data.

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TILL GEOCHEMICAL STUDIES IN THE BABINE PORPHYRY BELT: REGIONAL SURVEYS AND DEPOSIT-SCALE STUDIES (NTS 93 L/16, M/1, M/2, M/7, M/8)

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KEYWORDS: Applied geochemistry, surficial mapping, till, mineral deposits, porphyry copper, mineral exploration

INTRODUCTION

Two approaches to till geochemical studies in the Babine porphyry belt have been employed by the British Columbia Geological Survey: 1) regional geochemical surveys to identify geochemically anomalous sites for follow-up by the mineral exploration industry and 2) detailed investigations around areas of known mineralization to evaluate the effects of surficial processes on geochemical distribution patterns, refine models of glacial dispersal in montane and plateau areas and develop methods of drift exploration applicable to the Interior Plateau. This paper provides an overview of these two components of the Babine till geochemistry program.

The study area is centered on northern Babine Lake and covers the entirety of the Babine porphyry belt (Figure 1). Copper porphyry mineralization in the study area is hosted in the Eocene Babine intrusives. Major deposits include the former Bell and Granisle copper mines. Porphyry copper deposits remain the primary exploration target in this region and several active porphyry properties, including the Hearne Hill, Nak and Trail Peak prospects, are within the bounds of the study area.

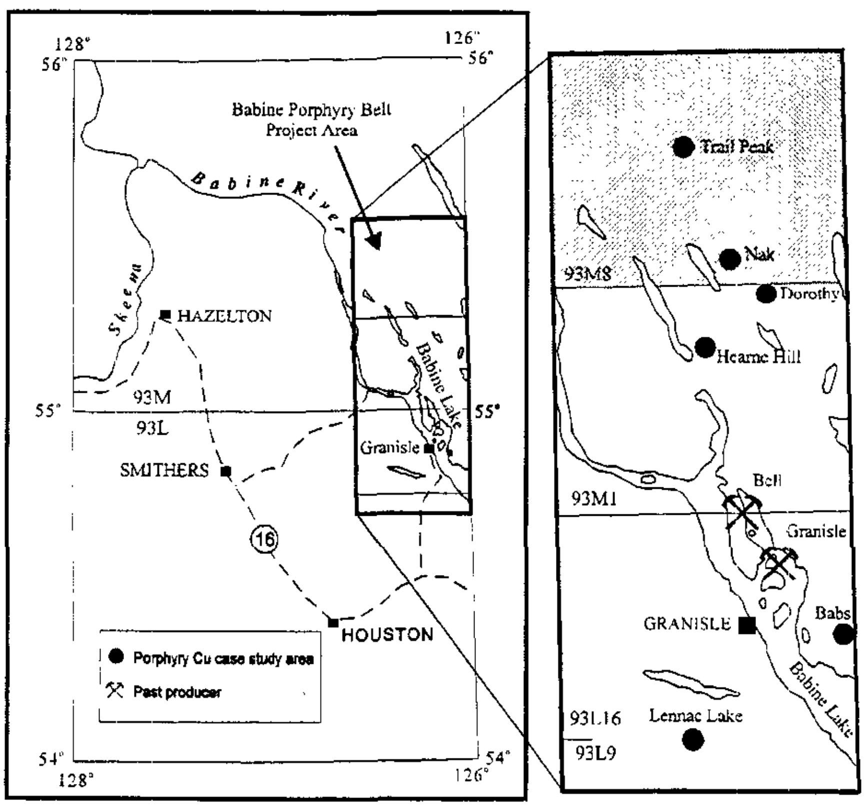

Figure 1. Location map of the study region and case study areas.

The purpose of the regional till geochemistry program is to improve the existing geochemical database of the Nechako Plateau area. This information will help to better assess the mineral potential of the region and thus increase the possibility of new discoveries. The Nechako Plateau is characterized by subdued topography, an extensive drift cover and poor bedrock exposure. For these reasons, mineral exploration in the Babine porphyry belt has been hindered. Results of the till geochemical surveys are expected to provide useful new data to stimulate further exploration.

The purpose of the detailed case studies in the Babine porphyry belt is to determine the most effective geochemical exploration methods for discovering, in till, the dispersed remnants of buried Babine porphyry Cu-Au deposits and their associated hydrothermal systems. These case study investigations include lithologic studies used to determine regional dispersal patterns in different types of sample media, needed for appropriate design of exploration programs. Stratigraphic and sedimentologic studies of Quaternary deposits are also included in order to define the glacial history and aid in interpreting till geochemical data.

Complementary regional geochemical surveys (till and lake sediments) and bedrock mapping surveys have proven highly effective in stimulating mineral exploration in low-lying drift-covered regions of the northern Interior Plateau. For example, prior till and lake sediment geochemistry surveys in the Nechako River map area (NTS 93F) to the south were successful in delineating several areas of known mineralization (Cook *et al.*, 1995) and in revealing locations of new mineralized zones. For this reason, till geochemical studies in the Babine porphyry belt have been conducted in conjunction with ongoing bedrock geology mapping (MacIntyre *et al.*, 1997), surficial geology mapping (Levson *et al.*, 1997) and regional lake sediment geochemistry (Cook *et al.*, 1997) components. These studies are part of the Nechako National Mapping (NATMAP) Project, a joint project of the British Columbia Geological Survey Branch, the Geological Survey of Canada, and university researchers.

PREVIOUS WORK

The bedrock geology of the Babine porphyry belt has been described by Carter (1973) and MacIntyre *et al.* (1996, 1997). The surficial geology of the region was discussed by Huntley *et al.* (1996) and Levson *et al.* (in press, 1997). Tipper (1971) and Plouffe (1994a, b) completed reconnaissance mapping of Quaternary deposits in the Nechako Plateau. Recent till geochemical studies in the plateau were discussed by Levson and Giles (in press). Several case study investigations have been conducted to date, as part of the NATMAP and Interior Plateau programs (Levson and Giles, 1995, in press; O'Brien *et al.*, 1995; O'Brien, 1996; Stumpf *et al.*, 1996, 1997). Kerr and Levson (1995) provided an annotated bibliography of published studies dealing with glacial dispersal processes in British Columbia. An overview of drift prospecting methods and research of particular relevance to the Interior Plateau region was completed by Kerr and Levson (in press). A discussion of current methods of exploration in the southern Nechako Plateau area, typical problems encountered and information that can be used to develop and refine drift exploration methods, was provided by Levson and Giles (in press). Reconnaissance till geochemical sampling programs in the Interior Plateau have been conducted in the Manson River - Fort Fraser area (93K, N) by Plouffe and Ballantyne (1993) and Plouffe (1995).

LABORATORY METHODS AND QUALITY CONTROL

Till samples collected during the regional geochemical surveys (each 3-5 kg in weight) are air dried, split and sieved to -230 mesh (<62.5 μm). This fraction is analyzed by instrumental neutron activation analysis (INA) and inductively coupled plasma analysis - atomic emission spectroscopy (ICP-AES). Half of each sample split is reserved for grain size or other follow-up analyses. For the detailed case study investigations, heavy mineral concentrates and magnetic separates of selected samples are also analyzed in the laboratory.

A number of quality control measures are included in both the field and laboratory analysis components of the program in order to discriminate geochemical trends, related to geological factors, from those that result from spurious sampling or analytical errors. These measures include the use of field duplicates, analytical or blind duplicates and control standards, one of each being randomly inserted into each set of 17 routine field samples to make a block of 20 samples that are submitted for analysis. Field duplicates are taken from randomly selected field locations and are subjected to the identical laboratory preparation procedures as their replicate pairs. Analytical duplicates consist of sample splits taken after laboratory preparation procedures but prior to analysis. Control reference standards include several British Columbia Geological Survey (Analytical Sciences Unit) geochemical reference materials comprising the -180 micron size fraction of a variety of bulk samples.

1) REGIONAL TILL GEOCHEMISTRY PROGRAM

OBJECTIVES

The primary objectives of regional till geochemical studies conducted in the Babine region were to identify geochemically anomalous sites that reflect areas of buried mineralization and to investigate patterns of glacial dispersal. Till geochemical anomalies identify areas where glaciers eroded mineralized bedrock and redeposited the mineral debris in down-ice dispersal trains. As glacial dispersal trains may be hundreds to thousands of times larger in area than their original bedrock source, they provide a cost effective target for mineral exploration programs in drift-covered terrains (Shilts, 1976; DiLabio, 1990; Levson and Giles, 1995, in press). In addition, tills are 'first-derivative' products of bedrock and, having been transported to their present location mainly by the relatively linear flow of glaciers during one or more glacial episodes, they are more readily traced to source than higher order derivatives such as glaciofluvial or glaciolacustrine sediments (Shilts, 1993).

SAMPLING MEDIUM

Basal till was selected as the preferred sampling medium for this program rather than other types of surficial materials because mineral anomalies in basal till tend to be large, relatively easily detected and more readily traced to their origin than other sediment types (Levson and Giles, in press). In addition, the dominance of one main regional ice-flow direction throughout much of the last glacial period in the survey area (Levson *et al.*, 1997), resulted in a simple linear, down-ice transport of material. This makes tracing of basal till anomalies to source relatively easy compared to regions with a more complex ice-flow history.

Basal tills typically consist of compact, fissile, matrix-supported, sandy-silt diamicton (Photo 1). They are typically over-consolidated and often exhibit moderate to strong subhorizontal fissility. Vertical jointing and blocky structure are also common, especially in dry exposures. Oxidation of the till, characterized by reddish brown staining, is common and may occur pervasively or along vertical joint planes and horizontal partings. Subhorizontal slickensided surfaces are sometimes present, especially in clay-rich parts of the till. Clasts are mainly medium to large pebbles but they range in size from granules to large boulders. Total gravel content generally is between 10 and 30% but locally may be up to 50%. Subangular to subrounded clasts are most common and typically up to about 20% and are glacially abraded. Striated clasts are commonly bullet shaped, faceted or lodged; the a-axes of elongate clasts are often aligned parallel to ice-flow direction. Lower contacts of basal till units are usually sharp and planar. All of these characteristics are consistent with a basal melt-out or lodgement till origin (Levson and Rutter, 1988; Dreimanis, 1990).

Photo 1. Massive, matrix-supported diamicton interpreted as basal till; note the variety of clast sizes, fine-grained matrix and presence of subrounded to subangular clasts.

Basal till deposits can be confused with other facies of morainal sediments such as glacigenic debris-flow deposits or with other poorly sorted sediments such as colluvial deposits. 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 observed in others. Basal tills are first order derivative products whereas glacigenic debris-flow deposits and colluvial deposits have undergone a second depositional phase, related either to the paleo-ice surface or the present topography, and they are therefore more difficult to trace to their source. Glacigenic debris-flow deposits include some supraglacial tills and basal tills reworked by gravity or water. They typically consist of loose, massive to stratified, sandy or gravelly diamicton often with lenses and beds of sorted silt, sand and gravel. They often gradationally overlie basal till. Colluvial diamictons are differentiated from basal tills by their loose unconsolidated character, the presence of coarse, angular clasts of local bedrock, crude stratification and lenses of sorted sand and gravel.

