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Cover illustration

Looking southeast at an approximately 35 m thick flow of columnar basalt of probable Miocene age near Natuza Lake of the Interior Plateau of central British Columbia. The flow was open to the north where columns curve to a subhorizontal position. The aphanitic basalt is part of Neogene volcanic centres and flows throughout the central and southern interior of the Canadian Cordillera. *See* paper by Struik et al., this volume. Photograph by L.C. Struik. GSC 1998-068

Photo en page couverture

Vue vers le sud-est d'une coulée de basaltes prismés qui remonte vraisemblablement au Miocène. La coulée se trouve vers près du lac Natuza, dans le plateau de l'intérieur de la Colombie-Britannique centrale. Au nord, les prismes s'incurvent pour atteindre une position subhorizontale. Le basalte aphanitique fait partie de coulées et centres volcaniques néogènes que l'on retrouve partout dans la partie intérieure centrale et méridionale de la Cordillère du Canada. Voir l'article de Struik et al. dans le présent volume. Photo : L.C. Struik. GSC 1998-068

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INTERIOR PLAINS AND ARCTIC CANADA PLAINES INTÉRIEURES ET RÉGION ARCTIQUE DU CANADA

Early Miocene or younger normal faults and other Tertiary structures in west Nass River map area, northwest British Columbia, and adjacent parts of Alaska

C.A. Evenchick, M.L. Crawford[1], V.J. McNicoll[2], L.D. Currie[3], and P.B. O'Sullivan[4]
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Evenchick, C.A., Crawford, M.L., McNicoll, V.J., Currie, L.D., and O'Sullivan, P.B., 1999: Early Miocene or younger normal faults and other Tertiary structures in west Nass River map area, northwest British Columbia, and adjacent parts of Alaska; in *Current Research 1999-A; Geological Survey of Canada, p. 1–11.*

Abstract: Steeply dipping brittle faults which strike 350° cut early Tertiary and older rocks in the Coast Belt along, east of, and west of Portland Canal. The Big Dam Fault is a west-side-down brittle fault zone 2 km wide which cuts ca. 61–53 Ma granite. The Portland Canal Fault is interpreted to have east-side-down displacement postdating 22 Ma, and possibly 5 Ma. Parallel faults in early Tertiary granite between northerly projections of the two faults are steeply east and west dipping, and extensional in nature. The Big Dam and Portland Canal faults are assumed to be related to the other faults of similar character postdating the early Tertiary, and therefore extensional. The presence of these faults has implications for interpretation of ACCRETE seismic data, which were acquired in Portland Canal, along a transect which is coplanar with the Portland Canal Fault for a distance of 20–50 km.

Résumé : Des failles ductiles à fort pendage, orientées vers 350°, recoupent des roches du Tertiaire précoce et d'âge plus ancien dans le Domaine côtier le long du chenal Portland et à l'est et à l'ouest de cette dernière. La faille de Big Dam correspond à une zone de failles cassantes à compartiment de gauche abaissé de 2 km de largeur qui recoupe du granite d'environ 61 à 53 Ma. Le compartiment de droite de la faille de Portland aurait été abaissé après 22 Ma et possiblement 5 Ma. Des failles parallèles observées dans du granite du Tertiaire précoce entre les prolongements nord de ces deux failles montrent un fort pendage vers l'est et l'ouest et sont des failles de distension. Les failles de Big Dam et de Portland Canal seraient apparentées aux autres failles postérieures au Tertiaire précoce qui sont de nature similaire et donc des failles de distension. La présence de ces dernières influe sur l'interprétation des données sismiques ACCRETE, qui ont été prélevées dans le chenal Portland le long d'un transect qui se trouve dans le même plan que la faille de Portland Canal sur une distance de 20 à 50 km.

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INTRODUCTION

Previous work in the vicinity of Observatory Inlet and Portland Canal showed that the Big Dam Fault, a brittle fault striking 350°, cuts early Tertiary rock units, and it was suggested that lineaments with similar trend (i.e. Hastings Arm, Portland Canal), are also the sites of Tertiary, and possibly late Tertiary or Quaternary faults (Evenchick et al., 1997; Evenchick and Holm, 1997). The previous mapping also identified volcanic rocks assumed to be of Tertiary age capping a peak of Tertiary granite east of Portland Canal (Evenchick et al., 1997). This paper presents preliminary results of more recent geochronological, structural, and uplift studies. These studies elucidate the nature and age of what is now considered to be a widespread suite of Miocene or younger brittle faults which accommodated roughly east-west extension. The faults are a primary control on geomorphology. Many of the observations and measurements of mesoscopic faults and related features presented below were made either in the course of regional mapping or during reconnaissance of regional features. The purpose of this paper is not to present a detailed structural analysis, but rather to highlight the presence of a suite of faults not previously recognized.

This work is part of a multiyear regional study of the geological framework of Nass River (NTS 103 P) area (*see* Evenchick and Mustard, 1996). In 1998 efforts were focused on stratigraphy and structure of the Georgie River area (Evenchick and Snyder, 1999), and on mapping the region between Anyox pendant and Georgie River area, with emphasis on analysis of structures (presented herein). The work is also part of the ACCRETE project funded by the Continental Dynamics Program of the U.S. National Science Foundation. A main focus of the ACCRETE project was a co-ordinated seismic and geological study along Portland Inlet and Portland Canal to investigate the structure of the crust across the Coast Mountains orogen east and west of Ketchikan, Alaska and Prince Rupert, British Columbia.

Regional geology and previous work

An overview of the regional geology and previous work in Nass River area is presented in Evenchick and Mustard (1996). Most bedrock can be assigned to one of three broad groups (Fig. 1), Triassic and Lower to Middle Jurassic rocks of Stikinia; Middle Jurassic to Lower Cretaceous rocks of the Bowser Basin; and Mesozoic and Cenozoic granitoid rocks of the Coast Belt. Minor constituents are Cretaceous rocks of the Skeena Group, upper Tertiary and Quaternary volcanic rocks, and metamorphic rocks of unknown age.

Previous regional mapping in western Nass River area was by Carter and Grove (1972) and Grove (1986). That reconnaissance mapping focused on Stikinia west of the Bowser Basin; Tertiary intrusive rocks received subordinate attention. Some plutonic rocks were studied by Carter (1981) in a regional analysis of porphyry Cu and Mo deposits. Twenty K-Ar age determinations in and around these Cu and Mo deposits in Nass River area range from 55–49 Ma (Carter, 1981; recalculated using decay constants of Steiger and Jäger, 1977). Cataclastic zones within pendant rocks were

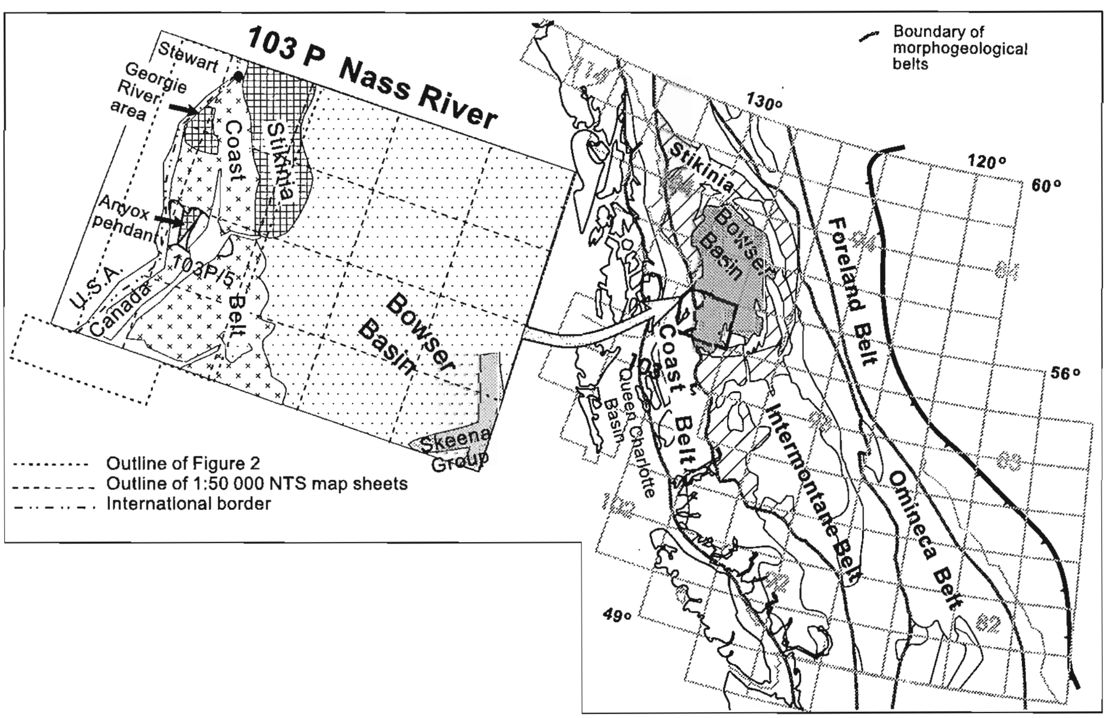

Figure 1. Location of Nass River (NTS 103 P) map area and its major geological elements. Areas discussed in report are outlined in inset.

recognized in reconnaissance mapping (Carter and Grove, 1972; Grove, 1986), but were considered to be Jurassic. Sharp (1980) studied the Anyox mining camp in east-central Anyox pendant and delineated units and structures, including the northern part of the Big Dam Fault.

ROCKS, GEOCHRONOLOGY, STRUCTURES, AND UPLIFT HISTORY

Most of the information that bears on this interpretation of Tertiary faults is from Tertiary rocks. Although brittle and brittle to ductile structures occur in older rocks of the Georgie River area and Anyox pendant (Fig. 2), many of them are probably pre-Tertiary. A focus on structures in Tertiary rocks ensures that the structures are Tertiary or younger. Uranium-lead and $^{40}Ar/^{39}Ar$ ages of Tertiary plutons, dykes, and stratified rocks more closely constrain the ages of different features; studies of uplift history from fission tracks may provide additional constraints.

Early Tertiary rocks

Granitic rock

Granitic rocks are dominantly granite, with lesser quartz monzonite to quartz monzodiorite. They are white to cream and light grey weathering, leucocratic, and commonly have 5–15% fresh biotite and/or hornblende. Garnet, and locally muscovite, occur in mafic-poor varieties in the vicinity of Anyox pendant. Texture varies from equigranular to K-feldspar megacrystic. Xenoliths of more mafic granitoid rocks are uncommon, but in western Alice Arm they form 10–20% of the rock. Xenoliths of metamorphic rock are rare. At least 98% of granitic rock shown in Figure 2 is unfoliated; with the exception of the brittle structures described below, it is monotonous massive rock. Several phases of subtly different Tertiary plutonic rocks could be distinguished with more detailed study of the region around, east of, and south of, Anyox pendant. The area between Anyox pendant and Georgie River area, however, is underlain by remarkably homogeneous, medium-grained, equigranular, biotite-hornblende granite with euhedral sphene up to 3 mm across. Contacts with country rocks are sharp, and in most places country rocks are intensely deformed in a zone up to 1 km surrounding the plutonic rocks. The contact aureole contains andalusite, cordierite, and biotite.

Preliminary U-Pb dates on five samples of the granitic rock from the east shore of Observatory Inlet and immediately south of Anyox pendant range in age from 61 to 53 Ma (Fig. 2; V. McNicoll, unpub. data, 1998). These dates confirm the Tertiary age reported by Carter (1981), but indicate a wider range of somewhat older ages.

Two ages from plutonic rock on the west shore of Portland Canal, west of Anyox pendant, are 53.3 ± 1.0 and 51.7 ± 1.0 Ma (G. Gehrels, pers. comm., 1998), but the extent of Tertiary rock west of Portland Canal is poorly known.

Dykes

The two most common varieties of dykes in west Nass River area are parallel with the dominant regional joint and lineament trends (Fig. 3). Gabbro or diorite is the predominant dyke rock and is common throughout the region; lamprophyre dykes are rare. The mafic dykes are dark grey, green, and brown weathering, aphanitic to coarse grained, equigranular or porphyritic, and massive. They commonly dip steeply to the northwest or southeast (Fig. 3), and are typically 10 cm to several metres wide, although they range from less than a centimetre to about 10 m wide. Preliminary $^{40}Ar/^{39}Ar$ ages (hornblende) on two of these dykes are ca. 39-38 Ma; a U-Pb age of ca. 38.5 Ma was obtained for a third mafic dyke (V. McNicoll, unpub. data, 1998). The presence of mafic dykes in a ca. 22 Ma granitic stock (*see* below) indicates that even younger mafic dykes are present.

The second major type of dyke forms a geographically restricted swarm of distinctive plagioclase porphyritic dykes called the Larcom dyke swarm (Evenchick and Holm, 1997). The steeply dipping, northwest-trending dykes occur in northern Observatory Inlet–southern Hastings Arm, and are cut by mafic dykes. A U-Pb age on a sample of Larcom dyke is 52 ± 1 Ma (V. McNicoll, unpub. data, 1998). Another northwest-trending dyke swarm farther north (between 55°55'N and 56°06'N), called the Portland Canal dyke swarm, is composed of rhyolite, dacite-rhyolite, and monzonite dykes of ca. 50.5 Ma age (Green et al., 1995).

Miocene rocks

Stratified rock

Dark, blocky weathering, massive, felsic to intermediate volcanic flows and breccia, and minor rounded granite- and volcanic-cobble conglomerate occur on the northern ridge of Mount Newport (Fig. 2; Evenchick et al., 1997). They cap the ridge as a west-dipping unit more than 500 m thick. The base at the west, on the slopes east of Portland Canal, is at about 820 m elevation. Based on the lack of tectonic fabric and metamorphism they were assumed to be Tertiary (Evenchick and Holm, 1997). A preliminary whole rock $^{40}Ar/^{39}Ar$ age for dacite from near the top of the succession is 21.8 ± 0.4 Ma (V. McNicoll, unpub. data, 1998).

Plutonic rock

A stock of medium- to coarse-grained, miarolitic, biotite-hornblende granite previously reported to have a U-Pb age of 19 Ma occurs on the west side of Portland Canal west of Mount Newport, and rises to abt 300 m elevation (Fig. 2; Berg et al., 1988). New data (G. Gehrels, pers. comm., 1998) gives the stock an age of 22.2 ± 0.8 Ma. Based on the similarity of age and composition with th rocks located 4 km to the east, the stock and volcanic rocks are inferred to be comagmatic. The ages and relative positions of these rocks are key parts of the argument for the presence of a fault postdating 22 Ma in Portland Canal, described below as the Portland Canal Fault.

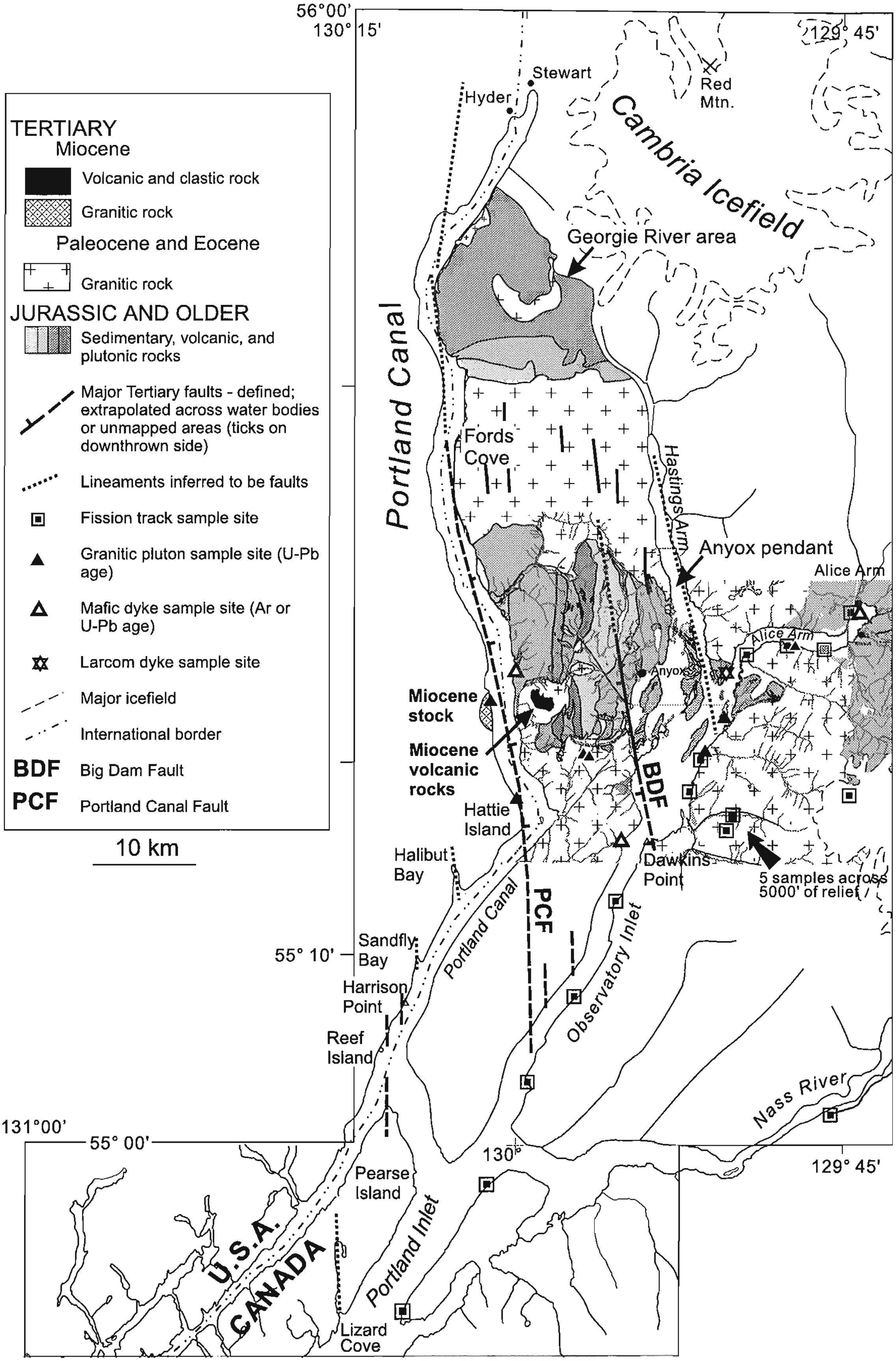

Figure 2. Sketch map of geology in west Nass River area, with locations of Tertiary faults, geological features referred to in text, and locations of rocks dated by U-Pb, $^{40}Ar/^{39}Ar$, and fission-track methods.

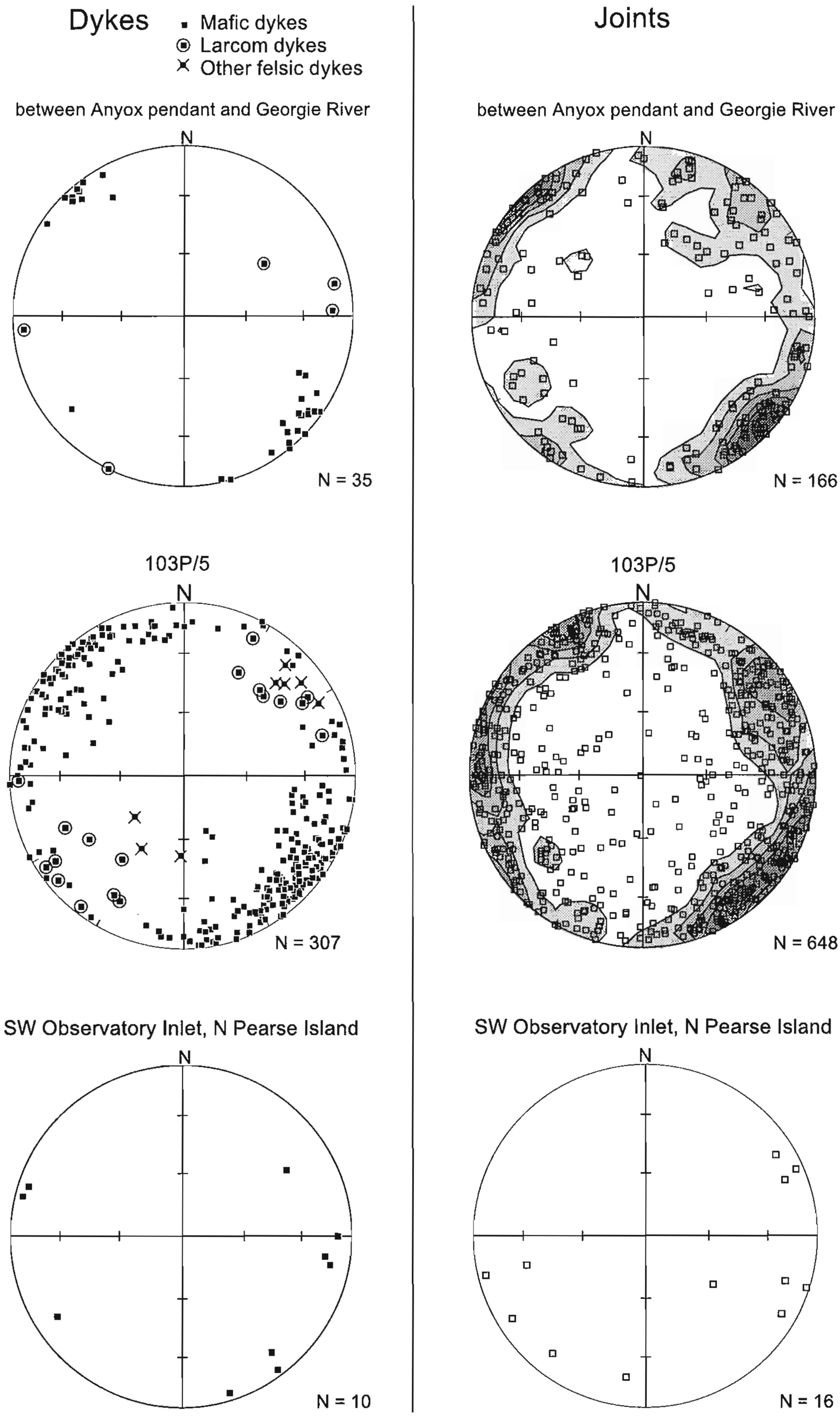

Figure 3. *Lower hemisphere, equal area projections of dykes and joints in western Nass River area.*

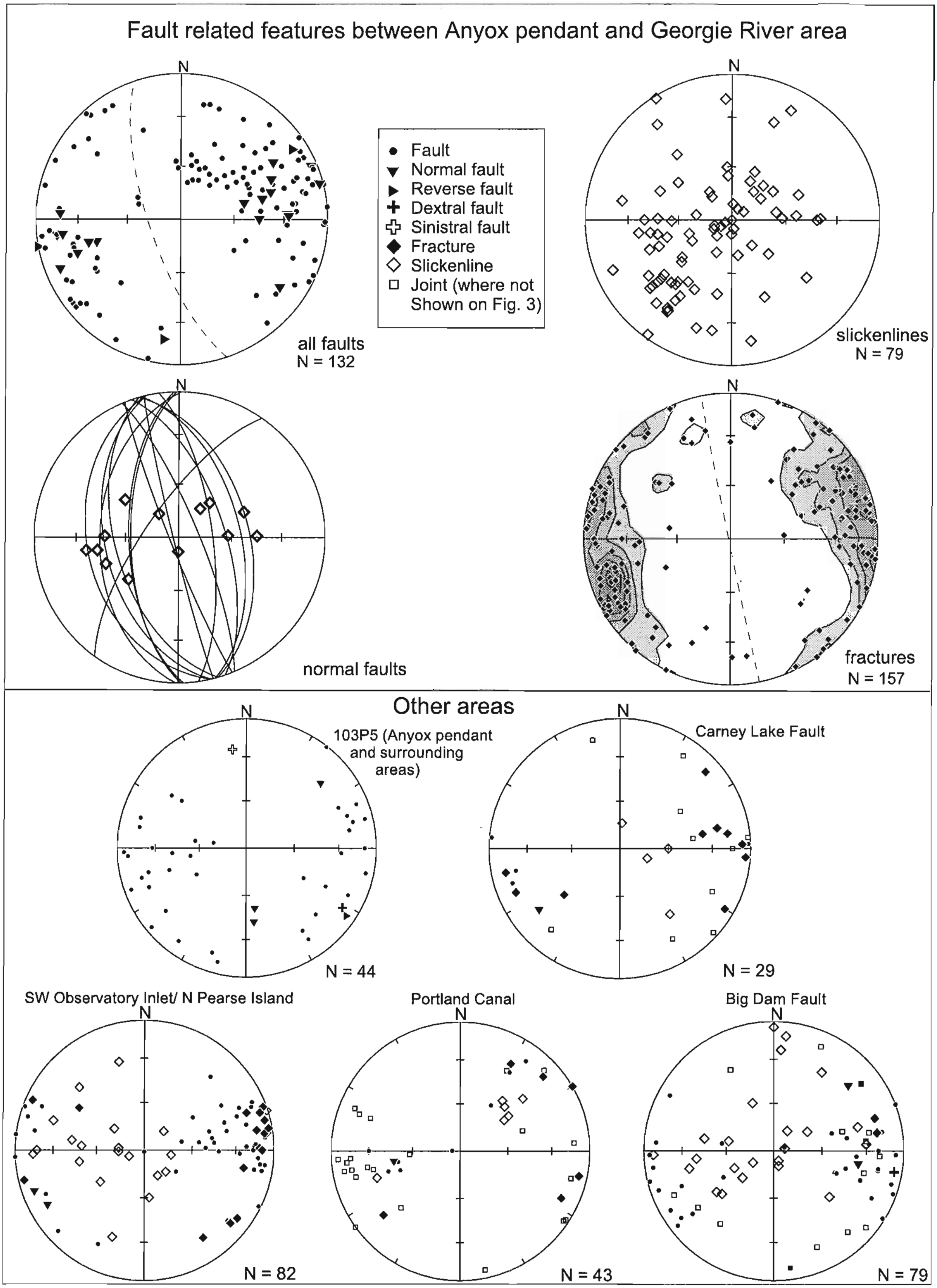

Figure 4. *Lower hemisphere, equal area projections of fault-related features in western Nass River area.*

Hornblende geobarometry indicates pressure of about 2 kbar during emplacement of the granite stock (G.J. Woodsworth, pers. comm., 1998).

Faults

Big Dam Fault

The Big Dam Fault is a steep, brittle, north-trending fault zone which crosses Anyox pendant and the shores of Observatory Inlet (Fig. 2; Evenchick et al., 1997). The southernmost place where the fault was examined is on the southeast shore of Observatory Inlet, east of Dawkins Point. It is expressed there as a zone of highly fractured and faulted rock more than 1 km wide within otherwise massive biotite-hornblende granitic rock and minor foliated granitic rock (Fig. 5). On the northwest shore of Observatory Inlet, the west boundary of the fault zone is a contact between massive biotite-hornblende granite with screens of metasedimentary rock on the west, and highly fractured and faulted muscovite±garnet±biotite granitic rock on the east. This contact coincides with a lineament 12 km long, the northern part of which is along a fault recognized by Sharp (1980). On the shoreline of Observatory Inlet west of the contact are local northerly trending brittle faults and fractures. East of the contact, the muscovite-bearing granite is highly fractured and faulted for about 2 km across strike (Fig. 6, 7). Most structural features at both shoreline exposures of the fault zone are steeply east- or west-dipping fractures spaced 1 mm to a few centimetres (Fig. 4, 5); less common are zones of fault breccia and polished fault surfaces with or without slickenlines (Fig. 6, 7). Slickenlines generally plunge downdip, but a few gently plunging ones indicate oblique strike-slip. Rare quartz slickenfibres are the primary criteria for sense of displacement; most are indicative of normal motion, but dextral-normal motion is indicated for one of the oblique strike-slip faults (Fig. 4).

Mapped contacts and folds in Anyox pendant indicate that the fault accommodated west-side-down displacement. Away from the shoreline, rocks are poorly exposed, and the common brittle features in granite are not as prominent in stratified rocks at outcrop scale. North of the abandoned Anyox townsite, in a belt extending 3 km east of the Big Dam Fault, lineaments reflecting bedding are cut by lineaments

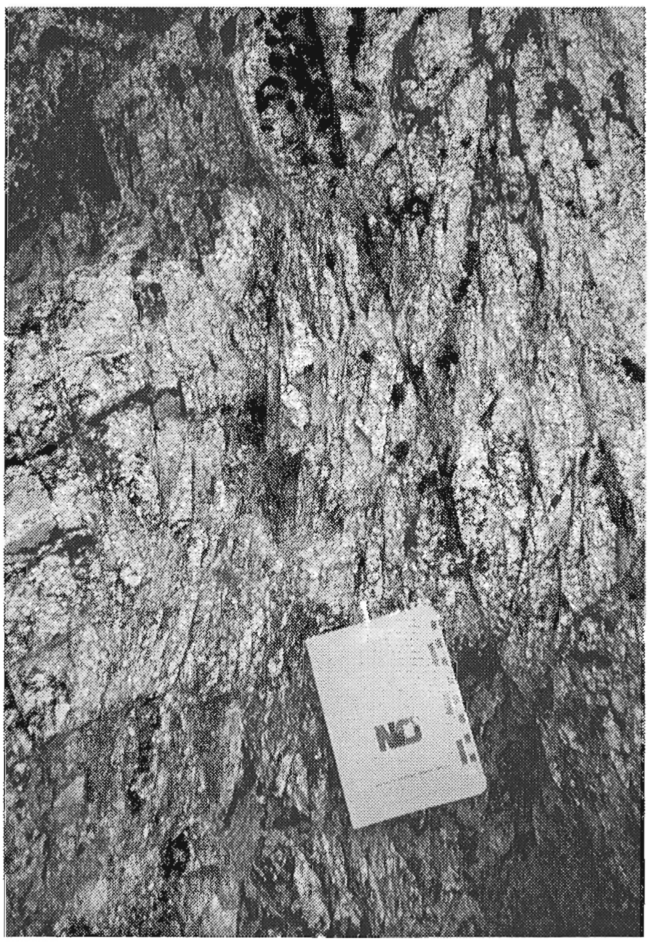

__Figure 5.__ Faulted Tertiary granite in Big Dam Fault, about 2 km east northeast of Dawkins Point. View is down; top is south.

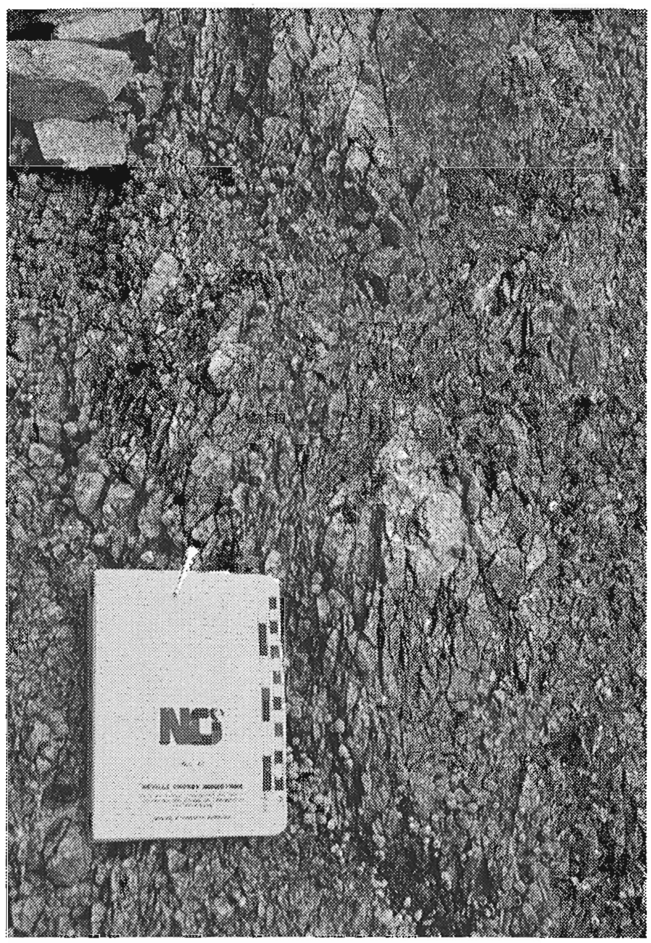

__Figure 6.__ Fault breccia at east side of Big Dam Fault as marked on Figure 2, where the fault crosses the northwest side of Observatory Inlet. View is down; top is south.

parallel with the fault. The latter are assumed to be brittle faults; one of these is on trend with a fault mapped by Sharp (1980) near the Hidden Creek mine.

In summary, the Big Dam Fault is a 2 km wide brittle fault zone which is expressed as a band of highly fractured and faulted rock where it cuts Tertiary granite, and as a zone of discrete faults over a similar width where it cuts older stratified rocks. Displacement was west-side-down. Dip is steep, but direction of dip of the zone as a whole, or of a master fault, is unknown. Most of the faults are dip-slip; the few whose sense of displacement can be determined are normal. Strike-slip faults are rare; one is dextral with a minor normal component.

Portland Canal Fault

Brittle faults and fractures occur on the east and west shores of Portland Canal west of Anyox pendant and farther north. Rocks east of Portland Canal are Paleozoic and Mesozoic greenschist to lower amphibolite facies volcanic, sedimentary, and igneous rocks of Anyox pendant, surrounded by massive Tertiary granitic rock. Miocene (ca. 22 Ma) volcanic rock (described above) is 1.5 km east of the canal at an elevation of about 820 m. West of Portland Canal are a variety of foliated to migmatitic granitoid rocks, intruded by ca. 22 Ma granite (described above). The difference in metamorphic grade, and position of volcanic rocks 500 m above a coeval, and assumed comagmatic pluton emplaced at about 2 kbar pressure, requires a fault postdating 22 Ma in Portland Canal west of Anyox pendant, with east-side-down displacement. Brittle structural features are common, and locally overprint ductile ones. They include closely spaced fractures, normal faults, and Reidel shears (Fig. 4). Although much of the direct evidence for this fault has been removed during formation of the Portland Canal fjord, the data shown in Figure 4 are consistent with the presence of a northerly trending, steeply dipping fault in Portland Canal. At Fords Cove, north of Anyox pendant on the east shore of Portland Canal, brittle fault zones are present in Tertiary biotite-hornblende granite (Fig. 8).

Carney Lake Fault

Approximately 2 km west of the south end of Hastings Arm a north-trending lineament (topographic depression) crosses the contact between Bowser Lake Group on the south, and Tertiary granite on the north. South of the contact the lineament is parallel with, and potentially resulting from, bedding in the Jurassic stratified rocks. North of the contact it can only be the result of features postdating the Early Tertiary, and is defined by a narrow gully along the crest of a ridge. The results of brief examination of a few hundred metres of the lineament are that joints have a range of orientations, but many are steep. Faults and fractures dip steeply east or west, and slickenlines are steep (Fig. 4). Fault gouge occurs at several places along the lineament. The feature is inferred to be a dip-slip, possibly normal, fault.

Faults in south Observatory Inlet

The northwest shore of Observatory Inlet south of Dawkins Point was examined briefly with the intention of locating the southern extension of the Portland Canal Fault, or other major faults. In the north, large areas of massive biotite-hornblende granite with widely spaced joints are punctuated by zones, generally less than a few metres wide, of northerly trending fractures (Fig. 3, 4, 9). South of about 55°10' N (Fig. 2), the rock is foliated granitic rock, and brittle faults with polished surfaces and cataclasite are present in addition to common fractures. Northerly trending lineaments are common in southern Observatory Inlet, and many coincide with zones of brittle faults, some up to 10 m wide; two are normal faults

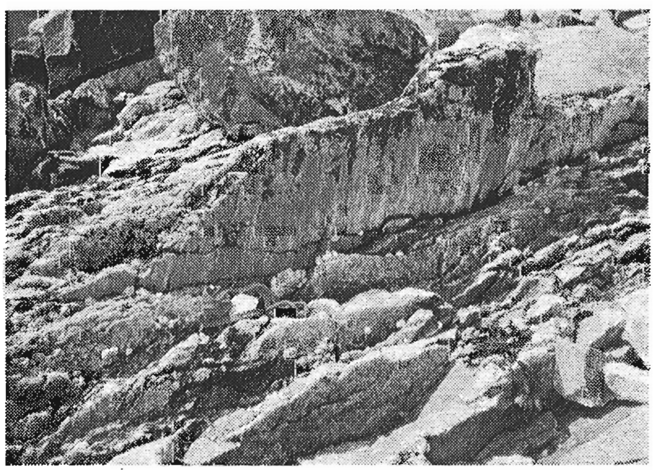

Figure 7. Polished fault surface with downdip slickenlines, in Big Dam Fault about 1.5 km northeast of where the position of the fault as shown in Figure 2. View is to 290°; fault surface dip-direction and dip are 076°/88°; slickenline orientation is 154°/83°.