1996 REGIONAL TILL GEOCHEMICAL SAMPLING PROGRAM

Regional till geochemical sampling in 1996 focused on the Nakinilerak map sheet (NTS 93 M/8) where 321 samples were collected. The 1996 regional program was combined with surficial geology mapping and, together with the 1995 program on NTS map sheets 93 L/16 and M/1, completes coverage of the Babine porphyry belt. Sample density on 93 M/8, M/1 and L/16, is one sample per 2.75, 2.0 and 3.0 square kilometres, respectively. An additional 42 samples were taken on adjoining parts of the Harold Price Creek and Netalzul Mountain (NTS 93 M/2 and M/7, respectively) map sheets. The western limit of sampling in the latter two map areas was the west arm of Babine Lake and the Babine River. Sample sites were selected to provide complete coverage of the map areas, with the greatest density of samples along transects perpendicular to established ice-flow direction. Along transects parallel to ice flow, where samples repeatedly represent the same terrain directly up-ice and therefore duplicate each other, wide spaced sampling was used. An intermediate sample spacing was used on transects oblique to flow. Sample sites included natural river cuts, wave-cut benches on lake shorelines and man-made exposures (roadcuts, borrow pits, soil pits and trenches). Average sample depth was 0.96 metre but ranged from 0.2 to 7.0 metres. Locations were plotted on a 1:50 000 topographic base maps.

Logging road access to the 1996 map area was limited to the westernmost and easternmost sides of the map sheet. All terrain vehicles, boats and helicopters were used to access other parts of the map area.

Sedimentologic data were collected at all sample sites in order to distinguish basal till from other sediment types. Data collected at each sample site included descriptions of sediment type, primary and secondary structures, matrix texture, presence of fissility, compactness, total percentage and modal size of clasts, rounding of clasts, presence of striated clasts, and sediment genesis and thickness. Further information was noted on soil horizons, local slope, bedrock striae, bedrock lithology, clast provenance and abundance and type of mineralized clasts.

The till sampling program 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) subangular to angular clasts in the basal tills with little or no evidence of glacial transport (*i.e.* clasts of very local origin); 2) distally derived surface erratics (*i.e.* clasts of probable supraglacial origin; often cobble to boulder sized); 3) clasts showing abundant evidence of glacial abrasion such as striae and faceting (*i.e.* basally transported clasts of probable local to intermediate provenance); 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.

REGIONAL GEOCHEMICAL RESULTS

Geochemical analyses of till samples from the Nakinilerak map sheet (93 M/8) were not available at the time of writing but results from the 1995 sampling program on the adjoining Old Fort Mountain map sheet (93 M/1) were available. Median concentrations (in ppm) of copper, molybdenum, lead, zinc, nickel, arsenic and antimony in the regional data set were 44, 1, 11, 103, 30, 18 and 1.6, respectively. In nearly every case these median concentrations are higher than was encountered in the Fawnie Creek map area (NTS 93 F/3) in the southern Nechako Plateau where median concentrations of the same elements (in ppm) are 24, 1, 8, 65, 12, 9.2 and 1.2, respectively (Levson *et al.*, 1994 and Cook *et al.*, 1995). The only exception to this is gold which had a median concentration of 4 ppb in the southern Nechako Plateau rather than 2 ppb in the Babine study area.

Maximum concentrations of the same elements are also generally higher in the Babine area. These concentrations are (in ppm, with southern Nechako concentrations in parentheses): 1550 (66) for copper, 38 (7) for molybdenum, 97 (58) for lead, 626 (168) for zinc, 39 (35) for nickel, 130 (170) for arsenic and 4.2 (4.3) for antimony. The higher median and maximum concentrations of these elements in the regional till samples in the Babine area compared to the southern Nechako probably reflects the higher base metal potential of the former. This is especially apparent for copper, where background (median) concentrations in till, as expected, are nearly twice as high in the Babine area as in the Fawnie area (44 ppm vs 24 ppm) and maximum copper concentrations are an order of magnitude higher (1550 ppm vs 66 ppm).

2) TILL GEOCHEMISTRY CASE STUDIES

OBJECTIVES

The Babine porphyry belt has excellent potential for hosting additional Cu-Au porphyry deposits, but geochemical exploration in the region is difficult due to an extensive drift cover and the widespread distribution of post-glacial lake sediments. Surficial mapping conducted during the first year of the Nechako NATMAP Project has demonstrated the usefulness of glacial till as a geochemical sampling medium, but sedimentological studies of till must be complemented with detailed investigations into the till geochemical expression of the hydrothermal alteration zones associated with the deposits.

The main objectives of the detailed geochemical investigations are two fold:

a) identify geochemical dispersal patterns in till, and the most effective pathfinder elements associated with Babine porphyry deposits,

b) identify, in the field and laboratory, the most effective methods of identifying the geochemical signatures of dispersed remnants of hydrothermal alteration zones in till around Babine deposits.

1996 GEOCHEMICAL CASE STUDIES

Alteration zones associated with Babine porphyry deposits are typically more extensive than the mineralized zones themselves, offering potentially larger exploration targets, provided that the geochemical and mineralogical expressions of the alteration mineralogy can be recognized in till. The porphyry deposits typically have potassic and propylitic alteration zones around a smaller central ore zone of Cu-sulphide minerals, as well as extensive pyrite halos with marginal polymetallic veins. The main purpose of the study was to identify, in till, the geochemical response of the dispersed remnants of hydrothermal alteration zones associated with the porphyry mineralization. The project will identify those geochemical exploration methods which most reliably reflect the alteration signatures, thus increasing the likelihood of future mineral deposit discoveries.

Case study investigations were conducted at five porphyry copper prospects in the Babine porphyry belt in 1996: Lennac (MINFILE 93L 190, 191), Hearne Hill (MINFILE 93M 006), Trail Peak (MINFILE 93M 011), Nak (MINFILE 93M 010) and Dorothy (MINFILE 93M 008) properties (Figure 1). A total of 321 till samples were obtained at these sites. Samples were collected along linear or fan-shaped traverses down-ice of the prospects to provide a clearer understanding of glacial dispersal processes and transport distances. Numerous profile samples (Photo 2) were also taken from trenches and soil pits on the properties and, at the Nak prospect, from diamond drill holes (Photo 3). Till samples from the latter were recovered by Hera Resources Ltd. during their drilling program. The drill core samples were analyzed before the regional till geochemical samples so that the preliminary results could be discussed here (see below).

A collaborative detailed till and biogeochemical study was also undertaken at the Lennac prospect with Colin Dunn (Geological Survey of Canada). In this study the principal biogeochemical sample medium was lodgepole pine outer bark, supplemented with samples of alder. Lodgepole pine bark samples were obtained from more than 120 sites over the general vicinity of the Lennac prospect.

NAK CASE STUDY RESULTS

The preliminary results of geochemical analyses of unique till samples recovered from diamond drill core at the Nak property are presented here. A total of 53 till samples were recovered from 19 of the 57 cores investigated (Figure 2). Wherever possible, more than one sample was taken at any one drill hole at varying depths. Nine of the 19 sampled cores yielded two or more samples, for total of 48. The largest number of samples obtained in any one hole was 17. These came from between 31 and 61 metres depth at hole 57. Copper concentrations in these nine holes in relation to depth are shown in Figure 3.

The median concentration of copper in all till samples recovered from core on the Nak property is 56 ppm. This value is elevated relative to the regional background (median) value of 44 ppm copper in tills on the Old Fort Mountain map sheet (93 M/1; see above), just south of the Nak property (Figure 1). Every till sample analyzed yielded copper values higher than the 75 percentile value (53 ppm) for the regional data set on 93 M/1, except two samples. These were both taken from cores on the northwest side of the property (holes 42 and 45; Figure 2) up-glacier of the main porphyry target. The lowest copper concentration (26 ppm) was obtained from the farthest up-ice location sampled (hole 42, located on the northern most side of the drill zone; Figure 2). Likewise, the highest copper concentrations obtained on the property came from two sites located on the southeastern most or down-glacier side of the main porphyry target zone (holes 13 and 35; Figure 2).

Seven holes yielded at least one till sample with copper concentrations above 100 ppm. These are all located on the down-ice side of the property except hole 50 which occurs at a much lower elevation (70 to 200 m lower) than the other six sites. High copper (404 ppm) in till at hole 50 probably reflects a greater depth of sampling within the till sheet at that location as well as a possible copper source to the northeast of that site. In

Photo 2. Vertical sampling profile at the Trail Peak property in colluvial sediments overlying till.

Photo 3. Indurated basal till in drill core at the Nak property.

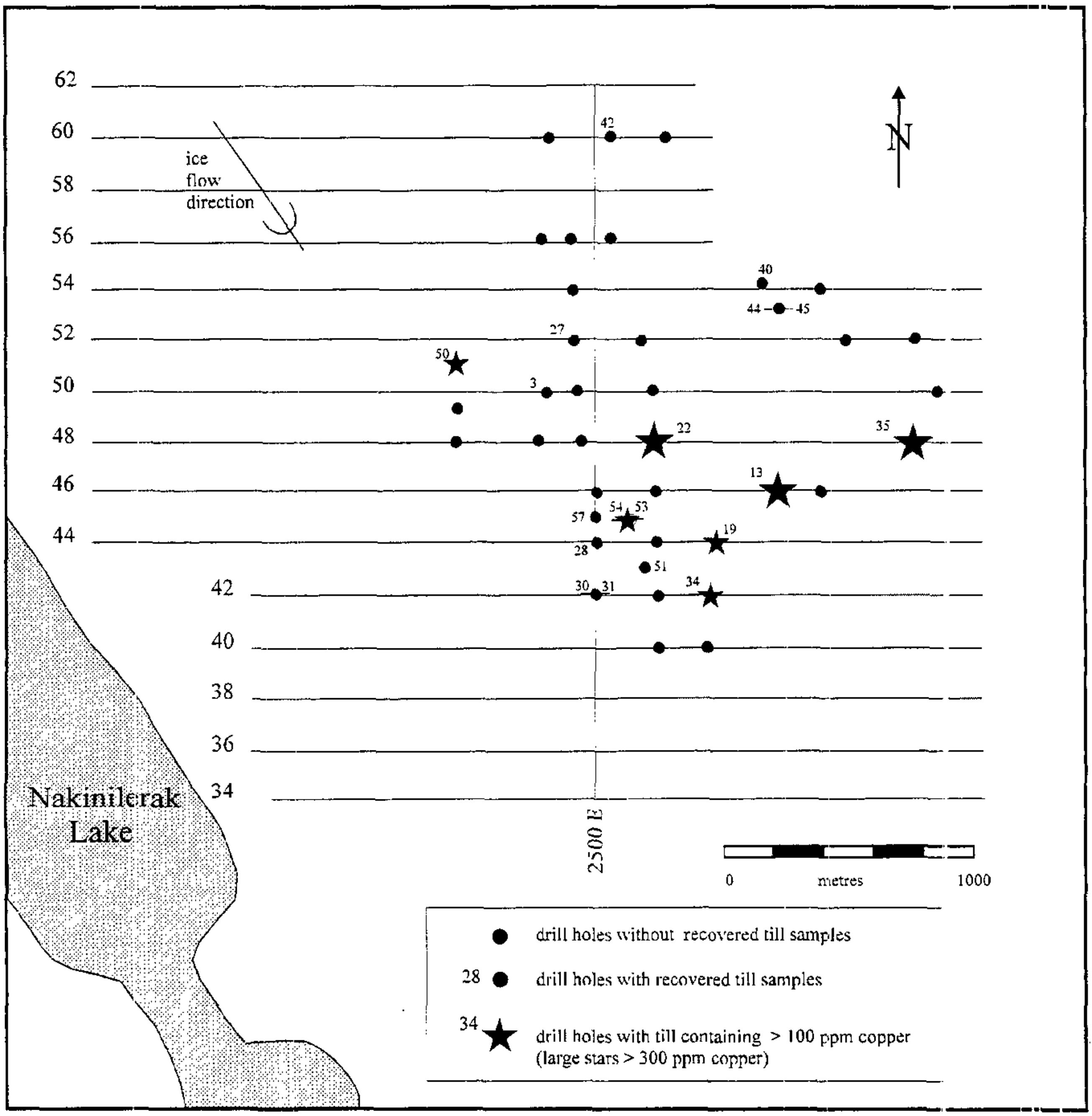

Figure 2. Location map of drill holes at the Nak property showing holes with recovered till (numbered) and holes with highly anomalous copper concentrations in till.

addition, the high copper concentrations in till at holes 13, 19, 22, 34 and 54 suggests an up-glacier copper source to the northwest of these sites, possibly in the region between holes 22 and 27 or even further northwest.

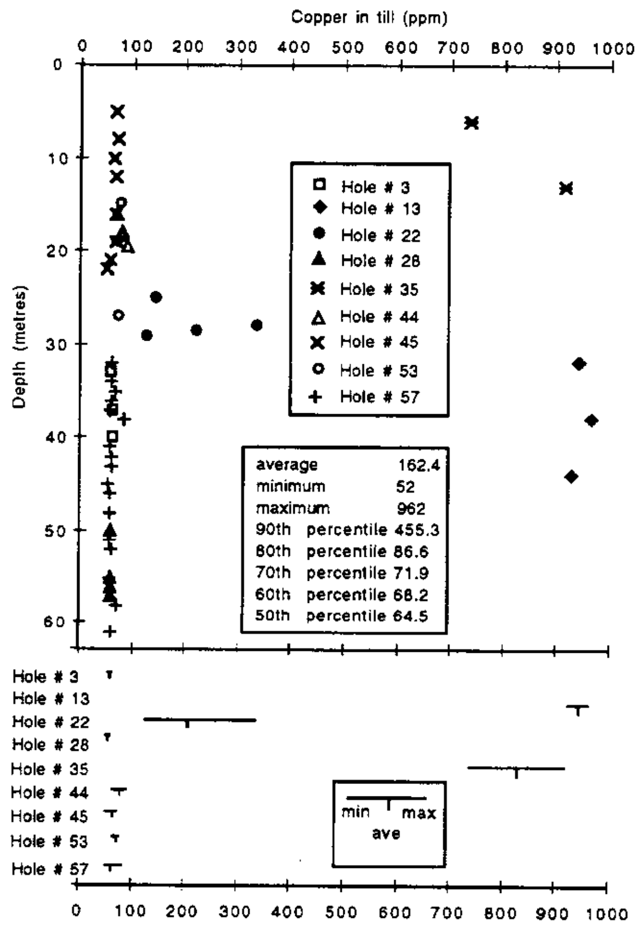

Figure 3. Copper concentrations in basal till (-63 μm fraction, analyzed by ICP) recovered from diamond drill holes at the Nak prospect versus depth; the lower half shows the range of variation in each hole (see text for explanation).

Copper concentrations in till at the Nak property, as shown by the drill hole data, are remarkably uniform over a substantial thickness (> 60 m) at many of the drill hole sites (Figure 3). Of the 9 holes with more than one sample, only three (holes 13, 22 and 35) yielded copper values greater than 100 ppm. Significantly, all three of these holes occur in the same part of the drill zone and there are few holes located between them. Copper concentrations in the remaining six holes have a relatively narrow range, generally between 55 and 80 ppm (Figure 3, lower half). These data strongly suggest that compositional stratification in the till is not well developed. This geochemical homogeneity may be a reflection of the relatively large size of the porphyry copper prospect that underlies the till.

The three holes at the site (13, 22 and 35) that show very high copper concentrations in till (Figures 2 and 3), indicate that at least one pronounced dispersal plume is present in the subsurface in the area. This high concentration plume (or plumes) apparently is superimposed on a much larger, till geochemical anomaly with elevated, but not extremely high, copper concentrations. Copper values in the high concentration plume show a relatively wide range compared with other till samples in the area (Figure 3, lower half) as expected. However, at one site (hole 13; Figure 3) highly anomalous copper concentrations are relatively uniform over at least a 12 metre thick interval, between about 32 and 44 metres depth. This observation, combined with copper concentrations in till at this site that are higher than at any other hole in the area, suggests that exploration for a higher grade copper zone in the porphyry may be warranted in the area northwest of hole 13. Since relatively few holes have been drilled in this region, the potential for a new, higher grade discovery in that area is enhanced.

The interpretations presented here are considered preliminary, as no attempt has been made to reconcile the till geochemical data with the results of recent drilling in the area. The information presented is provided only as an illustration of how till geochemical data from drill holes might be applied on an exploration property of this type.

SUMMARY

Current geochemical studies in the Babine porphyry belt include both regional (1:50 000 scale) till sampling programs and detailed (property scale) case study investigations. Regional till geochemical sampling is combined with surficial geology mapping and has been completed on five NTS map sheets including all of 93 L/16, M/1 and M/8 and parts of 93 M/2 and M/7. The purpose of these programs is to detect geochemical anomalies associated with glacial dispersal of mineralized bedrock. These anomalies may be readily detected by regional surveys because they are up to several kilometres long and a few kilometres wide. Regional till geochemical sample density in the Babine belt is about 1 per 3 square kilometres.

Although typically much larger than soil anomalies, till dispersal plumes are more subtle. For example, maximum element concentrations in till on the Old Fort Mountain map sheet (93 M/1) are 1550 ppm copper, 84 ppb gold, 38 ppm molybdenum, 97 ppm lead, 626 ppm zinc, 39 ppm nickel, 130 ppm arsenic and 4.2 ppm antimony. Till anomalies are elongated parallel to ice-flow direction, with mineralized source rocks occurring at or near the up-ice end of the dispersal plume. In areas of thick till, bedrock sources do not immediately underlie the anomaly but may occur 500 metres or more in the up-glacier direction. Exploration targets in these areas should be up-ice, rather than in the centre or at the head, of the geochemical anomaly. In order to understand mineral anomaly patterns, sedimentologic data should be collected at all sample sites so that till can be distinguished from other surficial sediment types with different processes of transportation and deposition.

Geochemical case study investigations in 1996 were conducted at the Lennac, Hearne Hill, Trail Peak, Nak and Dorothy porphyry copper prospects. Preliminary results of a unique study of till recovered from diamond drill core at the Nak property, show that copper concentrations in tills overlying the porphyry prospect are invariably elevated above regional background values but they are surprisingly uniform over great depths. Copper in till generally increases in the down-glacier direction. Localized areas of highly anomalous copper concentrations suggest that specific, and possibly undiscovered, zones of relatively high-grade copper mineralization are present within the Nak porphyry.

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EARTHQUAKE HAZARD ASSESSMENT IN GREATER VICTORIA, BRITISH COLUMBIA: DEVELOPMENT OF A SHEAR-WAVE VELOCITY MODEL FOR THE QUATERNARY DEPOSITS
(92B/6 & B/11)

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KEYWORDS: Victoria, earthquakes, geological hazards, seismic microzonation, geotechnical engineering, cone penetration testing, shear-wave modeling, surficial geology, Quaternary

ABSTRACT

In order to assess the earthquake ground-motion amplification hazard in Greater Victoria, a field testing program was conducted in the spring of 1996 to obtain shear-wave velocity data in the principal Quaternary geologic units. Twelve seismic cone penetration tests (SCPTs) were conducted to depths ranging from 4 to 41 metres and four tests using the spectral analysis of surface waves (SASW) technique were conducted where the soils are too dense for cone penetration. Based on these data, a shear-wave velocity model was developed that will provide the basis both for estimating ground-motion amplification locally and mapping the amplification hazard regionally. Shear-wave velocities in the grey clay facies of the late glacial glaciomarine Victoria Clay are generally between 100 and 160 m/sec. These deposits occur in low lying areas, where they are commonly greater than 10 metres thick. Where these deposits are present, high amplification of ground-motion could occur during an earthquake, particularly where they are overlain by Holocene organic clay and peat. The fundamental site periods for sites underlain by grey clay range from 0.27 to 1 second, so that resonance will occur at ground motion periods less than 1 second at most sites. Generally, shear-wave velocities in the dessicated brown clay facies of the Victoria Clay are between 160 and 270 m/sec. These deposits are generally less than 6 metres thick, so that site effects will be primarily controlled by the underlying materials. In the sands and gravels of the late glacial Colwood delta, shear-wave velocities are generally between 280 and 390 m/sec, and where these deposits are sufficiently thick, moderate ground-motion amplification could occur. In the till of the Late Winsonsinan Fraser Glaciation and older Pleistocene deposits shear-wave velocities are generally between 400 and 600 m/sec and sites underlain by these deposits have low susceptibility to ground-motion amplification.

INTRODUCTION

Greater Victoria, on the southern tip of Vancouver Island, is located in one of the most seismically active regions of Canada. Vancouver Island has experienced two large historic earthquakes, in 1918 (M=7.0) and 1946 (M=7.3). The latter was the most damaging in western Canada and caused minor damage in the Victoria area (Hodgson, 1946; Wuorinen, 1974, 1976; Rogers, 1994). In addition, there is the potential for a very large (M~9) earthquake on the Cascadia subduction zone west of Vancouver Island (Rogers, 1988, 1994).

Because the effects of earthquakes vary considerably due to variations in local ground conditions, the British Columbia Geological Survey is preparing an earthquake hazard map of the area. The principal earthquake hazard here is the amplification of ground-motion that can occur at sites underlain by thick deposits of soft sediments.