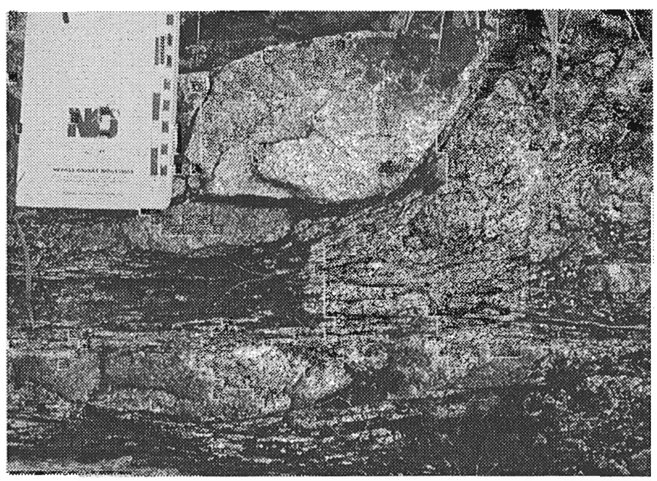

Figure 8. Fault at Fords Cove, Portland Canal, with zones of highly fractured rock and lenses of unfractured rock. View is down; top is east. Fault dip-direction and dip are 100°/85°.

(Fig. 4). Cursory observations to the south indicated that the rock changes from weakly, variably foliated leucocratic or mesocratic granitic rock to strongly foliated, more mafic granitic rock. This change, at about 55°06' N, is the most prominent lithological change, and is assumed to be the position of Portland Canal Fault on the northwest shore of Observatory Inlet (Fig. 2).

Faults west of the Portland Canal Fault

Between Hattie Island and Reef Island (Fig. 2) numerous brittle fractures with polished surfaces, fault breccia and/or slickenlines cut granite along the northwest shore of Portland Canal. Their age is uncertain because the extent of Tertiary rocks is poorly defined. Where displacement can be determined from slickenlines it is generally steep, although north- and south-plunging slickenlines were also observed. Two topographic features, Halibut Bay and Sandfly Bay, parallel these fractures and are inferred to represent eroded, highly fractured zones. Similar north- to northwest- trending lineaments and brittle fault zones, including cataclasite, are present in a 2 km wide zone that extends from Harrison Point through the north end of Pearse Island. In this zone maroon- and grey-weathering feldspar porphyritic dykes as well as mafic dykes are also north to northwest trending, and are an indication of easterly extension. Their age may constrain the timing of faulting.

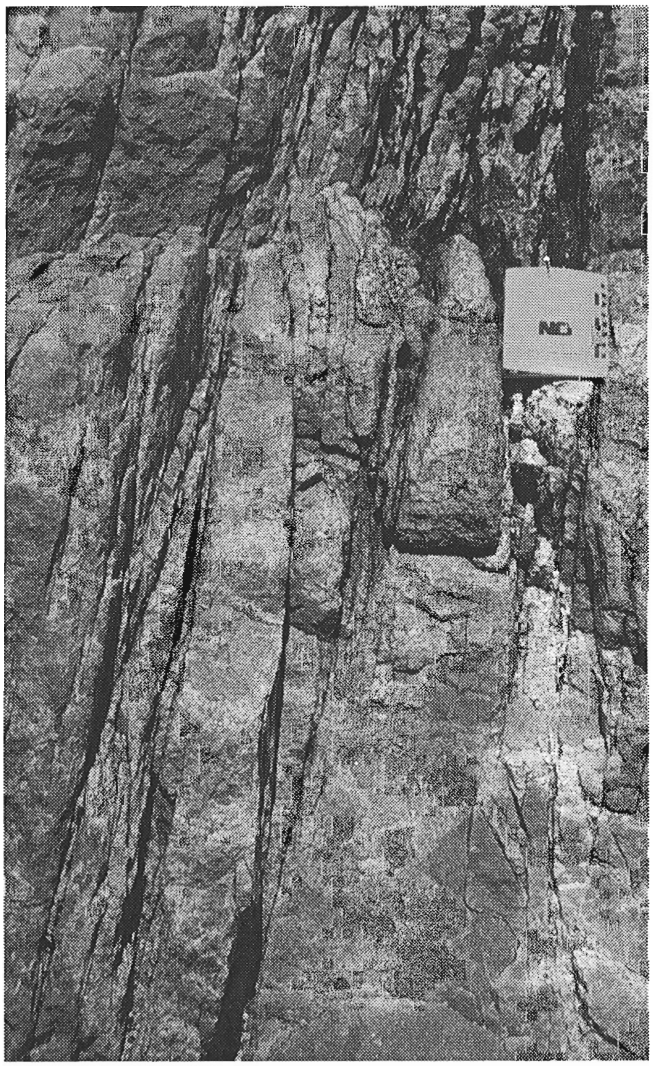

Figure 9. Fractures in massive granite on northwest shore of Observatory Inlet, 5 km southwest of Dawkins Point. View is to north; typical dip-direction and dip of fractures are 250°/75°.

Yet further west it is again difficult to identify Miocene or younger faults as the bedrock is predominantly orthogneiss and paragneiss and plutonic rocks older than 50 Ma. However, at several locations young felsic dykes and stocks are found which are similar in appearance to the feldspar porphyritic dykes at the north end of Pearse Island. One concentration of felsic dykes is at the northern end of a marked lineament that strikes north across Pearse Island; the southern end of this lineament is in Lizard Cove, the location of the Pirate Point pluton. With the dykes are north- to north-northeast-striking brittle fractures and minor faults. The presence of distinctive fine-grained felsic porphyritic dykes and the early Miocene (R. Friedman, pers. comm., 1998; G.J. Woodsworth, pers. comm., 1998) Pirate Point pluton along this topographic lineament suggests the lineament marks another zone of fracturing and extension of a similar age to those described above.

Faults between Hastings Arm and Portland Canal

Homogeneous, Tertiary, biotite-hornblende granite underlies the region between Anyox pendant and Georgie River area. Where not cut by dykes, joints, or faults, it is structurally massive (Fig. 10). Dykes and joints have similar orientations as farther south (Fig. 3), with northeast-trending mafic dykes, northwest-trending granitic dykes, and steep joints of both orientations. The most common features are northerly trending zones a few centimetres to several metres wide of highly

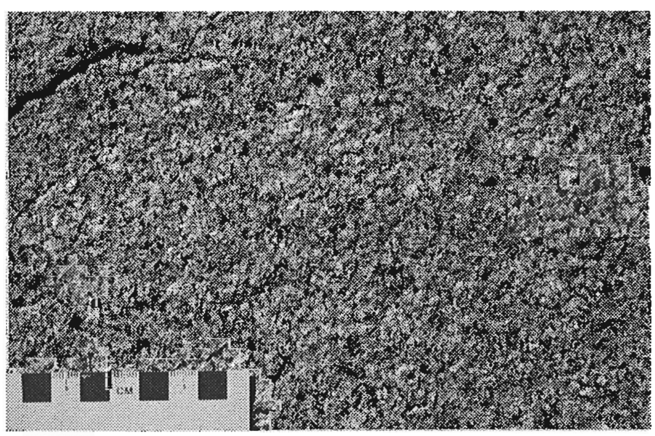

Figure 10. Massive biotite-hornblende granite typical of the Hyder pluton where not affected by brittle faults. In these areas northeast- and northwest-trending joints are commonly spaced a metre or more apart.

fractured granite (Fig. 4). Less common are northerly trending zones of similar style and scale with one or a few faults with steep quartz (and lesser calcite) slickenfibres (Fig. 4, 11, 12). Other common features are moderately southwest-dipping faults lined with chlorite with or without epidote, and downdip slickenlines. Faults on which sense of displacement can be determined by slickenfibres and/or offset aplite dykes (Fig. 13) define two concentrations of normal faults dipping steeply towards 080° and 260°. The acute angle between the two conjugate sets is about 60° (Fig. 4), similar to the relationships displayed in outcrop in Figure 13. Together they accommodated east-west extension. The common steeply dipping fractures have similar ranges in orientation as the faults, although the strike is more variable. Other features along faults are open-space fillings of quartz and calcite. The brittle structures are inferred to be a result of easterly extension across the region between Hastings Arm and Portland Canal.

Figure 11. Fault zone 7 km southeast of Fords Cove. Fractures separate blocks of massive granite of a variety of sizes. Left of the top of the notebook and near the centre of the photograph, a steeply dipping surface has downdip slickenlines. View is down, top is 255°.

Figure 12. Fault zone 6 km south southeast of Fords Cove. Granite with fractures spaced a few centimetres to 30 cm apart, with central zone (recessive zone about 1 m left of person) of fractures spaced 1–2 mm; within the central zone is one quartz slickenside surface with downdip slickenfibres. View is south. Fault zone dip-direction and dip are 070°/89°.

Fission-track dating

Preliminary zircon and apatite fission-track analysis of 32 rock samples from the Coast Belt, east of Portland Inlet and Portland Canal (from between 128°00 and 130°15'W, and 54°35' and 56°15'N), suggest that this area has experienced at least four major periods of rapid cooling during Cenozoic time. Of interest to this topic are the sea-level fission-track ages from the southeast side of Observatory Inlet and Alice Arm (Fig. 2). The apatite fission-track ages for these samples are from 10 to 5 Ma, and the zircon fission-track ages range from 47 to 19 Ma.

Both apatite and zircon fission-track ages from west of the Portland Canal Fault are younger than those from east of the fault. The difference in age is consistent with east-side-down displacement on the Portland Canal Fault; if the fault was responsible for the difference, then at least some motion occurred after ca. 5 Ma.

Apatite fission-track ages from east of the Big Dam Fault (ca. 8 Ma) are similar to those between the Portland Canal and Big Dam faults; the similarity indicates either that motion on the Big Dam Fault occurred before ca. 8 Ma, or the magnitude of the displacement was insufficient to have an effect on the apatite fission-track ages. Zircon fission-track ages from east of the Big Dam Fault are not yet available.

Because all of the samples analyzed are from the southeast side of Portland and Observatory inlets, samples were collected from northwest of the inlets during the 1998 field season. Fission-track age and track length data and the detailed interpretation of these data will be published once the northwestern samples have been analyzed.

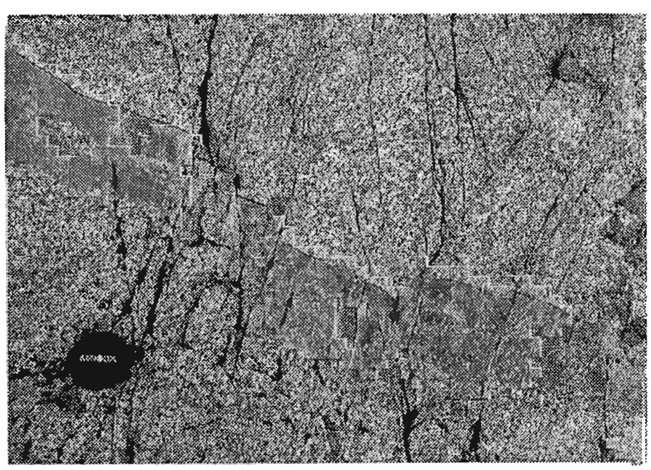

Figure 13. Faults cutting aplite dyke, 13 km east of Fords Cove.

SUMMARY OF TERTIARY STRUCTURES

Three ages of Tertiary structures can be distinguished. Two are early Tertiary (Eocene), and are expressed as two distinct orientations and compositions of dykes which are parallel with major joints and lineament trends. Granitic dykes are older (ca. 52 Ma) and northwest trending; gabbroic dykes are younger (ca. 39-38 Ma) and northeast trending. They record geographically restricted early Tertiary (Eocene) northeasterly extension (parallel with other swarms in the region) followed by regional early Tertiary (Eocene) northwesterly extension. The dykes and parallel joints account for the vast majority of lineaments in Tertiary rocks east and west of Hastings Arm and Observatory Inlet.

Along, and west of, Hastings Arm and northern Observatory Inlet, northerly trending lineaments are present in addition to the northeast- and northwest-trending ones noted above. They are parallel with steeply dipping, northerly trending (350°) brittle faults and fractures which cut early Tertiary and older rocks. Faults are common, but only two can be demonstrated to have accommodated significant displacement. The Big Dam Fault is a brittle fault zone 2 km wide which cuts granite ranging in age from ca. 61–53 Ma in Observatory Inlet. Offset contacts in Anyox pendant indicate west-side-down displacement. Farther west, the Portland Canal Fault separates migmatitic granitoid rocks and ca. 22 Ma massive granite on the west from greenschist facies rocks, massive ca. 60–58 Ma granite, and ca. 22 Ma volcanic rocks on the east. The difference in metamorphic grade, and position of volcanic rocks about 520 m above a coeval, and assumed comagmatic pluton, requires that Portland Canal Fault is an east-side-down fault postdating 22 Ma. Preliminary fission-track data permit speculation that some displacement may be younger than 5 Ma. Parallel faults in early Tertiary granite between northerly projections of the two faults are steeply east and west dipping and extensional. Dip directions of the Big Dam and Portland Canal faults are unknown, but the faults are assumed to be related to the other faults of similar character postdating the early Tertiary, and therefore extensional. If that assumption is correct, the region in and west of Observatory Inlet and Hastings Arm appears to have common Miocene or younger brittle faults which accommodated east-west extension. Preliminary observations on features west of the Portland Canal Fault suggest the Miocene faulting, extension, and associated igneous activity may extend across the entire Central Gneiss Complex. The Portland Canal Fault is approximately in the plane of the ACCRETE seismic survey for at least 20 km, perhaps 50 km, and crosses the survey line in at least two places. Similar faults have been documented farther west which obliquely intersect the seismic line.

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Mike Villeneuve and Fred Quigg are thanked for their meticulous work in obtaining the Ar-Ar ages at the GSC. Kaz Shimamura, Kris Holm, and Ben Johnson provided fine assistance during the three summers of fieldwork in which brittle faults were examined in the course of regional mapping. Shoreline work in 1997 and 1998 was funded by the ACCRETE project grant EAR 9527395 to M.L. Crawford. Cathie Hickson reviewed the manuscript.

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Geological Survey of Canada Project 950037

Geology of the Georgie River area of northwest Nass River map area, northwestern British Columbia

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Evenchick, C.A. and Snyder, L.D., 1999: Geology of the Georgie River area of northwest Nass River map area, northwestern British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 13–23.*

Abstract: Georgie River area (northwest 103 P) is underlain by volcanic flows, clastic rocks, and intrusive rocks. Primary volcanic rocks include pyroxene-porphyritic flows, feldspar-porphyritic flows, and rhyolite. Derived from these is a large volume of poorly sorted, massive, volcanic conglomerate and sandstone. A map unit of pyritic, black siltstone and shale is associated with rhyolite flows. Stratified units are assumed to be Hazelton Group. Volcaniclastic rocks are cut by Early Jurassic hornblende-biotite granodiorite, and plagioclase-porphyritic quartz monzonite assumed to be Jurassic. Stratified rocks are greenschist facies with common biotite hornfels overprint. Deformation in most places is brittle, but zones of ductile deformation are also present. All units are intruded by Tertiary granitic and mafic dykes.

Résumé : La région de la rivière Georgie (103 P nord-ouest) comporte des coulées volcaniques, des roches clastiques et des roches intrusives. Les roches volcaniques primaires comprennent des coulées à phénocristaux de pyroxène, des coulées à phénocristaux de feldspath et de la rhyolite. D'importants volumes de grès et de conglomérats volcaniques massifs, mal classés, en sont dérivés. Une unité cartographique de shale et de siltstone noirs pyriteux est associée à des coulées de rhyolite. Les unités stratifiées font vraisemblablement partie du Groupe de Hazelton. Les roches volcanoclastiques sont recoupées par de la granodiorite à hornblende et biotite du Jurassique précoce et par de la monzonite quartzique à phénocristaux de plagioclase d'âge supposé jurassique. Les roches stratifiées sont du faciès des schistes verts avec surimpression de cornéennes à biotite. Dans la plupart des cas, la déformation est cassante, mais on rencontre également des zones de déformation ductile. Toutes les unités sont recoupées par des dykes granitiques et mafiques du Tertiaire.

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INTRODUCTION

This study of the Georgie River area (parts of NTS maps 103-O/9, 103-O/16, 103 P/12, and 103 P/13) is part of a multi-year regional mapping project designed to increase understanding of the geology in Nass River (103 P) map area, and to compile the first 1:250 000 scale map of the area from more detailed maps. Background on the project goals is found in Evenchick and Mustard (1996). Results of recent mapping are in Evenchick (1996a, b, c), Evenchick and Holm (1997), Evenchick et al. (1997), Haggart et al. (1998), and McCuaig (1997).

In 1998 the goals were to 1) map the Georgie River pendant and outline its stratigraphic and structural framework, and 2) map the area between Georgie River and Anyox pendants (*see* Evenchick et al., 1999).

Regional geology and previous work

An overview of the regional geology and previous work in Nass River area is found in Evenchick and Mustard (1996). Most bedrock is divided into three broad groups (Fig. 1): 1) Triassic and Lower to Middle Jurassic rocks of Stikinia; 2) Middle Jurassic to Lower Cretaceous rocks of the Bowser Basin; and 3) Mesozoic and Cenozoic granitoid rocks of the Coast Belt. Minor constituents are Cretaceous rocks of the Skeena Group, Upper Tertiary and Quaternary volcanic rocks, and metamorphic rocks of unknown age.

In a reconnaissance survey of Stikinia west of the Bowser Basin, Grove (1986) correlated all strata in the Georgie River area with the Unuk River Formation, a dominantly grey-weathering volcaniclastic unit in the lower part of the Hazelton Group. He outlined one belt of cataclastic rocks and depicted the stratified rocks as a pendant within Tertiary granitoid rocks.

STRATIGRAPHY AND STRUCTURE

Introduction

The Georgie River area is underlain by volcanic, volcaniclastic, and sedimentary rocks, and Mesozoic and Cenozoic plutonic rocks (Fig. 2). Stratified rocks are greenschist facies, and are faulted and locally penetratively deformed. The best exposed areas are described below.

Mount Guanton

North and northwest ridges of Mount Guanton are underlain by volcaniclastic rocks. Most (~60%) are green-, grey-, and rarely maroon-weathering, heterolithic, poorly sorted, matrix-supported, massive volcanic conglomerate (Fig. 3); bedding is rare. Rounded to subrounded clasts range in size from 1 cm to greater than 1 m and consist of texturally varied plagioclase±amphibole-porphyritic volcanic, and possibly plutonic rocks. Conglomerate matrix is coarse- to

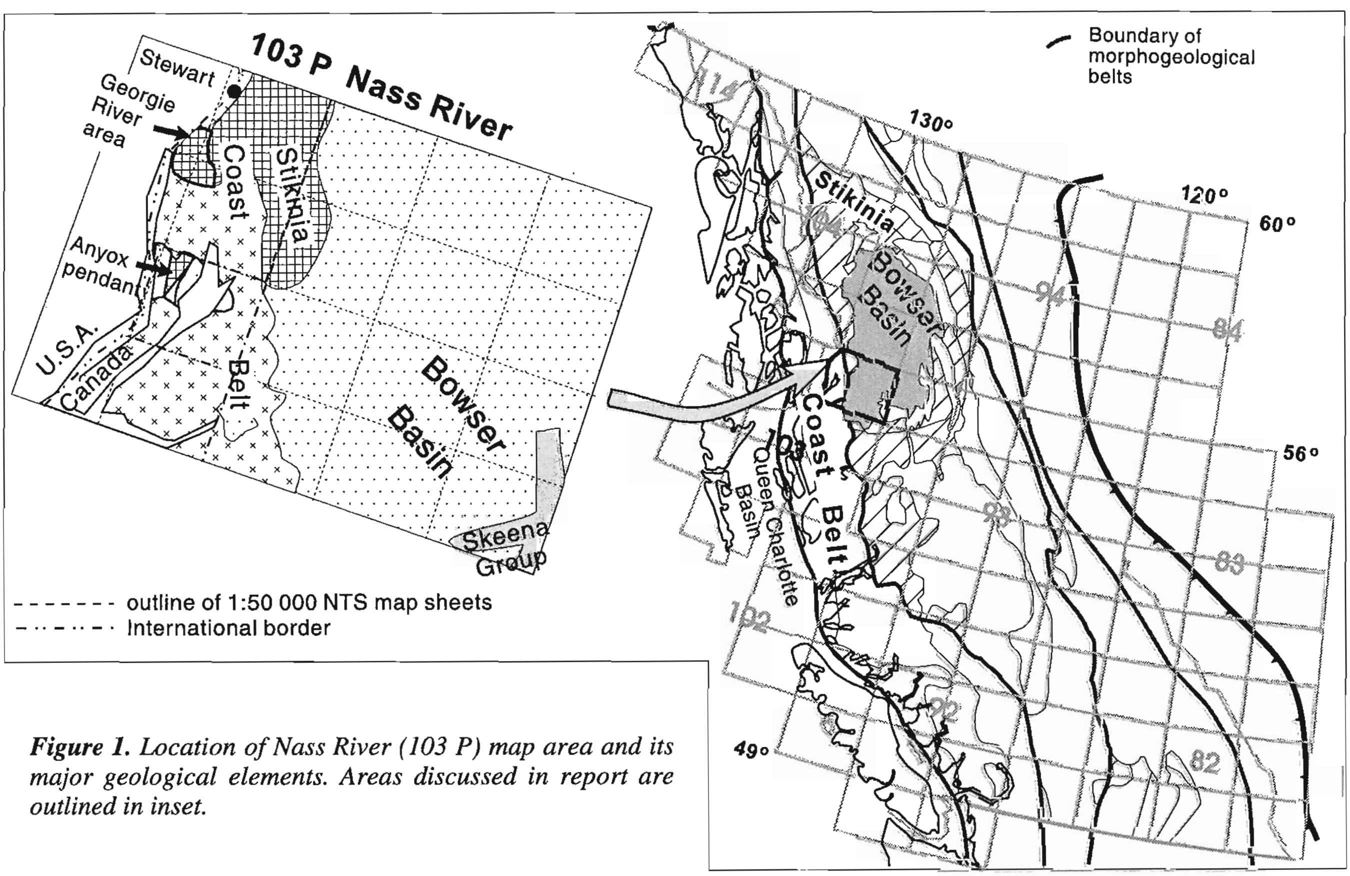

Figure 1. Location of Nass River (103 P) map area and its major geological elements. Areas discussed in report are outlined in inset.

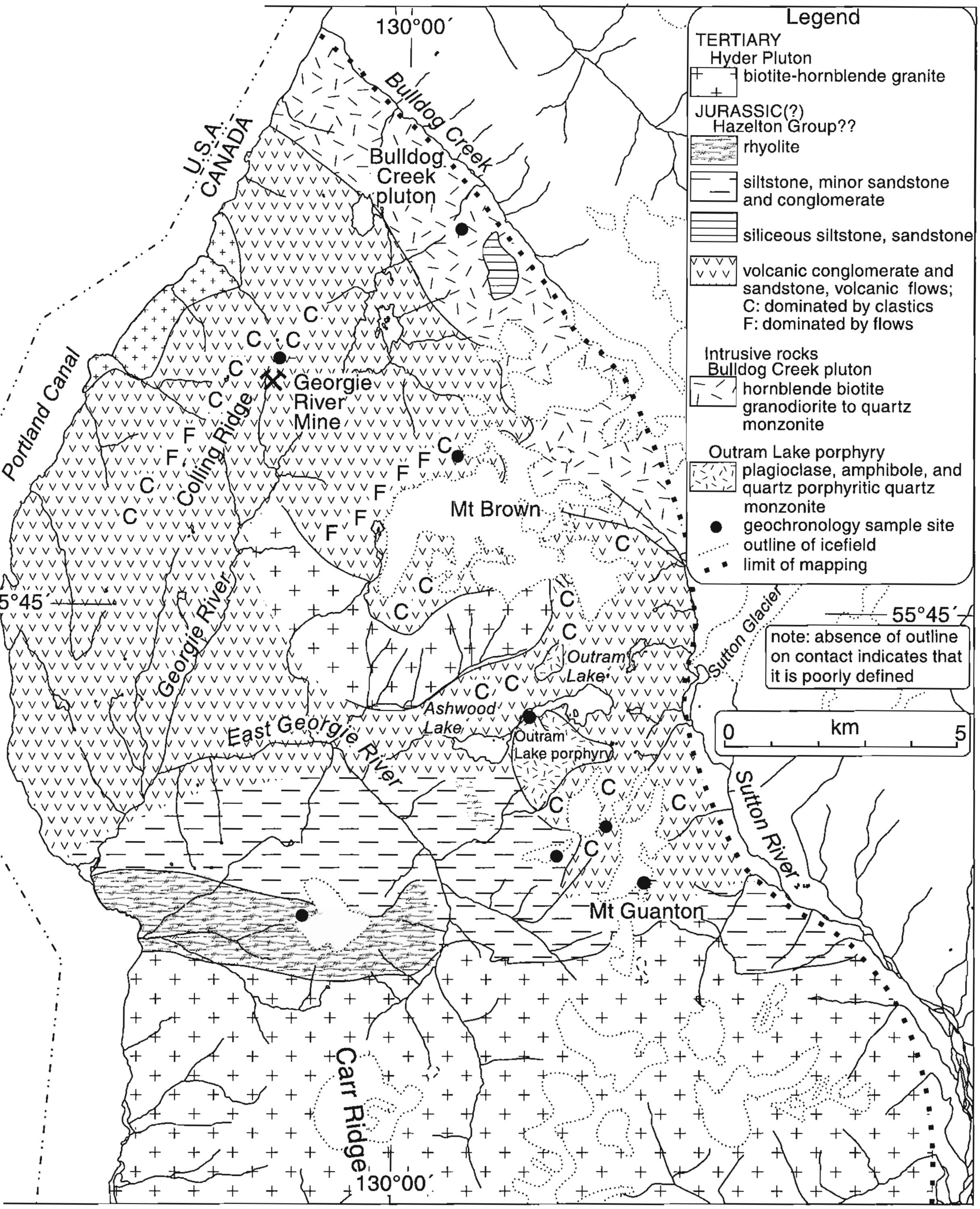

Figure 2. Sketch map of geology in the Georgie River area.

fine-grained sand compositionally similar to the clasts, with 20–40% angular to subrounded plagioclase crystals, 15–20% mafic mineral fragments, and rare quartz. Approximately 20% of volcanic conglomerate is monolithic, suggesting derivation from a single eruptive event. Poor sorting, lack of bedding, and matrix-supported nature are inferred to indicate deposition as proximal debris flows.

Conglomerate units metres to tens of metres thick are interbedded with lesser amounts of green-grey-weathering, medium- to coarse-grained, immature, feldspathic, volcanic sandstone. Sandstone makes up about 35% of exposure and is poorly to moderately well sorted and massive to vaguely bedded. It contains up to 30% saussuritized or epidotized feldspar that is commonly angular to subangular, suggesting rapid deposition from a nearby source. Rusty- or grey-weathering, thinly bedded to laminated, fine sandstone or siltstone with rare thin siliceous (tuffaceous?) beds and graded or convoluted bedding make up 5% of the succession and probably represent distal turbidite deposits.

Andesitic crystal tuff at least 50 m thick on the northwest side of Mount Guanton contains 30% 1–3 mm subhedral plagioclase crystals and 10% 2 mm to1 cm acicular amphibole crystals. It stratigraphically overlies maroon- and grey-weathering volcanic conglomerate, and, near the base, amphibole crystals are aligned parallel with the contact; subtle contact-parallel layering is common (Fig. 4). The lower contact is concave, resulting from postdepositional folding, or topographic control on deposition. Texture and composition of the tuff are similar to some of the clasts in the volcanic conglomerate and the Outram Lake porphyry (described below).

Overlying the volcaniclastic succession is a dark-rusty-weathering unit, 80% of which is pyritic siltstone and very fine-grained sandstone, in laminated or thin to medium massive beds. Characteristic dark rusty weathering is a result of abundant, disseminated, 0.5 mm, euhedral pyrite cubes or amorphous pyrite blebs along bedding planes and fractures.

***Figure 3.** Massive, poorly sorted, matrix-supported, volcanic conglomerate, common north of the southern belt of siltstone and rhyolite. North ridge of Mount Guanton.*

***Figure 4.** Plagioclase-amphibole crystal tuff overlying volcanic conglomerate, northwest of Mount Guanton.*

Minor constituents in the unit are 10% medium-grained massive and parallel-bedded volcanic sandstone, and 5% light-grey- to white-weathering, siliceous, thinly bedded or laminated siltstone and fine-grained sandstone. Finer grained units exhibit convolute and rare graded bedding and are probably distal turbidite deposits. Conglomerate, in beds a few metres thick, makes up less than 1% of the unit. It is clast supported and consists dominantly of light and dark grey rounded and angular clasts of either chert or aphanitic rhyolite.

Volcaniclastic rocks have brittle faults and rare foliation. In the rusty siltstone unit, several fault zones subparallel with bedding result in highly chaotic fault zones; minor folds with wavelengths of a few centimetres are rare, and changes in vergence suggest larger scale folds. Isoclinal folds with southwest-dipping axial surfaces are exposed on the southwest ridge of Mount Guanton. Quartz veins are ubiquitous and epidote alteration is locally abundant.

The clastic units are inferred to be intruded by a quartz monzonite, the Outram Lake porphyry (named informally herein). Near Outram Lake, it consists of 15–20% plagioclase, rarely as megacrysts up to 4 cm, 5–15% 3 mm to 1 cm amphibole phenocrysts, and 5–8% quartz (Fig. 2, 5). Plagioclase megacrysts are commonly poikilitic with mafic mineral trains along the growth planes. The matrix is fine grained and dark grey on fresh surfaces. To the southeast, the unit is less megacrystic and quartz phenocrysts decrease in abundance. Near the southeast contact, numerous dykes and pod-shaped bodies of various felsic and intermediate compositions and textures crosscut volcaniclastic rocks. Tabular bodies, possibly dykes or sills, of similar composition cut volcaniclastic rocks farther south.

North of Carr Ridge

The peak north of Carr Ridge (Fig. 2) is mainly rusty-weathering pyritic siltstone and rhyolite. Minor rocks include andesite flows, volcanic conglomerate, and sandstone. Lower

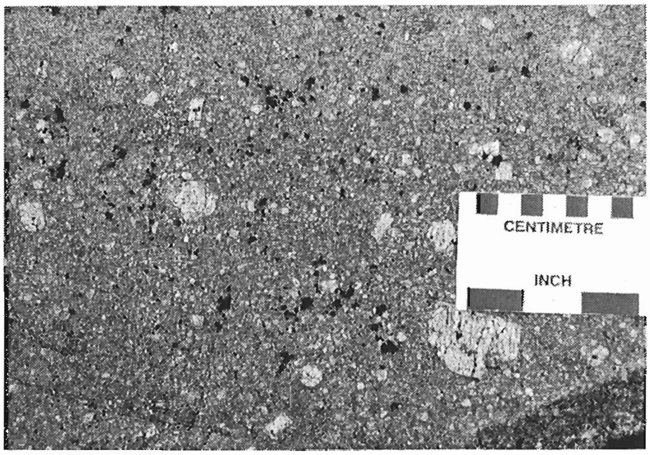

***Figure 5.** Megacrystic quartz monzonite of the Outram Lake porphyry. Mouth of Outram Lake.*

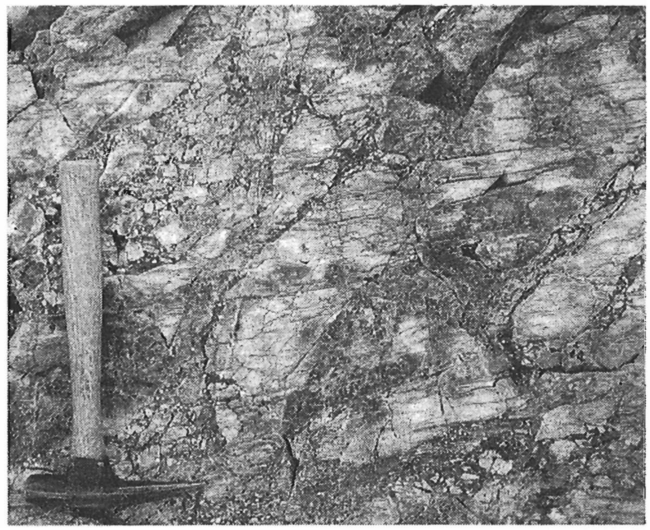

***Figure 6.** In situ breccia in rhyolite north of Carr Ridge. Note consistent orientation of flow lamination in clasts.*

greenschist-facies metamorphism is overprinted by biotite hornfels. Isoclinal folding and penetrative foliation are common in siltstone, but rare in other rocks, which have numerous brittle faults.

Structurally lowest on the east ridge is a mixed unit of volcaniclastic rocks, minor siltstone, and rhyolite. Volcaniclastic rocks are generally massive, poorly sorted sandstone to pebble conglomerate, with abundant felsite volcanic clasts, and locally abundant diorite cobbles. The mixed unit is overlain by rusty-weathering siltstone and shale with a structural thickness of about 200 m. Siltstone varies from massive to phyllitic and spotted, and locally has mesoscopic isoclinal folds. It includes rare carbonate pods and lenses, and is overlain by a unit of massive volcanic sandstone and conglomerate. The latter is overlain by eutaxitic felsic lithic tuff, followed by heterogeneous rhyolite with flow lamination, breccia, and spherulites.

On the west ridge, a similar succession has pyritic siltstone and shale cut by pyritic felsite dykes, structurally overlain by 10 m of flow-layered, brecciated, spherulitic rhyolite, massive volcanic sandstone interbedded with minor fine-grained clastic rocks, and andesitic flow rock. This lower, mainly clastic, succession is overlain by a thick unit of heterogeneous rhyolite with flow layering, spherulites, breccia, volcanic conglomerate, and interbedded sedimentary rocks, similar to the rhyolite described above. The base of the thick rhyolite is dominated by massive rhyolite and monolithic breccia to conglomerate. Angular to rounded rhyolite clasts have a green-weathering, recrystallized matrix. The abundance of fragmental rhyolite, geometry of the succession, and morphology of the fragments and matrix is suggestive of a hyaloclastite breccia dome. Upsection to the south, texture of the rhyolite is dominated by consistent flow lamination with minor breccia and no spherulites. It is sparsely quartz-, feldspar-, or amphibole-phyric, with phenocrysts up to 1 mm. Breccias include in situ breccia with unrotated clasts (Fig. 6), and thin layers of flow breccia. Within the rhyolite unit is a fault sliver of andesite flow rock. The steeply south-dipping rhyolite unit is at least 1 km thick.

Stratigraphic facing can be inferred low in the mixed volcanic clastic/siltstone/rhyolite succession, where fine-grained clastic material has filled open spaces in a thin, rhyolitic, flow breccia, indicating that strata are upright. Facing can also be inferred structurally higher, in the thick rhyolite unit. The lower part changes southward and up, from massive flow rocks to more common resedimented rhyolite (shown by breccias and conglomerates), indicating that the rocks are upright.

Assuming that the siltstone unit is internally deformed, but the overall stratigraphic succession not disturbed, the section is as follows. The base is a mixed unit of volcanic conglomerate and siltstone, with small rhyolite domes. It is overlain by pyritic shale and siltstone with a structural thickness of at least 200 m. These lower units have thin lenses of carbonate, rare rhyolite flows(?), and felsite dykes. The siltstone unit is overlain by volcanic sandstone and conglomerate which is thicker on the northeast; on the southwest, a few tens of metres of rhyolite lie between the siltstone and the volcanic sandstone. The lower clastic units with minor rhyolite are overlain by a succession of rhyolite more than 1 km thick, which is locally underlain by thin eutaxitic tuff. The base of the rhyolite is heterogeneous, with massive flow rocks, flow layering, monolithic breccia, and spherulites. Interbedded sedimentary rocks occur higher in the succession, and the upper part is flow laminated, with lesser breccia, including in situ breccia. The overall character is indicative of a hyaloclastite breccia dome.

The succession is inferred to represent a period dominated by coarse volcaniclastic input followed by relatively distal shale/siltstone deposition, with minor rhyolite flows. This was followed by more proximal volcanic input as debris flows (sandstone, conglomerate), and finally development of a thick rhyolite dome. Tuff at the base of the rhyolite indicates subaerial or shallow marine deposition, and sandstone and conglomerate within the rhyolite as well as in situ breccia are indicative of submarine deposition.

Rusty-weathering pyritic siltstone and shale is similar to that at Mount Guanton; at both places it overlies a unit of volcanic conglomerate. The thick rhyolite unit does not appear elsewhere, but thinner rhyolite is associated with rusty-weathering siltstone south of Ashwood Lake.

Mount Brown

Underlying the southern ridges of Mount Brown (Fig. 2) is a succession of volcaniclastic rocks intruded by rocks similar to the Outram Lake porphyry. The upper slopes of the mountain are dominantly rusty- to green-weathering, heterolithic, poorly sorted, unbedded, matrix-supported volcanic conglomerate. Clasts range from 1 cm to greater than 1 m, and consist largely of light- and dark-grey-weathering, coarsely porphyritic or coarse-grained, plagioclase- and amphibole-rich volcanic rocks. The matrix is coarse- to medium-grained sandstone with angular to subangular feldspar and mafic mineral crystals and fragments, and up to 5% quartz; disseminated pyrite is locally abundant and results in rusty weathering. Minor coarse sandy interbeds and thin- to medium-bedded feldspathic sandstone units 1 m thick are also present. These coarse-grained volcaniclastic rocks represent proximal debris-flow deposits.