Shear-wave velocity (Vs) data for unlithified deposits overlying bedrock are critical to the assessment of the ground-motion amplification hazard. For example, the National Earthquake Hazard Reduction Program (NEHRP) site classes for susceptibility to ground-motion amplification in the United States are defined primarily in terms of Vs (Table 1, Finn, 1996). In order to assess this hazard in the Greater Victoria area, a program was conducted to determine shear wave velocities in the principal Quaternary geologic units in the spring of 1996 (Figure 1). The objective of this paper is to present a Vs model of the Quaternary geologic units of the Victoria area based on this testing program.

An earthquake hazard map of the City of Victoria was prepared by Wuorinen (1974, 1976). His assessment was based on the distribution of the Quaternary deposits using a large volume of geotechnical testholes and also on the accounts of eyewitnesses to the 1946 Vancouver Island earthquake. Damage in Victoria was concentrated in low lying areas that are underlain by thick deposits of soft clay and organic soils, and the effects of the earthquake were the least where bedrock is close to the surface. The objectives of the current earthquake hazard mapping program are to extend the mapping throughout the Greater Victoria urban area and to assess the earthquake hazard in ways that were unavailable to Wuorinen, in particular by the application of shear-wave velocity data.

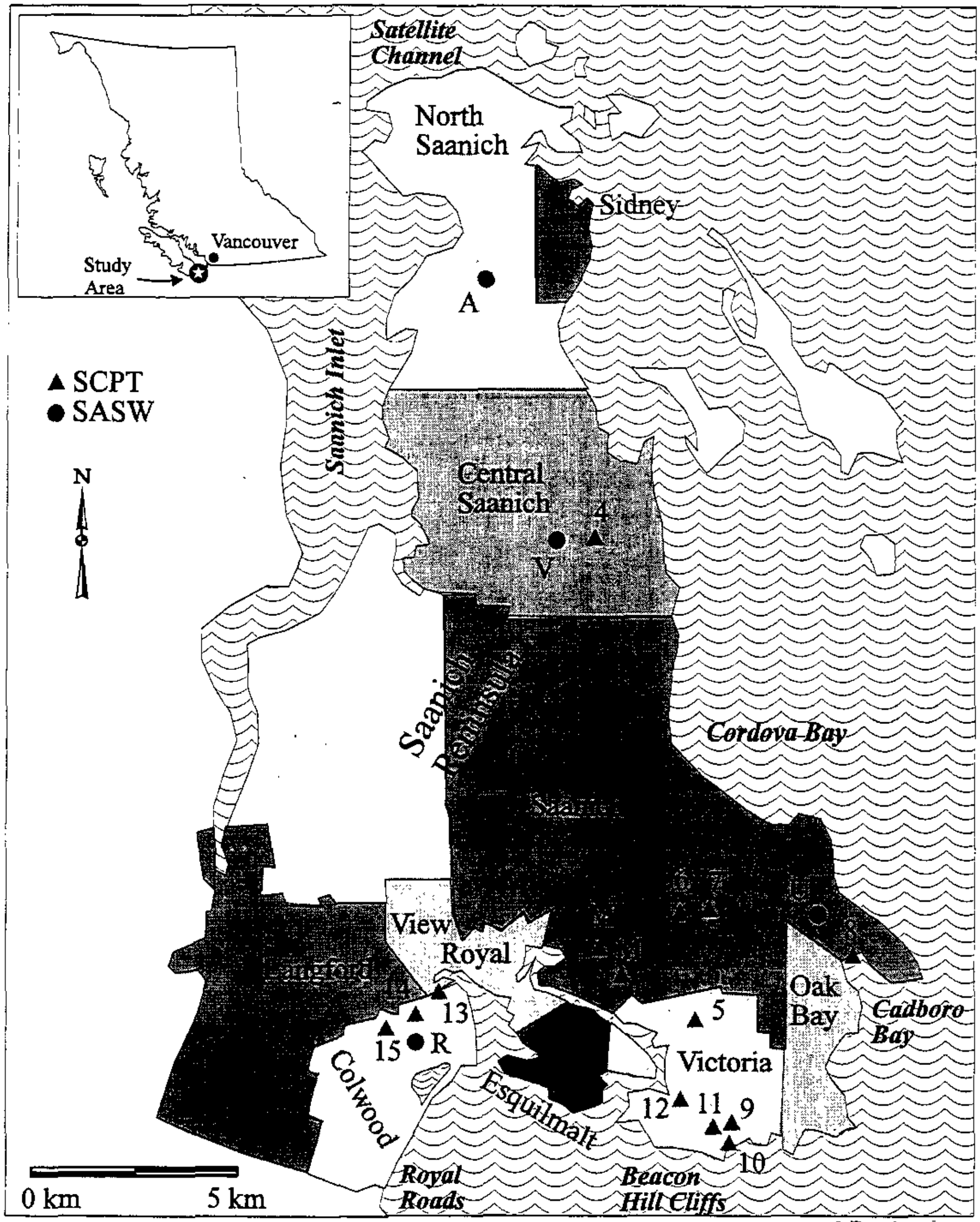

Figure 1. Map of the Greater Victoria area showing the location of the shear-wave test sites. The SCPT sites are numbered, see Table 3 for details. M indicates SCPTs provided by the Ministry of Transportation and Highways. The SASW sites are lettered: Site A is at Victoria Airport; V is on Veyaness Avenue; U is at the University of Victoria; and R is at Royal Roads University.

SITE AMPLIFICATION

The NEHRP site classes for amplification are defined primarily on the basis of the average shear-wave velocity in the upper 30 metres (V_{s30}), and are summarized in Table 1 (Finn, 1996; see that paper for complete descriptions). They range from "hard rock" and "rock" (Classes A and B respectively), in which V_{s30} exceeds 760 m/sec and which have no to very low susceptibility to amplification, to "soft soil" (Class E), in which V_{s30} is less than 180 m/sec and which has a high susceptibility to amplification. Site Class E also includes sites underlain by more than 3 metres of soft clay or silt, which is defined as having a plasticity index greater than 20%, a water content greater than 40% and an undrained shear strength less than 25 kPa. In terms of shear-wave velocity, soft clay has been defined as having a shear-wave velocity less than 150 m/sec (Seed *et al.*, 1992). A specific objective of the shear-wave testing program was to determine if the sites in Victoria that had experienced the strongest ground shaking during the 1946 earthquake meet the criteria for Class E.

TABLE 1. SITE CLASSES FOR SOIL SUSCEPTIBILITY TO AMPLIFICATION (SIMPLIFIED FROM FINN, 1993 AND 1996; KLOHN-CRIPPEN 1994; FOR FULL DESCRIPTIONS REFER TO FINN, 1996).

Site Class	General Description	average shear-wave velocity in upper 30 m (Vs30), m/sec	Susceptibility Rating
A	Hard rock	>1500	Nil
B	Rock	760 - 1500	Very Low
C	Very dense soil and soft rock	360 - 760	Low
D	Stiff soils	180 - 360	Moderate
E	Soft soils, or soil profile with >3 m soft silt and clay	< 180	High

The amount of ground-motion amplification varies with the intensity of ground-motion (Table 2). Where accelerations of 0.1 g occur on bedrock, accelerations on Class E sites can be amplified 2.5 times. Such was the case in the San Francisco Bay area during the 1989 Loma Prieta earthquake, which was nearly 100 km north of the epicentre. Accelerations there on bedrock sites were generally less than 0.1 g, whereas on nearby soft soil sites accelerations were amplified to 0.25 g and greater (Clough *et al.*, 1994). However, at higher accelerations, amplification factors diminish, such that at bedrock accelerations of 0.4 g there is generally little or no amplification on soft soil sites, because of the non linear behaviour of soils.

TABLE 2. AMPLIFICATION FACTORS (FINN, 1996)

Site Class	Peak surface horizontal firm ground acceleration				
	0.1 g	0.2 g	0.3 g	0.4 g	0.5 g
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	[illegible]	1
C	1.2	1.2	1.1	1	1
D	1.6	1.4	1.2	1.1	1
E	2.5	1.7	1.2	0.9	

Furthermore, the amplification of specific periods of ground motion due to resonance in the soil can be much greater than shown in Table 2 and can be particularly damaging to structures whose natural periods match those of the site (Rial, 1992; Reiter, 1990). The fundamental period (T) of a site (Finn 1994) can theoretically be calculated by:

$$T = 4H/V \qquad 1)$$

where:

H = thickness of the soil layer
V = average shear-wave velocity of the soil layer

Equation 1 is applicable to low strain ground motion, because Vs is a low strain property of soil. Site periods are greater for larger amplitudes of ground motion. Nonetheless, equation 1 provides a reasonable order of magnitude estimate for the site period that would occur during an earthquake.

The natural period of a building can be estimated in an approximate way by multiplying the number of stories by 0.1 second.

THE QUATERNARY GEOLOGY OF THE VICTORIA AREA (FIGURE 2)

The Quaternary deposits of the Greater Victoria area overlie a very irregular glacially-scoured bedrock surface. The depth to bedrock can vary from near surface to over 30 metres within the space of a city block (Crawford and Sutherland, 1969; Wuorinen, 1974, 1976; Nasmith and Buck, in press). Bedrock consists of high grade metamorphics throughout much of the area, with metavolcanics and intrusive rocks in the central and northern parts of the Saanich Peninsula, sedimentary rocks at the northern tip of the Saanich Peninsula, and volcanics in the Colwood area (Muller, 1983; Massey *et al.*, 1994).

Pleistocene deposits underlying the Vashon Till of the Late Wisconsinan Fraser Glaciation occur in the central and eastern parts of the Saanich Peninsula, where they have commonly been sculpted into a series of north trending drumlinoid ridges. These deposits are best known from the sea cliffs on the east side of the

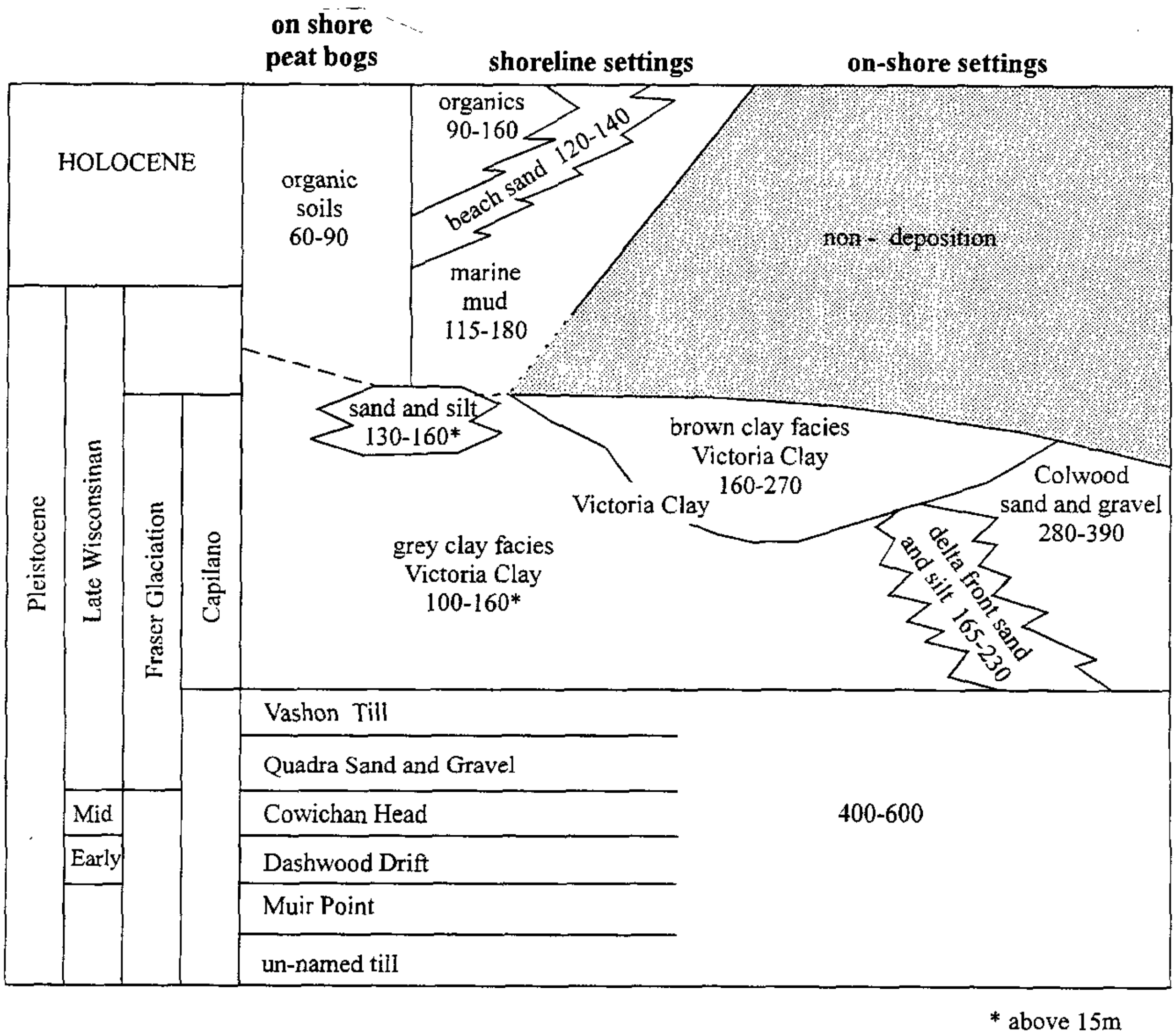

Figure 2. Table of Quaternary Formations in the Greater Victoria area showing general range of shear-wave velocities (approximately ± 1 standard deviation).

peninsula. The following units have been recognized, in ascending order: an undated till; interbedded sand and gravel of the non-glacial Pre-Wisconsinan Muir Point Formation; till and glaciomarine deposits assigned to the early Wisconsinan Dashwood Drift; sand, silt and gravel of the middle Wisconsinan non-glacial Cowichan Head Formation; and sand and gravel of the late Wisconsinan Quadra Formation, which has been interpreted as proglacial outwash from the advancing glaciers of the Fraser Glaciation (Clague, 1976, 1977; Alley, 1979; Howes and Nasmith, 1983; Hicock and Armstrong, 1983; and Nasmith, 1993, 1995; Bean and Buck, 1996; Nasmith and Buck, in press). The total thickness of these deposits locally exceeds 50 metres.

The Vashon Till of the late Wisconsinan Fraser Glaciation overlies the earlier Pleistocene deposits where they are present but overlies bedrock directly in much of the Greater Victoria area. It is a discontinuous unit, generally a few metres thick, but is locally up to 15 metres thick, as along the Beacon Hill sea cliffs (Hicock *et al.*, 1981; Nasmith and Buck, in press). In the following discussions, the Vashon Till and underlying Quaternary deposits are grouped together as "older Pleistocene deposits", because they have been glacially overriden, the shear-wave velocities are expected to be similar, and the internal stratigraphy of the package cannot be readily resolved with the techniques used here to obtain shear-wave velocities.

The Vashon Till is overlain by the Capilano Sediments, which were deposited at the close of the Fraser Glaciation when sea level was higher than present (Armstrong, 1981, 1984). Two principal units of the Capilano Sediments are represented in the Victoria area - the Victoria Clay and the Colwood Sand and Gravel. Shells in these units have provided several radiocarbon dates between 12,100 and 12,750 years B.P. (Dyck *et al.*, 1965, 1966). These deposits are equivalent to those of the Everson Interstade of Northwestern Washington (Easterbrook, 1992, Dethier et al., 1995).

The Victoria Clay is a unit of glaciomarine silt with scattered pebbles that forms a blanket-like deposit over the area below an elevation of 70 metres. It infills much

Figure 3. Drilling rig on site at SCPT 6, Saanich Public Works Yard. The data are recorded digitally in the truck to the right of the drilling rig.

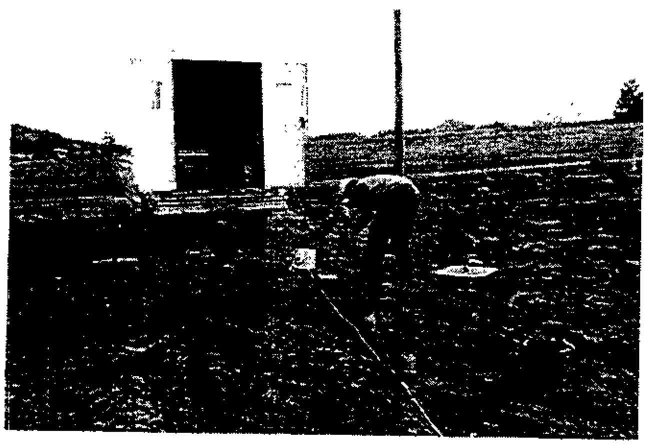

Figure 4. SASW test at site V, Veyaness Rd. Note the two geophones in the foreground beside the measuring tape that leads from the truck and the man striking a rubber plate with a sledge hammer.

of the pre-existing topography, and ranges in thickness from zero over bedrock knolls to over 30 metres in preexisting topographic depressions. The Victoria Clay has two distinct facies. A lower soft to firm grey clay infills low areas on the preexisting topographic surface and is called the grey clay facies in this paper. An upper desiccated and oxidized, stiff brown clay is up to 6 metres thick and is called the brown clay facies in this paper. The contact between the two facies is gradational. The two facies are distinguished on the basis of post depositional changes and they were not deposited in different depositional environments. The Victoria Clay commonly coarsens slightly upward, and is locally capped by sands that may represent shoreline and nearshore deposits formed as sea level fell following deglaciation (Crawford and Sutherland, 1971; Buchanan, 1993, 1995; Nasmith and Buck, in press).

The brown clay facies of Victoria Clay is at the surface in most of the Victoria area. However, in low lying areas, the Victoria Clay is commonly comprised entirely of the grey clay facies and is gradationally overlain by organic silts and peat up to 6 metres thick. The organic soils represent post glacial Pleistocene to Holocene lake and bog deposits and are referred to as Holocene organic soils in this paper (Dyck et al., 1966; Lowdon *et al.*, 1971; Nasmith and Buck, in press).

In shoreline settings, the brown clay facies extends below modern sea level, because sea level fell at least 10 metres below its modern position in the latest Pleistocene and earliest Holocene. In these settings, the brown clay facies is overlain by Holocene muds deposited during the mid to late Holocene rise in sea level (Mathews *et al.*, 1970; Crawford and Sutherland, 1971; Lowdon *et al.*, 1971; Hutchinson, 1992). Holocene muds are locally overlain by prograding shoreline sands derived from erosion of nearby sandy headlands and which are in turn locally overlain by peat. Shoreline peat deposits are locally overlain by intertidal sediments due to continued sea level rise during the Holocene as well as possible earthquake-related elevation changes (Clague, 1989; Clague and Bobrowsky, 1990; Bobrowsky and Clague, 1992; Mathewes and Clague, 1994).

The Colwood Sand and Gravel is a unit of outwash and deltaic sand and gravel deposited by a glacial outwash stream flowing south from Saanich Inlet. The surface of the outwash plain is at 75 metres elevation and has been incised by late stage channels that are partially infilled with peat (Blyth and Levson, 1993; Huntley, 1995; Yorath and Nasmith, 1995).

SHEAR-WAVE VELOCITY (VS) INVESTIGATIONS

Vs data for the principal Quaternary geological units were obtained by means of seismic cone penetration tests (SCPTs; Robertson et al, 1992) and spectral analysis of surface waves (SASW; Stokoe et al, 1994). The field work and data processing to generate the Vs profiles were conducted by ConeTec Investigations Ltd. of Vancouver.

A cone penetration test (CPT) is performed by pushing an instrumented cone-tipped rod into the ground at a constant rate using a modified drilling rig (Figure 3). A load cell at the tip records the resistance to penetration (tip resistance) and a friction sleeve above the tip records the frictional resistance of the sediment. A pore pressure element, usually located above the tip records the dynamic pore pressures during penetration. The parameters discussed in the following sections are the tip resistance, corrected for pore pressure effects (q_t), and the friction ratio (R_f), which is the ratio of the sleeve friction to q_t. In a SCPT, a geophone is added near the cone tip to record shear wave arrivals.

The SCPTs in this program were performed using a cone with a standard 10 cm^2 tip projection area, a 150 cm^2 friction sleeve, a pore pressure filter is located immediately behind the tip, and a geophone located 20 cm above the tip. The tip resistance, sleeve friction, and the dynamic pore pressure were recorded digitally every 5 cm. Shear waves were generated by using a sledge hammer to strike either a horizontal steel beam beneath the drill rig or an auger inserted into the ground. Shear wave arrivals were recorded every metre and interval

TABLE 3. SUMMARY OF SCPT DATA AND SITE PERIODS

SCPT	Location	Depth m	Vs average m/sec	Site period sec	Comments
4	Lochside Dr. at Island View Rd., Central Saanich	9.7	141	0.27	may overlie thick older Pleistocene; 5 m grey clay
5	Fifth St. at Vista Heights, Victoria	13.6	123	0.44	12 m grey clay
6	Public Works Yard, Saanich	29.8	141+	0.85+	no Vs recorded below 23.6 m; Vs average and site period minimum values; 24 m grey clay
7	Blenkinsop Rd. at McKenzie Ave., Saanich	4.05	136+	0.12+	refusal in rock fill ; Vs average and site period minimum values
8	Gyro Park, Saanich	41.8	166+	1.0+	Vs30=157 m/sec; did not reach refusal; Vs average and site period minimum values; 26+ m grey clay; Figure 8.
9	Brooke St. Park, Victoria	17.5	113	0.62	12 m grey clay; Figure 9.
10	Bushby St. Park, Victoria	16.35	124	0.54	14 m grey clay
11	Chapman-May Lane, Victoria	25.1	147	0.68	18 m grey clay; Figure 10.
12	Humboldt St., Victoria	13.45	175	0.31	4 m grey clay; Figure 11.
13	Old Island Highway, View Royal	6.45	262	0.1	Brown clay; Figure 12.
14	Wale Road, Colwood	12.55	199	0.25	Colwood delta front; Figure 7.
15	Aldeane Avenue, Colwood	9.15	313+	0.12+	did not encounter base of deposits; Vs average and site period minimum values; Colwood sand and gravel; Figure 6.
	Colquitz River Bridge 2655, Island Highway and Interurban Rd., Saanich	16.77	163	0.41	Data from MOTH; 10 m grey clay
	Colquitz River Bridge 2728, McKenzie Ave. and Interurban Rd., Saanich	15.15	176	0.34	Data from MOTH: 11 m grey clay

velocities calculated by subtraction of the arrival times between successive readings.