Conglomerate exposed on the major south-trending ridge north of Outram Lake is intruded by tabular and pod-shaped bodies of porphyritic to sparsely feldspar-megacrystic quartz-amphibole-plagioclase porphyry. Phenocryst content is 20–25% plagioclase, 10–15% amphibole, locally with subparallel alignment, and 5–8% quartz. This unit is tentatively correlated with the Outram Lake porphyry. Many clasts in the volcanic conglomerate are similar in texture and composition to these intrusive rocks; they are evenly distributed throughout the conglomerate and the contact between the units is intrusive. The pluton may have been a source for extrusive rocks of similar composition and texture which then became fragments in the conglomerate.

Farther south along the south-trending ridge, clasts and matrix of the volcaniclastic rocks decrease in size. Clasts are aphyric to mildly plagioclase±amphibole porphyritic, and the matrix is a fine- to medium-grained feldspathic sandstone. This 'fining' trend continues south where conglomerate becomes subordinate in volume to volcanic sandstone. Sandstones are green-grey-weathering, fine to medium grained, unbedded or weakly bedded, moderately to well sorted, and contain at least 10–15% angular to subangular feldspar, 5–15% mafic component (most likely amphibole) and 0–5% quartz. Thinly bedded to laminated fine-grained sandstone and siltstone units are rare. They are T_{AE}, T_{ADE}, and T_{ACE} turbidites in intervals no more than 10 m thick, which locally exhibit graded bedding and synsedimentary deformation structures. Disseminated pyrite cubes occur throughout much of the volcanic sandstone and siltstone sequence.

The western ridge of Mount Brown is composed mainly of green-weathering, coarsely pyroxene-porphyritic basalt flows and associated pyroxene-rich volcaniclastic rocks. Flow rocks dominate in the central portion of the ridge. They contain 5–20% 1 mm to 1 cm euhedral to subhedral pyroxene phenocrysts, and, locally, 5–10% 1–2 mm plagioclase phenocrysts in a finely crystalline groundmass. They are usually homogeneous and massive, but are occasionally pillowed or exhibit crude flow layering defined by aligned pyroxene phenocrysts. The rocks are rarely amygdaloidal and flow breccia is a minor constituent. Locally, the flow succession contains fine-grained sedimentary rock inclusions up to 10 cm across. Fine-grained sedimentary interbeds make up less than 1% of the flow-dominated succession. Minor amounts of andesitic flow rocks occur mainly in the southwest. They are grey weathering, massive to rarely pillowed, and range from aphanitic to plagioclase or plagioclase and pyroxene porphyritic. Southwest of the primary volcanic succession, flow rocks are interlayered with units 5–10 m thick of coarse volcanic conglomerate (clasts up to 25 cm), pebbly conglomerate, and sandstone. Most volcaniclastic rocks are distinctly pyroxene rich (Fig. 7), indicating derivation directly from the adjacent flow rocks. Lesser amounts of rusty-weathering, thinly bedded to rarely laminated, feldspathic, fine- to medium-grained volcanic sandstones are also interbedded with the more mafic clastic material. Rare, siliceous, fine-grained beds may represent felsic tuff deposits. At the southernmost end of the ridge, clastic rocks increase in abundance, and at least 15% of the exposure is clastic units 10–15 m thick; they are interbedded with mafic and intermediate flow rocks.

The Mount Brown area exhibits abundant brittle deformation features, including fractures in a wide range of orientations, seams of cataclasite, and brittle faults. Zones of foliated rock and ductile shear zones are rare. The Outram Lake porphyry has anastomosing thin shear zones with chlorite. Near the peak of Mount Brown, penetrative fabric is absent, but elsewhere, and particularly to the south, foliation is common. Tertiary granitic dykes are common.

***Figure 7.** Bedded immature pyroxene sandstone on the southwest ridge of Mount Brown. It is spatially associated with massive pyroxene flows and debris-flow conglomerate.*

Colling Ridge

The north, central, and south parts of Colling Ridge (Fig. 2) have different proportions and types of volcanic flows, volcanogenic sedimentary rocks, and intrusive rocks. Northern Colling Ridge is underlain by volcaniclastic and volcanogenic sedimentary rocks intercalated with thin pyroxene-phyric mafic flows and a few tuffs, and tabular and pod-shaped intrusions of rhyolite. Rhyolite is alkali-feldspar megacrystic to strongly porphyritic, with 5% quartz phenocrysts up to 3 mm, 10–15% feldspar phenocrysts 1–10 mm (Fig. 8), and common inclusions of sedimentary rock up to 0.5 m across. Dykes and sills locally comprise up to 50% of outcrop. Tabular rhyolitic bodies vary from a few metres to at least 20 m x 80 m, are pyritic and have minor breccia. Coarse-grained sedimentary rocks vary from heterolithic volcanic, to lithic pebble to cobble conglomerate. Conglomerate is poorly sorted and most likely represents debris-flow deposits; limestone clasts in one flow are indicative of shallow-marine conditions. One well preserved 20 m section of volcaniclastic rock fines upward from several metres of massive, poorly sorted conglomerate, to fine pebble conglomerate, medium-grained sandstone, and finally to interbedded medium-grained sandstone and siltstone. Elsewhere, 1–2 m of massive sandstone alternates with similar thicknesses of thin well bedded sandstone and siltstone; these deposits are interpreted as turbidites. Sandstones are generally well sorted, feldspathic, and massive or rarely bedded. Siliceous grey-black-rusty siltstone and fine-grained sandstone constitute less than 10% of the clastic succession.

Strata on central Colling Ridge have many similarities with those farther north, but rhyolite is minor and sandstone is abundant. Pyroxene-phyric basalt or andesite flows and flow breccias form units less than 10 m thick. They have up to 10% pyroxene phenocrysts in a fine-grained or aphanitic matrix. Rare plagioclase-phyric andesite flows and debris flows are also present. Quartz-feldspar-porphyritic rhyolite intrusions occur as 1 or 2 units less than 5 m thick. Volcanic sandstone is medium- and coarse-grained, massive feldspathic wacke to pebbly sandstone with abundant feldspar crystals. Bedding is rare. Siltstone, fine-grained sandstone, chlorite phyllite, and psammitic fine-grained sandstone are minor constituents.

Southern Colling Ridge has some of the features described above, but flows and conglomerate are more abundant; fine- and medium-grained clastics are minor; and rhyolite is absent. Plagioclase-porphyritic and aphyric andesite flows include rare pillowed flows and thick massive flows; both are interbedded with minor, thin, fine-grained clastic rocks. Massive pyroxene-phyric basalt flows have phenocrysts 1 mm to 1 cm long which constitute up to 25% of the rock. Flows decrease in proportion from more than 80% in the north, to less than 10% in the south, where they are less than 10 m thick. Massive, matrix-supported, and poorly sorted volcanic conglomerate dominates the southern section. It is both monolithic, made of pyroxene-phyric volcanic clasts 1–20 cm across, and heterolithic, made of plagioclase-, plagioclase+pyroxene-, and pyroxene-phyric clasts.

In summary, Colling Ridge is underlain by interbedded volcanic and volcaniclastic rocks intruded by feldspar- and quartz-phyric rhyolite. Flows are pyroxene-phyric basalt or andesite, and plagioclase-phyric andesite. Most are massive, but rare pillowed plagioclase-phyric flows occur in the south. Flows are commonly less than 10 m thick; in the north they make up less than 10% of outcrop, and in the south up to 90%. Debris-flow conglomerate and flow breccia derived from both types of flows are common, and in the south make up 80% of outcrop. Massive, immature feldspathic sandstone in units at least 10 m thick is common in the north and is locally interbedded on the scale of several metres with thin-bedded fine-grained sandstone. Fine-grained sandstone and siltstone constitute less than 10% of the succession. Porphyritic rhyolite intrusions are common in the north, rare in the central area, and absent in the south. All areas have similar structural style, with zones tens to hundreds of metres wide of little or no penetrative deformation (in massive sandstone, conglomerate, and rhyolite). Similar-scale zones of weak to strong penetrative foliation locally obscure all primary features, and are typically in finer grained clastic rocks, and locally in sandstone, debris flows, and volcanic flows. Foliation is defined by flattened clasts, orientation of platy minerals, and crenulation cleavage. Transposition, boudinage of rhyolite, crenulation cleavage, and tight to isoclinal folding of foliation occur in the central area (Fig. 9). The latter indicates either polyphase deformation or progressive deformation. North- and northwest-trending brittle faults are common, and offset Tertiary dykes. Greenschist-facies metamorphism is everywhere overprinted by hornfels. Massive and brecciated quartz veins and Tertiary dykes are common, as are disseminated sulphides.

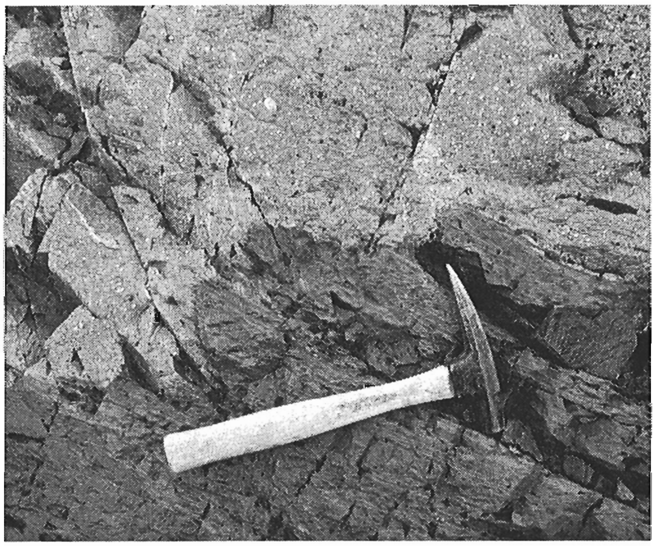

***Figure 8.** Intrusive contact between fine-grained sandstone and siltstone (lower), and K-feldspar-and quartz-porphyritic rhyolite (upper). Bedding in siltstone dips gently to right, parallel with the surface the hammer head is on. Northern Colling Ridge.*

Figure 9. Folds of foliation in phyllite on central Colling Ridge.

Figure 10. Fault breccia in the Bulldog Creek pluton, south of Bulldog Creek.

Strata in the south are somewhat similar to those east of Georgie River, but pyroxene flows are less common on Colling Ridge. In both places pyroxene-phyric and plagioclase-phyric flows are interbedded with minor fine-grained clastic rocks. Rhyolite intrusions are unique to the northern part of Colling Ridge, but are possibly related to the thick rhyolite succession north of Carr Ridge. As at Mount Brown, common flows, and flow breccias and a thick succession of immature, feldspathic, medium- and coarse-grained volcaniclastic rocks (debris flows) indicate proximity to an andesitic or basaltic volcanic centre. Rare pillows indicate submarine deposition, as do rare interbedded fine-grained clastic rocks presumably deposited during times of volcanic quiescence.

Bulldog Creek

The ridge south of Bulldog Creek (Fig. 2) is underlain by medium-grained, equigranular to slightly porphyritic, biotite-hornblende granodiorite to quartz monzonite. Biotite constitutes 5% of the rock and hornblende 10%. Both are chloritized, and plagioclase is saussuritized. The rock is white-, tan-, grey-, or green-weathering with dark green fracture surfaces and fine-grained green and pink groundmass; it is locally pyritic. Granodiorite is homogeneous, with some leucocratic aplitic zones and minor fine-grained zones; epidote veins with chlorite and local, weak, K-feldspar alteration envelopes up to several centimetres wide are ubiquitous. Cataclastic fault zones millimetres to several metres wide are common (Fig. 10), and rare semiductile shear zones less than a few centimetres wide are present. The rock is lithologically similar to the Bulldog Creek pluton north of Bulldog Creek, which is 181 ± 8 Ma (K-Ar on hornblende, Greig et al., 1995).

A small pendant within the pluton consists of a white-weathering, siliceous (possibly tuffaceous) clastic succession at least 50 m thick. It is dominated by massive medium-and coarse-grained siliceous sandstone to quartzofeldspathic wacke. Siltstone and fine-grained sandstone are massive, or, less commonly, thin bedded, laminated, and crosslaminated, with disseminated pyrite cubes. Brittle fault zones and fault breccia are common.

TERTIARY IGNEOUS ROCKS

The rocks described above are bounded on the south by Tertiary plutonic rocks of the Coast Belt. Rocks of this suite also form a stock southwest of Mount Brown. They are equigranular, porphyritic or slightly K-feldspar-megacrystic, biotite±hornblende granite and granodiorite. Potassium-argon age determination on biotite from granitic rocks to the east and northeast are 48.3 ± 2.6, 50.5 ± 2.4, and 51.9 ± 2.6 Ma (Greig et al., 1995). Uranium-lead age determinations on Tertiary granitic rocks east of the Anyox area range from 53 to 61 Ma (V. McNicoll, unpub. data, 1998).

Stratified rocks are also cut by abundant dykes 1–25 m wide of similar texture, freshness, and composition to the larger bodies. White-, cream-, or rusty-weathering dykes strike northwest, and are fine- to coarse-grained, equigranular to porphyritic, biotite, hornblende, or biotite+hornblende granite, granodiorite, quartz monzonite, and monzodiorite. Porphyritic rhyolite dykes on Mount Brown are unaltered, and contain a few per cent biotite, 5% K-feldspar, and 8–10% 2–5 mm quartz phenocrysts in a finely crystalline groundmass. Brown- and green-weathering, aphyric to plagioclase± pyroxene-porphyritic, mafic dykes with chilled margins are common throughout Georgie River area; most strike northeast (Fig. 11). Both suites of dykes are cut by brittle faults.

STRUCTURE

Pre-Tertiary rocks display brittle deformation and local ductile deformation features. Rocks are folded on mesoscopic and larger scale, but the lack of bedding in most areas generally precludes identification of large-scale folds,

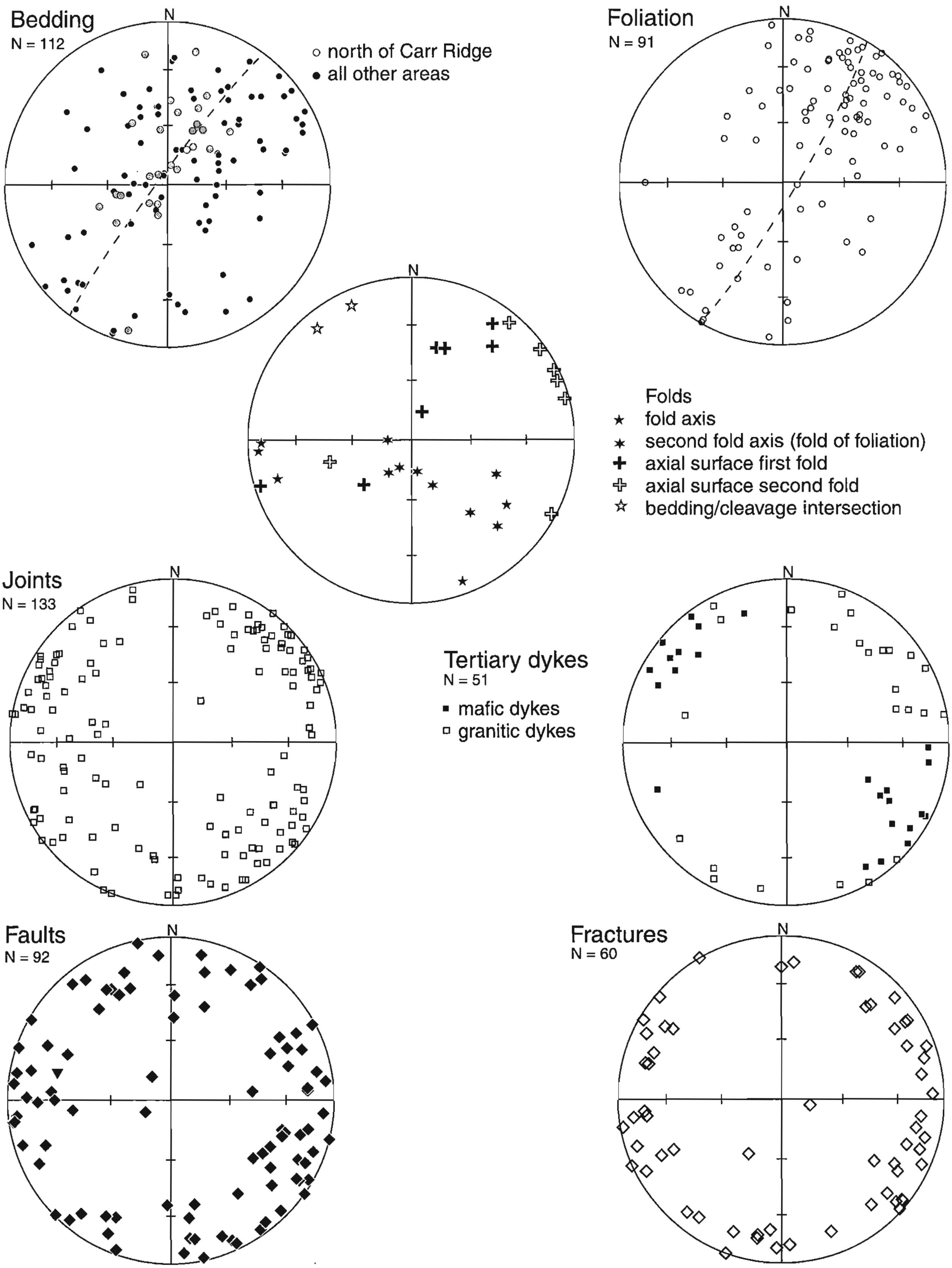

Figure 11. *Lower-hemisphere equal-area projections of linear features and poles to planar features.*

although poles to bedding indicate west-northwest-trending folds. Exceptions are north of Carr Ridge, where folds can be observed, and bedding defines west-northwest-trending folds (Fig. 11), and isoclinal folds on Mount Guanton. Brittle deformation features include thin cataclasite seams to wide fault breccia zones, in addition to narrow faults with slickenlines (slickenside lineations). Most are steeply dipping (Fig. 11). North-trending, steep, dip-slip faults common in Tertiary granite farther south (Evenchick et al., 1999) are apparent. At the Georgia River mine on Colling Ridge, mineralization is associated with north-trending faults (Alldrick et al., 1996). Based on Pb isotope data, Alldrick et al. (1996) speculated that gold-bearing northwest- and north-trending veins are Tertiary. Recognition that north-trending faults are probably younger than 22 Ma (*see* Evenchick et al., 1999) further constrains the age of mineralization. Foliated rocks occur sporadically throughout the area, but are most common on Colling Ridge and the two ridges east of Georgie River and west of Mount Brown. There, zones of strongly foliated rock tens to hundreds of metres wide are separated by zones with little or no apparent penetrative fabric. Foliation is commonly steep and northwest trending (Fig. 11). Features include boudinage, intense foliation, crenulation cleavage, and tight folds of foliation. Farther east, structures are brittle, except for rare thin shear zones. The Bulldog Creek pluton is characterized by common fault-breccia zones.

COMPARISON WITH THE ANYOX PENDANT

The primary lithological similarity between Georgie River area and Anyox pendant is the presence of feldspar-phyric flows, although in Anyox pendant they are more abundant, and commonly pillowed. Volcaniclastic rocks in Anyox pendant are subordinate and are generally fine- and medium-grained mature sandstone, whereas in Georgie River area they are mainly volcanic conglomerate to coarse-grained immature sandstone. Large numbers of gabbroic sills and/or dykes characteristic of Anyox pendant, and Devonian mafic intrusive complexes are absent in Georgie River area, and Anyox pendant does not include significant amounts of pyritic siltstone or thick accumulations of rhyolite or pyroxene-phyric flows. Both areas are at greenschist-facies metamorphism, but Anyox pendant locally reaches upper greenschist to lower amphibolite facies. Both areas include zones of brittle and ductile deformation, and strain is concentrated in anastomosing zones surrounding areas of unstrained or weakly strained rock. Ductile deformation is significantly more common in Anyox pendant.

SUMMARY

Several distinctive lithological units occur in the Georgie River area. Previous maps depict the rocks as a pendant within Tertiary granite of the Coast Belt (Grove, 1986). Continuation of the Bulldog Creek pluton south into areas formerly considered to be Tertiary granite illustrates that strata in the Georgie River area are contiguous with those surrounding the Cambria Icefield (Greig et al., 1995), and are not an isolated pendant.

Stratified rocks are dominantly volcanic flows and volcaniclastic rocks derived from primary volcanic rocks. They include large volumes of poorly sorted, matrix-supported, unbedded, volcanic conglomerate with an immature, medium- and coarse-grained sandstone matrix. The coarse volcaniclastic rocks are commonly interbedded with poorly sorted, immature, coarse- and fine-grained sandstone, or with intermediate to mafic flow rock. In most areas, the composition of the flows is similar to the volcaniclastic rocks. Textures and relationships indicate proximity to source areas for the volcaniclastic rocks and that material was derived directly from primary volcanic rocks and deposited as debris flows. Fine-grained and bedded sedimentary units intercalated with the coarser grained rocks represent periods of local quiescence and more distal turbidite deposition.

Mafic mineral component varies significantly. Some rocks contain almost exclusively hornblende, whereas other areas are pyrite rich. This holds true for both the primary volcanic and volcaniclastic rocks found in a given area. In addition, compositional and textural similarities between some of the extrusive rocks and the plutonic rocks (e.g. Outram Lake porphyry, Bulldog Creek pluton) suggest that there may have been coeval plutonism.

Correlation between areas is possible in a few cases. North of Carr Ridge and at Mount Guanton rusty-weathering pyritic siltstone overlies a unit of coarse volcaniclastic rocks, and is associated with rhyolite flows. A plutonic unit, the Outram Lake porphyry, occurs in the Mount Guanton and Mount Brown areas; it is assumed to be Mesozoic because of the degree of alteration. Lastly, the pyroxene-porphyritic basalt flow and volcaniclastic sequence occurs in a belt from the southwestern ridge of Mount Brown to southern Colling Ridge. Rocks in the Georgie River map area are tentatively correlated with the Lower to Middle Jurassic Hazelton Group based on lithology. Correlation of north-trending faults at Georgie River mine with similar structures farther south leads to speculation that the age of gold mineralization is younger than 22 Ma.

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Surficial geology drilling results, Nass Valley, British Columbia

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Abstract: Drilling and geophysical logging were used to delineate basin stratigraphy and glacial history in part of the Nass Valley, northwestern British Columbia. The stratigraphic succession from oldest to youngest comprises subglacial lodgement till, interbedded proximal glaciomarine subaqueous outwash, distal glaciomarine silty clay, and glaciofluvial braidplain gravel. Fan delta deposits may be present locally. Glacial history was inferred from this succession. First, ice flow in the valley deposited till. Later, during deglaciation, marine water invaded the isostatically depressed valley, setting the stage for proximal to distal glaciomarine sedimentation that followed a retreating tidewater glacier front. Fan delta deposition from valley sides may have contributed coarse debris to distal glaciomarine environments at this time. Subsequently, ice left the valley entirely and sea level dropped. Meltwater rivers incised the exposed glaciomarine clay, forming two large sandurs. Sea level then dropped to its present position and postglacial stream incision began.

Résumé : La stratigraphie des bassins et l'histoire glaciaire d'une partie de la vallée de la rivière Nass, dans le nord-ouest de la Colombie-Britannique, ont été définies à l'aide de sondages et de diagraphies géophysiques. La succession stratigraphique est la suivante, des roches les plus anciennes au plus récentes : till de fond sous-glaciaire; dépôts d'épandage fluvioglaciaire interstratifiés, subaquatiques, glaciomarins, proximaux; argile silteuse glaciomarine distale; et gravier fluvioglaciaire de plaine anastomosée. Des dépôts de delta alluvionnaire peuvent être présents par endroits. Cette succession traduirait l'histoire glaciaire suivante. D'abord, des écoulements glaciaires ont déposé du till dans la vallée. Plus tard, au cours de la déglaciation, la vallée, déprimée isostatiquement, a été envahie par l'eau de la mer, ce qui a préparé la voie à la sédimentation glaciomarine proximale à distale qui a suivi le recul du front du glacier de marée. À ce stade, les dépôts de delta alluvionnaire provenant des versants de la vallée auraient contribués des matériaux détritiques grossiers aux milieux glaciomarins distaux. Puis, la glace s'est retirée complètement de la vallée et le niveau de la mer a baissé. Des rivières formées par des eaux de fonte ont incisé l'argile glaciomarine exposée, formant deux grandes plaines d'épandage fluvioglaciaire. Le niveau de la mer est alors tombé à sa position actuelle, ouvrant la voie à l'approfondissement postglaciaire des cours d'eau.

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INTRODUCTION

The Nass Valley is a large, formerly glaciated basin in northwestern British Columbia. It hosts a complex sequence of glacial sediments, most of which are preserved in the northeastern part of the valley.

This paper outlines the results of a drilling program carried out in the summer of 1998, as part of an ongoing investigation into the glacial history and surficial geology of the Nass Valley. Surficial geology was mapped in 1996 and a preliminary synopsis of glacial history was outlined (McCuaig, 1997); two 1:100 000 scale surficial geology maps of the area are nearing completion. In 1997 and 1998, work was focused on the thick deposits found in the northeastern part of the valley (Fig. 1). Seismic-reflection and ground-penetrating-radar data were also obtained and are currently being digitally processed.

GLACIAL HISTORY

At the height of the last glaciation, ice flowed southwest over the entire Nass River region, depositing up to 20 m of compact till in the southwest-trending Nass Valley. During deglaciation, ice became restricted to valleys and fiords, but till continued to be deposited by ice flowing southwest down the valley. As deglaciation progressed, silty clay, gravel, and sand were deposited over till in the northeastern part of the valley. Because very few natural exposures are available in this remote area, drilling was carried out to clarify basin stratigraphy.

METHODS

Drilling

Drillholes were drilled on or near previously shot seismic lines using a Mobile B-53 mud-rotary drill rig mounted on a 5 ton International Harvester truck (Fig. 2, 3). An 8.4 cm tricone drill bit was used. Cuttings from each drillhole were logged for grain size, with the aid of a 1 mm grid sieve to catch coarser material (Fig. 2).

At sites where gravel or gravelly sand were encountered, augering with 15 cm solid-stem or 20 cm hollow-stem flight augers was substituted for mud-rotary drilling (Fig. 3). These methods also were employed at each hole to drill through the extremely hard upper levels of weathered silty clay.

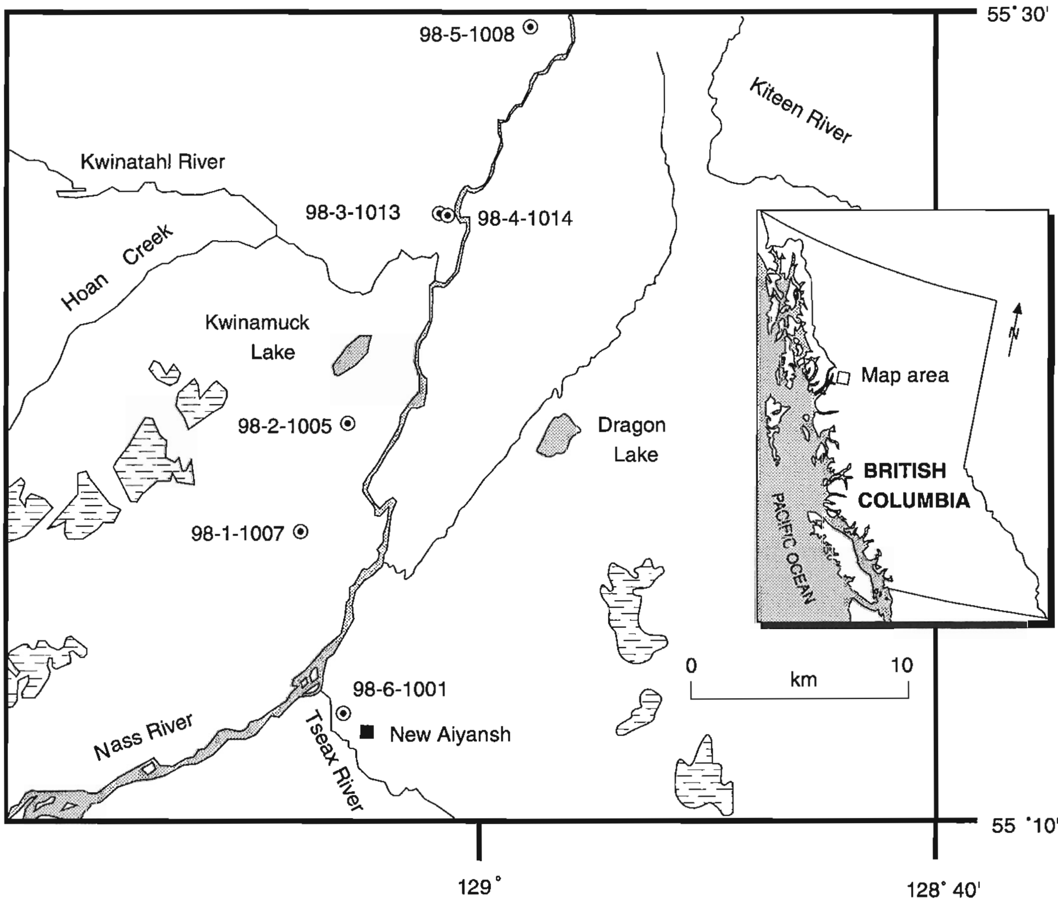

Figure 1. Location of drillholes in the northern Nass Valley. Glaciers are hatched and water bodies are shaded.

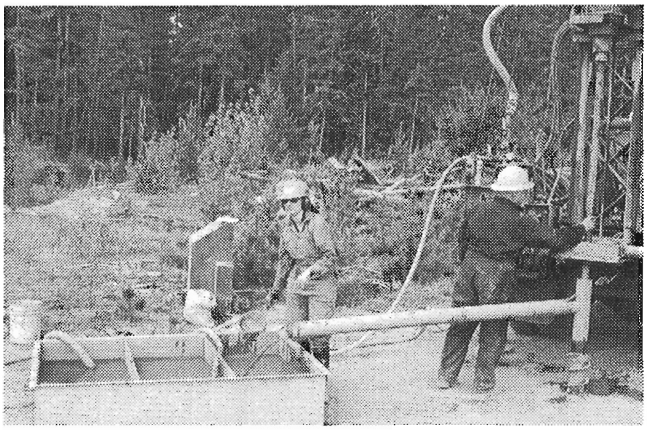

Figure 2. Mud-rotary drilling at drillhole 98-5-1008, using a sieve to log larger grain sizes. A 20 cm hollow-stem flight auger is used as casing.

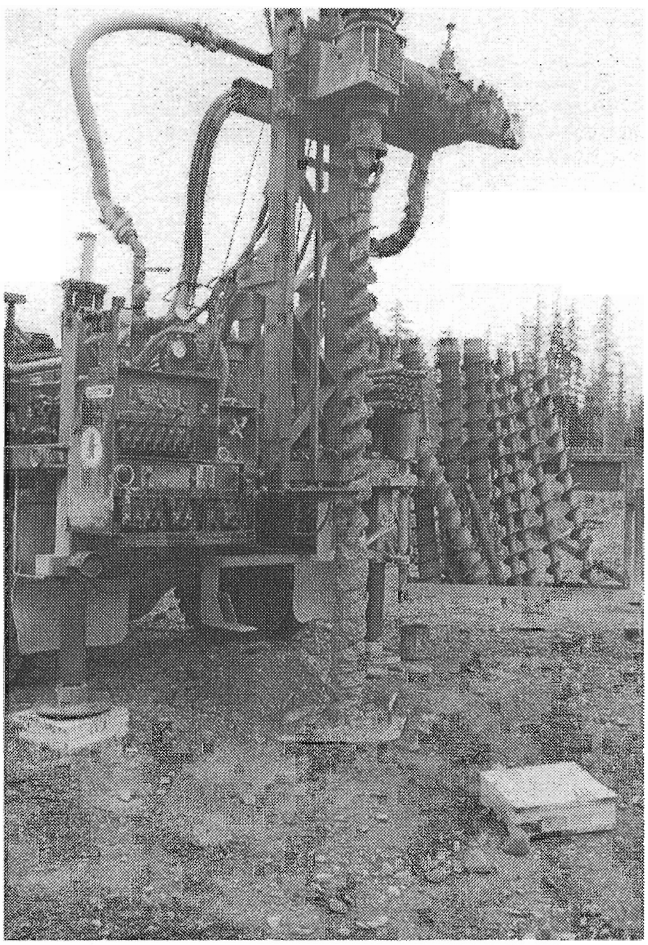

Figure 3. Solid-stem augering at site 98-1-1007. Relatively undisturbed massive silty clay has been retrieved.

Unfortunately, flight augers were not able to penetrate to great depths and drilling rates when using them were relatively slow (drilling speeds were fastest in unweathered silty clay with the mud-rotary method). The large hollow-stem augers were also used to case the upper part of all mud-rotary holes. Samples were taken at various intervals with a split-spoon sampler.

Sedimentary structure is commonly difficult to define with mud-rotary drilling because continuous core is not retrieved. However, because the upper part of each hole was augered, resulting in relatively undisturbed sediment acquisition (Fig. 3), the sites will be referred to as drillholes instead of boreholes.

Vibracoring was also attempted but was unsuccessful, due to the plastic nature of the silty clay and its tendency to liquefy when agitated.

Geophysical logs

Geophysical logs were taken at three of the drill holes to provide an aid in stratigraphic interpretations. Gamma ray (γ), spontaneous potential (SP), and resistivity (R) were measured using a Mt. Sopris logger. This particular tool measures natural gamma radiation, electric current, and relative resistance of a given volume of sediment. Measurements were obtained as the tool was pulled upward inside the hole. The steel casing over the upper 3 m prevented collection of SP and R records at the top of the holes. Because SP and R require conductive fluid between the tool and the borehole wall, these logs are not reliable above the water table. Drillholes were not cased below the upper 3 m, but wall collapse was not a problem.

RESULTS

The data obtained from six drillholes are presented in Table 1 and Figures 4, 5 and 6. The drillhole locations are shown in Figure 1.

Drill Hole 98-1-1007

Additional description

This drillhole was located 1.5 km east of a modern alluvial fan on the valley's western edge.

Interpretation

The modern alluvial fan may have been present as a fan delta during the deposition of glaciomarine silty clay. If so, it was much smaller then, with only occasional turbidite flows (evidenced by possible graded beds) reaching deeper marine waters. Immediately prior to the end of marine deposition, the fan grew considerably. It was at this time that the thick debris-flow bed found near the surface was deposited. However, if the fan was growing at that time, an increase in coarser debris toward the top of the drillhole would be expected (Fig. 4). This was not observed in this drillhole. An alternative explanation is that the coarse interbeds from 6.7 to 14.9 m are distal deposits of subaqueous outwash from a receding ice front. This interpretation is supported by the upward thinning and less common occurrence of coarse-grained interbeds toward the surface. However, one or both of these depositional sources may have been operative.

Drill Hole 98-2-1005

Additional description

This drillhole was drilled in an area of extensive surficial clay deposits, 2 km east of two modern alluvial fans. Samples A and B were taken at 9.9 and 23.8 m respectively. Both samples revealed massive, sticky, silty clay over a 50–55 cm interval (Fig. 7).

Table 1. Summary description of core and cutting lithologies, and preliminary facies interpretations.