SCPTs were conducted at 12 sites (Figure 1, Table 3). They were pushed to refusal, indicating that either bedrock or dense soil such as till had been encountered, at all sites but one. In addition to those SCPTs conducted in this program, data from two SCPTs conducted by the Ministry of Transportation and Highways (MOTH) were used to develop the shear-wave velocity model.

SASW testing is a non-intrusive geophysical technique that uses the variation in the velocity of surface (Rayleigh) waves with depth to model the Vs profile of a site. The depth to which a surface wave penetrates is determined by its wavelength.

SASW tests were conducted at 4 sites, where the soils were considered to be too dense or too gravelly to be penetrated by a SCPT (Figure 1). Rayleigh waves were generated by hammer impacts on a metal or hard rubber plate, and were recorded by a pair of geophones spaced 1 to 10 metres apart and located up to 20 metres from the plate (Figure 4). The data were recorded digitally. In this program, the depth of investigation using the SASW method varied from 9 to 17 m.

At each site the lithology and the stratigraphy were interpreted on the basis of the SCPT data, the Vs profiles and data from nearby testholes. Average shear-wave velocities were then determined for each stratigraphic unit.

In uniform materials, V_S increases with increasing effective overburden stress (Robertson et al, 1991; Olsen, 1994) according the following expression:

$$V_{S1} = V_S \, (P_a / \sigma'_{vo})^{v} \qquad 2)$$

where:

V_{S1}= normalized shear-wave velocity
P_a = reference stress, normally atmospheric pressure
σ'_{vo}= effective vertical overburden stress, in the same units as P_a
v = shear-wave stress exponent

V_{S1} was calculated at atmospheric pressure, at a depth of approximately 10 metres. The shear-wave stress exponent, v, varies from approximately 0.5 to 0.1, decreasing with increasing grain size and degree of consolidation (Olsen, 1994). V_{S1} and v were calculated in the grey clay facies of the Victoria Clay , the sand and silt facies of the Victoria Clay, and the Holocene marine mud. Overburden stresses were estimated using an average unit weight of 17.5 to 18 kN/m^3, based on interpretations of the SCPT by ConeTec and using the CPT interpretation program CPTINT (Campanella, 1993).

At each SCPT site, the average shear-wave velocity was calculated and the fundamental site period was derived using this value in equation 1.

RESULTS

The location, average shear-wave velocity, fundamental site period and thickness of the grey clay facies at each SCPT site are summarized in Table 3. At 3 sites, the calculated average shear-wave velocity and site period are minimum values because the thickness of the soil column is unknown: at SCPT 8, where the cone was pushed to a depth of 41.8 metres without meeting refusal; at SCPT 7, where the cone met refusal at 4 metres within probable rock fill (C.N. Ryzuk, personal communication); and at SCPT 15, where the cone was pushed to refusal at a depth of 9.15 metres within a sequence of dense sands and gravels. The calculated average shear-wave velocity and site period are also probably minimum values at SCPT 6, where Vs was not recorded in the lower part of the section. The Vs characteristics (average, average ± 1 standard deviation, minimum, and maximum) for the various Quaternary geological units investigated are summarized in Table 4, shown on Fig 2, and described in more detail below.

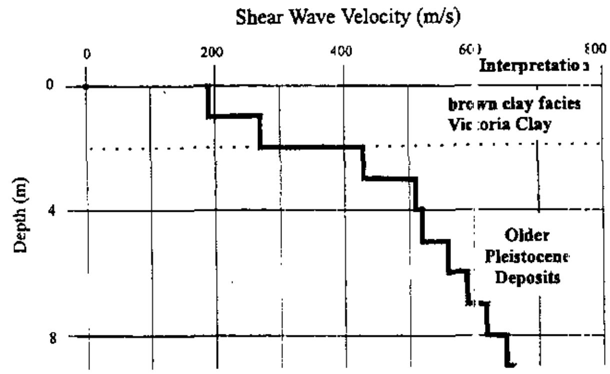

Figure 5. Shear-wave velocity profile at SASW site V, Veyaness Avenue, with stratigraphic interpretation. At this site older Pleistocene deposits are interpreted to underlie the brown clay facies of the Victoria Clay.

OLDER PLEISTOCENE DEPOSITS

Older Pleistocene deposits are inferred to be present at three SASW sites (Sites A, V and U, Figure 1) , where high velocity sediments occur beneath an abrupt Vs increase and are overlain by a thin low velocity surficial layer 2 to 4 metres thick (Figure 5). The latter is interpreted to be the brown clay facies of the Victoria Clay on the basis of Vs data. Vs in deposits interpreted to be the older Pleistocene deposits averages 500 m/sec and is generally between 420 to 580 m/sec. These values cover a considerable range, probably due to the variety of older Pleistocene units in the area, including glaciofluvial sands and gravels, till, and glaciomarine silts and clays.

CAPILANO DEPOSITS

DEPOSITS OF THE COLWOOD DELTA

Deposits of the Colwood Delta occur at three sites - at two sites on the level surface of the delta plain and at a

TABLE 4. V_S SUMMARY BY GEOLOGICAL UNIT

Stratigraphic unit	number of sites	number of values	Vs average m/sec	Vs av ± 1 SD m/sec	Vs min m/sec	Vs max m/sec
Artificial Fill	3	4	130	111-149	102	143
Holocene organic soils	3	9	85	52-113	40	164
Holocene beach Sand	1	4	131	122-140	120	140
Holocene marine mud	2	4	147	121-173	117	1[illegible]8
Victoria sand and silt	2	7	165	131-199	126	217
Victoria brown clay	8	28	213	164-262	121	298
Victoria grey clay	10	126	147	114-180	89	2[illegible]9
Victoria grey clay <15 m depth	9	69	132	104-160	89	214
Colwood delta top	2	15	335	282-388	225	4[illegible]5
Colwood delta front	1	10	199	165-233	133	2[illegible]7
Older Pleistocene	3	17	499	420-577	350	650

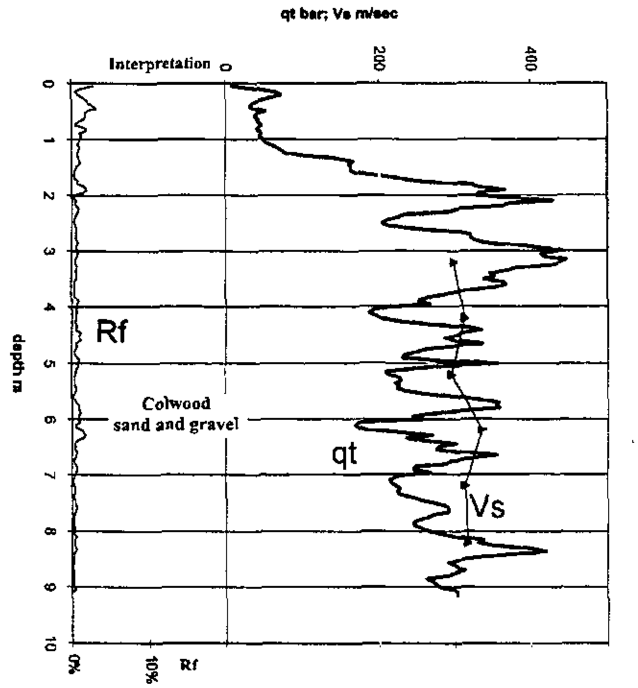

Figure 6. SCPT 15 Aldeane Avenue, Colwood, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio.

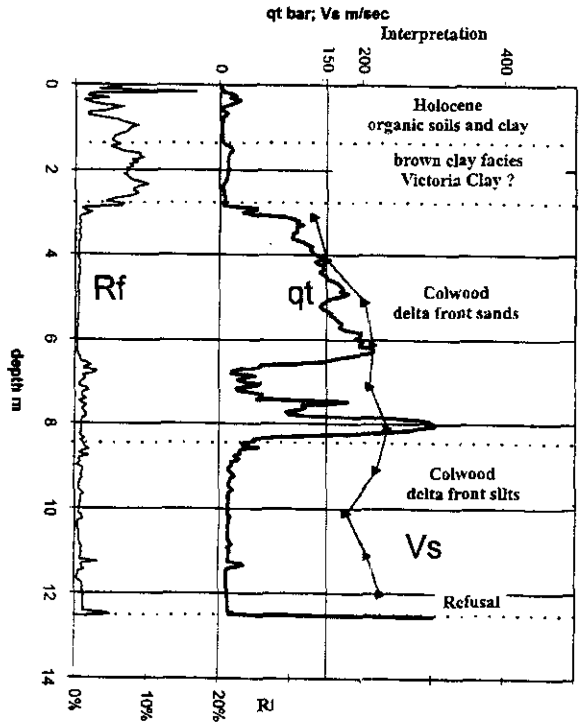

Figure 7. SCPT 14, Wale Road, Colwood, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio.

third on the north slope of the delta. Those on the delta plain include SCPT 15, where the deposits consist of 9 metres of dense sand and gravel (Figure 6), and SASW site R (Figure 1). There, Vs averages 335 m/sec and is generally 282 and 388 m/sec. At SCPT 14, on the north delta slope on Wale Road in Colwood, a section consisting of 4 metres of sandy silt overlain by 5 metres of sand is interpreted to be a delta front deposit (Figure 7). The sand is sharply overlain by 3 metres of silt and organics that includes the brown clay facies of the Victoria Clay as well as Holocene deposits. In the delta front deposits at this site, Vs averages 199 m/sec and is generally 165 and 233 m/sec).