Drillhole	Depth (m)	Description	Facies Interpretation
98-1-1007	0-0.6	silty clay, massive, sticky, blue-grey	distal glaciomarine
	0.6-3.0	silty, sandy pebble/cobble gravel, poorly sorted, loose, subangular clasts, dark blue-grey	mid fan to distal fan delta debris flow
	3.0-14.9	silty clay, massive, sticky, blue-grey; interbedded with very fine-sand, medium-sand, clayey silt, some very fine-sand beds with granules or pebbles at base (graded beds?)	distal glaciomarine; coarser beds either distal subaqueous outwash turbidites or distal fan delta turbidites
98-2-1005	0-34.1	clay and silty clay, massive, sticky, blue-grey, upper 4 m of silty clay is weathered to pale brown and is extremely hard, weathered to unweathered zone gradational; interbedded with clayey silt, silty fine-sand, very fine sand, fine sand, medium sand	distal glaciomarine; coarser beds either distal subaqueous outwash turbidites or distal fan delta turbidites
	34.1-35.7	diamicton, poorly sorted (clay to pebble gravel), striated clasts, extremely hard, blue-grey, subround to angular clasts (plugged the drill bit)	subglacial lodgement till
98-3-1013	0-5.4	silty clay, blue-grey, upper 3 m weathered to pale brown (gradational contact)	distal glaciomarine
98-4-1014	varies, 0-2.4	very coarse-sand with pebbles and granules, poorly to moderately sorted	glaciofluvial braidplain overbank deposits
	1.2-5.2	coarse-sand to pebble gravel, (hole D only), upward coarsening, moderately sorted	glaciofluvial braidplain bar (channel deposit)
	0-13.0	sandy pebble gravel (exposure only)	glaciofluvial braidplain channel deposits
	varies, 2.4-14	silty clay, massive, sticky, blue-grey	distal glaciomarine
98-5-1008	0-3.4	fine-sand, medium-sand, coarse-sand interbeds	glaciofluvial braidplain overbank deposits
	3.4-12.2	silty clay, massive, sticky, blue-grey, weathered gradationally to 4.3 m	distal glaciomarine
	12.2-17.2	silty clay, silt, fine-sand, medium-sand interbeds, well sorted	mid-proximal glaciomarine
	17.2-17.7	gravel, poorly sorted	proximal glaciomarine
98-6-1001	0-24.2	silty clay, massive, locally finely laminated, sticky, blue-grey, weathered gradationally to 6.4 m	distal glaciomarine
	24.2-41.5	silty clay, silt, very fine-sand, fine-sand, medium-sand, coarse-sand, granule gravel interbeds, rare pebble gravel beds	proximal subaqueous outwash
	41.5-47.0	diamicton, stiff, blue-grey, compact, poorly sorted (plugged the drill bit)	subglacial lodgement till

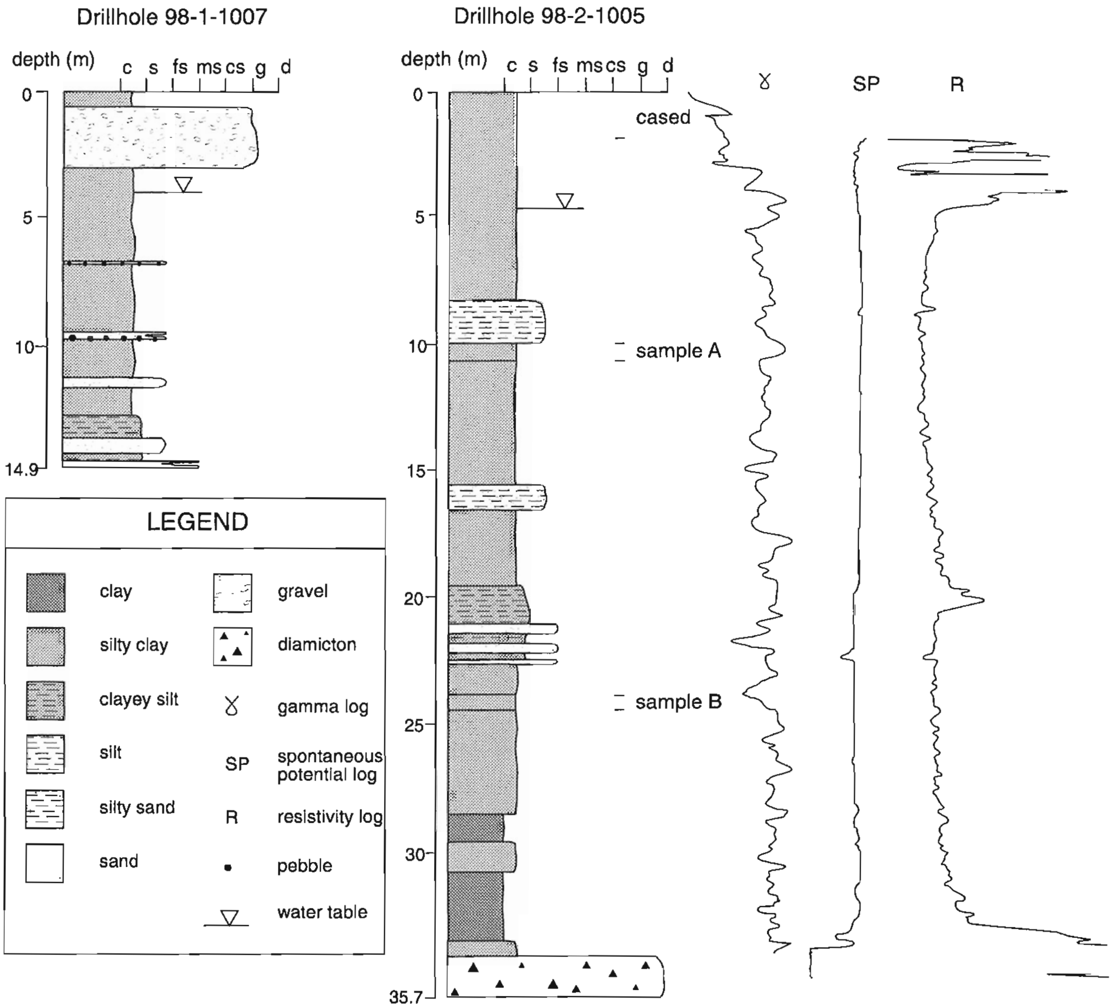

Figure 4. Lithological logs of drillholes 98-1-1007 and 98-2-1005. Geophysical logs run on hole 98-2-1005 are shown on the right.

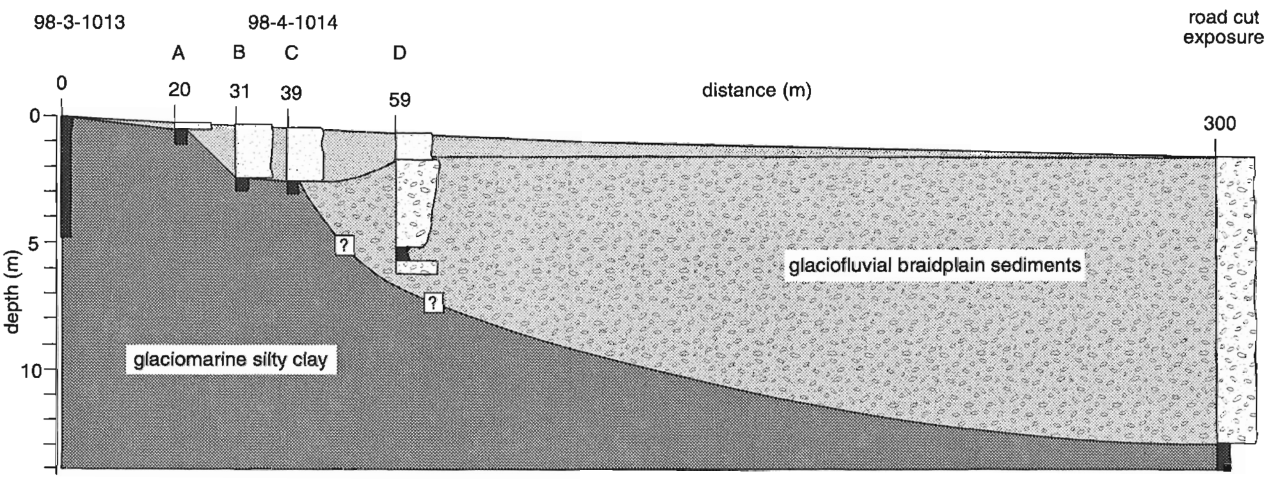

Figure 5. Generalized cross-section of glaciofluvial braidplain and glaciomarine silty clay deposits, using evidence from drillholes 98-3-1013 and 98-4-1014 A-D. The lithological log on the right is a section exposed in an earthflow in the braidplain area. The drillholes penetrate the western edge of the glaciofluvial plain and delineate the extent of the subsurface contact of glaciofluvial gravel/sand and underlying glaciomarine clay. The channel edge is clearly shown. Legend same as Figure 4, but silty clay is shown darker to emphasize the marine clay environment and entire braidplain is shaded.

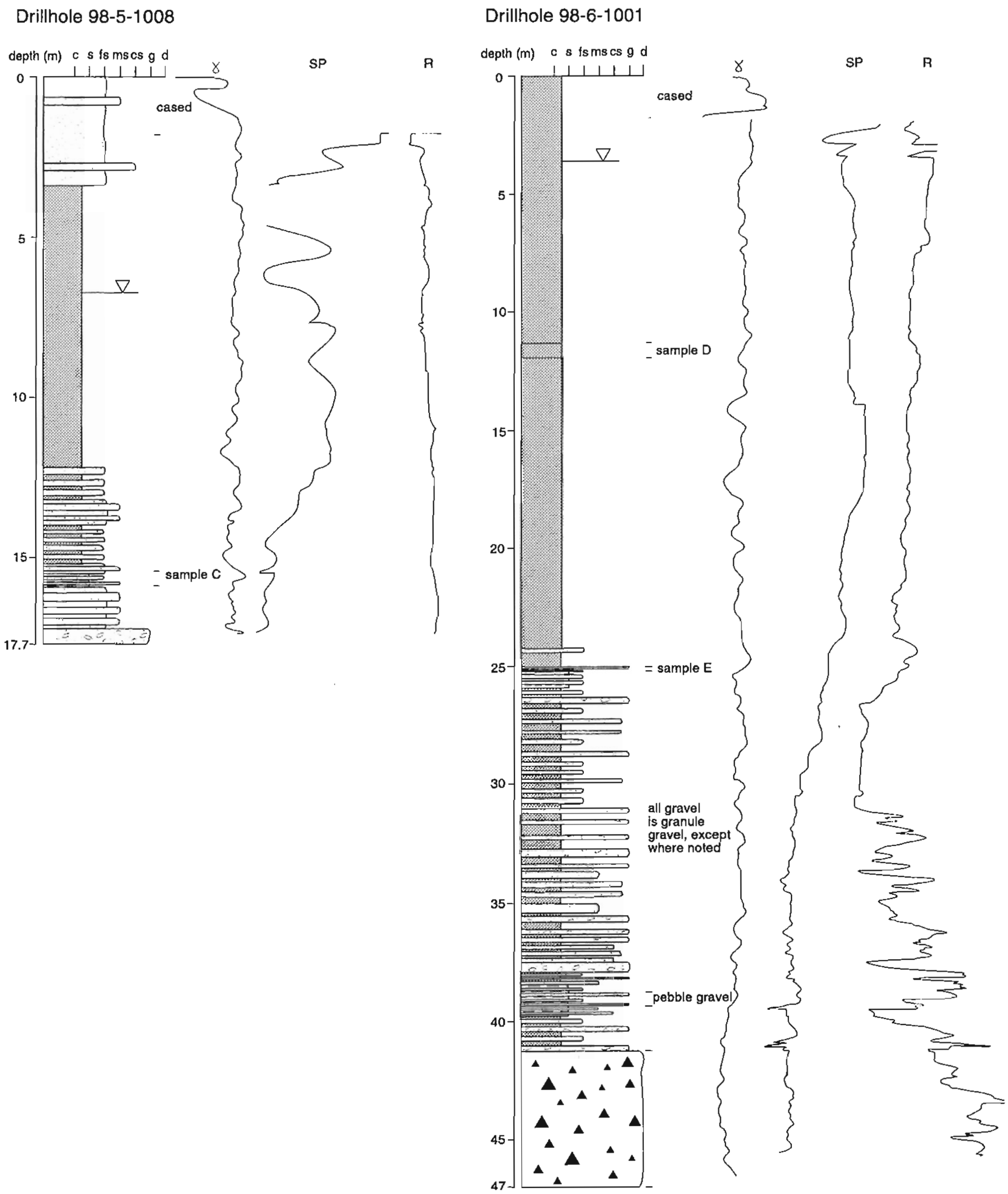

Figure 6. Drillholes 98-5-1008 and 98-6-1001, lithological logs with geophysical logs to right. Legend same as Figure 4.

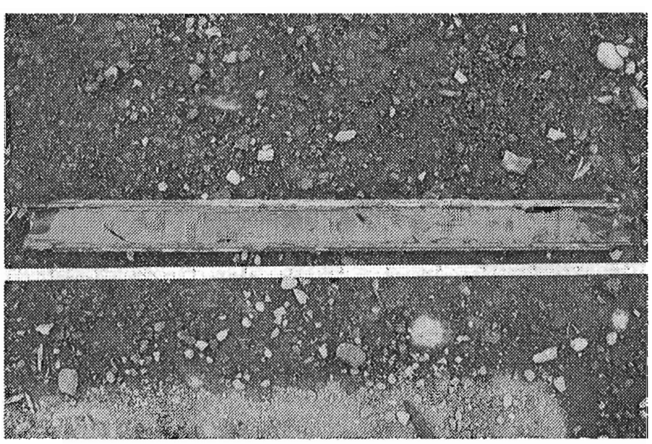

Figure 7.

Sample A, from drill hole 98-2-1005, showing massive silty clay from 9.9 to 10.45 m. No structure is evident.

The three geophysical logs are fairly uniform to a depth of 34 m (the top of the diamicton bed), at which point they deviate or disappear entirely (Fig. 4). The diamicton bed is distinctly different from the strata above. The deflections in the upper part of the R log indicate that the water table was encountered at 5 m, thus the electrical logs above this point are unreliable. All logs are more or less uniform, so there is no major upward fining or coarsening in the sequence.

Interpretation

Actively flowing ice deposited the compact diamicton, which is interpreted as till due to its compact nature, poor sorting, and striated clasts (all visible in the plugged drill bit). It is very similar to Kwinatahl till, a lodgement till common in the area (McCuaig, 1997). Formation of the diamicton by rainout is possible, but is considered unlikely due to the highly compacted nature and high matrix-to-clast ratio of the till.

The fine-grained sediment beds within the silty clay are interpreted as the tail end of sediment flows from either valley-side fan deltas or from subglacial meltwater influx at a grounded ice margin. Beds do not show any upward fining, thinning, or coarsening trend, so it is difficult to say which source area interpretation is correct for this hole.

The massive nature of the silty clay itself indicates continuous and fairly rapid deposition of rock flour that settled from suspension during the marine phase of deposition. It represents the homogeneous 'bergstone mud' environment distal to the tidewater front in fiord systems (Powell and Molnia, 1989). However, dropstone influx is not evident here, and quiet deposition occurred for a long enough period of time to accumulate 35 m of fine-grained sediment.

Drill Hole 98-3-1013

Additional description

This drillhole is at the edge of a major clay-gravel gradational contact at the surface, and the intent of drilling this hole and the next was to delineate the subsurface nature of this contact. The western portion of the contact area is a large surficial clay unit, whereas the eastern portion is mapped as a glaciofluvial braidplain with localized earthflows.

Interpretation

The silty clay at this site represents the same glaciomarine clay as that of the previous drillhole. Since there is no gravel, the subsurface contact was not encountered here (Fig. 5).

Drill Hole 98-4-1014

Additional description

This site consists of four drillholes, labelled A to D, and a roadcut exposure (Fig. 5). Each one is successively further east from drillhole 98-3-1013. The exposure is in an area affected by earthflows.

Interpretation

The relationship of fluvial gravel and sand overlying marine clay is evident in Figure 5. Airphoto interpretation indicates that the sand and gravel are part of a large sandur. Drilling evidence shows that the sandur braidplain incises the marine clay, with finer, possibly overbank, coarse-grained sands on top and at its edge (Fig. 5). Further reconnaissance in the area revealed the presence of thin, localized overbank fines (fine sand) overlying marine clays just west of, and also south of, hole 98-3-1013. These probably represent a series of splays. Clearly, the braidplain was deposited after the marine sediments and the lower contact is erosive.

Drill Hole 98-5-1008

Additional description

This hole was drilled near the edge of a large earthflow, just west of the Nass River. It is located on a more northern part of the braidplain shown in Figure 5.

Sample C, taken at 15.5 m, unfortunately spans only a 4 cm interval (Fig. 6). However, medium-grained sand, silt, and fine-grained sand interbeds, 1 cm thick, with sharp contacts, are present in the sample. Beds are well sorted but otherwise lacking in structure.

The geophysical logs are not very informative at this site, except for the spontaneous potential (SP) log, which shows a general upward fining from 17.2 m to 12.2 m (Fig. 6). The deviations in the upper part of the SP log are probably due to the location of the water table at about 6.5 m and are considered unreliable. The resistivity (R) log is therefore unreliable to this depth as well.

Interpretation

It is difficult to tell with certainty whether the lowermost unit is gravel or diamicton, due to clast crushing during drilling. The geophysical logs do not deviate significantly enough to suggest that it is a till (as they do at 98-2-1005), so this unit is considered to be a gravel. Overlying deposits become progressively finer grained, leading to the inference that the ice margin was initially nearby but gradually withdrew, until only silty clay was deposited. The source for these sediments was probably one or more subaqueous fluvial jets. Finally, glaciofluvial (overbank?) sands were deposited over the glaciomarine clay when sea level dropped and the ice front had retreated even further.

Drill Hole 98-6-1001

Additional description

This site is located in an extensive surficial clay unit near the town of New Aiyansh (Fig. 1). The silty clay was very dry and hard compared to that of sites west of the Nass River. Coherent pieces of clay came up in the mud return, possibly due to this hardness. The diamicton at the base of the hole eventually plugged the drill bit.

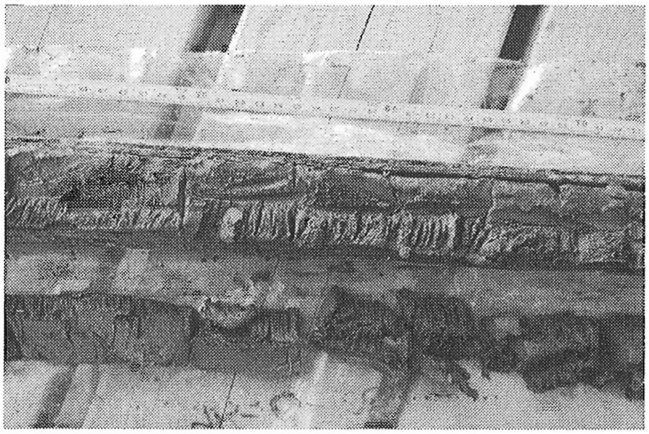

Figure 8. Sample D, 98-6-1001, laminated silty clay. This is the only location where structure was identified in silty clay.

Samples D and E were taken at 11.3 and 25 m, respectively (Fig. 6). Sample D is a finely laminated silty clay (Fig. 8). It is the only laminated example of the ubiquitous silty clay, which is also massive near the surface at this site. Sample E consists of 6 cm of angular (crushed?) granule gravel, 10 cm of silt, and 24 cm of very well sorted, fine-grained sand, with one 2 mm silt interbed. The silt is blue-grey and finely laminated, whereas the fine-grained sand is massive and dark grey.

The electric logs show the water table to be at 3.5 m. Slight deviations in the SP log and major deviations in the R log indicate a general upward-fining trend from 41 to 25 m, although it is not immediately apparent from the lithological log (Fig. 6). The R log shows a different peak pattern in the diamicton bed. The SP and R logs are also largely undeviating throughout the homogeneous clay from 24.2 to 3.5 m. As with the other holes, the gamma log is not very informative. Gamma radiation does not vary significantly in these siliciclastic sediments, possibly because they are all derived from the same source rocks or because clay minerals are rare.

Interpretation

The diamicton is interpreted as lodgement till due to its compactness, poor sorting, resistivity-log deflection, and high matrix-to-clast ratio. The till was deposited by ice of either the early or late phase of glaciation (McCuaig, 1997). The area was below marine limit when ice retreated, but the ice margin was not far away when the interbedded sand, gravel, and clay were deposited. The upward-fining trend evident in the geophysical logs indicates that ice receded from this position as these deposits were formed. These deposits are suggested to be proximal subaqueous outwash deposits. The abrupt transition to silty clay deposition is due to a rapid change to a distal depositional environment once the ice front moved away from the area (Stevens, 1990). Distal, glaciomarine, silty clay deposition continued uninterrupted at the site for some time, but was slightly episodic, resulting in a laminated silty clay in some places.

DISCUSSION

Drilling has revealed that compact Kwinatahl till (McCuaig, 1997) is overlain by proximal to distal subaqueous outwash deposits (with possible fan delta deposits) and glaciomarine silty clay. In places, outwash braidplains overlie all three units.

Since marine limit is 230 m (McCuaig, 1997), marine incursion must have occurred in the upper Nass Valley during deglaciation. Extensive, blue-grey, silty clay deposits below marine limit are related to this marine inundation. Although the clays are largely massive and contain neither macrofossils nor microfossils, other evidence points to a marine origin. The paucity of dropstones, the great thickness of clay, and the lack of fossils together suggest that sedimentation rates were very high and basinal waters were turbid. Barren sediment is common in modern tidewater glacier fiords in Alaska (Cowan et al., 1997), where sedimentation rates are high. Iceberg deposition may have simply been swamped by subglacial outwash deposition, a situation known to be common in modern tidewater fiords (Molnia, 1983) and in both proximal and distal glaciomarine deposits of the last glaciation (Stevens, 1990). In fact, Stevens (1990) describes dropstones only in "very distal" glaciomarine sequences (100 km from the ice front). In addition, earthflows are common, both in marine sediments near Terrace (Clague, 1984) and in Nass Valley clay deposits the shear strengths of Nass Valley clays are extremely low (Geertsema, 1998), a common characteristic of marine quick clays. Liquefaction of the clay by vibracoring further indicates a quick clay tendency. Furthermore, salt crusts identified in Nass Valley silty clays (M. Geertsema, pers. comm., 1998) are similar to those in earthflow glaciomarine clays near Terrace. These salt crusts are used as salt licks by domestic and wild animals in some parts of the valley. However, they are not associated with glaciomarine clays everywhere. Marine fossils and dropstones are present in glaciomarine clays of the Terrace area, but natural salt licks are not found in all of those glaciomarine sequences (Clague, 1984).

It is concluded, therefore, that the Nass Valley silty clays are distal glaciomarine deposits related to the 230 m sea-level highstand. Coarser grained sediments are proximal glaciomarine deposits that formed prior to distal clay deposition. Some silty and sandy interbeds may have been deposited as distal facies by fan deltas in basinal areas near the valley edge.

Considering the great width of the valley (10–15 km), deposition of 25–35 m of fine-grained sediment indicates an immense amount of clastic influx. Since the majority of silty clay deposits are massive, it is possible that deposition was continuous. However, the presence of laminations in sample D (Fig. 8) indicates minor pauses in deposition. It is possible that the massive nature of Nass Valley clays is due to liquefaction, since laminated structures are absent at the vast majority of sites, and the clays are known to be readily liquefiable (Geertsema, 1998).

At some later time, sea level dropped to 150–160 m (McCuaig, 1997), where it remained for some time. The ice margin was well inland by this point. Two glaciofluvial outwash plains flanking a bedrock high formed (one of which was drilled), incising the marine clay deposits and debouching into marine water in the vicinity of New Aiyansh. Deltas formed at the south end of each outwash plain are currently being investigated with seismic-reflection and ground-penetrating-radar data.

Fiords in northern British Columbia generally show the same depositional sequence as that seen here: till overlain by interbedded ice-contact deposits and capped by glaciomarine mud (McCann and Kostaschuk, 1987). All evidence points to continuous, rapid retreat of ice in the Nass Valley. Our drilling did not detect morainal banks or subaqueous fan ridges indicative of a stillstands during glacial retreat. Powell (1981) describes several facies associations for fiord type deposition. The one that best describes the sediment package of the Nass Valley is "Facies Association I: facies of rapidly retreating tidewater glaciers with ice fronts actively calving in deep water". In this scenario, till, gravel, and sand are deposited at the ice front. Subglacial meltwater deposits gravel and sand that fine distally to laminated sand and mud. Mud (possibly with dropstones) is deposited beyond this zone, but intertongues with it. The lack of dropstones in the study area could be due to excessive rock-flour deposition or due to warm-water conditions causing potentially small icebergs of the valley glacier to melt within 5–10 km of the glacier (Powell, 1984). Ice rafting has been shown to be a very minor component of clastic influx in Alaskan fiords today (Molnia, 1983).

Input of coarse-grained debris by fan deltas is not commonly identified in modern fiords. This could be because ice-proximal deposits are the major sediment producer or perhaps because fan deltaic deposition has simply been overlooked.

The Nass Valley basin is quite different from that of the Terrace–Kitimat–Skeena area to the south. However, fiord depositional processes are affected by a number of parameters, including topography, climate, and glacial history. It is not uncommon for basin fills to be unique to individual fiords (Syvitski, 1993). Although macrofossils are common in glaciomarine clays of the Terrace area, they are much rarer in Alaska. Stillstands during glacial retreat occurred in the Terrace–Kitimat area where bedrock ridges and narrowing of the valleys to 3–5 km wide provided pinning points (Clague, 1984). The Nass Valley in the study area is wide and there are there are no such pinning points. Constrictions do occur east of a major bedrock ridge north of New Aiyansh and down-valley near the mouth of the Nass River, but any sediment accumulations that may have formed at these locations are now covered with glaciofluvial and fluvial deposits, respectively.

CONCLUSION

Data derived from drilling has shown that glaciers flowing in the Nass Valley deposited compact, clay-rich Kwinatahl till. Ice subsequently receded and marine water invaded the isostatically depressed landscape to a height of 230 m a.s.l. The valley glacier retreated continuously, apparently experiencing no stillstands. Near the receding ice margin, subaqueous jets deposited alternating beds of silty clay, sand, and gravel that fine distally. As ice continued its retreat, basinal areas farther down-valley received only silty clay input, with or without local turbidite influx of slightly coarser grained debris from fan deltas or subaqueous outwash. Subaqueous ice-proximal deposition continued up-valley at the ice margin.

Later, ice left the valley entirely and marine limit dropped to 150–160 m a.s.l. Two large glacial rivers fed by meltwater developed on either side of a small bedrock rise in the valley centre. These formed wide braidplains and incised the exposed glaciomarine clays, depositing gravel and sand on the clay. Down-valley, marine water was still present and the rivers flowed into it, forming braid deltas. Marine water eventually withdrew entirely from the valley and modern river incision began. Where braidplain gravel and sand overlie clay and are undercut by stream erosion, earthflows have formed.

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M. Newman Bennett and E. Roberts were able drilling assistants. The Nisga'a Tribal Council kindly granted permission to drill in proposed land claim areas. L.E. Jackson, J. MacEachern, and J.L. Luternauer also provided thoughtful reviews of a draft of this paper. Funding was provided by Simon Fraser University, M.C. Roberts (NSERC operating grant), and Terrain Sciences Division of the GSC.

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Geological Survey of Canada Project 930043

Preliminary report on mapping surficial geology of Trutch map area, northeastern British Columbia[1]

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Bednarski, J., 1999: Preliminary report on mapping surficial geology of Trutch map area, northeastern British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 35–43.*

Abstract: Field investigations have started on mapping the surficial geology of the Trutch map area, northeastern British Columbia, as part of the Central Forelands NATMAP Project. Glacial geomorphology and erratic dispersal shows that this area was extensively glaciated by Cordilleran ice, originating from the mountains and foothills in the west, and by Laurentide ice from the east. In places, the western advance predates the last Laurentide advance that reached the mountain front. In other places, Laurentide and Cordilleran advances may have been synchronous. During deglaciation, the retreating Laurentide Ice Sheet blocked drainage and extensive proglacial lakes formed on the plains and in the mountain valleys.

Various types of mass movements are common in the area because of steep slopes and a weak substrate. The surficial mapping program includes mapping these features to provide a database for risk assessment.

Résumé : Les études de terrain ont débuté en vue de cartographier la géologie des dépôts de surface dans la région cartographique de Trutch, dans le nord-est de la Colombie-Britannique, dans le cadre du Projet de l'avant-pays central du CARTNAT. La géomorphologie glaciaire et la dispersion des blocs erratiques montrent qu'une grande partie de la région a été envahie par les glaces de l'Inlandsis de la Cordillère en provenance des montagnes et des piémonts dans l'ouest et celles de l'Inlandsis laurentidien en provenance de l'est. Par endroits, l'avancée des glaces de l'ouest est antérieure à la dernière avancée de l'Inlandsis laurentidien qui a atteint le front de la montagne. À d'autres endroits, l'avancée de l'Inlandsis de la Cordillère et celle de l'Inlandsis laurentidienne ont peut-être été synchrones. Au cours de la déglaciation, l'Inlandsis laurentidien en retrait a bloqué le drainage, ce qui a donné naissance à de vastes lacs proglaciaires qui se sont formés sur les plaines et dans les vallées des montagnes.

Des mouvements de masse de divers types se produisent fréquemment dans la région en raison de la présence de fortes pentes et de la faiblesse du substratum. Le programme de cartographie des dépôts de surface porte sur ces éléments et vise à constituer une base de données destinée à l'évaluation des risques naturels.

[1] Contribution to the Central Forelands NATMAP Project

INTRODUCTION

Part of the Central Forelands NATMAP Project involves mapping the surficial geology of the Trutch map area NTS 94 G (Fig. 1). This work includes detailed studies of stratigraphy, geochronology, and till dispersal related to interaction of Laurentide and Cordilleran ice sheets along the Rocky Mountain front. The mapping encompasses an inventory of granular resources and potential landslide hazards. The primary outputs will be a 1:250 000 scale map of surficial geology and relational databases. The databases will be compatible with bedrock maps and geophysical databases under a GIS standard.

Investigations began during the 1998 field season with extensive helicopter surveys of the mountainous western part of the map area and reconnaissance on the Interior Plains to the east. A review of current knowledge and essential findings related to the Quaternary history are presented here.

Physiographic setting

The Trutch map sheet straddles the Rocky Mountains, Rocky Mountain foothills, and Interior Plains (Fig. 1). The Muskwa Range, trending along the western edge of the map area, approaches 2800 m in elevation. This contrasts with the rolling plains of the Alberta Plateau, part of the Interior Plains comprising the eastern half of the map area that are less than 900 m a.s.l. The eastern edge of the Muskwa Range defines the easternmost fault on which Paleozoic rocks, as old as the Cambrian, that are thrust over folded Triassic units comprising the Rocky Mountain foothills (Holland, 1964). Longitudinal fold- and fault-controlled valleys trending northward characterize the mountains and foothills. Generally, the mountainous western part has been extensively modified by alpine glaciers and the intensity of glacial erosion decreases eastward across the foothills. The highest peaks in the southwest part still harbour small glaciers in north-facing cirques. The transition from the foothills to the plains is abrupt.

Large east-trending valleys crosscut the longitudinal valleys through the foothills every 15–25 km. Major rivers such as the Muskwa, Prophet, Sikinni Chief, and Halfway flow eastward through the crosscutting valleys onto the Alberta Plateau from headwaters in the Rocky Mountains. Many of the upper tributaries change their direction several times, as they exploit the crosscutting pattern of the valley systems. It is evident that the rivers and creeks have experienced several generations of stream piracy.

Both the eastern foothills and Alberta Plateau bear remnants of several eastward-dipping erosional surfaces. The oldest surface may be Miocene (Williams, 1944), however, there has been only one reported occurrence of preglacial gravel, located north of the Sikinni Chief River near the Alaska Highway (Denny, 1952). Larger deposits of preglacial gravels lie southeast of Trutch in the Charlie Lake area (Mathews, 1978). The Alberta Plateau is underlain by thick sequences of sandstone and shale of Cretaceous age that are flat-lying or dip gently eastward, except for a folded belt immediately east of the foothills. On the plains, the drainage swings to the northeast, into the Liard River system, part of the Mackenzie River drainage basin. The topography is characterized by low plateaus and cuestas dissected by the major rivers (Fig. 1). Resistant sandstone units of the upper Cretaceous Dunvegan Formation form prominent cliffs, whereas, most low areas and major valley bottoms are underlain by recessive shales of the Fort St. John Group. In the extreme northeast part of map area, erosion by the Muskwa, Prophet, and Sikanni Chief rivers formed the Fort Nelson lowland. The lowland is very flat and poorly drained with extensive muskeg terrain, less than 600 m a.s.l.

Previous work

The fact that the mountains of north-central British Columbia have been extensively glaciated in the past has been known since Dawson's time (Dawson, 1888, 1890). Dawson (1888) proposed the term "Cordilleran Glacier" for a mountain ice sheet centred between 55°N and 59°N, flowing to the northwest and southeast. Subsequently, distinct stages or types of glaciation have been recognized in northern British Columbia. Several workers have postulated a progressive expansion of ice from alpine cirque glaciers, to valley glaciers, to mountain ice caps, to a regional ice sheet whose movement was independent of the underlying topography (e.g. Kerr, 1934; Armstrong and Tipper, 1948). Alpine glaciers sculpted cirques around the summits, whereas, through valleys were eroded by outlet glaciers moving from alpine accumulation areas. During deglaciation, the stages were presumably reversed: as the Cordilleran Ice Sheet waned, it was succeeded by alpine and cirque glaciation, developing associated landforms.

In general, northeastern British Columbia was affected by three major glacial systems at various times. Major glaciation occurred by continental Laurentide ice, which advanced from the north and east and deposited erratics from the Canadian Shield. Secondly, local glaciation occurred when coalescent montane ice, originating from numerous cirques and ice fields in the Rocky Mountains and foothills, flowed down trunk valleys, reaching the mountain front. The third style of glaciation was by Cordilleran ice, which originated in the interior of British Columbia west of the Rocky Mountain Trench and flowed eastward across the topographic trend of the mountains onto the plains (Mathews, 1978, 1980). Each of the glacial systems had distinctive source areas that can be identified by ice-flow patterns and diagnostic erratics (Fig. 2). Nevertheless, there has been some disagreement about the spatial and temporal interaction of these three glacial systems (cf. Bobrowsky and Rutter, 1992).

On the plains, the Laurentide Ice Sheet reached the Rocky Mountain front during past glaciation(s). This is indicated by distinct red granite and gneiss debris originating from the Canadian Shield. However, in Peace River country, Beach and Spivak (1943) suspected that some erratics may have entered valleys at the mountain front by ice rafting westward across proglacial lakes from the Laurentide ice margin. Mathews (1980) noted that till and outwash derived from

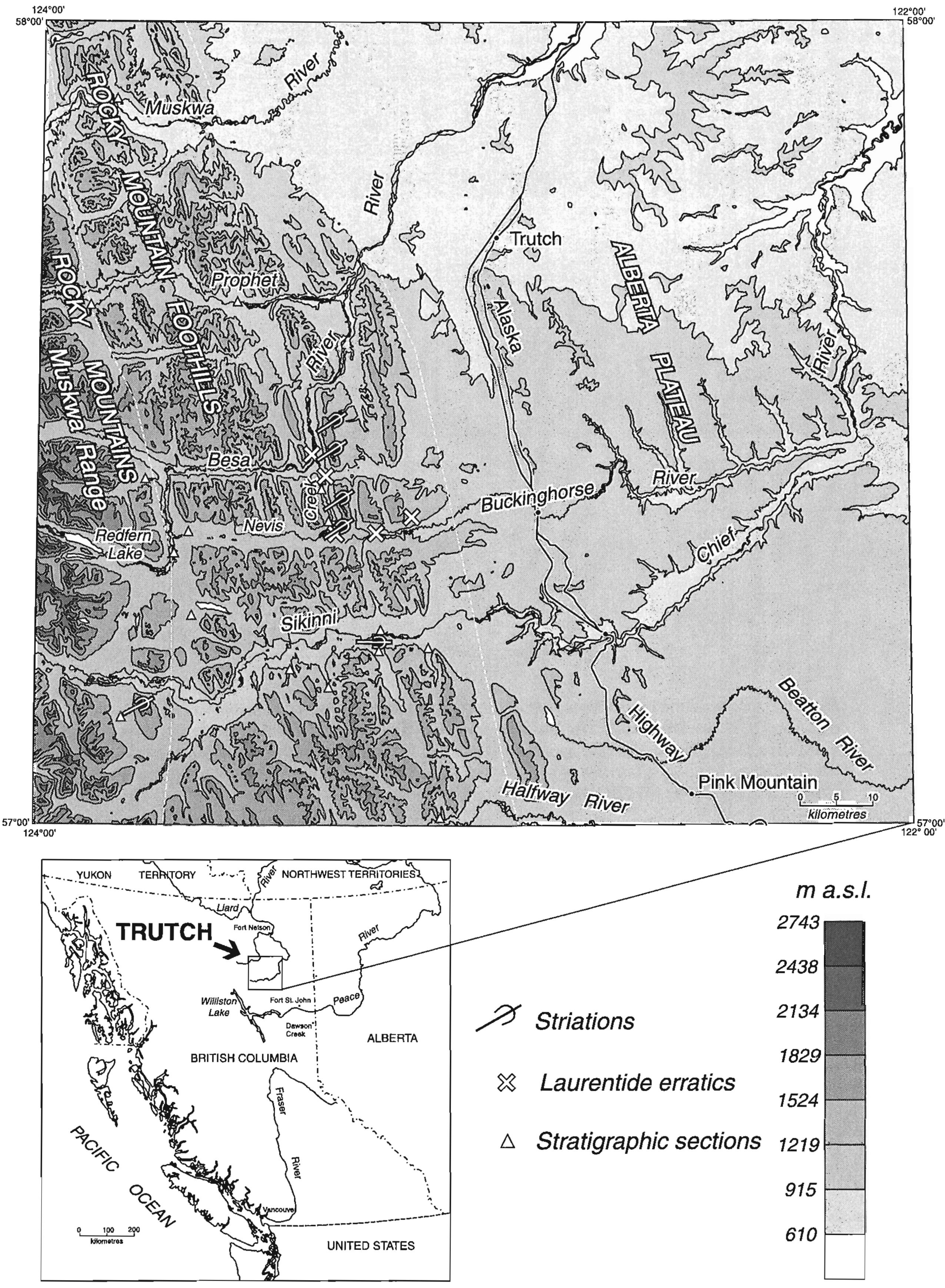

Figure 1. *Location of Trutch map area (NTS 94 G) with place names and physiography. The Rocky Mountains, Rocky Mountain foothills, and Alberta Plateau are delineated by the dashed line. The Prophet and Sikinni Chief river valleys below 610 m a.s.l. are part of the Fort Nelson lowland.*

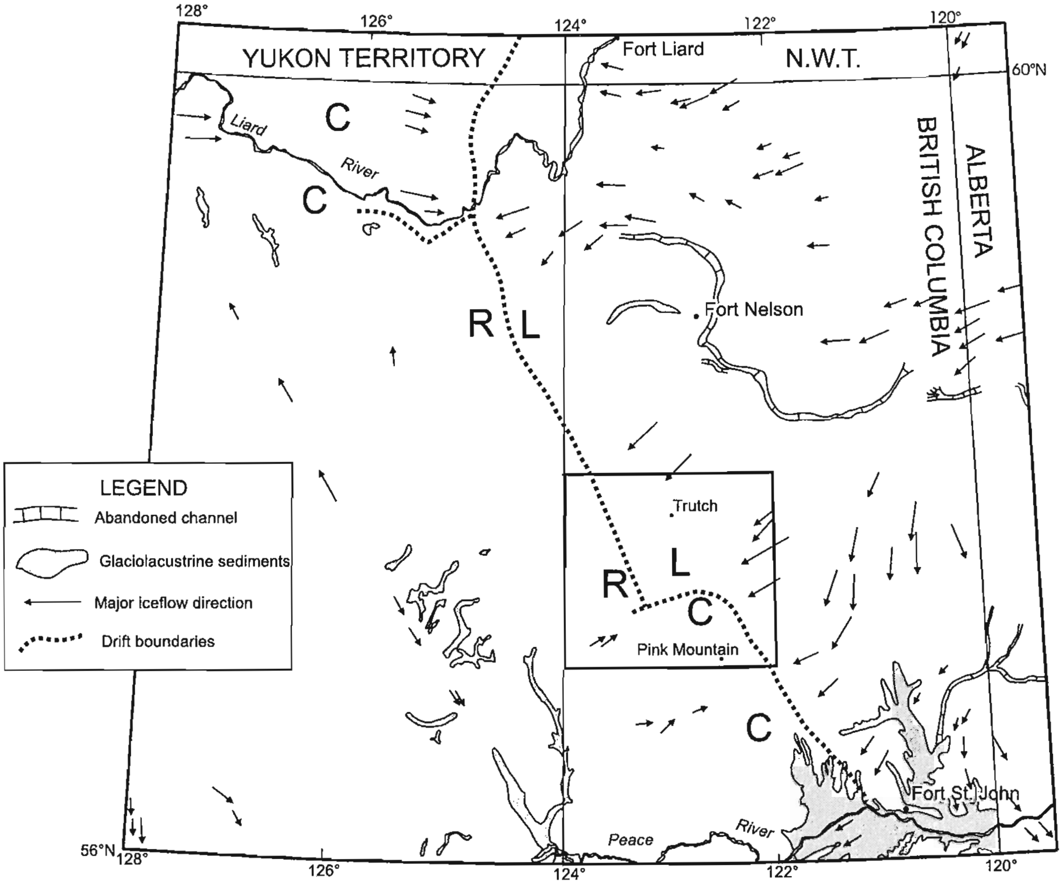

Figure 2. Glacial limits in northeastern British Columbia as mapped by Mathews (1980). Three distinct drift sheets were identified based on provenance: C, drift of western origin deposited by Cordilleran ice, R, local Rocky Mountain drift, and L, drift deposited by the Laurentide Ice Sheet. The Williston Reservoir, occupying the Rocky Mountain Trench, is not shown on this map. The Trutch map area (box) lies at the junction of all three drift types.

Cordilleran ice occasionally contains shield erratics that may have been initially deposited by a more extensive Laurentide ice sheet before the last glaciation.

Armstrong and Tipper (1948) recognized at least two large advances of Cordilleran ice from accumulation areas on the Coast Mountains. Based on ice-flow patterns, Tipper (1971) thought that there were at least two, possibly three, major glaciations in the area. During the last, Fraser Glaciation (Late Wisconsinan), ice was thought to have accumulated in the Coast and Cariboo mountains, flowed into the interior as a piedmont glacier, and then northeasterly as an ice sheet toward the Rocky Mountains. A limited readvance of the Cordilleran Ice Sheet occurred during Fraser deglaciation. Tipper (1971) did not believe that a central ice dome existed over central British Columbia during the Fraser Glaciation. He considered glacial erosional features and erratics at elevations above the level of the Fraser Glaciation, such as those cited by Mathews (1946, 1963), were caused by a major ice dome dating from an earlier glaciation(s). Nevertheless, Mathews (1963, 1980) thought that the Cordilleran ice that crossed the Rocky Mountains near Fort St. John, reaching at least 1830 m a.s.l., was late Wisconsinan.

Hage (1944) and Denny (1952), in working along the Alaska Highway between Fort St. John and Fort Nelson, noted that two distinct tills were separated by bedded clays up to 15 m thick. The lower till was marked by quartzite and sandstone pebbles, whereas the upper till had an abundance of igneous and metamorphic pebbles and boulders. This shows that at least one major Cordilleran and Laurentide advance were not synchronous. Nevertheless, in exposures along the north bank of Peace River, Mathews (1978) identified a single till sheet near the surface that he attributed to "late or 'Classical' " Wisconsinan glaciation (Mathews, 1980, p. 4). The continuous till sheet had Cordilleran lithologies in the west and Laurentide lithologies in the east, which led Mathews (1978, 1980) to conclude that Cordilleran and Laurentide ice masses were contemporaneous and coalescent during the last glaciation. Thus, minor changes in glacier regime caused the contact line between Laurentide and Cordilleran ice to fluctuate along a narrow overlapping zone. A subsequent Cordilleran readvance was thought to have occurred near the Sikinni Chief River after the Laurentide Ice Sheet retreated from its maximum position during the last glaciation. Deglaciation caused major flooding of the Fort Nelson lowland which discharged into the Liard and

Mackenzie rivers via outlets and meltwater channels (Mathews, 1980). Figure 2 shows the limits of Cordilleran, local Rocky Mountain, and Laurentide tills as mapped by Mathews (1980).

In contrast, Catto et al. (1996) examined stratigraphy and radiocarbon dates in the Peace River–Grand Prairie area and concluded that no contact between Cordilleran–Montane and Laurentide ice occurred during the entire Quaternary. They concluded that an extensive pre-Late Wisconsinan Cordilleran advance (>51 ka) was followed by a Late Wisconsinan Laurentide advance after ca. 22 ka. When the Laurentide ice retreated, a restricted montane ice advance occurred within major outlet valleys such as the Peace River.

GLACIAL GEOMORPHOLOGY

Glacial deposits in the Trutch map area reflect the three styles of glaciation that affected northeastern British Columbia, outlined above. The Alberta Plateau is covered by various thicknesses of till containing shield erratics deposited by the Laurentide Ice Sheet during the last glaciation. Most of the plateau is sparsely covered by till, although Hage (1944) reported glacial drift up to 222 m thick from well data near Fort Nelson, and tens of metres thick along the Prophet River. More commonly, Dunvagen Formation sandstone outcrops on the plateau uplands, but thicker till is found in lowlands and to the west near the mountain front. The predominant flow direction by the Laurentide Ice Sheet over the Alberta Plateau is shown by southwest-oriented flutings on the east side of the map area (Fig. 2).

The Laurentide Ice Sheet did not leave extensive moraines or outwash deposits marking its advance or retreat over the Alberta Plateau, however, meltwater channels and spillways related to drainage blocked by the ice sheet, are common. When the Laurentide Ice Sheet blocked drainage to the northeast, extensive glaciolacustrine sediments were deposited throughout the lowlands and stream valleys. Today, many valleys have very flat bottoms filled with glaciolacustrine sediments. Near the Alaska Highway, the Sikinni Chief River is deeply incised, and exposes up to 15 m of bedded clay overlain by gravels. Similar thicknesses of glaciolacustrine deposits were reported along the Beatton, Halfway, Minaker, and Prophet river valleys (Hage, 1944; Denny, 1952). Distinct varves were not found outside the mountain front during the current fieldwork, but Hage (1944) described at least 100 varves in the Beatton River valley. Denny (1952) reported varves along the Alaska Highway near the Sikinni Chief and Prophet rivers.

It is clear that large areas of glaciolacustrine sediment form the uppermost unit and probably date from recession of the Laurentide Ice Sheet. Nevertheless, the stratigraphic relationship of all glaciolacustrine exposures outside the mountain front is yet to be established. Hage (1944) noted that lake deposits exposed along the Halfway and Minaker rivers, and for 160 km south of Fort Nelson in the Prophet River valley, all rest on Montane till. This was not yet confirmed by this study; however, the same stratigraphic relationship was found in the upper Sikinni Chief River (Fig. 3) and several other valleys in the foothills.

The extent of the Laurentide Ice Sheet during the last glaciation can be inferred from the westernmost extent of surface till containing abundant shield erratics. Along the Alaska Highway, shield boulders are uncommon from Pink Mountain to Sikinni Chief, but pebbles and boulders of granite and gneiss become abundant in till from the Buckinghorse River northward. The large increase of shield erratics at the Buckinghorse River coincides with the westernmost extension of Laurentide till into the mountain front. During this study, the western limit of till containing abundant shield erratics was mapped along the upper Buckinghorse River where Laurentide ice apparently pushed into the mountain front (Fig. 1). On the north side of the valley mouth, the uppermost level of granite and gneiss-rich till lies at 1380 m a.s.l. Sandy till and outwash containing granite pebbles outcrops about 5 km

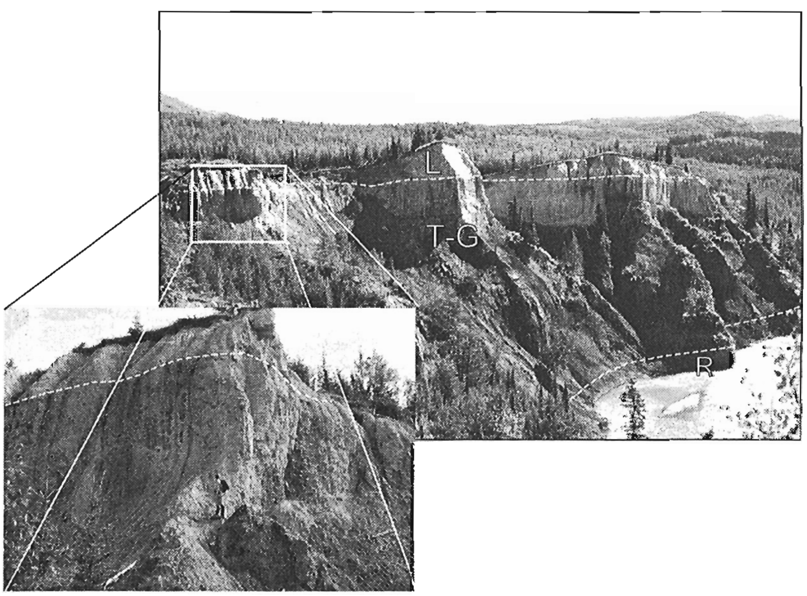

Figure 3.

Stratigraphic section along the upper Sikinni Chief River. Dark shale (R) is overlain by a thick complex of glacial till (T) and ice-contact stratified drift (G), in turn, overlain by the uppermost unit, glaciolacustrine silt (L). The ice advanced from the foreground to the horizon, downvalley. Note the person standing beside the exposure in the inset, for scale.

upvalley on the valley bottom at 1234 m a.s.l. For about 12 km upvalley, shield erratics are abundant on the surface and up to an elevation of 1360 m, but granite till is absent. In these cases, the shield erratics may have been ice-rafted up the valleys. Erratics were also redeposited by stream transport. For example, the upper Buckinghorse River has been pirated by Nevis Creek, which transported shield erratics northward to Besa River, albeit to lower elevations.

The relative decrease in shield erratics south of Buckinghorse River, led Mathews (1980) to suggest that there may have been a late readvance of the Cordilleran ice onto the plains, effectively diluting the pre-existing Laurentide till with Cordilleran till. According to Mathews (1980), the Buckinghorse River also coincides with the southern end of local Rocky Mountain glaciation. Mathews' zone of local glaciation extends northward for 245 km to the Liard River (Fig. 2). Till within this zone is composed of only local rocks, with no diagnostic Cordilleran erratics. Nevertheless, this study shows that Cordilleran ice covered this area, probably during the last glaciation. North of the upper Buckinghorse River, striations measured along mountain crests up to 1860 m a.s.l., suggest that Cordilleran ice inundated the foothills in this area (Fig. 1). Moreover, the measured east-northeastward flow runs across the major topographic trend, implying that a significant thickness of ice flowed across the ranges, unimpeded by topography. Striated bedrock with the same flow direction also occurs at lower elevations, within the zone of Laurentide erratics in the upper Buckinghorse

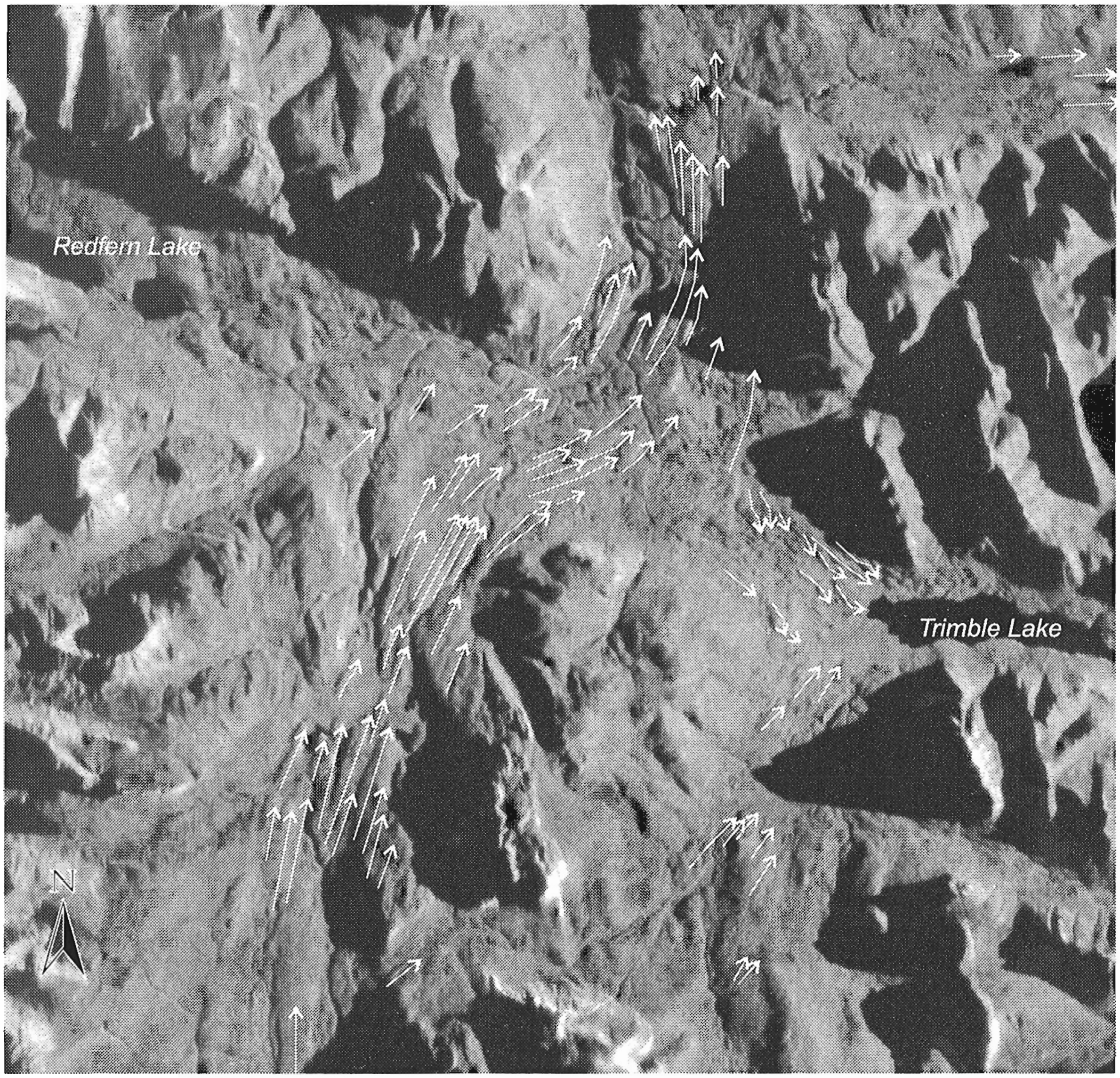

***Figure 4.** Drumlin and flutings, west of Redfern Lake in the Besa River valley, formed by the Cordilleran Ice Sheet during a stage in deglaciation when the underlying topography influenced glacial flow, diverting flow to the north. With further deglaciation, the ice was diverted eastward, through the valley now occupied by Trimble Lake (STAR-1 radar image courtesy of Crestar Energy Inc.).*

River valley. If the upper and lower striations are of the same age, this implies that the Laurentide erratics were deposited after the Cordilleran advance. Samples of the upper striated bedrock were collected for ^{36}Cl exposure dating.

Mapping in the Trutch map area supports the conclusions of early workers, that Cordilleran glaciation went through progressive stages of build up and decay during the last glaciation. This hypothesis implies that the late glacial presence of local ice does not preclude previous ice cover by the Cordilleran Ice Sheet during the last glaciation. During the onset of glaciation, there was undoubtedly growth of local cirque glaciers, which eventually fed valley systems. At later stages, however, this system was overwhelmed by expanding Cordilleran ice from the west and the combined ice mass was thick enough to flow across the foothills unimpeded by topography. Thus, high-level striae on the summits of foothills were made during the last glacial maximum by Cordilleran ice, although the tills at lower elevations are predominantly of local origin. Moreover, diagnostic erratics of Cordilleran till may not have been preserved everywhere. These are predominantly friable pebbles of slate and schist, derived from Hadrynian exposures along the Rocky Mountain Trench (Mathews, 1980), and they may have been extensively comminuted during glacial transport.

During deglaciation, as the Cordilleran ice thinned, the underlying topography exerted greater control on glacial flow. This is evidenced by drumlin and fluting fields within Rocky Mountain valleys (Fig. 4). In some areas, drumlin and fluting fields crosscut one another, suggesting large swings in flow directions as the ice thinned. Eventually, the diminished Cordilleran ice would acquire the character of alpine glaciation as a system of cirque-fed valley glaciers. At this stage, western till, originating from the Rocky Mountain Trench and beyond, was no longer transported to the map area. In the final stages of deglaciation, the valleys became ice free and only cirque glaciers remained. During the Holocene most of the cirque glaciers have completely ablated.

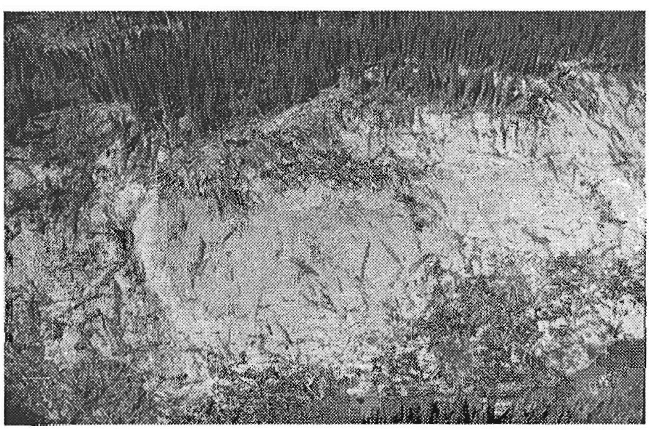

Figure 5. Photograph of a large slump along a cutbank of the lower Sikinni Chief River, were it is deeply incised into the Alberta Plateau. The valley bottom is underlain by recessive shale that readily destabilizes the overlying sandstone.

STRATIGRAPHY

Most of the stratigraphic sections logged during the fieldwork relate to the advance and retreat of montane ice within the valleys (Fig. 1). In general, these involve thick sequences of outwash, ice-contact stratified drift, till, and glaciolacustrine sediments. For example, thick sections along the upper Sikinni Chief River show a lower dark, indurated gravel, overlain by a dark, silty diamicton, in turn, overlain by a bedded diamicton (Fig. 3). The whole sequence is capped by laminated silt. It is apparent that the upper Sikinni Chief River valley was dammed to the east after mountain ice retreated from the area. Several sections within crosscutting valleys are topped by glaciolacustrine silt, suggesting that Laurentide ice was blocking drainage at or near the mountain front at this time. As noted above, shield erratics overlying Cordilleran striations suggest that a the Cordilleran ice advanced prior to the Laurentide ice reaching the mountain front. Nevertheless, stratigraphic sections showing both Laurentide and mountain glaciations, as shown by Hage (1944), have not yet been found during this study.

Outside the mountains on the Alberta Plateau, stratigraphic sections of Quaternary sediments tend to be poor because of excessive slumping. Much of this area is underlain by thick recessive shale and the banks of most rivers are covered by colluvium. This is particularly true of the deeply incised Buckinghorse and Sikinni Chief rivers, where whole forests are slumping into the river (Fig. 5).

MASS WASTING

The Trutch map area is underlain by thick sequences of interbedded sandstone and shale that are prone to failure. Various types of mass movements are common reflected by distinct landforms. These features range in size and rapidity, as well as age. Both active and relic landforms are common; suggesting that activity has been relatively steady throughout postglacial time. Rapid, catastrophic failures such as mudflows and debris flows are usually restricted in size, occurring on mountain slopes. A very large landslide-earthflow along Besa River represents the other end of the spectrum. This feature, approximately 7 km^2, probably has been mobile for decades. Large slabs of forested bedrock are sliding over a slowly deforming substrate.

Large catastrophic failures have also occurred in the area. For example, a particularly large landslide occurred along in a tributary valley to the Halfway River sometime during the spring of 1998 (Fig. 6). The side of the valley failed along a steep slope (25°) and sent debris, including huge sandstone blocks for distances up to 1.25 km, filling the valley bottom. The landslide covers an area of 0.4 km^2 and currently dams a small lake upvalley. These events obviously pose a significant hazard and their occurrence unpredictable. Aerial photographs, taken years before the landslide, do not show any signs of the impending event. An objective of this project is to try to evaluate areas of potential landslide hazards.

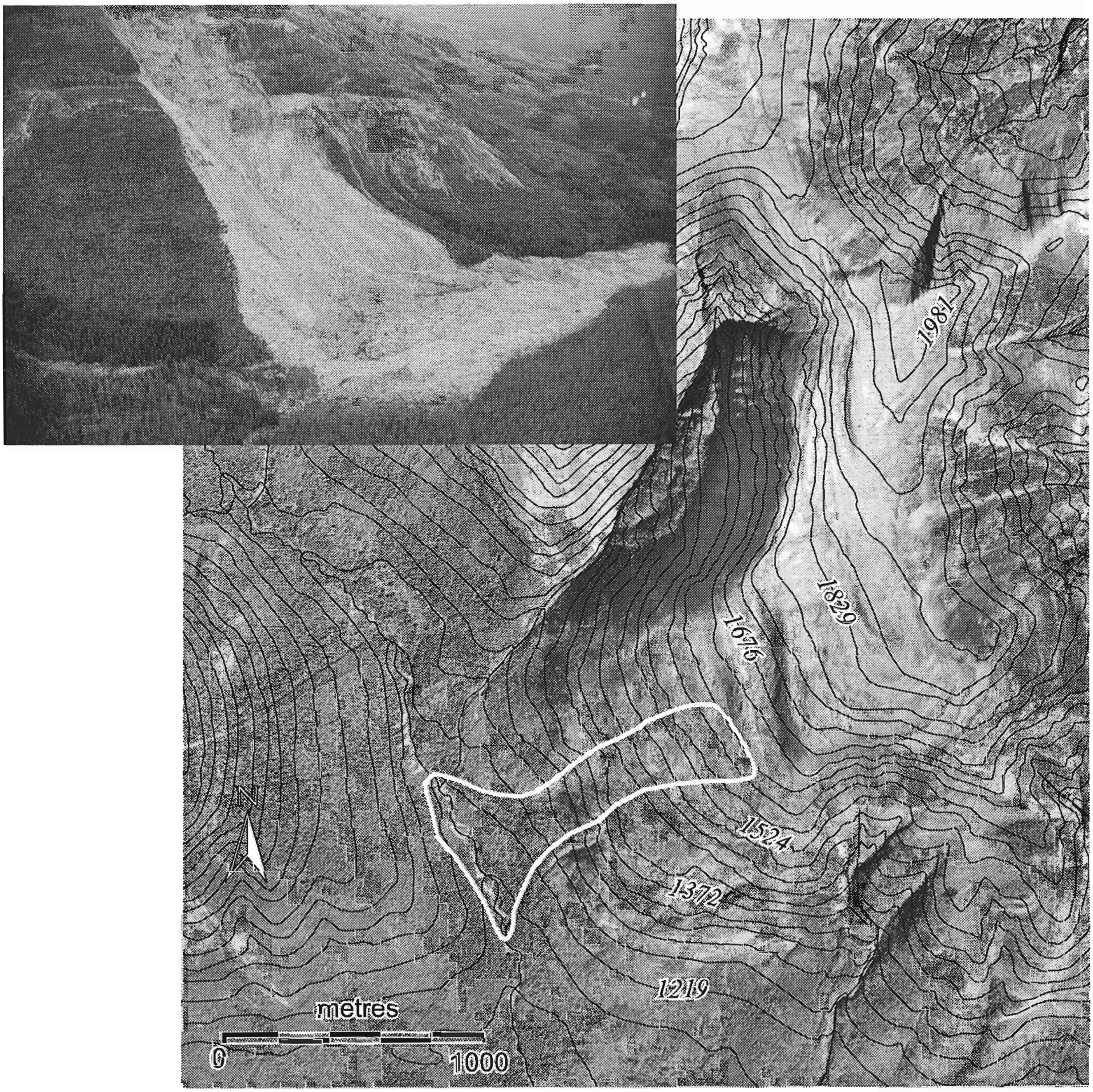

Figure 6. Map and photographs are of a catastrophic landslide in a tributary valley to the Halfway River. The photograph is looking to the southeast. The contour interval is 30.5 m (100 feet). The cropped aerial photograph is NAPL A17165-22.

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Geological Survey of Canada Project 980004

Conodont faunas and Upper Triassic stratigraphy, Trutch map area, northeastern British Columbia[1]

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Orchard, M.J., 1999: Conodont faunas and Upper Triassic stratigraphy, Trutch map area, northeastern British Columbia; in *Current Research 1999–A; Geological Survey of Canada, p. 45–50.*

Abstract: Archival Triassic conodont collections from Trutch map area (NTS 94 G) are documented as part of the Central Foreland NATMAP Project. Two Ladinian collections come from the Toad Formation but all others come from Upper Triassic Baldonnel and Pardonet formations. The discrimination of Upper Triassic units is problematic in the eastern foothills where the character of the Pardonet Formation differs from that in its type area on Williston Lake. The base of the Pardonet Formation is a transgressive surface that generally approximates the Carnian–Norian boundary. In central Trutch map area, the Pardonet Formation includes Lower to lower Middle Norian cliff-forming limestones that have been confused with both the Baldonnel and Bocock formations. These Pardonet Formation carbonates largely predate the informal unit P4 in the Sukunka region subsurface, and are believed to have developed in relatively shallow water during a lowstand that preceded a Middle Norian transgression. Both Norian flooding events are marked by abundant *Norigondolella.*

Résumé : Les assemblages archivés de conodontes du Trias provenant de la région cartographique de Trutch (SNRC 94 G) ont été étudiés dans le cadre du Projet de l'avant-pays central du CARTNAT. Deux assemblages du Ladinien proviennent de la Formation de Toad, mais tous les autres ont été recueillis dans les formations de Baldonnel et de Pardonet du Trias supérieur. L'individualisation des unités du Trias supérieur pose problème dans les avant-monts de l'est où les traits caractéristiques de la Formation de Pardonet diffèrent de ceux dans sa région type sur le lac Williston. La base de la Formation de Pardonet est une surface transgressive qui représente généralement la limite du Carnien et du Norien. Dans la partie centrale de la région cartographique de Trutch, la Formation de Pardonet comporte des calcaires s'échelonnant du Norien inférieur à la base du Norien moyen et formant une falaise, que l'on a confondus avec ceux des formations de Baldonnel et de Bocock. Ces roches carbonatées de la Formation de Pardonet sont de loin plus anciennes que l'unité P4 informelle dans la subsurface de la région de Sukunka; elles se seraient formées en eau relativement peu profonde pendant une période de bas niveau marin ayant précédé une transgression au Norien moyen. Les deux inondations qui se sont produites au cours du Norien sont marquées par la présence d'abondantes Norigondolella.

[1] Contribution to the Central Foreland NATMAP Project

INTRODUCTION

The Central Foreland NATMAP Project in Trutch map area (NTS 94 G) affords an opportunity to undertake detailed conodont biostratigraphic studies in a region that has been important in Triassic stratigraphic and paleontological studies (Hage, 1944; McLearn, 1946; McLearn and Kindle, 1950; Pelletier and Stott, 1963; Pelletier, 1964; Tozer, 1967; Gibson, 1971, 1975). Furthermore, northeastern British Columbia has been a crucial area in the development of the standard biochronology for the marine Triassic of North America (Tozer, 1967, 1994; Orchard, 1983, 1991a, c; Orchard and Tozer, 1997). On Williston Lake, to the south of Trutch map area, a comprehensive conodont biochronology has been developed and intercalibrated with ammonoid zones of the Upper Carnian and Norian stages of the Upper Triassic (Orchard, 1991c). In the absence of macrofossils, this has enabled the dating and correlation of Triassic strata extending from the subsurface of the Western Canada Sedimentary Basin westward to the allochthonous terranes of the Cordillera (Orchard, 1991b; Orchard and Tozer, 1997).

During the summer of 1998, Triassic formations in Trutch and northern Halfway River map areas were sampled for conodonts and other fossils (*see* Johns et al., 1999) in order to provide a temporal framework for other studies, to establish detailed regional stratigraphy and facies relationships, and to generally test and refine the conodont zonal scheme. As a prelude to anticipated new data, this paper reviews and summarizes archival data from several sites in Trutch map area, mostly from the Upper Triassic Baldonnel and Pardonet formations. Combined with new field observations, the data, although limited, emphasizes the differing nature of the Upper Triassic succession in Trutch map area compared with that seen to the south on Williston Lake. Conodont data from the subsurface and sequence stratigraphic interpretations are combined to provide a provisional stratigraphic framework for the latest Triassic of the eastern foothills.

CONODONT BIOSTRATIGRAPHY

The basis of the Triassic conodont biochronology currently available for the Western Canada Sedimentary Basin is summarized by Orchard and Tozer (1997). At present, Lower Triassic conodonts are unknown from the map area, and only two Middle Triassic faunas are known. The two faunas come from the Toad Formation at Mount Withrow and were obtained from the matrix of ammonoids referred to the Ladinian Poseidon (or possibly Matutinum) and Meginae zones (Tozer, 1994, p. 317, 334; E.T. Tozer, pers. comm., 1997). The former conodont fauna (GSC loc. 74758) is dominated by *Neogondolella* ex gr. *constricta* allied to *N. aldae* from the Upper Anisian–Lower Ladinian of Nevada and *N. pseudolonga* from Europe. The younger fauna (GSC loc. 50043) was reported by Mosher (1973) to contain single specimens of *Metapolygnathus excelsus* and *Neospathodus* sp. D. The first (unfigured) specimen could be one of several *Paragondolella* species currently recognized in the Ladinian, whereas the *"Neospathodus"* is reassigned here to an unnamed Pb element.

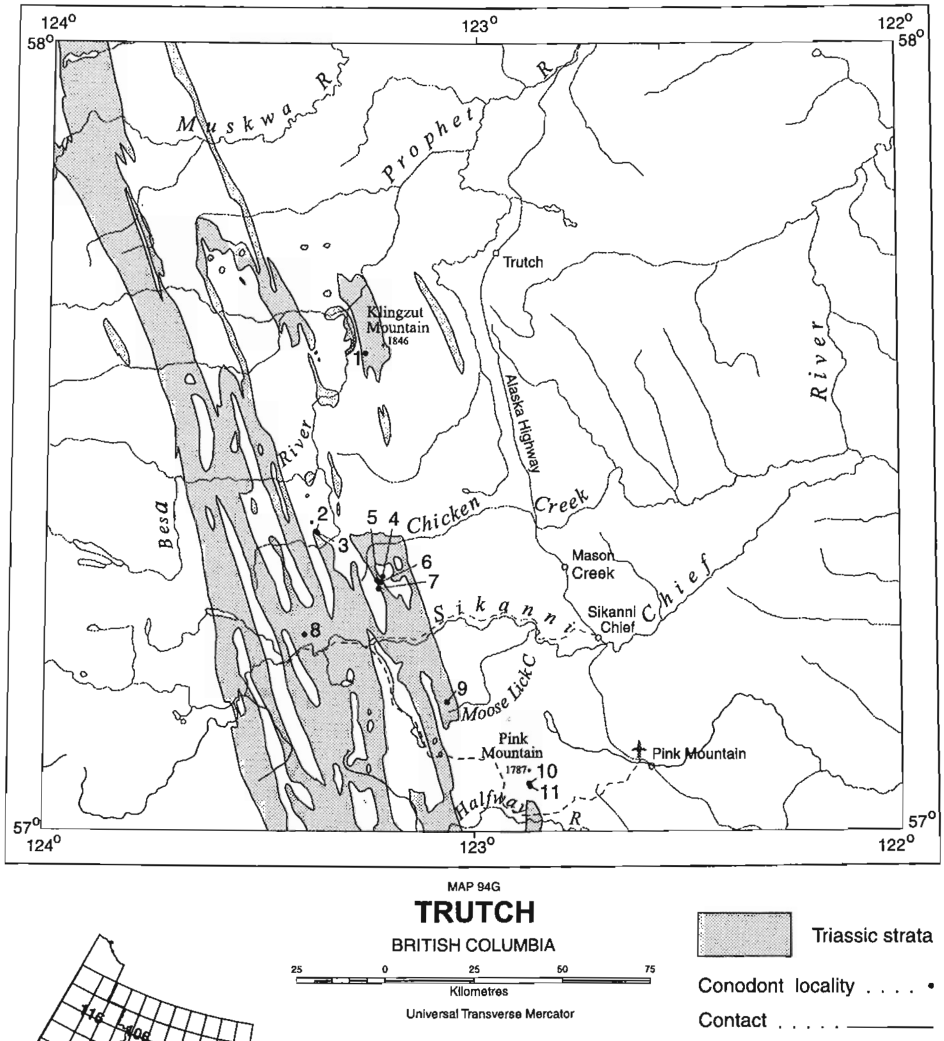
Twenty-three Upper Triassic conodont collections are currently known from five localities in Trutch map area (Fig. 1). As is often the case, a variety of other microfossils occur in the acid-insoluble residues, such as ichthyoliths, micromolluscs, echinoderm fragments, and uncommon ostracodes and foraminifers. Samples from the Baldonnel Formation commonly contain some of these microfossils but lack conodonts, as is the case in several collections from south of the Muskwa River in northwest Trutch map area. However, conodont collections have been recovered from the upper Baldonnel Formation at Nevis Ranch and Klingzut Mountain, where they are dated as Carnian and possibly basal Norian (Fig. 2). Collections from the Pardonet Formation at Nevis Ranch and Pink Mountain are Lower and Middle Norian. This data broadly corresponds to the situation on Williston Lake where the Baldonnel-Pardonet formation contact is diachronous about the Carnian–Norian boundary, being latest Carnian in the west at Pardonet Hill and Early Norian in the east at Carbon Creek (Orchard and Tozer, 1997, Fig. 8). In Trutch map area however, Early and Middle Norian conodont collections from Chicken Creek and Moose Lick Creek come from resistant, ledge-forming limestones superficially similar to those within the Baldonnel Formation. These limestone units occur within the Pardonet Formation over a wide area in the eastern foothills where they have sometimes been assigned to the Baldonnel or Bocock formations.

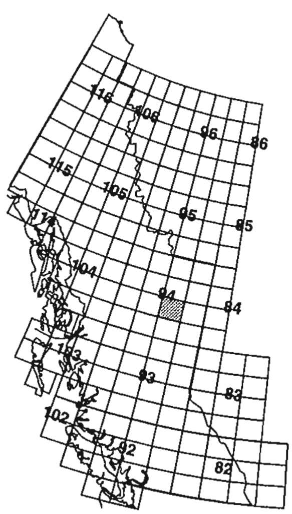
ASSIGNMENT OF UNITS: BALDONNEL OR PARDONET OR BOCOCK?

The Upper Triassic stratigraphic succession in the eastern foothills commonly consists of (in ascending order) the Charlie Lake, Baldonnel, and Pardonet formations. The Ludington Formation is a western, relatively offshore equivalent of the Charlie Lake and Baldonnel formations and, in places (e.g. Black Bear Ridge on Williston Lake), the basal part of the Pardonet Formation (Orchard and Tozer, 1997). The Rhaetian Bocock limestone overlies the Pardonet Formation in the westernmost foothills between Williston Lake and Pine River. Time correlative strata have only been identified for certain to the west at Ne Parle Pas Point on Williston Lake where a Pardonet Formation facies extends into the Rhaetian (Orchard and Tozer, 1997). There is as yet no fossil evidence of the Bocock limestone occurring to the north. The following discussion focuses on the upper Baldonnel Formation and younger stratigraphy.