GREY CLAY FACIES OF THE VICTORIA CLAY

Deposits of the grey clay facies occur at 10 sites, where they range from 4 metres to greater than 26 metres in thickness. These deposits are characterized by very low tip resistance, generally 5 bars or less at a depth of 5 metres and increasing linearly with depth in response to increasing effective overburden stress (Figures 8, 9, 10 and 11; see Robertson, 1990; Olsen, 1994). The deepest tip resistance measurements in this facies are greater than 18 bars at a depth of greater than 41 metres. The base of the grey clay facies is marked by refusal on the SCPTs, indicating the presence of older overconsolidated Pleistocene sediments or bedrock. The grey clay facies is gradationally overlain by either the brown clay facies of the Victoria Clay, which is characterized by higher tip resistance (Figure 11), or in low lying areas by Holocene organic silts and peats, which are characterized by higher friction ratio values (Figure 9). Locally, an interval of

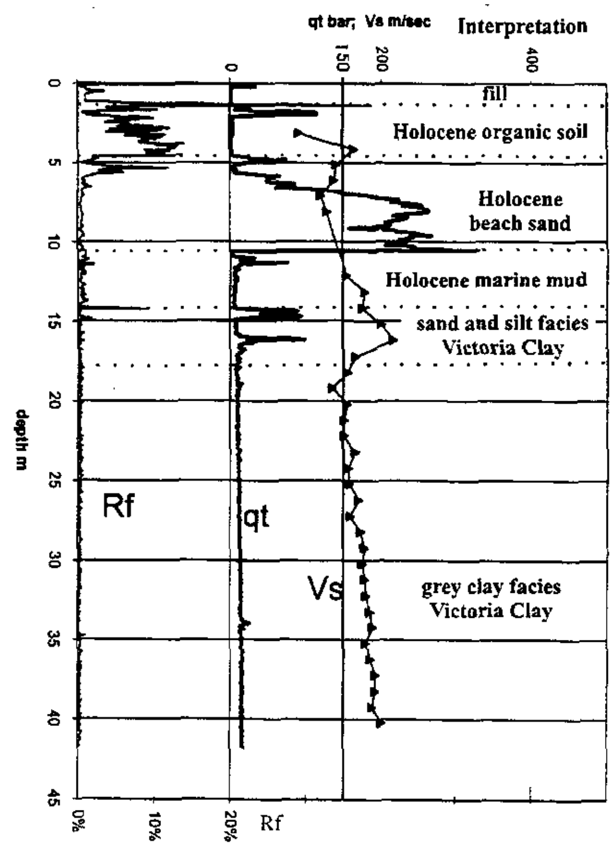

Figure 8. SCPT 8, Gyro Park, Saanich, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio.

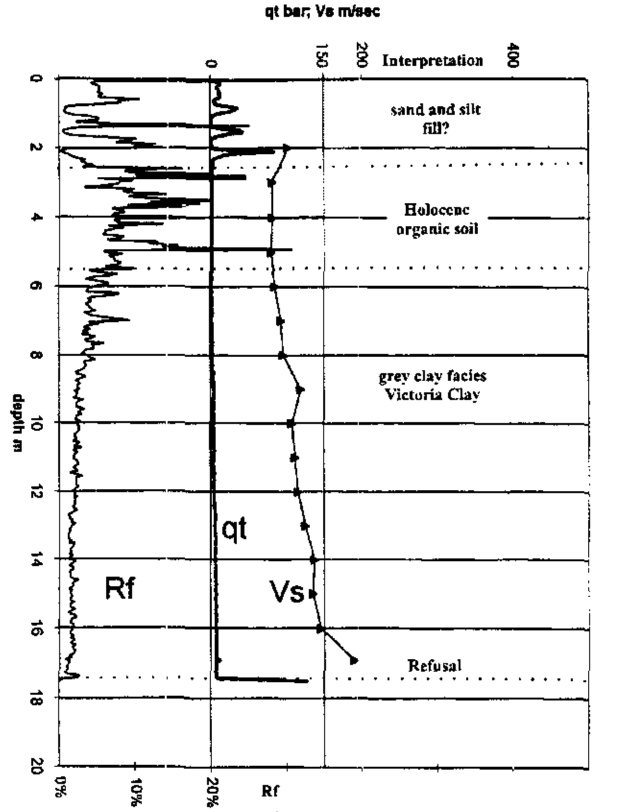

Figure 9. SCPT 9, Brooke Street Park, Victoria, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio. Note the low tip resistance and high friction ratios in the Holocene organic soils; the increase in Vs with depth in the grey clay facies; and the presence of sandy clay at the base of the grey clay indicated by slightly higher tip resistance and higher Vs.

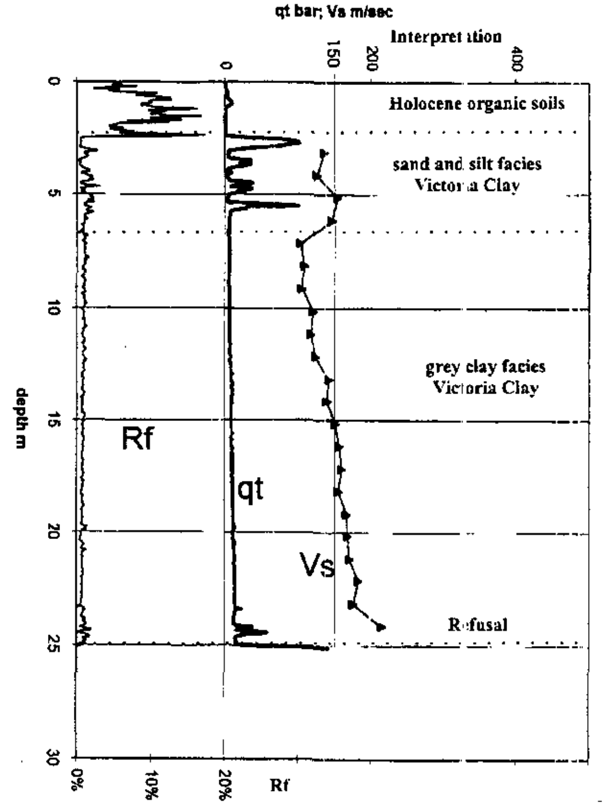

Figure 10. SCPT 10, Chapman-May Lane, Victoria, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio. Note the low tip resistance and high friction ratios in the Holocene organic soils; the increase in Vs with depth in the grey clay facies; and the presence of sandy clay at the base of the grey clay indicated by higher tip resistance and higher Vs.

interbedded sand and silt occurs at the top of the grey clay facies (Figures 8 and 10); this sand and silt unit is discussed separately below.

In the grey clay facies, Vs averages 147 m/sec and is generally between 114 and 180 m/sec. Above average Vs values occur near the contact with the overlying brown clay facies and in sandy intervals, which commonly occur near the base (Figures 9 and 10) and less commonly throughout the grey clay unit. Where the grey clay facies is thicker than 12 metres or where it is not overlain by the brown clay facies, Vs also increases with depth in response to increased overburden stress, so that at depths of over 40 metres Vs exceeds 200 m/sec (Fig 8,9 and 10). However, within 15 metres of the ground surface, where most deposits of the grey clay occur, Vs averages 132 m/sec and is generally between 104 and 160 m/sec. Interestingly, the increase of Vs with depth is not generally evident in sections of grey clay that are thinner than 12 metres and are overlain by the brown clay facies.

In order for future workers to predict Vs for grey clay in very thick sections beyond the depths investigated in this study, the normalized shear-wave velocity (V_{S1}; Vs at 1 atmosphere or ~10 metres) and the shear-wave stress exponent, v, were calculated from equation 2 at 4 sites where Vs increases with depth. At those sites, V_{S1} averages 127 m/sec (119 to 139 m/sec range), and v averages 0.52 (0.40 to 0.58 range).

BROWN CLAY FACIES OF THE VICTORIA CLAY

Deposits of the brown clay facies, 2 to 6 metres thick, occur at 5 SCPTs and 3 SASW sites. These deposits are distinguished from the underlying grey clay facies by higher tip resistance values, generally between 20 and 40 bars, and higher friction ratio values. Higher friction ratios in clays are indicative of overconsolidation (Robertson, 1990), which in this case is an apparent overconsolidation due to desiccation. In these deposits, Vs averages 213 m/sec and is generally between 160 and 270 m/sec. A typical expression is shown in Figure 12, where the deposits are 6 metres thick and overlie bedrock or till. This unit extends below sea level in shoreline settings. At SCPT 12 (Figure 11), for example, the brown clay facies gradationally overlies the grey clay facies and is in turn gradationally overlain by Holocene marine mud and fill for the Empress Hotel (Crawford and Sutherland, 1971). At this site, the elevated Vs resulting from early Holocene desiccation has survived resubmergence during the mid to late Holocene marine transgression. At the SASW sites, the brown clay facies was interpreted to be present in those intervals with Vs

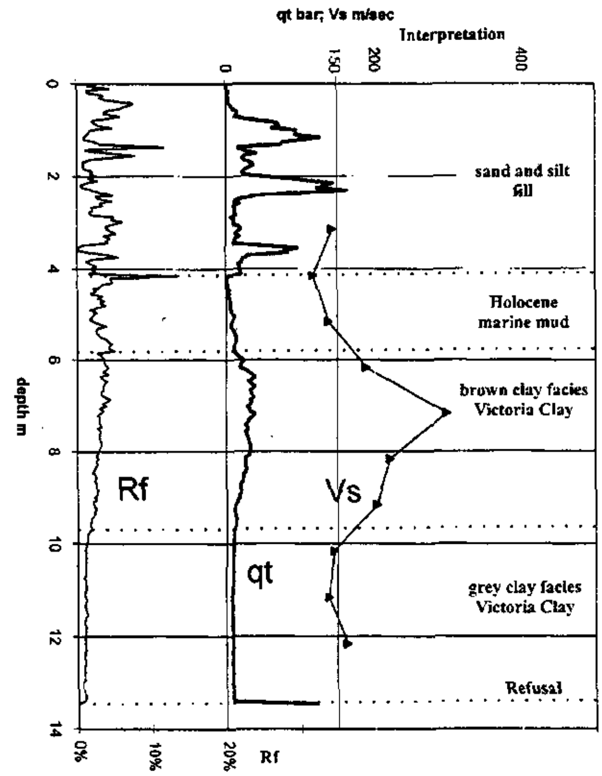

Figure 11. SCPT 12, Humboldt Street, Victoria, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio. Note the higher Vs, tip resistance, and friction ratio values in the brown clay facies than in the grey clay facies.

values similar to those in the brown clay facies in the SCPTs. Nearby boreholes support these interpretations.

SAND AND SILT FACIES OF THE VICTORIA CLAY

Interbedded sands and silts are present at two sites above deposits of the grey clay facies. These sediments are interpreted to have been deposited in a nearshore setting as sea level dropped following deglaciation. At SCPT 11 the sands are silts are overlain by Holocene organic soils (Figure 10) and at SCPT 8, they are overlain by muds interpreted to be Holocene marine deposits (Figure 8). At the latter site, the sand and silt facies has been observed in core, where it contains a shelly marine fauna (Bobrowsky and Clague, 1992), and may include sediments deposited during the early Holocene transgression.