The Baldonnel Formation (formerly upper "Grey Beds" of McLearn, 1940) is typically a light-grey weathering, resistant cliff-forming limestone and dolostone with minor siliciclastic beds, chert nodules, and bioclastic beds. The Pardonet Formation is characteristically dark brownish-grey weathering, more recessive, and composed of dark, carbonaceous-fetid and platy limestones and calcareous siltstones, with lesser shale and dolomite; coquinas of the flat-clams (*Halobia, Eomonotis, Monotis*) are common, and some levels include common ammonoids and/or bone beds. The Bocock Formation is a cliff-forming, light-grey-weathering, medium- to thick-bedded, relatively pure, finely crystalline to bioclastic limestone.

Delineation of the boundary between the Baldonnel and Pardonet formations may not always be clear-cut, whereas the Bocock limestone is quite distinctive in its type area. The contact between the first two formations was regarded as gradational by McLearn and Kindle (1950, p. 53), although Gibson (1971, p. 21; 1975, p. 7) noted that the contact is generally sharp and distinct. Where gradational, as for example in the area south of Peace River, Gibson (1975) placed the base of the Pardonet Formation at the level where finely laminated, thinly bedded strata formed the predominant lithology. At Pink Mountain, Gibson (1971, section 6) drew the base of the Pardonet Formation below a distinctive 'oolite-pisolite' (or 'pseudo-oolith') limestone marker, which occurs a little below the lowest recessive *Halobia*-shale unit typical of the Pardonet Formation. To the north of Sikanni Chief River, D.W. Gibson (pers. comm., 1996) noted that a light-grey- to white-weathering limestone marks the top of the Baldonnel, as at Chicken Creek, where the basal beds of the Pardonet Formation are brownish-grey-weathering dolomitic





SAMPLE SITES

MAP NO.	LOCALITY	UTM ZONE 10
1	Klingzut Mountain	484600E, 6384700N
2	Nevis Ranch	477600E, 6359600N
3	Nevis Ranch	477800E, 6359400N
4	Loc. B, Chicken Creek	487100E, 6353200N
5	Chicken Creek 2	486300E, 6352700N
6	Loc. C, Chicken Creek	486850E, 6352400N
7	Loc. D, Chicken Creek	486550E, 6351500N
8	Mount Withrow	476000E, 6345000N
9	Moose Lick Creek	496100E, 6335500N
10	Pink Mountain	507700E, 6324000N
11	SW flank, Pink Mountain	507900E, 6323600N

Figure 1.

Trutch map area showing Triassic outcrops and sites from which conodont collections have been recovered prior to 1998. Sites 1–3, 5, 10 were sampled by D.W. Gibson; sites 4, 6, 7 by E.L. Nichols, site 8 by B.R. Pelletier and E.T. Tozer, and sites 9, 11 by the author. Inset is location of Trutch map area in western Canada.

siltstones or silty dolomite. Pelletier (1964, p. 9) also drew the base of the Pardonet Formation at the top of the "rather resistant limestone that generally weathers light grey."

In Trutch map area, the focus on ledge-forming, grey-weathering limestones to define a top to the Baldonnel Formation has, in practice, resulted in younger strata than is typical being included in the formation. At Chicken Creek, for example, grey ledge-forming limestones included in the Baldonnel Formation (Pelletier, 1964, section 8, unit 22) are late Early Norian in age, whereas Gibson's collections from the top of the Baldonnel Formation (in his sense) in that area are latest Carnian. In this case, the Lower Norian grey limestones are apparently developed as a shallower water facies of the Pardonet Formation. Similar limestones are seen at Pink Mountain and again at Moose Lick Creek, where they are as young as early Middle Norian (Fig. 2). These carbonates are recognized here as a member of the Pardonet Formation. In some areas, for example west of Klingzut Mountain, cliff-forming limestone units such as these are accurately recognized to lie above a Pardonet Formation facies, which has led to them being erroneously compared with the Bocock limestone.

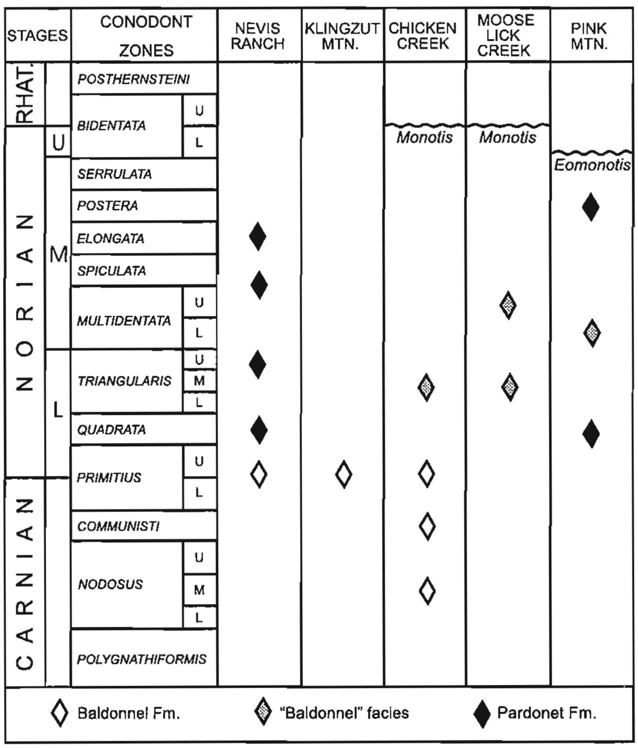


Figure 2. *Upper Triassic conodont zones and the age of collections (indicated by rhombi) from five localities showed in Figure 1. Note age of conodont collections from undisputed Baldonnel and Pardonet formations, and of Baldonnel-like limestones within the Pardonet Formation. The youngest preserved Triassic stratum below the sub-Jurassic unconformity (wavy line) is based on the named fossil bivalves.*

At both the easternmost section on Williston Lake near Carbon Creek, and at several localities in the eastern foothills of Trutch map area, some resistant limestone beds within the Lower Norian Pardonet Formation contain abundant *Gryphaea* and other benthic bivalves. McLearn and Kindle (1950, p. 50) regarded *Gryphaea* beds on Sikanni Chief River as probable 'Grey Beds' (=Baldonnel) but available evidence indicates that this fauna is typical of the Pardonet Formation, as was originally stated by McLearn (1946, p. 9). *Gryphaea* also occurs with *Halobia* in recessive platy strata typical of the Pardonet Formation that underlies the resistant carbonate rocks.

In the subsurface, the base of the Pardonet Formation is sharp and usually defined at the base of shaly siltstones with high gamma radiation (Barss and Montandon, 1981, p. 299). Davies (1997, p. 653) has reviewed the character of this boundary. Based on the signature of the gamma-sonic log, the Pardonet Formation in the subsurface of the Sukunka River region of the southern foothills has been subdivided into informal units (P1–P4) by Barss and Montandon (1981). Unit P1 and P2 are dominated by silty shales and limestones whereas P3 and P4 are characterized by relatively clean limestones and dolomites. Davies (1997, p. 653) has contrasted the pelagic 'type' Pardonet Formation facies with the mainly dolomitic 'ramp facies' of P1–P3 and the silty-sandy limestone of P4. A change from ramp to pelagic facies occurs in the subsurface to the northwest of Sukunka region. Consequently, the subsurface Pardonet Formation units have not been widely recognized in the outcrop belt, although it has been speculated that unit P4 may be correlated to the Bocock limestone (Barss and Montandon, 1981, p. 310; Davies, 1997, p. 648). This suggestion is viewed as unlikely because three conodont collections from P4 subsurface strata in the Sukunka region are early Middle Norian (Orchard and Tozer, 1997, p. 691), in contrast to the Rhaetian Bocock limestone.

Embry and Gibson (1995), Embry (1997), and Davies (1997) have considered the Western Canada Basin Triassic succession in terms of its sequence stratigraphy. The Baldonnel-Pardonet formation contact is regarded as a second order T–R sequence which demonstrably corresponds to, or approximates the Carnian–Norian boundary. A major change in depositional regimes sometimes accompanied by unconformity characterize such a sequence boundary. Unlike in the subsurface, there is no evidence of an unconformity between the Baldonnel and Pardonet formations in Trutch map area but the sharp contact seen at some localities and the character of the bounding strata is consistent with a deepening event, and the incoming of the 'pelagic' conodont *Norigondolella navicula* at (or near) the base of the Norian may signify the flooding surface.

The 'mid'-Norian is regarded by Embry (1997) as a third order sequence boundary, which in general are characterized by widespread transgressive surfaces, marginal unconformities, and by subtle changes in depositional regimes. In the Sukunka region subsurface, this boundary is recognized as an unconformity between Pardonet Formation members P3 and P4 (Embry, 1997, p. 427; Davies, 1997, p. 655) and is marked by a change from shallower to deeper water limestone with a phosphate lag deposit at their contact. Conodont data suggests that the Lower–Middle Norian boundary lies beneath Pardonet Formation unit P4 (*see* above). Gibson and Edwards (1990, p. 157) note the similarity of the subsurface Pardonet Formation limestone lithologies to those of the Baldonnel Formation, and the same comparison can be made with the cliff-forming limestones in Trutch map area, which generally underlie the Lower–Middle Norian boundary. On Williston Lake, this boundary is a conformable surface but is nevertheless an important faunal turnover and a vertebrate bone horizon occurs at this level at McLay Spur and Carbon Creek. During the Middle Norian (within the *postera* conodont Zone), a 'surge' of the pelagic conodont *Norigondolella steinbergensis*, probably marks a flooding surface comparable with the Early Norian *N. navicula* biofacies. This event apparently wiped out the *Gryphea* community in the Trutch map area sections and introduced a typical Pardonet Formation facies throughout northeast British Columbia.

In Trutch map area, the Lower Jurassic Fernie Formation disconformably overlies the Pardonet Formation whereas farther north Cretaceous strata rest directly on the Triassic; the magnitude of the break increases to the northeast (Pelletier, 1964, p. 2). The youngest Triassic strata proven in Trutch map area are Upper Norian *Monotis*-bearing strata at Moose Lick Creek, Chicken Creek, west of Mount Stearns, and on the south bank of Halfway River. Twelve metres (40 feet) of *Monotis* beds are reported beneath the Lower Jurassic Fernie Formation at Mount Stearns (Pelletier, 1964) but only half that thickness occurs at Moose Lick Creek and even less at Chicken Creek. Further east at Pink Mountain the youngest Triassic strata preserved is upper Middle Norian, *Eomonotis*-bearing carbonate rocks (Fig. 2). There is currently no evidence that Rhaetian strata survived erosion, or that the Bocock limestone was ever developed in the Trutch map area.

SUMMARY

The base of Pardonet Formation, which approximates the Carnian–Norian boundary, is recognized by the lowest occurrence of dark and recessive, fissile shaly and often coquinid carbonate, and brown siltstone. These strata overlie grey-weathering limestone of the Baldonnel Formation. In the eastern foothills of Trutch map area, Early Norian to early Middle Norian, resistant carbonates form cliffs, ledges, and resistant ribs within the Pardonet Formation. The youngest carbonate beds correlate to some strata assigned to Pardonet Formation member P4 in the Sukunka region subsurface but most are older. The carbonate is a shallower water facies compared to typical Pardonet Formation and supports the notion of a mid-Norian regressive interval prior to a widespread early Middle Norian transgression. In Trutch map area, the top of the carbonate member lies a little above the Lower–Middle Norian boundary and may be correlated with the third-order sequence boundary recognized in the subsurface. Both the Lower and Middle Norian transgressions are marked by 'floods' of the conodont *Norigondolella.*

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Progress on Triassic ichthyolith biostratigraphy and regional thermal-maturation studies, Trutch and Halfway map areas, northeastern British Columbia

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Abstract: Ichthyolith (fish tooth and scale) biostratigraphic and thermal-maturation studies in Trutch (94 G) and Halfway River (94 B) map areas have been directly calibrated with ammonoid and conodont zonations, and the conodont geothermometric index. The goals of this study, supported through the LITHOPROBE SNORCLE and the Central Foreland NATMAP projects, are a refinement of the current provisional ichthyolith zonation, development of an ichthyolith colour alteration index for maturation assessments, and interpretation of environmental and paleogeographic factors that effect ichthyolith distributions. Ichthyoliths are a new tool for the development of a tectonostratigraphic framework for Triassic rocks of the region and in future hydrocarbon exploration.

Résumé : Les études portant sur la biostratigraphie et la maturation thermale des ichthyolithes (dents et écailles de poissons) dans les régions cartographiques de Trutch (94 G) et de la rivière Halfway (94 B) ont été étalonnées directement avec des zonations d'ammonoïdés et de conodontes et l'indice géothermométrique des conodontes. Les objectifs de la présente étude, qui a reçu l'appui du transect SNORCLE du projet LITHOPROBE et du Projet de l'avant-pays central du CARTNAT, sont de mieux définir la zonation provisoire des ichthyolithes, d'élaborer un indice d'altération des couleurs des ichthyolithes à des fins d'évaluer de la maturation, et d'interpréter les facteurs environnementaux et paléogéographiques qui ont une incidence sur la répartition des ichthyolithes. Ces ichthyolithes constituent un nouvel outil pour l'exploration des gisements d'hydrocarbures et pour la définition du cadre tectonostratigraphique des roches triasiques de la région.

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INTRODUCTION

Triassic strata are exposed in both the Trutch (94 G) and Halfway (94 B) map areas and extend north into the Yukon and south through the eastern Cordillera. The current LITHOPROBE SNORCLE Corridors 2 and 3 program, as well as the GSC Central Foreland NATMAP project in the Trutch map area, provide an excellent opportunity for a multidisciplinary study of Triassic strata in this region.

Central to these studies are the development, refinement, and application of intercalibrated fossil zonations. Triassic biochronology has direct geological application in the tectonically disrupted terranes of the western Cordillera, and in the subsurface of the Western Canadian Sedimentary Basin, known for its petroleum fields (Edwards et al., 1994). One-third of discovered in-place gas reserves of the Triassic are located in the Cordilleran Foreland Belt (Bird et al., 1994). Correlation of outcrop and subsurface stratigraphy is essential for petroleum exploration, as is understanding the controlling factors on transgressive-regressive events, tectonic activity, underlying topography, variations in sediment supply, and climate and sea-level changes.

This report outlines progress on the study of ichthyoliths and how they are being used to develop a baseline ichthyolith biostratigraphy and biofacies in Triassic strata. Ichthyoliths are microscopic disarticulated structures of fishes, including teeth, scales, and bones. They have a broad distribution in pelagic environments, may be recovered from small samples of both marine and nonmarine sedimentary rocks, have a long range (Cambrian to Recent), and are naturally resilient during diagenetic and laboratory processes. The project builds on earlier work in the southern and central Halfway map area (Johns, 1993, 1996; Johns et al., 1997) that demonstrated the abundance of well preserved ichthyoliths in Triassic strata, established a preliminary ichthyolith biostratigraphy for the Middle and Upper Triassic, and intercalibrated these data with conodont and ammonoid zonations in the region.

PROJECT OBJECTIVES

The principal objectives of this project are as follows:

1. to test, calibrate, and refine the provisional Middle and Upper Triassic ichthyolith zonation of northeastern British Columbia and extend stratigraphic coverage to include the Lower Triassic and Lower Jurassic;
2. to recognize and interpret regional variations in ichthyolith successions and biofacies along and across the strike of the foreland belt;
3. to develop an ichthyolith colour alteration index and recognize regional thermal-maturation patterns;
4. to analyze differences between fauna recovered from shale and limestone beds; and
5. to investigate key stratigraphic and biological event intervals (e.g. Phosphate Zone; Carnian–Norian boundary, Triassic–Jurassic boundary).

The combination of the ichthyolith studies with other stratigraphic and biostratigraphic work should help to resolve the regional tectonostratigraphic framework for the western margin of the Western Canada Sedimentary Basin during the early Mesozoic.

STRATIGRAPHIC CONTEXT

Edwards et al. (1994) and Davies (1997) provided an overview of Triassic stratigraphy in the Western Canadian Sedimentary Basin. Nomenclature and correlation of Triassic formations in northeastern British Columbia (Gibson, 1993) is shown in Figure 1. Stratigraphic revisions and mapping in the Trutch map area and vicinity were undertaken in the 1960s and 1970s (summarized in Edwards et al., 1994). Pelletier (1964) and Pelletier and Stott (1963) discussed stratigraphy and sections specifically in the Trutch map area. Gibson (1990, 1991, 1993) more recently refined the northern British Columbia stratigraphy. Thompson's (1989) work specifically addressed the structure and geological evolution of the Halfway map area. Transgressive-regressive

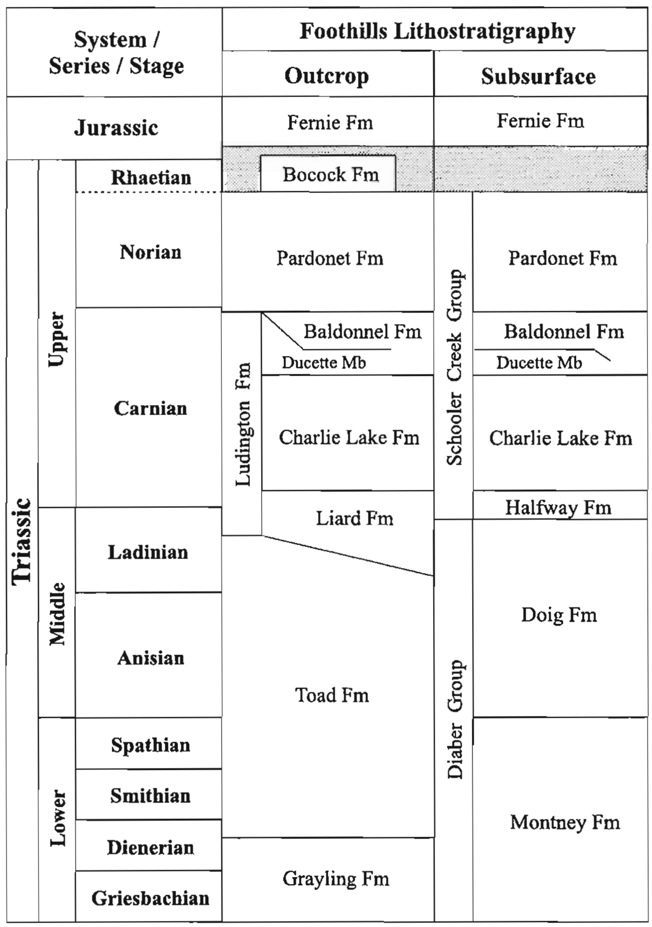

Figure 1. Triassic stratigraphy of northeastern British Columbia (after Gibson, 1993). The extent of the hiatus at the top of the Upper Triassic is uncertain.

cycles, including 12 global high-order sequence boundaries in the Triassic succession of the Western Canadian Sedimentary Basin are discussed by Embry (1997).

Triassic basin sedimentation was easterly derived, kept up with subsidence, and reached a thickness of over 1200 m in the western foothills and thinned to about 600 m at the British Columbia–Alberta border (Cant, 1988; Gibson and Edwards, 1990; Gibson, 1991). Sedimentary rocks to the east represent shallow-water environments including lagoons, sabkha and tidal flats, while those to the west represent deeper marine-shelf facies (Gibson and Barclay, 1989; Gibson and Edwards, 1990).

A biochronological framework for the Triassic rocks of the Peace River area has been provided for ammonoids and conodonts by Tozer (1967, 1994), Orchard (1983, 1991), and Orchard and Tozer (1997). Recently, work on Middle and Late Triassic ichthyoliths from northeastern British Columbia (Johns, 1993, 1996; Johns et al., 1997) has established a provisional ichthyolith zonation that is calibrated with the conodont and ammonoid zonations (Fig. 2). Development of a zonation based on fishes will supplement the biochronological framework and provide important data on the distribution of Triassic fishes.

Triassic articulated fossil fishes in British Columbia have been reported from the Sulphur Mountain Formation in the Wapiti Lake area (Schaeffer and Mangus, 1976; Neuman, 1992) and the Kakwa Recreation Area, north of Wapiti Lake

SERIES	STAGE	SUBSTAGE	AMMONOID ZONES Tozer 1994		CONODONT ZONES Orchard 1991	PROVISIONAL ICHTHYOLITH ZONES Halfway River area Johns, et al. 1997
UPPER TRIASSIC	RHAETIAN		*C. crickmayi*		*M. posthernsteini*	
			P. amoenum		*E. mosheri*	
	NORIAN	U	*G. cordilleranus*		*E. bidentata*	
		M	*M. columbianus*	IV	*E. serrulata*	*Synechodus incremuntum*
				III		
				II	*E. postera*	
				I	*E. elongata*	
					E. spiculata	
			D. rutherfordi		*E. multidentata*	
		L	*J. magnus*		*E. triangularis*	
			M. dawsoni		*E. quadrata*	
			S. kerri		*M. primitius*	
	CARNIAN	U	*K. macrolobatus*		*M. communisti*	*Synechodus multinodosus*
			T. welleri	II	*M. nodosus*	
				I		
			T. dilleri		*M. polygnathiformis*	unzoned
		L	*S. nanseni*			
			A. obesum			
			T. desatoyense			
MIDDLE TRIASSIC	LADINIAN		*F. sutherlandi*		*B. mungoensis*	*Coniunctio aequirugosa*
			M. maclearni			
			M. meginae		*B. hungaricus*	
			T. poseidon		*Ng. aldae* / [*B. trumpyi*]	
			E. matutinum			

Figure 2. *Ladinian and Upper Triassic biochronology, northeastern British Columbia, showing intercalibration of ammonoid and conodont zones (Orchard and Tozer, 1997) and ichthyolith zones (Johns et al., 1997).*

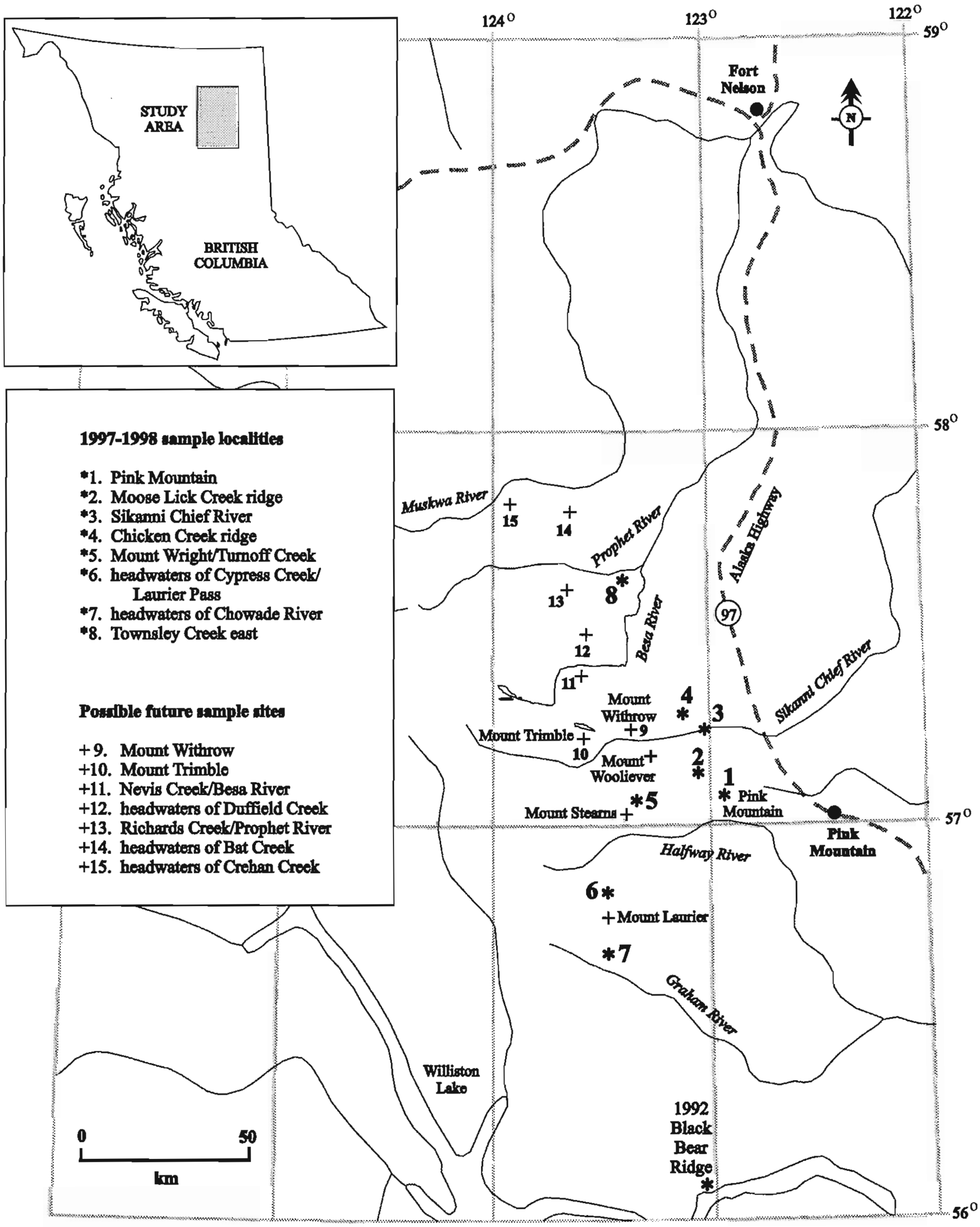

Figure 3. Index map of northeastern British Columbia illustrating sites where microfossil samples were collected in 1997 and 1998, and possible future collection sites.

(Pell and Hammack, 1991). The fishes are diverse, commonly occupy specific paleoecological niches, and are similar to those found in other Triassic rock localities in East Greenland, Spitzbergen, and Madagascar (Neuman, 1992). During the Triassic, the new sharks (neoselachians) and the earliest modern bony fishes (teleosts) were first developing. In addition, there were sharks and bony fishes that shared more characteristics with older Paleozoic forms.

1998 FIELDWORK

During the summer of 1998, studies were focused on the southern Trutch and northern Halfway map areas on outcrops along mountain ridges and slopes at approximately 1800 to 2400 m elevation (Fig. 3). Approximately 140 limestone and 75 shale samples were collected. Localities and formations sampled in the Trutch map area include Pink Mountain (Baldonnel, Pardonet, and Fernie formations), Moose Lick Creek ridge (Charlie Lake, Baldonnel, and Pardonet formations), Chicken Creek ridge (Pardonet Formation), Mount Wright/Turnoff Creek (Liard, Charlie Lake, Baldonnel, and Pardonet formations) (Fig. 4), Sikanni Chief River (Pardonet Formation), and Townsley Creek east (Pardonet Formation). In the Halfway map area, sections were sampled on a ridge at the headwaters of Chowade River (Grayling and Toad formations), and a ridge at the headwaters of Cypress Creek at Laurier Pass (Charlie Lake and Baldonnel formations). Macrofossils were collected at most sites.

Plans for 1999 fieldwork will be based on microfossil recovery and results from 1998 samples. New site targets for sampling are shown in Figure 3. Geological mapping during 1998 and 1999 will assist in locating the best Triassic and Lower Jurassic sections for microfossil sampling.

ICHTHYOLITH FAUNAS

Preliminary results are based on good ichthyolith recovery from 11 spot samples collected by Orchard in 1997 at Pink Mountain (GSC loc. 303439 to 303444) and Moose Lick Creek ridge (GSC loc. 303445 to 303449). All the samples at Moose Lick Creek ridge contain ichthyoliths and most contain conodonts (Orchard, 1999). Three of these samples contain important elasmobranch (shark) faunas, diagnostic of the Lower and Middle Norian *Synechodus incrementum* ichthyolith Zone (Johns et al., 1997) (Plate 1, figs. 6–9). One sample from the uppermost Upper Norian strata contains a new ichthyolith elasmobranch assemblage, not previously described from northeastern British Columbia (Plate 1, figs. 1-5). This fauna and a new terrane ichthyolith assemblage currently being studied from the latest Triassic Tyaughton Group in southern British Columbia (NTS 92-O; Umhoefer and Tipper, 1998), will be important to refine the *Synechodus incrementum* ichthyolith Zone in the Upper Norian and understand biotic changes at the Triassic–Jurassic boundary.

Three 1997 samples collected at Pink Mountain contain ichthyoliths and conodonts from the Lower, Middle, and uppermost Middle Norian strata (Orchard, 1999). Ichthyoliths in these samples were dominated by actinopterygian teeth that also are common in the Moose Lick Creek ridge samples. Both these sites show considerable promise for Norian ichthyolith studies. Examples of Upper Triassic ichthyoliths are illustrated in Plate 1.

THERMAL MATURATION STUDIES

Conodonts show progressive and irreversible chemical and colour change in response to burial time and thermal conditions in sedimentary basins (Epstein et al., 1977; Legall et al., 1981; Nowlan and Barnes, 1987; Rejebian et al., 1987; Orchard and Forster, 1991). This is useful for assessing organic maturation and hydrocarbon potential (Fig. 5).

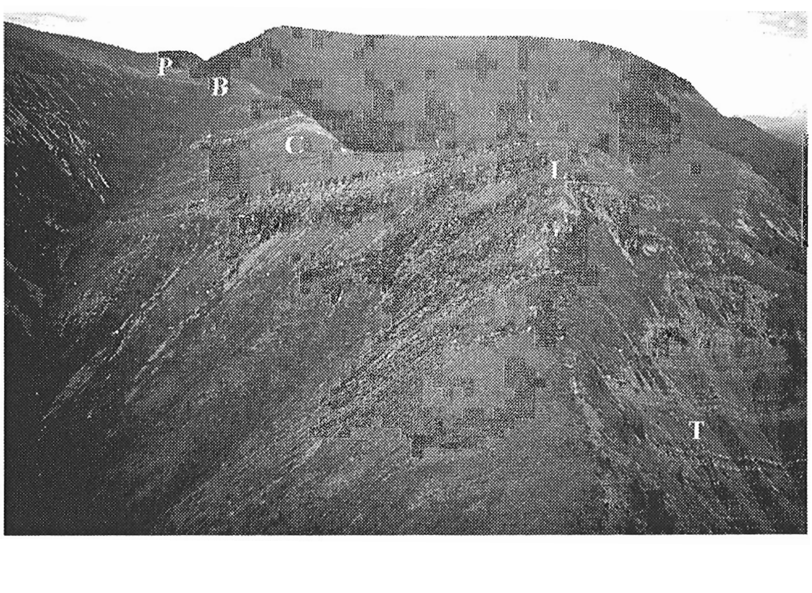

Figure 4.

The west flank of Mount Wright above Turnoff Creek. Triassic strata showing the predominantly darker beds of the Toad Formation (T) and looking up-section (and left) to the cliff forming units of the Liard Formation (L), the Charlie Lake Formation (C) mainly in cover in the saddle, the Baldonnel Formation (B) exposed on the upper ridge, and the Pardonet Formation (P) mainly in cover at the top of the section.

CAI	Temperature °C	Hydrocarbon generation	Conodont and ichthyolith alteration range
1.0	- 50	under-mature	
1.5	50 - 90	early dry gas, wet gas, oil	Moose Lick Creek ridge and Pink Mountain
2.0	60 - 140	heavy to light oil, wet gas	
3.0	110 - 200		
4.0	190 - 300	dry gas	
5.0	300 - 480	barren	
6.0	360 - 550		
6.5	440 - 610		
7.0	480 - 720		
8.0	600 -		

Figure 5. *Correlation of temperature values with conodont colour alteration index (CAI) ranges (Epstein et al., 1977; Rejebian et al., 1987), hydrocarbon generation values (Legall et al., 1981), and conodont and ichthyolith colour alteration range from samples at Moose Lick Creek ridge and Pink Mountain.*

Like conodonts, ichthyoliths show similar colour change patterns (Tway et al., 1986; Johns et al., 1995). An actinopterygian (bony fish) tooth, *Birgeria* sp.1 is particularly useful for colour analysis. This species has a simple form (Plate 1, figs. 14, 15), is abundant, and is long ranging — it occurs in most of the samples so far studied in the Middle and Upper Triassic. Using this species in thermal assessments will provide consistent results. An ichthyolith colour alteration index is currently under development.

Ichthyolith colour changes in northeastern British Columbia occur within a spectrum of conodont colour alteration indices (CAI) ranging from about 1.5 to 5.0. Triassic samples from the eastern Peace Reach (Williston Lake) area containing both conodonts and ichthyoliths are less altered than those in western sections. Initial analyses of ichthyolith colour in the 1997 spot samples (Fig. 5) correlate with a conodont CAI of 1.5 to 2.0 at Moose Lick Creek ridge and Pink Mountain. Both sites are in the hydrocarbon window.

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Geological Survey of Canada Project 870069

Plate 1

Scanning electron microscope images of Upper Triassic ichthyoliths from northeastern British Columbia.

Figures 1-5. Moose Lick Creek ridge, sample 97-OF-ML-11, GSC loc. C-303449; Upper Norian; x92.
Figure 1. Unidentified elasmobranch tooth, Type A1, GSC 118202, width = 325 microns.
Figure 2. Unidentified elasmobranch tooth, Type A2, GSC 118203, width = 290 microns.
Figure 3. Unidentified new form species of elasmobranch scale, f.sp. B1, GSC 118204, width = 180 microns.
Figure 4. Unidentified new form species of elasmobranch scale, f.sp. B2, GSC 118205, width = 265 microns.
Figure 5. Unidentified new form species of elasmobranch scale, f.sp. B3, GSC 118206, width = 237 microns.

Figures 6-9. Moose Lick Creek ridge, sample 97-OF-ML-7, GSC loc. C-303445; uppermost Lower Norian; x52.
Figure 6. Elasmobranch tooth, *Synechodus incrementum* Johns 1997; GSC 118207, width = 1.74 mm.
Figure 7. Elasmobranch scale, *Fragilicorona labribrevirostrum* s.f. Johns 1997; GSC 118208, width = 350 microns.
Figure 8. Elasmobranch scale, *Glabrisubcorona vadosidevexa* s.f. Johns 1997; GSC 118209, width = 460 microns.
Figure 9. Elasmobranch scale, *Suaviloquentia longilingua* s.f. Johns 1997; GSC 118210, height = 842 microns.

Figure 10. Black Bear Ridge, sample 82-OF-BBR-1, GSC loc. C-101002; Upper Carnian. Elasmobranch tooth, *Synechodus multinodosus* Type A Johns 1997; GSC 118211, width = 1.31 mm; x52.

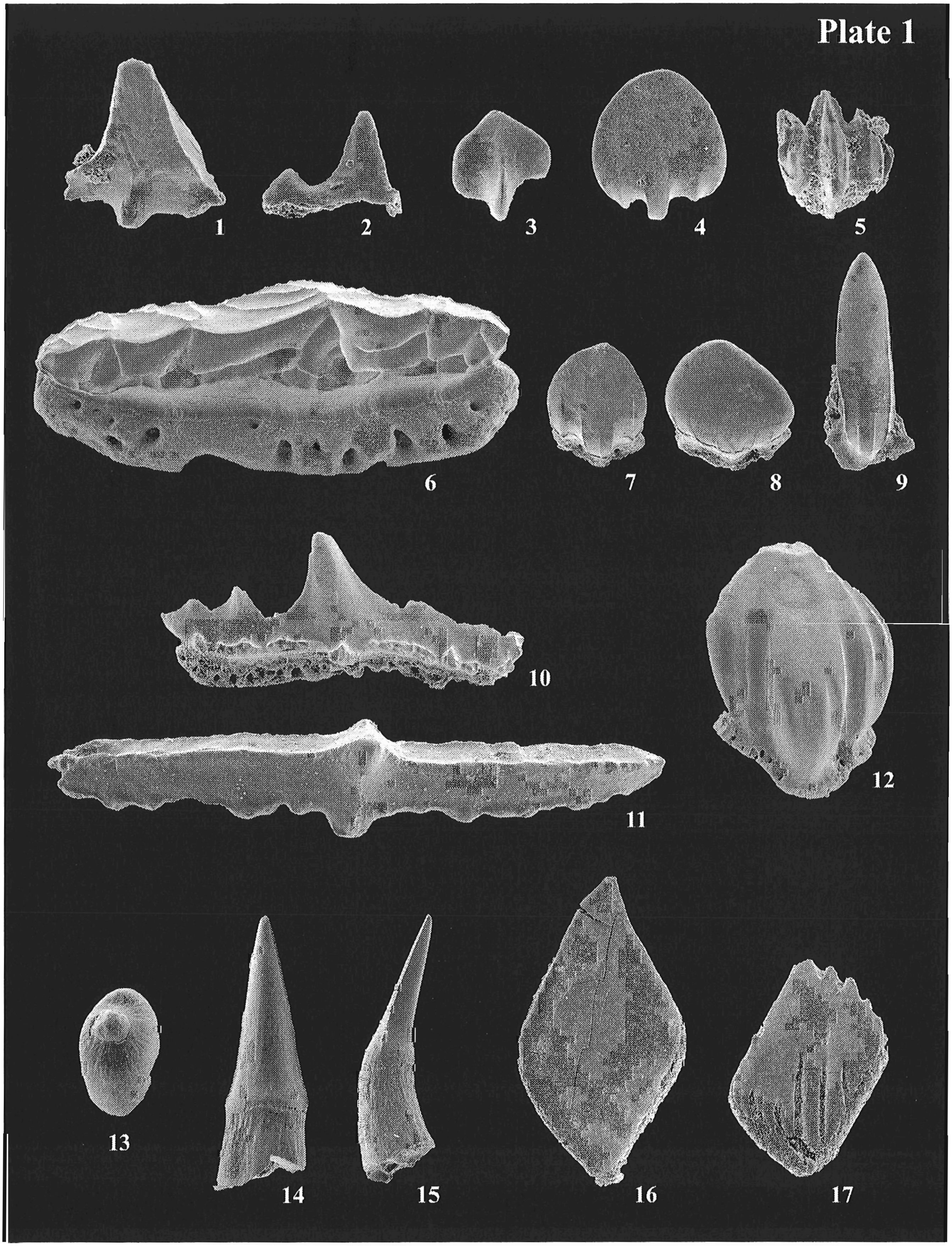
Figure 11. Black Bear Ridge, sample 92-OF-BBR-1, GSC loc. C-201927; Upper Carnian. Elasmobranch tooth, *Synechodus multinodosus* Type B Johns 1997; GSC 118212 width = 2.16 mm, x52.