In sand and silt facies, Vs averages 165 m/sec and is generally between 131 and 199 m/sec. However, these deposits are 10 metres deeper at one site than at the other, and Vs values average 140 m/sec at the site where the unit occurs at a depth of 5 metres (SCPT 11). Vs normalized for effective overburden stress (V_{S1}) using a shear-wave stress exponent of 0.25 in equation 2, typical for normally consolidated sands (Olsen, 1994), has a much narrower range, demonstrating that the sediments are similar at both sites: V_{S1} averages 179 m/sec and is generally between 165 and 193 m/sec. The Vs characteristics of this facies presented here are based on data from only two sites. At other sites, where thicker sands occur, Vs could be higher.

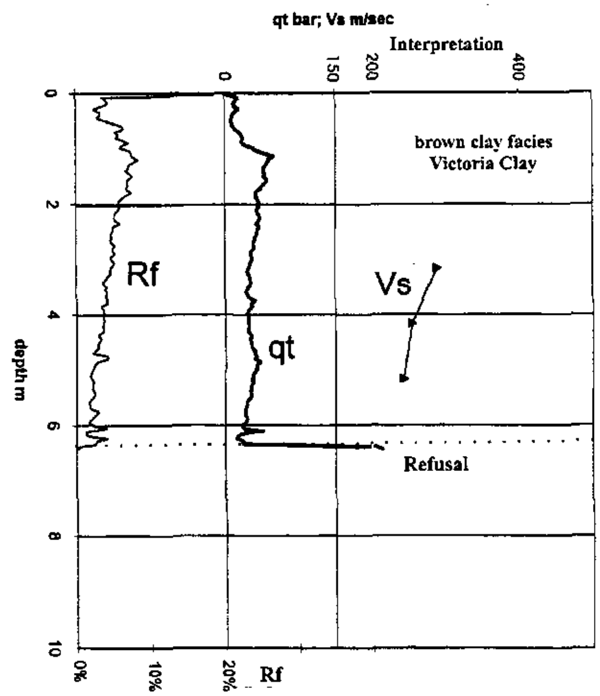

Figure 12. SCPT 13, Old Island Highway, View Royal, with stratigraphic interpretation. SCPT parameters: Vs= shear-wave velocity; qt=tip resistance; and Rf = friction ratio. Note the high Vs, tip resistance, and friction ratio values in the brown clay facies compared to the grey clay facies in Figures 8 to 11.

HOLOCENE DEPOSITS

HOLOCENE ORGANIC SOILS

Deposits of organic silt and peat that represent Holocene bog deposits occur at four sites, where they are distinguished by low tip resistance values and high friction ratios. These sites are in low lying areas that were swamps and bogs in historic times. At two sites, SCPT 6 and SCPT 9 (Figure 9), the organic deposits gradationally overlie the grey clay facies, and at SCPT 11 (Figure 10) they overlie the sand and silt facies of the Victoria Clay that in turn overlies the grey clay facies. At the fourth site, SCPT 8 (Figure 8) the organic deposits overlie Holocene beach sand (Bobrowsky and Clague, 1992). All the Vs measurements in this unit were taken at depths between 3 and 6 metres; in these deposits, Vs averages 85 m/sec and is generally between 52 and 113 m/sec. The range is skewed by one high value of 164 m/sec at SCPT 8 . Excluding this value, Vs averages 75 m/sec and is generally between 59 and 91 m/sec.

HOLOCENE MARINE MUD

Deposits interpreted to be Holocene marine muds are present in two sites in nearshore settings. These deposits are characterized by an interval with low tip resistance, generally 2 to 10 bars, occurring between the sand and silt facies of the Victoria Clay and Holocene beach sand at SCPT 8 (Figure 8), and between the brown clay facies and artificial fill at SCPT 12 (Figure 11; Crawford and Sutherland, 1971). The latter site is adjacent to the Empress Hotel, where radiocarbon dating has confirmed the Holocene age of this unit (Lowdon *et al.*, 1971). Vs averages 147 m/sec and is generally between 121 and 173 m/sec. However, these deposits are 10 metres deeper at one site than at the other, and Vs values average 127 m/sec at the site where the unit occurs at a depth of 4 to 5 metres. Vs normalized for effective overburden stress (V_{S1}) using a shear-wave stress exponent of 0.5 in equation 2, typical for normally consolidated sits and clays (Olsen, 1994), has a much narrower range: V_{S1} averages 150 m/sec and is generally between 139 and 161 m/sec.

HOLOCENE BEACH SAND

Holocene beach sand occurs at SCPT 8, where it overlies Holocene marine muds and is overlain by Holocene peat (Figure 8). Tip resistance is generally high in this unit, exceeding 200 bars, although lower values occur at the top. Vs averages 131 m/sec and ranges between 120 and 140 m/sec. These values are low for Holocene sands, and may not be representative of beach deposits elsewhere.

ARTIFICIAL FILL

Artificial fill occurs at three sites. In two cases the unit is characterized by interbedded sand and silt; at SCPT 12, the sand and silt fill occurs above Holocene marine mud and is well known to be fill (Fig 11; Crawford and Sutherland, 1971), and at SCPT 9, the sand and silt is inferred to be fill based on its position above Holocene organic soils (Figure 9). At SCPT 7, the fill consists of 4 metres of silty sand at a site where fill was known to have been placed (C.N. Ryzuk, personal communication). Vs in fill averages 130 m/sec and ranges between 102 and 143 m/sec.

DISCUSSION

Shear-wave velocities in Quaternary deposits of the Victoria area cover a wide range of values. Where sufficiently thick, the older Pleistocene deposits meet the criteria for NEHRP Site Class C and have low susceptibility to amplification, and the deposits of the Colwood delta meet the criteria for Class D, susceptible to moderate amplification (Table 1).

Where present, sites underlain by the grey clay facies of the Victoria Clay potentially meet the criteria for Site Class E, *susceptible to high amplification*. At SCPT 8 (Figure 8;, Table 3), the V_{s30} is 157 m/sec, within the range defined for this site class. Site Class E also includes sites with more than 3 metres of soft silt and clay, which is defined as having a plasticity index greater than 20%, a water content greater than 40%, an undrained shear strength less than 25 kPa, and a shear-wave velocity less than 150 m/sec (Seed *et al.*, 1992; Finn 1996). Vs in the grey clay facies is generally below 150 m/sec (Figures 8, 9, 10, 11), so that sites with greater than 3 metres of this facies are potentially in this site class, both where the overlying brown clay facies is present and where it is absent. The principal exceptions to this generalization are sandy intervals in the grey clay, that can be identified by higher than average tip resistance, and reduce the total thickness of soft silt and clay to less than 3 metres.

A preliminary review of other geotechnical data obtained for the earthquake hazard mapping program indicates that the grey clay facies commonly, but not always, meets the plasticity, water content, and undrained shear strength criteria for soft silt and clay. Vs does not increase with depth in the grey clay facies where it is less than 12 metres thick and overlain by the brown clay facies, likely due to a greater degree of consolidation (probably caused by partial desiccation) in the upper part of the grey clay facies compared to where it is overlain by Holocene organic soils. Nasmith and Buck (in press) report that the grey clay is slightly overconsolidated where overlain by the brown clay facies but normally consolidated where overlain by Holocene organic soils. These observations suggest that a greater thickness of grey clay is required to meet the criteria for Site Class E where the grey clay is overlain by brown clay than where it is overlain by Holocene organic soils.

Holocene marine muds and organic rich silts and peat overlying the grey clay facies can potentially add to the thickness of soft silt and clay to meet the criteria for Site Class E, although the contribution of peat to site amplification requires additional study (Klohn-Crippen, 1994; Finn, 1996). More importantly for regional mapping, where the grey clay is overlain by Holocene organic soils, not only is the grey clay facies likely to be thick, but more of the grey clay facies is likely to meet all the criteria for Site Class E. In the Victoria area, the 1946 Vancouver Island earthquake was felt most strongly in those areas underlain by thick accumulations of grey clay, capped by either Holocene organic soils or shoreline fill (Figs 9, 11; Hodgson, 1946; Wuorinen, 1974, 1976). Although the site shown in Fig 11 marginally meets the criteria for Site Class E, the grey clay facies thickens to over 20 metres less than 100 metres to the west, where the criteria for site class E are potentially met.

The average shear-wave velocity and site period calculated for the grey clay sites that reached refusal (Table 3) are minimum values and may be increased by an undefined thickness of till or other older Pleistocene deposits below the base of the test. However, this effect is likely to be small: the older deposits are generally thin and the largest Vs contrast in most cases occurs at the contact between the grey clay and underlying materials. Due to the extreme irregularity of the bedrock surface, site periods must vary considerably in the Victoria area, even within a city block. However, the calculated site periods at the grey clay sites are between 0.27 and 1 second, indicating that amplification due to resonance is likely to occur at ground motion periods generally less than 1 second in the low-lying areas underlain by grey clay in the Victoria area, within the natural period of many buildings.

Holocene and late glacial sandy deposits have low Vs values and would contribute to a low V_{s30} for a site, but not to the total thickness of soft silt. At sites where only the brown clay is present, it is likely to be less than 6 metres thick and the site effect will be dominated primarily by the underlying deposits.

CONCLUSIONS

A shear-wave velocity testing program in the Greater Victoria area based on SCPT and SASW tests has provided the basic data for a shear-wave velocity model, required to assess the amplification of ground-motion hazard due to earthquakes. This model provides the basis for mapping the amplification of ground-motion hazard on a regional scale and for estimating the fundamental period at sites where the stratigraphy is known.

Till of the Fraser Glaciation and earlier Pleistocene deposits have shear-wave velocities generally in the range of 400 to 600 m/sec and have low susceptibility to amplification. Late glacial sands and gravels of the Colwood delta have shear-wave velocities generally in the range of 300-400 m/sec and sites underlain by a sufficient thickness of these deposits are susceptible to moderate amplification.

Within 15 metres of the surface, the grey clay facies of the late glacial glaciomarine Victoria Clay has shear-wave velocities generally between 100 and 160 m/sec, and sites underlain by more than 3 metres of these deposits are potentially susceptible to high ground-motion amplification. This is particularly true where they are overlain by Holocene organic sediments or marine muds, in which shear-wave velocities average 85 and 147 m/sec respectively. These Holocene deposits may contribute to the total thickness of soft silts, and the presence of organic sediments indicates that the underlying grey clay facies has been subjected to less consolidation than where it is overlain by the brown clay facies. These conclusions are consistent with those of Wuorinen (1974, 1976), who showed that the highest ground shaking during the 1946 earthquake occurred in former swamps, in which organic deposits overlie thick accumulations of the grey clay.

The fundamental site periods for sites underlain by grey clay at the sites investigated in this program range between 0.27 and 1 second, so that amplification due to resonance is likely to occur at ground motion periods generally less than 1 second in the low lying areas underlain by the grey clay facies in the Victoria area.

The brown clay facies of the Victoria Clay has shear-wave velocities generally in the range of 160 to 270 m/sec; however, these deposits are thin and the site effects will be primarily controlled by the underlying deposits.

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