Figure 12. Black Bear Ridge, sample 92-OF-BBR-3, GSC loc. C-201929; Upper Carnian. Elasmobranch scale, *Labascicorona mediflexura* s.f. Johns 1997; GSC 118213, width = 696 microns, x52.

Figures 13-15. Pink Mountain, sample 97-OF-PINK-4, GSC loc. C-303442; Lower Norian. Actinopterygian teeth.
Figure 13. *Colobodus* sp.1 (in Johns 1993), GSC 118214, width = 253 microns, height = 385 microns, x62.
Figure 14. *Birgeria* sp.1 (in Johns 1993), GSC 118215, height = 1.32 mm, x39.
Figure 15. *Birgeria* sp.1 (in Johns 1993), side view, GSC 118216, height = 1.29 mm, x39.

Figure 16. Black Bear Ridge, sample 92-OF-BBR-4, GSC loc. C-201930; Upper Carnian. Unidentified actinopterygian scale, Type GS-2 (in Johns 1993), GSC 118217, height = 1.74 mm, x31.

Figure 17. Black Bear Ridge, sample 92-OF-BBR-1, GSC loc. C-201927; Upper Carnian. Unidentified actinopterygian scale, Type GS-1 (in Johns 1993), GSC 118218, height = 1.23 mm, x31.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A new look at the Robb Lake carbonate-hosted lead-zinc deposit, northeastern British Columbia[1]

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Paradis, S., Nelson, J.L., and Zantvoort, W., 1999: A new look at the Robb Lake carbonate-hosted lead-zinc deposit, northeastern British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 61–70.*

Abstract: The Robb Lake Pb-Zn deposit occurs in platform carbonate rocks of the Silurian–Devonian Muncho and McConnell formations, northeastern British Columbia. It consists of approximately 19 known stratabound lead-zinc showings hosted by interconnected bedding-parallel and crosscutting breccia bodies in as much as 200 m of stratigraphic sequence. The main sulphide minerals are sphalerite, galena, and pyrite. Not all the breccias are mineralized. The favorable mineralized sections form a broad stratabound zone occupying the upper 200 m of the lower unit of the Muncho and McConnell formations and the lower 130 m of upper unit of the Muncho and McConnell formations. The origin and timing of brecciation and mineralization are unknown and will be the subjects of future studies.

Résumé : Le gisement de Pb-Zn de Robb Lake se rencontre dans des roches carbonatées de plate-forme dans les formations siluriennes–dévoniennes de Muncho et de McConnell, dans le nord-est de la Colombie-Britannique. Il comporte environ 19 indices stratoïdes connus de plomb et de zinc encaissés dans des brèches reliées les unes aux autres qui sont parallèles à la stratification ou la recoupent sur jusqu'à 200 m de la succession stratigraphique. Les principaux minéraux sulfurés sont la sphalérite, la galène et la pyrite. Les brèches ne sont pas toutes minéralisées. Les sections minéralisées favorables forment une large zone stratoïde dans les 200 m supérieurs de l'unité inférieure et les 130 m inférieurs de l'unité supérieure des formations de Muncho et de McConnell. L'origine et l'âge de la bréchification et de la minéralisation sont inconnus et feront l'objet de futures études.

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INTRODUCTION

The Robb Lake Pb-Zn deposit is located in the platform carbonate rocks of northeastern British Columbia (56°56'N, 123°43'W; 94 B/13; Fig. 1). The deposit consists of a series of interconnected bedding-parallel and crosscutting breccia bodies within the Silurian–Devonian dolostone of the Muncho and McConnell formations. The main sulphide minerals are sphalerite, galena, and pyrite, and the gangue minerals are quartz, calcite, and pyrobitumen. Robb Lake has an estimated resource of 7.1 million tonnes at 4.7% Zn and 1.5% Pb (A.J. Boronowski and S.C. James, unpub. Report, 1982).

The timing and mode of origin of the Robb Lake mineralization are controversial. The host breccias were attributed to early karst collapse by Taylor (1977) and to collapse related to evaporite dissolution by Manns (1981). In these models, mineralization was a late diagenetic or early postdiagenetic process of mainly passive infilling and replacement. On the other hand, Macqueen and Thompson (1978) advocated hydraulic cracking as the mechanism of brecciation. They hypothesized a Laramide age for the deposit based on the co-occurrence of metals and petroleum, and on the observation that burial depths necessary to produce temperatures greater that 200°C in Silurian–Devonian strata were not achieved until the Mesozoic.

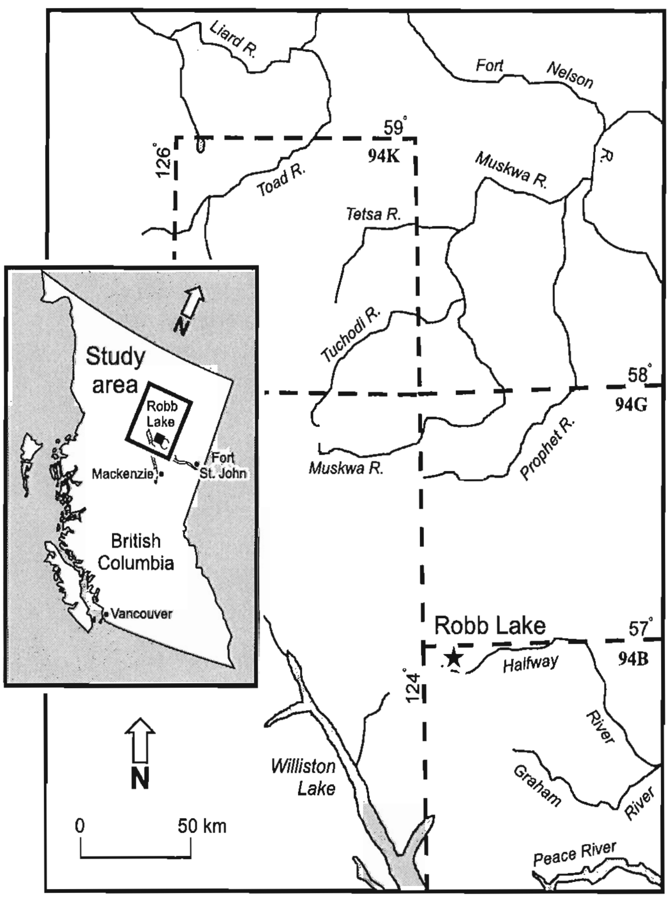


Figure 1. Location of the Robb Lake Pb-Zn deposit (modified from Thompson, 1989).

This re-evaluation of the Robb Lake deposit is a joint Geological Survey of Canada–British Columbia Geological Survey project. It has the following aims: 1) map the deposit area at a scale of 1:20 000, 2) describe the deposit and work toward a better understanding of the nature and origin of the breccias and the mineralization, and 3) produce an absolute age by Rb-Sr methods on sphalerite (Christensen et al., 1996). This paper summarizes the fieldwork done during the summer of 1998, and introduces the Rb-Sr analytical study that will be completed in 1999.

APPROACH

A total of ten samples from various lead-zinc showings of the Robb Lake area were submitted to the University of Michigan for Rb-Sr dating of sphalerite. The Rb-Sr dating of the Robb Lake mineralization, if successful, will provide an absolute age on the mineralization and constrain the timing of fluid flow in the Presqu'ile Barrier, an hypothesized paleoaquifer for the brines that produced Pine Point lead-zinc mineralization (Garven, 1985). Theory, methods, successes, and pitfalls of the technique are explained by Christensen et al. (1996).

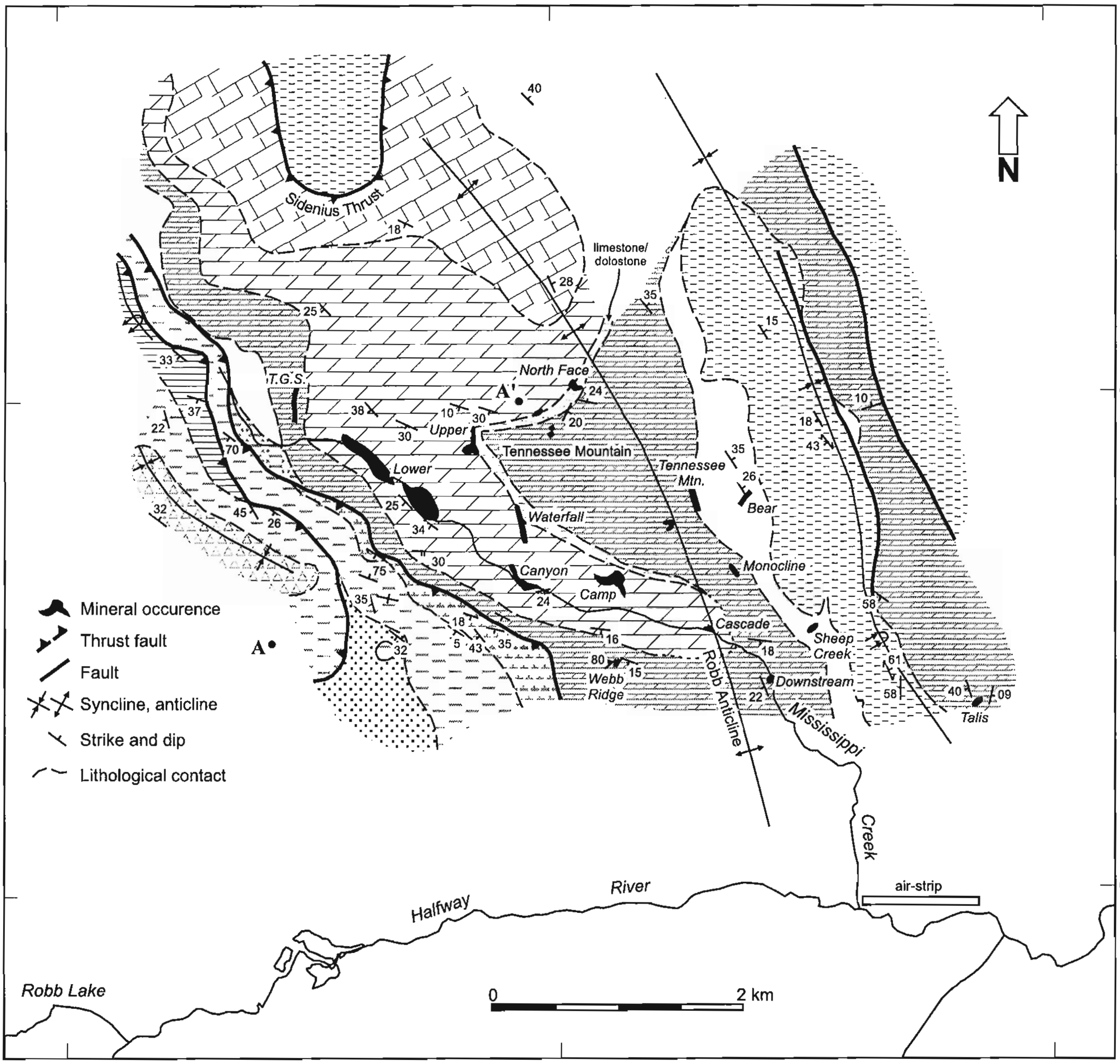
Carbonate samples were collected from surface exposures around the Robb Lake area for carbon and strontium isotope studies. Sulphide samples were collected from showings and from drill cored intervals of the Devonian Presqu'ile Barrier from the British Columbia subsurface, east of the Rocky Mountain front (cores stored at the Charlie Lake Core Storage facility) for lead and sulfur isotope studies. Lead signatures may help in tracing the fluid flow regimes that gave rise to regional carbonate-hosted sulphide mineralization.

PROPERTY GEOLOGY

The Robb Lake Pb-Zn deposit is part of a belt of Mississippi Valley-type deposits in the northern Rocky Mountain. The deposits are hosted by Silurian–Devonian platform dolostones that form part of the outcropping Paleozoic carbonate front (Thompson, 1989), which trends north-northwest and is flanked on the west by a shale basin. In the subsurface, the Devonian carbonate front turns eastward to become the Presqu'ile Barrier, which hosts the Pine Point lead-zinc deposit.

Most of the lead-zinc mineralization at Robb Lake occurs within the Muncho and McConnell formations, although a few occurrences lie within an overlying sequence attributed to the Stone and Dunedin formations (Fig. 2). As noted by Macqueen and Thompson (1978), Thompson (1989), and in the present study, the deposit is located next to the tectonically compressed shelf-slope facies boundary. The carbonate platformal strata that host the Robb Lake deposit form the immediate footwall of a major thrust fault, which carries deep-water, early Paleozoic basinal strata in its hanging wall.

Figure 2. Geology of the Robb Lake deposit area.



PLATFORMAL UNITS

Upper Devonian

Besa River Formation

Western facies: Black to dark grey siliceous argillite and shale, in part with silt laminae

Eastern facies: Light-brown- to grey-weathering, well laminated, soft calcareous mudstone/siltstone

Lower to Middle Devonian

Stone and Dunedin formations, undivided

Interbedded dark grey fossiliferous dolostone and light- to medium-grey nonfossiliferous dolostone

Silurian-Devonian

Muncho and McConnell formations

Upper unit: Thick- to medium-bedded, light- to medium-grey dolostone that alternate with thin bedded dolostone

Lower unit: Thick- to medium-bedded, light- to medium-grey dolostone. Limestone common near the top of unit, and fossiliferous beds present in the upper half of unit.

Silurian

Nonda Formation

Medium to dark grey fossiliferous dolostone

BASINAL UNITS

Silurian to Devonian

Dolostone and quartzite

Silurian

Dark grey dolostone breccia with secondary chert and fossil fragments

Ordovician to Silurian

Road River Group

Dark grey to black slate, calcareous slate; dark grey carbonaceous limestone; quartzite

Ordovician

Skoki Formation

Muddy, carbonaceous thick-bedded dolostone and thin-bedded, fossiliferous silty dolostone

Cambrian to Ordovician

Kechika Group

Laminated medium to dark grey, orange-brown- to olive-weathering flaggy calcareous slate

The main stratigraphic units encountered in the Robb Lake area are described below and their distribution is illustrated in Figure 2. They are divided into two disparate stratigraphic sequences (basinal and platformal units) separated by the major thrust fault southwest of Mississippi Creek. Basinal units in the hanging wall of the fault include the Cambrian–Ordovician Kechika Group, the Ordovician Skoki Formation, the Ordovician–Silurian Road River Group, and unnamed units of Silurian–Devonian quartzite-dolomite and Silurian dolostone breccia. Northeast of the fault, the platformal succession includes the Silurian Nonda Formation, the Silurian–Devonian Muncho and McConnell formations, the undivided Lower Devonian Stone and Middle Devonian Dunedin formations, and the Upper Devonian Besa River Formation.

Basinal units

Kechika Group

The Kechika Group is restricted to a single cliff-ridge top exposure in the immediate hanging wall of the major thrust fault. It consists of medium to dark grey, orange-brown- to olive-weathered, calcareous shale and slate characterized by very distinct colour laminations in the millimetre to centimetre range. It is very well cleaved, forming papery to flaggy cleavage fragments. These rocks resemble the eastern facies of the Besa River Formation and were assigned to it by Thompson (1989). However we have assigned them to the Kechika Group based on their slaty character, which contrasts with the softer, muddier Besa River shale units, and on their contact with the underlying Muncho and McConnell formations, which is nonoutcropping and structurally discordant at outcrop scale. If this contact is a thrust fault, then the complete absence of Stone and/or Dunedin strata along it is explained. These strata are overlain directly by the Road River Group; the Skoki Formation, which outcrops farther northwest in the headwaters of Mississippi Creek, is missing.

Skoki Formation

The Skoki Formation, which outcrops on the southwest wall of the cirque that heads Mississippi Creek, is subdivided into two distinct units. The lower part of the Skoki Formation consists of 70 m of thickly bedded, cliff-forming dolostone. It is light to medium grey, muddy, and carbonaceous. The upper Skoki Formation is a recessive unit of light-brown- to chalky-orange-weathering, light to medium grey, thinly bedded silty dolostone. Beds are up to 50 cm thick. This unit contains bivalves, abundant burrow structures, and rare trilobites.

Road River Group

The Road River Group is dominated by nonfossiliferous flaggy slate and calcareous slate and well cleaved, dark grey to black carbonaceous limestone. Less abundant are white quartzite and thickly bedded, highly fossiliferous carbonaceous limestone densely packed with fragments of corals and brachiopods. This highly heterogeneous section is typical of the Road River Group near shelf margins. It is overlain by an unnamed Silurian–Devonian dolostone and quartzite unit in the lower of the two thrust sheets, and by the Silurian breccia in the upper one.

Silurian breccia

The Silurian breccia is a thin, cliff-forming dolostone breccia that extends for 30 km from Lady Laurier Lake (south of Robb Lake) to Mount Kenny (immediately west of Robb Lake; Thompson, 1989). The breccia overlies the Road River Group on the ridge tops at the headwaters of Mississippi Creek (Fig. 2). Breccia beds consist of medium to dark grey, angular to subangular dolostone and black chert fragments in grey dolomite cement. They also contain abundant and well preserved fossil fragments of halysites, favosites, and colonial corals. The dolostone fragments exhibit grey-black laminations on the millimetre to centimetre scale. The breccia itself is bedded on the centimetre to decametre scale; sets of thin dolostone calcilutite and calc-arenite and small-clast breccia alternate with thick units of unsorted, matrix-supported megabreccia.

According to Thompson (1989), the fragments are all derived from the Nonda Formation, and the unit is interpreted as a debris flow (or succession of debris flows) deposited on the foreslope of a Nonda reef.

Silurian–Devonian dolostone and quartzite

This unnamed unit lies in exposed stratigraphic contact above the Road River Group on the ridge southwest of Mississippi Creek. It consists of a basal thick-bedded, grey quartzite, overlain by light grey, thick-bedded dolostone and quartzite. No fossils were seen. It is correlated with the Silurian–Devonian shelf dolostone-sandstone units farther northeast.

Platformal units

Nonda Formation

The Nonda Formation is a distinctive medium-grey- to dark-grey-weathering, fossiliferous dolostone. Fossils include crinoids, halycites, and favosites. The alternating medium to dark grey beds make the Nonda Formation unmistakable. Bedding thickness ranges from 0.15 to 2 m. Locally fine calcareous laminations are observed. Chert nodules and silicified fossils are common throughout the unit. The Nonda Formation exposed at Robb Lake forms the core of the Robb Anticline.

Muncho and McConnell formations

The Muncho and McConnell formations form most of the high peaks adjacent to the mountain front (Thompson, 1989). It consists almost entirely of light-grey-weathering resistant dolostone and sandy dolostone, except for a few beds of dark grey micritic limestone. The Muncho and McConnell formations are more than 500 m thick in the Robb Lake area, and consists of fine-grained crystalline dolomite that formed largely in a low energy, intertidal to supratidal environment.

At Robb Lake, the Muncho and McConnell formations can be subdivided into upper and lower units based on bedding thickness, and outcrop and bedding characters. The lower unit is a light to medium grey, thick- to medium-bedded dolostone approximately 250 m thick. On closer inspection, the lower unit consists of a cyclic repetition of thick dolostone beds, and thinner, often laminated and more recessive dolostone beds. A sandstone unit less than 50 m thick is present at the base of the lower unit. A marker bed, known as the "angular sand marker", is present within the dolostone sequence at about 110 m below the top of the unit (Manns, 1981). It corresponds to a local disconformity. The uppermost 30–50 m of the lower unit are particularly thick bedded and often form major cliffs. On Tennessee Mountain (i.e. near the North Face and Camp showings), parts of this upper section consists of thick-bedded to massive limestone pods that pass laterally and vertically into the typical thick dolostone beds. Sedimentary textures within the lower unit include abundant fenestrae, less common cryptalgal laminites, burrows, and rare intervals that show current laminations and rip-up clast breccias. Large brachiopods (average 5–10 cm long) are common within the thick dolostone beds of the upper half of the unit. Gastropods, amphiporids, stromatolites, fragments of bivalves, and other unidentified fossils were also observed in the lower unit. Taylor (1977) linked the presence of fossils within the Muncho and McConnell formations near Robb Lake to the proximity of the Silurian–Devonian facies front.

The upper unit is 250–300 m thick, and consists of thick- to medium-bedded, light to medium grey dolostone that alternates with thin-bedded, medium grey dolostone in a characteristic banded or stepped outcrop pattern. The rhythmic sequence of the upper unit is better developed than in the lower unit, and the thin bedded dolostone intervals are more extensive. The basal sequence (0–25 m) of the upper unit is composed of laminated dark grey silty dolomite mudstone with local sand concentrations. A marker bed known as the 'pale sand marker', 1–2 m thick, was identified in drill holes in Webb Ridge (Manns, 1981). Fragments of limestone beds are observed at the base of the mineralized breccia at the T.G.S. showing.

Taylor (1977) and Manns (1981) interpreted a disconformity to be at the top of the lower unit and at the top of the upper unit. These disconformities indicate the presence of significant erosion surfaces, as marked by the presence of sand markers (angular sand marker and pale sand marker), scour surfaces, and soft-sediment deformation features.

Stone and Dunedin formations

The Stone and Dunedin formations could not be distinguished in the Robb Lake area, so they are described together in this section. They consist of interbedded medium to dark grey fossiliferous, partly calcareous dolostone and light to medium grey, buff-weathering fossiliferous and nonfossiliferous dolostone. Some fossiliferous limestone is black (possibly reef-front) breccia. Fossils include brachiopods, gastropods, crinoids, rugosa and colonial corals, and locally crinoid wackestone.

This unit, which is thin and discontinuous, is nowhere capped by a single, thick, dark grey, fossiliferous carbonate unit assignable to the Dunedin Formation. Nevertheless it may be partly time-equivalent to it.

Besa River Formation

The Besa River Formation outcrops in three areas: in the core of a syncline east of the main showing area, in the footwall of the Sidenius thrust fault in the core of the Robb Anticline, and in a narrow band in the immediate footwall of the major thrust fault in the headwaters of Mississippi Creek (Fig. 2). In its eastern exposures, the Besa River Formation consists of soft brown-grey-weathering, finely laminated dark grey to black calcareous to noncalcareous argillite-shale and siltstone. In its western exposure, it consists of dark grey to black, siliceous argillite and shale with silt laminae.

MINERALIZATION

The Robb Lake deposit consists of approximately 19 known stratabound lead-zinc showings hosted by breccias of the Silurian–Devonian platform carbonate succession of the Muncho and McConnell formations. A few occurrences lie within the overlying sequence attributed to the Stone and Dunedin formations. Most of the showings occur along the valley of Mississippi Creek and the adjacent mountain slopes (Fig. 2).

The breccias are interconnected, bedding-parallel and/or crosscutting bodies in as much as 200 m of stratigraphic section (Fig. 3). Not all the breccias are mineralized. The favorable mineralized sections form a broad stratabound zone occupying the upper 200 m of the lower unit of the Muncho and McConnell formations and the lower 130 m of the upper unit; a 70 m thick, barren section separates the mineralized zones (A.J. Boronowski and S.C. James, unpub. report, 1982).

The mineralized zones have a northwesterly elongation and alignment, parallel to the strike direction and to the structural and paleofacies features. The breccia bodies form relatively thin and narrow horizons and pods that are both parallel to and crosscut bedding (Fig. 2, 3). Several bodies extend for more than 300 m along bedding and crosscut more than 50 m of section. The shape and extend of several breccia bodies are well exposed on the south and north slopes of Tennessee Mountain and along Mississippi Creek. It demonstrates that the showings along the creek, such as the Lower, Canyon, and Cascade zones, are stratigraphically equivalent to those on the south side of Tennessee Mountain (the Upper, Waterfall, and Camp zones, and potentially the North Face zone), i.e. the south slope of Tennessee Mountain is more or less a dip slope. This is well illustrated on the cross-section of the valley of Mississippi Creek (Fig. 4). In the East and West Webb zones on Webb Ridge, drilling has outlined up to four major mineralized horizons and numerous isolated pods in the lower and upper units of the Muncho and McConnell formations that are stacked and overlapped and may be connected at different levels laterally and vertically (A.J. Boronowski and S.C. James, unpub. report, 1982).

The geometry of the breccias is illustrated in Figure 3. The rock-matrix ('trash') breccias with combined zinc-lead grades in the order of 6% (A.J. Boronowski and S.C. James, unpub. report, 1982) are preferentially located within the upper half of lower unit of the Muncho and McConnell formations. Some of these breccias are also found in the upper unit but they rarely achieve ore-grade mineralization. In

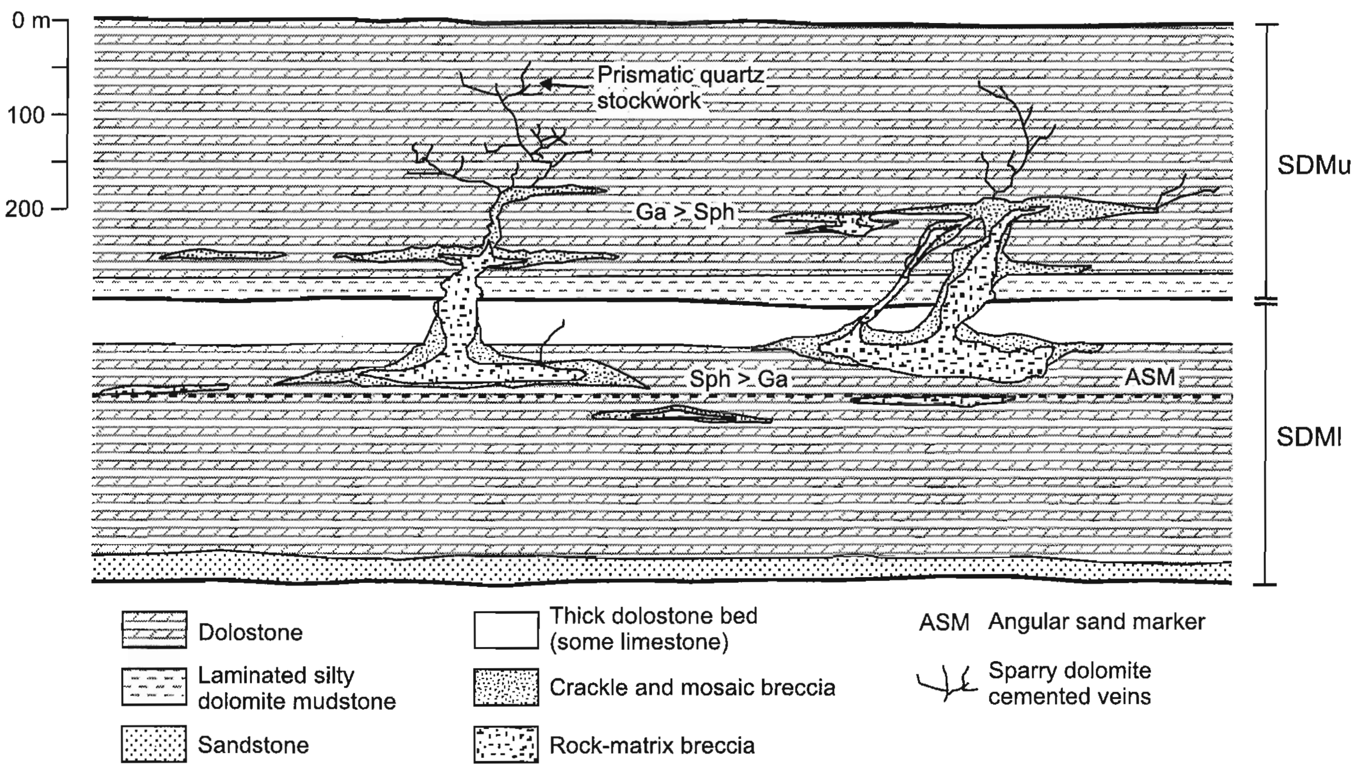


Figure 3. Schematic diagram illustrating the main breccia types, their relationships, and stratigraphic location. Ga - galena; Sph - sphalerite; SDMu - upper part, Muncho and McConnell formations; SDMl - lower part, Muncho and McConnell formations.

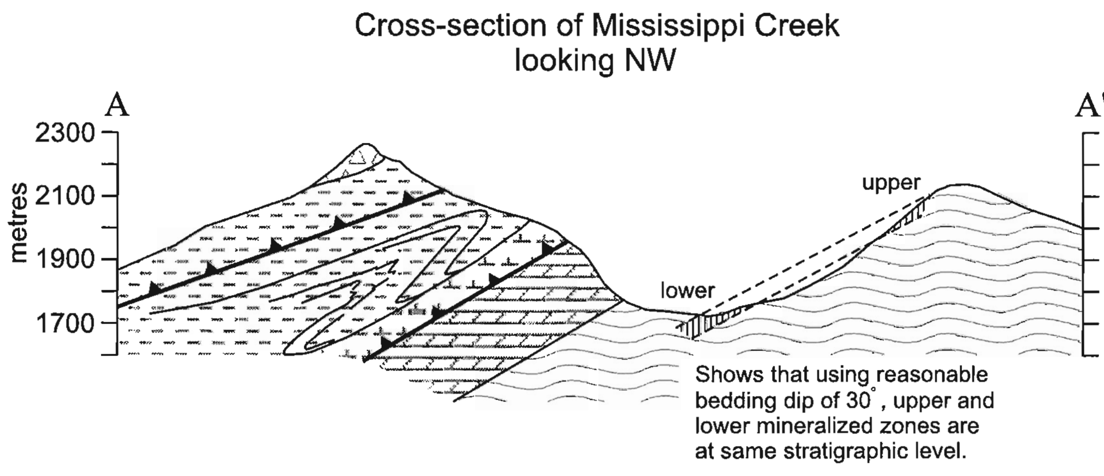


Figure 4. Cross-section of Mississippi Creek, looking NW; the lithological key and line A-A' are located on Figure 2.

general, the rock-matrix ('trash') breccias occur at the base of the breccia bodies and are overlain and fringed by the rubble, mosaic, and crackle breccias that are cemented by white sparry dolomite. Also, in the overall system, there is a predominance for the rock-matrix ('trash') breccias to be preferentially located within the lower unit and the dolomite-cemented rubble, mosaic, and crackle breccias to overlie the 'trash' breccias and be more abundant in the upper unit.

A broad mineral zonation is here recognized in the distribution of the sulphides and other minerals at Robb Lake. Sphalerite and galena are preferentially concentrated in the lower unit with approximate ratios of zinc to lead of 7:1 at the Lower showing, 1.5:1 at the West Webb showing, and 4.5:1 at the East Webb showing (Manns, 1981). Galena becomes more abundant in breccia zones located stratigraphically up section. It occurs without sphalerite in dolomite-drusy quartz veins high on the southeast ridge of Tennessee Mountain, and in dolomite matrix of a breccia peripheral to a sphalerite-rich 'trash' breccia in the North Face showing. In general, the galena-sphalerite ratio appears to increase in higher and more distal parts of the system. Drusy, crystalline quartz is more distal yet. It occurs as extensions to dolomite-galena veins on the southeast ridge of Tennessee Mountain; and is abundant elsewhere within open vugs and fractures in the upper unit. The best grade mineralization (hole 113-82 intersected 15.02% Pb+Zn over 3 m; A.J. Boronowski and S.C. James, unpub. report, 1982) which could reach a Zn:Pb ratio of 2:1, is predominantly associated with the pyrobitumen- and carbonaceous-rich matrix of the rock-matrix ('trash') breccias.

Characteristics and morphology of the breccias

There are a number of breccia types within the Muncho and McConnell formations, of primary and of secondary origin, some unrelated and some intimately related to sulphide mineralization. The most important ones with regard to the mineralization are the sparry dolomite-cemented crackle, mosaic, and rubble breccias, and the rock-matrix ('trash') breccias. This classification is texturally based.

Crackle and mosaic breccias

These terms represent end members of a continuum. The crackle breccias show little displacement of the fragments in coarse-grained, sparry white dolomite cement (Fig. 5A). The fragments consist exclusively of highly angular clasts of the variably altered crosscut dolostone host rock. The mosaic breccias have fragments that are largely but not wholly displaced (Fig. 5B). The fragments also consist of highly angular clasts of the crosscut dolostone host rock in a coarse-grained sparry white dolomite cement. Generally, mosaic breccias grade out through crackle breccias into unfractured dolostone. It is notable that in these breccias, individual clasts tend to be of somewhat uniform size, typically 5–20 cm across; although the fragments can range in size from one millimetre to several metres in longest dimension. Megabreccias of this type are rare. A substantial portion of the mineralization at Robb Lake occurs within the dolomite cement of the mosaic and crackle breccias.

Rubble breccias

In contrast with the crackle and mosaic breccias, the rubble breccias are polymictic, and the fragments are completely displaced and show no match with each other (Fig. 5C, 5D, 5E, 5F). By textural definition, this category includes the rock-matrix ('trash') breccias, which are rubble breccias with fragmental matrix instead of dolomite cement. The rubble breccias are by far the most volumetrically important types of breccias and the most varied. They contain a variety of clasts that are included in a fine-grained, dark grey fragmental matrix or in white sparry dolomite cement or in a mix of both. The breccias are generally grain-supported and locally matrix-supported. The fragments consist of a variety of altered and unaltered dolostone lithology (90 volume per cent), white sparry dolomite (i.e. subangular fragments and thin curviplanar segments of vein selvages; 5 volume per cent), shale/mudstone (2 volume per cent), finely laminated shaly carbonate (1 volume per cent), chert (1 volume per cent), pyrobitumen-rich material (<1 volume per cent); sulphides (<1 volume per cent), and fossils (brachiopods and gastropods; <1 volume per cent). The fragments are highly angular to subangular, and can vary in size from less than one millimetre to several metres. However, most breccias are dominated by fragments less than 10 cm in diameter. The matrix of the 'trash' breccias is a dark grey to black carbonaceous dolostone. On close inspection, this matrix is composed of fine fragments, cemented by overgrowths and interstitial dolospar and quartz. Some of the fine fragments are possibly pyrobituminous shale, however much of the dark colour of the matrix can be accounted for by the dark to medium grey dolostone fragments, occasional shale fragments, and the fine disseminated pyrite. The sulphides, i.e. sphalerite, galena, and pyrite, are concentrated in the matrix as individual grains and clusters, and as fracture filling material.

The spatial relationships between these breccias are illustrated on Figure 3. The rock-matrix ('trash') breccias crosscut the dolomite-cemented mosaic and crackle breccias and locally the dolomite cement of the crackle and mosaic breccias enclose fragments of the rock-matrix ('trash') breccia. We interpret this to mean that these breccias originated as an overlapping, multiepisodic sequence of events prior to and during mineralization. The incorporation of sulphide clasts in the rock-matrix ('trash') breccias is evidence that at least some brecciation and mineralization were contemporaneous.

Mineralogy and textural relationships

Sphalerite, galena, and pyrite are the main sulphide minerals; marcasite has been observed in thin sections by Taylor (1977) and Manns (1981).

Sphalerite is pale yellow, dark orange, red, or brown. It occurs as fine to coarse single or aggregates of anhedral crystals (1 mm to 1 cm) in white sparry dolomite cement of the

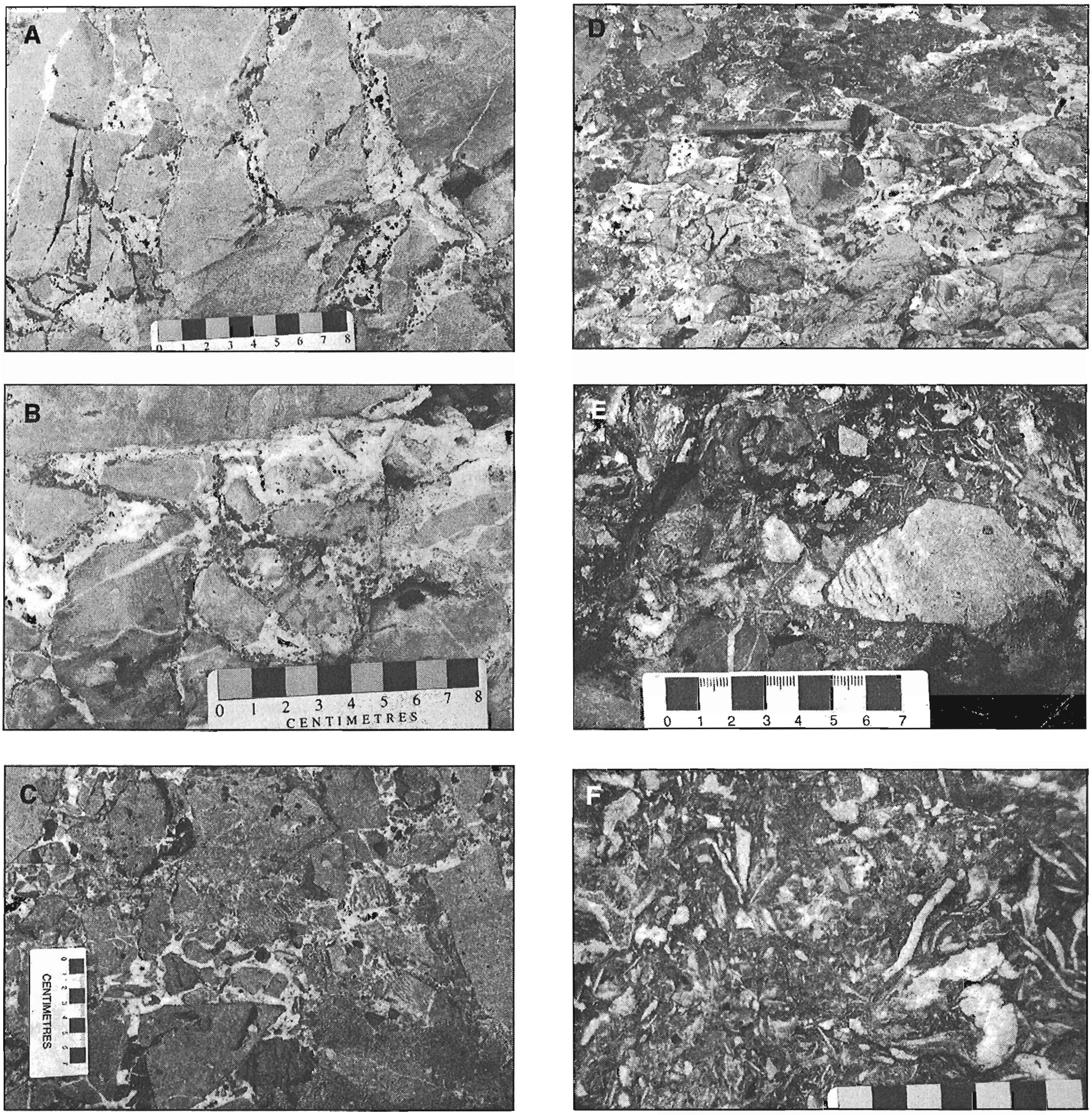


***Figure 5. A)** Crackle breccia with sphalerite crystals in white dolomite cement. **B)** Mosaic breccia with sphalerite crystals in white dolomite cement. **C)** Rubble breccia consisting of variably altered dolostone fragments and shale fragments in white dolomite cement. Note the dolostone fragments with zebra texture. **D)** Rubble breccia with a dolomite cement passing into a dark grey fragmental matrix in the upper part of the photograph. **E)** Rock-matrix ('trash') breccia with dolostone, shale, and white sparry dolomite fragments in dark grey fragmental matrix. Note the thin and elongated white sparry dolomite fragments. **F)** Rock-matrix ('trash') breccia with irregular patches of white sparry dolomite, and thin and elongated white sparry dolomite fragments.*

crackle, mosaic, and rubble breccia, and in the fine-grained carbonaceous dolostone matrix of the rock-matrix ('trash') breccia. Anhedral crystals or aggregates of crystals of sphalerite occur as rims on one or several sides of the angular dolostone fragments, or as scattered crystals within the white sparry dolomite cement. According to Manns (1981), geopetal sphalerite (i.e. 'snow on the roof' texture) is abundant at Robb Lake, but our observations on the various showings also pointed out that sphalerite also lines the bottoms of cavities and/or coats indiscriminately any or every side of fragments. Sphalerite crystals and aggregates range from less than 1 mm to 1.5 cm. Very fine-grained sphalerite (i.e. <1 mm) is only present in the matrix of the rock-matrix ('trash') breccia. Sphalerite crystals are usually anhedral and are commonly fractured. Colloform sphalerite has been reported at the Waterfall showing (Macqueen and Thompson, 1978; Manns, 1981).

Overall, galena is less abundant than sphalerite and pyrite. It commonly occurs as euhedral crystals (<1 cm to 2 cm) and less commonly as anhedral aggregates in the white sparry dolomite cement of the rubble, mosaic, and crackle breccias, and in the carbonaceous dolomite matrix of the rock-matrix ('trash') breccia. Galena also occurs as fracture fillings with or without sphalerite and quartz. Sangster and Carrière (1991) observed galena veinlets crosscutting sphalerite crystals and grains of sphalerite completely enclosed by galena.

In showings located in the lower unit of the Muncho and McConnell formations, galena is typically associated with sphalerite, and may have coprecipitated or precipitated slightly later. In the upper unit, galena frequently occurs by itself, as euhedral and anhedral crystals disseminated in the white sparry dolomite, and is often associated with quartz. When quartz is present and associated with galena, it occurs as fractures cutting galena or as inclusions in galena (Sangster and Carrière, 1991).

Pyrite occurs as disseminated fine-grained euhedral to subhedral crystals and aggregates in the rock-matrix ('trash') breccia, and as massive aggregates of fine-grained pyrite along stylolites, bedding planes, and fracture fillings.

Pyrobitumen commonly occurs within the various breccias where it fills small cavities and fractures. It potentially also forms a component of the rock-matrix ('trash') breccia, giving the dark grey colour to its matrix.

The paragenesis between the sulphides, the white sparry dolomite, and the pyrobitumen has not been fully determined yet.

Alteration

Megascopically, three distinct phases of dolomitization affected the carbonate rocks in the Robb Lake area. An early phase consists of a light-grey-weathering, medium and dark grey dolostone composed of fine-grained crystalline dolomite. This dolomite dominates the sequence regionally and is considered to be the result of very early diagenetic alteration of primary calcite. A later, coarse sparry and prismatic white to grey dolomite coats some dolostone fragments and is associated with the zebra texture. This texture is a common feature of carbonate rocks associated with Mississippi Valley-type deposits. It consists of thin dolostone layers (millimetre to centimetre scale) identical to, and connecting with, the surrounding homogeneous dolostone, but separated from each other by coarse sparry and prismatic white dolomite layers (millimetre to centimetre scale) or, in some cases, by voids of the same shape as the white layers, or by pyrobitumen, or by a combination of the three. The layering is either oriented parallel to bedding or in herringbone patterns that resemble crossbedding, the template for which is cryptic. It never extends continuously either vertically or laterally, for more than 30 cm or so. Zebra texture affects all the dolostone units of the Robb Lake area, and fragments of the zebra texture are incorporated in the mineralized breccias. The third dolomite in the Robb Lake area is a white sparry dolomite that forms the cement of the breccias, and fills the joints, fractures, vugs, and primary porosity such as fenestrae and fossil interiors.

With the help of cathodoluminescence petrography, Manns (1981) was able to observe several generations of dolomite: 1) fine-grained inert dolomite forming the regional host-rock dolostone; 2) inert coarse white sparry and prismatic dolomite lining cavities, coating dolostone fragments in breccias, and associated with the zebra texture; 3) luminescent dolomite forming the cement of the mineralized breccias and associated with sphalerite, galena, pyrite, and local pyrobitumen; and 4) inert dolomite filling the central portions of large cavities.

DISCUSSION

Brecciation and open-space filling are very important processes in the formation of Robb Lake as in most Mississippi Valley-type deposits. Temporal and genetic relationships between brecciation and mineralization at Robb Lake are controversial. Are the breccias that host mineralization the result of wall-rock dissolution by Mississippi Valley-type mineralizing brines or were they formed by other, earlier fluids, possibly related to regional weathering and karstification, which created an extensive paleoaquifer system for later Mississippi Valley-type brines (Sangster, 1988)? Did alteration and dissolution of carbonate wall rock in the breccias cause ore deposition at Robb Lake? These questions largely remain unanswered at Robb Lake, as indeed at other Mississippi Valley-type deposits around the world.

In some Mississippi Valley-type deposit districts, it is documented that solution of carbonate by ore-related brines has allowed collapse and brecciation of the overlying beds, and that gravity was an important force in the shattering. However, the fine median size and high degree of angularity of the fragments within the trash breccias and of the breccia bodies at Robb Lake suggest that other forces such as hydraulic fracturing may have supplemented simple collapse.

Other questions that we will try to resolve in the future with respect to the Robb Lake deposit include the following:

1. The age of mineralization is unknown and could be as old as late Devonian (equivalent to Pine Point deposit) or as young as Cretaceous or even younger. It is hoped that the proposed Rb-Sr sphalerite study will illuminate this issue.
2. How did the rock-matrix ('trash') breccias form? How does solution collapse promote the fine clast size and highly angular clast shapes seen in these; and by what collapse mechanism are entire vein selvages detached? On the other hand, what other mechanism of brecciation could be operative in the context of relatively cool brines (87° to 154°C with a mean of 119°C; Sangster and Carrière, 1991)?
3. Why do the mineralized and unmineralized breccias preferentially favor a stratigraphic interval, the base of the upper thick unit, which is otherwise lithologically indistinguishable from others in the Muncho and McConnell formations?
4. Are the deposits of the Robb Lake belt, Pb-Zn mineralization in the subsurface Presqu'ile Barrier, and Pine Point deposit cogenetic, the result of a single eastward 'flush' of Mississippi Valley-type brines or are they polygenetic? Are the Mississippi Valley-type deposits of the Robb Lake belt genetically related to the SEDEX deposits of the Kechika Trough?

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Geological Survey of Canada Project 940002SP

Nechako NATMAP Project overview, central British Columbia, year four: part 1[1]

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Struik, L.C. and MacIntyre, D.G., 1999: Nechako NATMAP Project overview, central British Columbia, year four: part 1; in *Current Research 1999-A; Geological Survey of Canada, p. 71–78.*

Abstract: Part one of this two-part overview summarizes 1998 bedrock and surficial mapping of the joint Geological Survey of Canada, British Columbia Geological Survey Branch, universities, and industry project. Sixteen university students assisted 25 government and university researchers this field season. Bedrock geology was mapped in fourteen areas and surficial geology in six areas, all at a scale of 1: 50 000. Researchers studied biostratigraphy; sampled for isotopic-age dating; conducted detailed sedimentological and stratigraphic studies; measured magnetism, gravity and density; and sampled till, silt, lodgepole pine, and rocks in various geochemical studies. New geoscience contributions include 1) extending the delineation of the Sitlika Group sedimentary and volcanic rocks southward through the Fort Fraser map area, 2) redefining large tracts of western Cache Creek Group as Stikine and Sitlika assemblages, 3) recognition of Jura-Cretaceous contraction like the Skeena fold belt to the north, and 4) better definition of the distribution and tectonics of Miocene and Eocene volcanic and intrusive suites.

Résumé : La première partie de cette aperçu à deux volets décrit brièvement le projet de cartographie des dépôts de surface et du substratum rocheux réalisé conjointement en 1998 par la Commission géologique du Canada, la Commission géologique de la Colombie-Britannique, des universités et l'industrie. Au cours de la présente campagne de terrain, 16 étudiants de niveau universitaire ont secondé dans leurs travaux 25 chercheurs gouvernementaux et universitaires. La géologie du substratum rocheux a été cartographiée dans quatorze régions à l'échelle du 1/50 000 et la géologie des dépôts de surface, dans six régions à la même échelle. Les chercheurs ont étudié la biostratigraphie, prélevé des échantillons à des fins de datations radiométriques, effectué des études sédimentologiques et stratigraphiques détaillées, mesuré le magnétisme, la gravimétrie et la densité, et échantillonné, dans le cadre de diverses études géochimiques, du till, du silt, le pin de Murray et des roches. Les nouvelles contributions géoscientifiques sont entre autres : 1) la poursuite de la délimitation des roches sédimentaires et volcaniques du Groupe de Sitlika vers le sud dans l'ensemble de la région cartographique de Fort Fraser; 2) la redéfinition de vastes étendues de la partie occidentale du Groupe de Cache Creek comme étant des assemblages des groupes de Stikine et de Sitlika; 3) la reconnaissance de la contraction jurassique–crétacée, telle que la ceinture de plissement de Skeena au nord; et 4) une meilleure définition de la répartition des suites volcaniques et intrusives du Miocène et de l'Éocène et du tectonisme dont elles ont été l'objet.

[1] Contribution to the Nechako NATMAP Project

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INTRODUCTION

This was the final year of fieldwork for the joint Nechako NATMAP project of the Geological Survey of Canada (GSC), British Columbia Geological Survey Branch (BCGSB), universities, and industry (Struik and McMillan, 1996; MacIntyre and Struik, 1998). The project has encompassed more than 30 000 km^2 in central British Columbia (Fig. 1, 2). It focused on improving the quality and detail of bedrock and surficial geology maps to help resolve several geological problems. In particular, the project addresses the following questions: 1) the extent and nature of Tertiary crustal extension, 2) Mesozoic compression and the manner of accretion of exotic terranes, 3) the geological and geophysical definition of the terranes, 4) the sequence of changing Pleistocene glacial ice-flow directions, and 5) the character and dispersion of glacial deposits.

Bedrock geology was mapped in fourteen areas and surficial geology in six areas, all at a scale of 1:50 000. That work, along with research in biostratigraphy, isotopic-age dating, sedimentology, and stratigraphy, is summarized here in this first of a two-part overview of the Nechako NATMAP project's fourth field season. Part two of the overview summarizes the activities and results of geophysical, geochemical, industrial mineral, and Geographic Information System (GIS) research (Struik and MacIntyre, 1999). The geophysical studies include integration of magnetic, gravity, and gamma-ray surveys with geochemical and geological mapping to better understand the geology, and particularly the alteration, of the Endako Batholith of the Endako molybdenum camp and the structures of the Vanderhoof Metamorphic Complex. The geochemical mapping included new sampling of glacial till, lodgepole pine bark, and rocks. Digital GIS projects included construction and addition to the digital field-mapping databases, cartography of geological maps, internet GIS data sharing, surficial-geology GIS data sets, analysis of RADARSAT and Landsat imagery, generation of Digital Elevation Models and creation of a general-interest geological map of the Fort Fraser map area. The distribution of all this work is summarized in Figure 3.

New geoscience contributions include 1) extending the delineation of the Sitlika Group sedimentary and volcanic rocks southward through the Fort Fraser map area (NTS 93 K), 2) redefining large tracts of western Cache Creek Group as Stikine and Sitlika assemblages, 3) recognition of Jura-Cretaceous contraction structures which may be correlative with Skeena Fold Belt structures to the north, 4) better

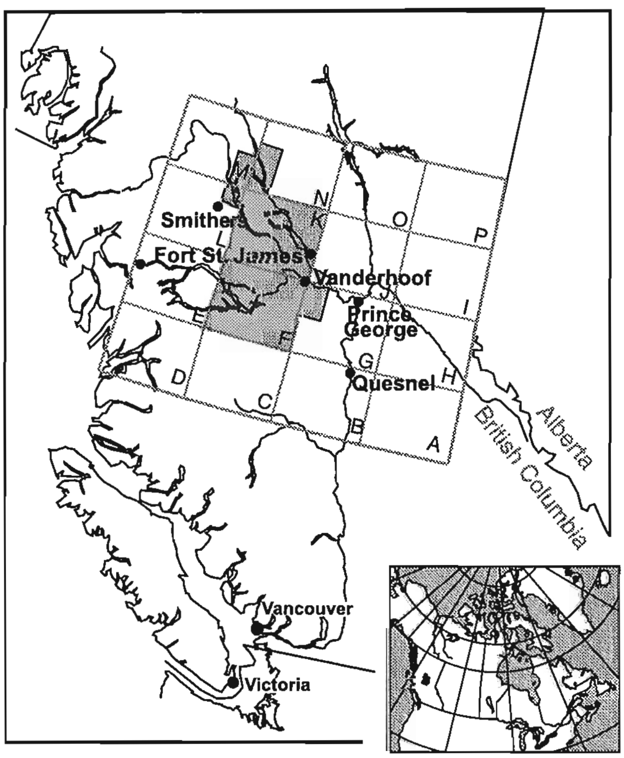

Figure 1. Location of the Nechako NATMAP project area within British Columbia. The Parsnip River (NTS 93) 1:1 000 000 scale map-sheet area and its 1:250 000 scale component map-sheet areas are shown for reference.

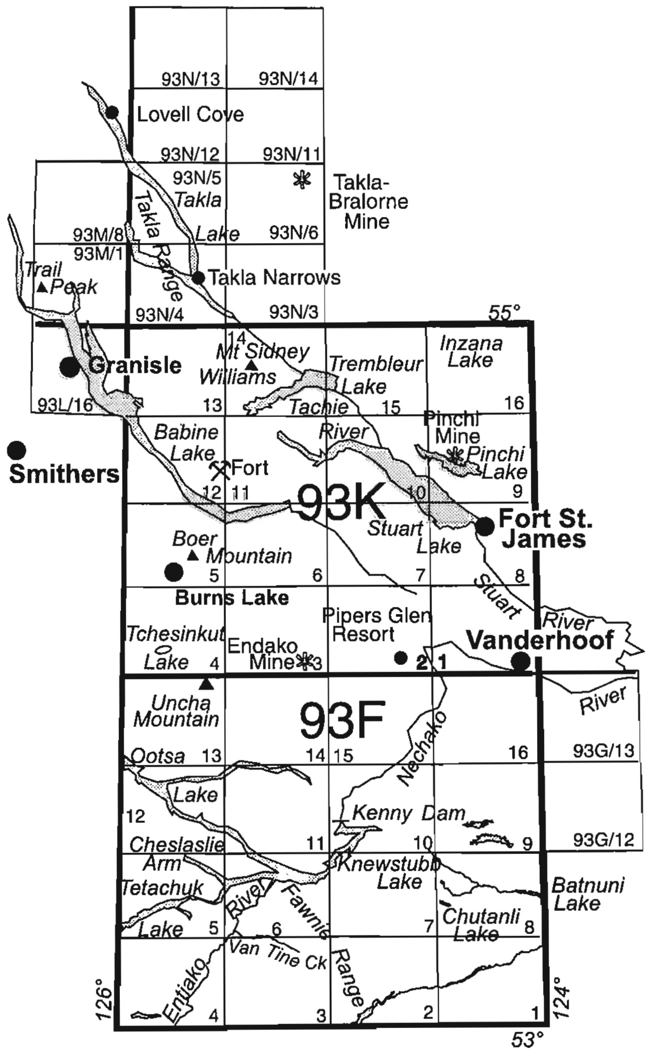

Figure 2. Reference map of geographic and NTS map locations mentioned in the text. See Figure 1 for the location of the Nechako NATMAP Project area within central British Columbia.

definition of the nature, distribution, and tectonic setting of the Neogene and Eocene basalt, andesite, and felsic volcanic and associated intrusive suites, 5) characterizing the geophysical and geochemical signature of the Endako Batholith and adjacent suites, and 6) establishing an area of high background mercury in till and lodgepole pine bark in the area north of Ootsa Lake in NTS map area 93 F.

This paper outlines research that is in many cases preliminary. References are given to more in-depth summaries in this volume and *Geological Fieldwork 1999* of the British Columbia Ministry of Employment and Investment. For others, the continuing research will lead to more comprehensive government and journal reports and maps. Analytical data is not reported in this paper.

OVERVIEW OF 1998 NECHAKO PROJECT BEDROCK AND SURFICIAL MAPPING

Babine Porphyry belt and Sitlika studies

In this fourth and final field season of the Nechako NATMAP project, the BCGSB did bedrock mapping in the Babine–Takla lakes area. D.G. MacIntyre and P. Schiarizza were coleaders of the bedrock mapping crew, which included geology students A. Justason (Camosun College), S. Modeland (University of Victoria), S. Munzar (University of British Columbia) and D. Tackaberry (University of Victoria).

Accomplishments

From early June until the end of August the main focus of work was 1:100 000 scale bedrock mapping of NTS map sheets 93 K/11, 12, 14 and 93 N/3 (Fig. 3). In addition, fill-in mapping was done in areas mapped in previous summers including map sheets 93 K/13, 93 N/4 and 5. In the Babine Porphyry belt, bedrock mapping was extended into adjoining areas covered by map sheets 93 L/9, 93 M/2 and 93 M/7 (Schiarizza and MacIntyre, in press). This work built on previous mapping in the Babine Porphyry belt (MacIntyre et al., 1996, 1997; MacIntyre, 1998) and in the Sitlika belt east of Takla Lake (Schiarizza and Payie, 1997; Schiarizza et al., 1998; MacIntyre et al., 1998).

The following are the main highlights of the work completed in 1998 (*see* Schiarizza and MacIntyre, in press, for details).

- significant revisions and refinements were made to the existing bedrock-geology maps for the northwest quadrant of the Fort Fraser map sheet (93 K/11, 12, 13 and 14), most of which were based on Armstrong's mapping and compilation (Armstrong, 1949).
- an area of limestone, metavolcanic and metasedimentary rocks intruded by pyroxenite and amphibole gabbro was mapped in the northwest corner of the 93 K/12 map sheet. These rocks, previously mapped as Jurassic Hazelton Group, are tentatively correlated with the Permian Asitka Group. They appear to stratigraphically underlie pyroxene porphyry flows of the Takla Group that are exposed further to the east.
- additional mapping in the western parts of 93 N/4 and 93 N/5 has revealed that the Takla Range, previously mapped as Upper Triassic Takla Group, also includes Jurassic strata of the Hazelton and Bowser Lake groups.
- mapping in the vicinity of the Fort prospect (Fig. 2) suggests mineralization formed as a result of relatively low-temperature open-space filling in a dilational breccia zone along the fault contact between a pyroxenite-gabbro-diorite-tonalite intrusive complex and Takla volcanic rocks. The pyroxenite intrusive complex intrudes chlorite schists and pyroxene-phyric metabasalts that may correlate with the Takla Group and/or the Asitka or Sitlika Assemblage.
- the Sitlika eastern clastic unit was traced southeastwards from 93 K/13, into 93 K/14, 93 K/11, and 93 K/12, where it was previously mapped as Cache Creek Group. Felsic and mafic metavolcanic rocks that form a narrow belt directly west of the eastern clastic unit are correlated with the Sitlika volcanic unit; a U-Pb geochronology sample was collected from one of the felsic volcanic members to test this correlation.
- new mapping in the southern part of 93 N/4, together with visits to previously mapped outcrops in 93 N/4 and 5, has resulted in an improved understanding of the Sitlika western clastic unit. Most of the unit is now interpreted as a structural repetition of the eastern clastic unit within a west-vergent fold-fault system. Chert-pebble conglomerate that dominates the unit where it was originally defined in 93 N/12 is interpreted as a fault-bounded panel derived from Stikine Terrane (Bowser Basin), which forms the footwall of this west-vergent thrust system.
- the ultramafic unit that marks the boundary between the Sitlika Assemblage and Cache Creek Group in 93 N continues southward along the contact through 93 K/13 and 14 and into 93 K/11. This unit includes serpentinite mélange, as well as coherent sections of tectonized harzburgite with dunite pods, gabbro-diorite intrusive complexes, and mafic volcanic rocks. A sheeted diabase-dyke complex was discovered along the eastern margin of the unit in 93 K/11, consistent with an ophiolitic origin for the ultramafic unit. Tonalite, which occurs locally as a late-stage differentiate within some of the gabbro-diorite intrusive complexes was sampled for U-Pb dating in an effort to determine the age of the ophiolite complex.
- from Stuart Lake to Tsitsutl Mountain, the Cache Creek Group directly east of the ultramafic unit is represented by a belt of mafic metavolcanic rocks and associated chert, phyllite, and minor limestone that is intruded by numerous mafic (locally ultramafic) sills and dykes. The dykes and sills are similar to intrusive rocks found within the adjacent ultramafic unit, suggesting that these rocks may represent the upper part of the ophiolite succession. The volcanic-sedimentary succession is, at least in part, Late Triassic, and displays evidence of synsedimentary intrusion and faulting. It represents the remnants of an active (back-arc?) basin that may have potential for VMS deposits of the Windy Craggy type.

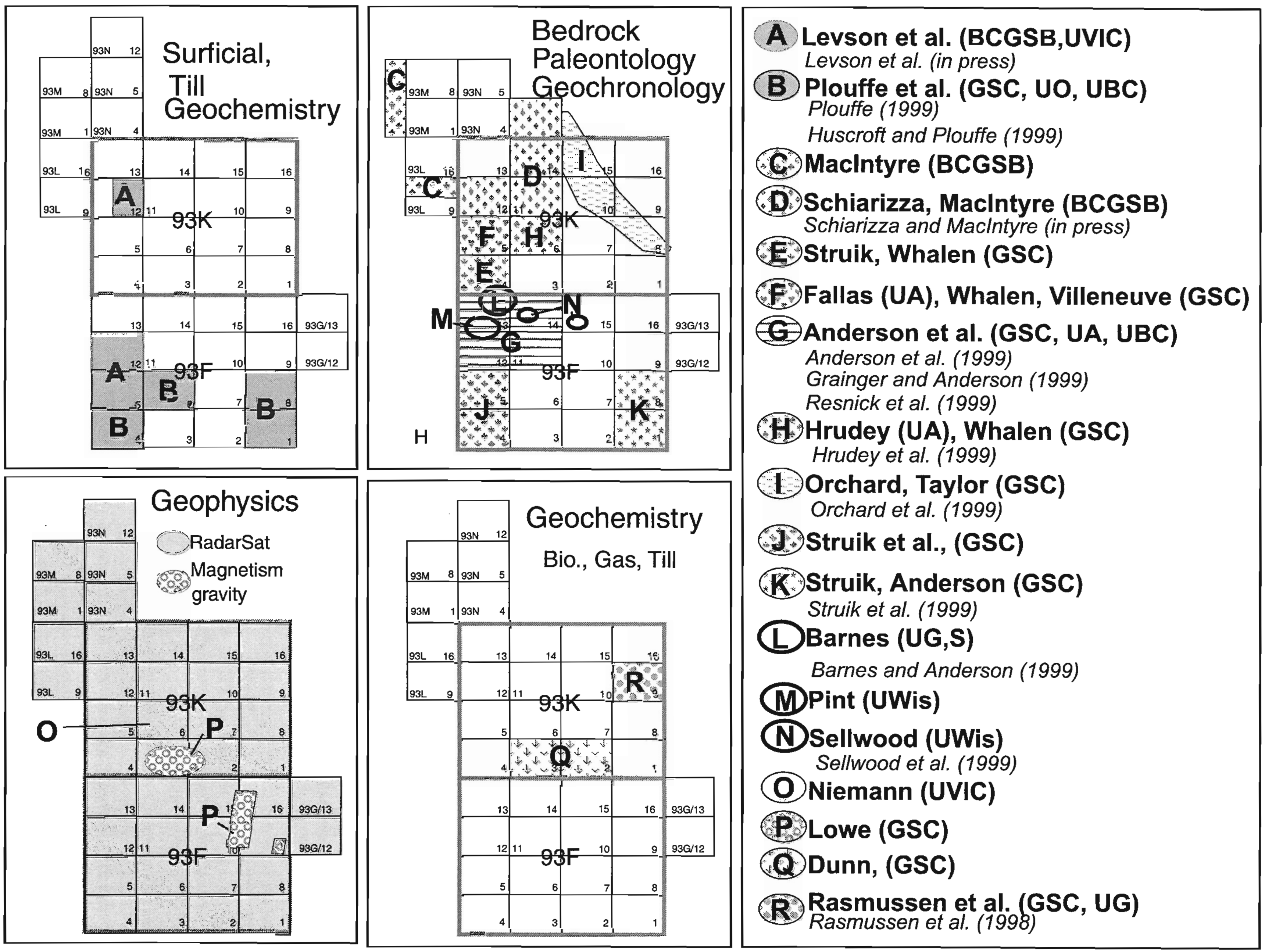

Figure 3. Location of various Nechako subprojects active in 1998.

Cache Creek Group tectonostratigraphic studies

Studies this season, in the Cache Creek Group of Fort Fraser and Manson River map areas, consisted of geochronological sampling. This work was conducted by H. Taylor (GSC) with assistance of M.G. Hrudey (University of Alberta), K. Franz (University of British Columbia), and P. Schiarizza (BCGSB). Primary access was by forest service roads branching from Fort St. James, and the extensive lake system.

Accomplishments

This sampling is meant to confirm and increase the size of unique conodont fossil collections made in previous years in the Cache Creek Group, Sitlika Formation and Stikine Terrane. These collections contain Permian and Early Triassic faunal assemblages rare or previously unknown in western North America and in particular to these rock assemblages (Orchard et al., 1999).

Endako plutonism and tectonics

Bedrock was mapped in detail within the Tchesinkut (93 K/4), Burns Lake (93 K/5), and Tintagel Lake (93 K/6) map areas (1:50 000 scale, Fig. 2, 3). This mapping built on previous mapping by the British Columbia Geological Survey, the Geological Survey of Canada and the Endako Mines group (Kimura et al., 1980; G. Johnson, pers. comm., 1997). J.B. Whalen (GSC) and L.C. Struik (GSC) were ably assisted by K. Fallas (University of Alberta), M.G. Hrudey (University of Alberta), M. Quat (GSC), C. Huscroft (University of British Columbia), S. Billesberger (University of British Columbia), K. Franz (University of British Columbia) and M. Clapham (University of British Columbia). C. Lowe (GSC) augmented investigations of the magnetic signature of the Endako molybdenum camp through detailed magnetic measurements within the Endako Mine. The area was accessed through forest roads and highways.

Accomplishments

Detailed bedrock maps of southwestern Fort Fraser map area (93 K/4, 5 and 6) were completed. Stratigraphic sequences in the Ootsa Lake and Endako groups were constrained within the limits of the poor exposure. N. Grainger (University of Alberta) and M. Villeneuve (GSC) sampled igneous suites for U-Pb and Ar-Ar isotopic dating in key areas concentrating on the Tertiary volcanic units to constrain their stratigraphy and the tectonic events that generated them. Representative samples of each of the Tertiary volcanic units and the Jura-Cretaceous plutonic phases were taken for detailed lithogeochemical analysis to constrain interpretations of the genetic history of those rocks. Samples were taken from within the Endako Mine and from Tertiary dykes and flows of the surrounding area for magnetic measurements to quantitatively constrain detailed aeromagnetic interpretations.

The following are the main highlights of the Endako study of 1998:

- Endako Group basalt occurs in small areas mainly in the southern and western parts of southwestern Fort Fraser map area. At one locality, Endako Group basalt is cut by rhyolite typical of the Ootsa Lake Group, previously considered to be entirely older than the Endako.
- The Eocene Ootsa Lake Group in southwestern Fort Fraser map area contains rhyolite, rhyodacite, and dacite flows, crystal tuffs, agglomerates, breccias, and conglomerates. Andesite and some dacite previously interpreted to be of the Ootsa Lake Group (Whalen et al., 1998) is now considered older; probably Cretaceous. Rhyolite of the group around Tchesinkut Lake commonly shows textures associated with deposition in shallow-water environments.
- The Boer pluton at Boer Mountain was determined to be a unique gabbro to diorite that is different from the various plutons mapped as Boer phase to the east and northeast.
- The Taltapin phase of the Endako Batholith occupies a much smaller area than previously mapped, as much of the Taltapin phase appears to be a more foliated variation of the McKnabb or Shass Mountain phase (Hrudey et al., 1999).
- Sitlika Assemblage andesite and sedimentary rocks mapped to the north (Schiarizza et al., 1998; Schiarizza and MacIntyre, in press) continue southeastward through the Taltapin map area (NTS 93 K/6; Hrudey et al., 1999). These were mapped as Cache Creek Group in the Fraser Lake area (Struik, 1997).
- Amphibolite, marble, quartzite and various foliated diorites of the Babine Lake area appear to be part of Stikine Terrane and are higher grade than those to the northwest or southeast (Hrudey et al., 1999). No clearly defined structures bound these medium-grade metamorphic rocks.

Nechako River map area bedrock mapping

Bedrock mapping at 1:100 000 and 1:50 000 scales continued in the Nechako River (NTS 93 F) map area by R.G. Anderson and L.C. Struik (GSC) and crews. C. Lowe and J. Baker recorded additional geophysical data to augment profiles previously initiated across the various shear zones surrounding the Vanderhoof Metamorphic Complex (*see* Struik and MacIntyre, 1999 for more details). Mapping concentrated on the Knapp Lake (NTS 93 F/14; Anderson et al., 1999), Takysie Lake (NTS 93 F/13), Marilla (NTS 93 F/12), Cheslatta Lake (NTS 93 F/11) and Tetachuck Lake (NTS 93 F/05) map areas. Contributions were made to improve the detail of the bedrock mapping in the Euchiniko River (NTS 93 F/08), Qualcho Lake (NTS 93 F/4) and Suscha Creek (NTS 93 F/01) map areas (Struik et al., 1999). R.G. Anderson's core crew of senior mappers, L.D. Snyder (University of Wisconsin at Eau Claire,), N. Grainger (University of Alberta), and J. Resnick (University of British Columbia) was augmented by volunteers E. Barnes (University of Glasgow), T. Pint (University of Wisconsin at Eau Claire), S. Sellwood (University of Wisconsin at Eau Claire), A. McCoy (Ottawa, Ontario), D. Jost (Berne, Switzerland), and N. Anderson (Langley, B.C.).

Assisting L.C. Struik were the Endako crew and S. Williams (GSC) and volunteers, R. Paterson (University of Melbourne) and C. Struik (Vancouver, British Columbia).

Accomplishments

In addition to completion of bedrock mapping in most of Nechako River map area (Anderson et al., 1999; Struik et al., 1999), several theses and directed-study projects were undertaken. Additional magnetic and gravity readings were taken along profiles crossing the Nulki Shear zone (Wetherup, 1997) in northeastern Nechako River map area. Profiles were extended to the west and south and the density of the measurements was increased in the vicinity of the suspected position of buried shear zones. The university theses and directed studies include the petrogenesis of Neogene basaltic centres (Resnick et al., 1999), geochronology and genesis of the Ootsa Lake Group felsic volcanic and related plutonic rocks (Grainger and Anderson, 1999), structural and stratigraphic mapping of the Jurassic and Tertiary volcanogenic and plutonic suites of Uncha Mountain in the northwest (Barnes and Anderson, 1999), structural studies of deformed Hazelton Group rocks; plutonic studies (Sellwood et al., 1999; S. Billesberger, University of British Columbia), and sedimentological and stratigraphic studies of the Hazelton Group to the southwest (M. Quat, GSC). Detailed laboratory studies include investigation of the development of saprolitic horizons beneath Miocene basalt by Resnick and a mineralogical identification by Barnes of the large variety of zeolite and other minerals that fill vesicles of basalt flows in Ootsa Lake and Endako groups, and less commonly in Miocene basalt.

Highlights of the Nechako River bedrock mapping for 1998 include:

- Recognition of important and widespread Cretaceous volcanic units in eastern Knapp Lake map area (Anderson et al., 1999). They include felsic feldspar-phenocryst-rich units and andesitic hornblende-plagioclase porphyry flows that strongly resemble the Upper Cretaceous Holy Cross porphyry andesite (Lane, 1995).
- A regional-scale reverse fault in the southern Takysie (NTS 93 F/13) and northern Marilla (NTS 93 F/12) areas juxtaposes Lower and Middle Jurassic Hazelton Group and Bowser Lake Group units, and is crosscut by a Cretaceous(?) porphyritic pluton (Anderson et al., 1999). Up to four generations of ductile and/or brittle minor structures were recognized by T. Pint (University of Wisconsin at Eau Claire) in the Hazelton Group hanging-wall rocks; equivalent Hazelton Group rocks elsewhere are comparatively undeformed. Interpreted thrust faulting in the Euchiniko River map area imbricated Lower and Middle Jurassic Hazelton Group volcanic and sedimentary rocks (Struik et al., 1999).
- Miocene basalt intrusive centres and associated lava flows are clearly distinguished from Eocene Endako Group basaltic andesite based on texture, olivine-phenocryst, megacryst and xenocryst content, and the common association of mantle and crustal xenoliths in the Miocene rocks (Resnick et al., 1999). Many centres occur along extensions of older fault systems, and locally, are themselves deformed, suggesting reactivation of Eocene faults and a Miocene extensional tectonic setting for emplacement.
- Ootsa Lake Group volcanic stratigraphy in northwestern Nechako River map area has been refined to include a generalized stratigraphy of amethyst-bearing, amygdaloidal andesite, flow-layered rhyolite, and rhyolitic tuff as well as a variety of flow-layered, aphanitic, and porphyritic high-level intrusions related to the volcanism (Grainger and Anderson, 1999). Mafic rocks are rare, but significant, in the upper part of the Ootsa Lake Group because they may provide the stratigraphic and petrological linkage to the Newman Volcanics recognized by D. MacIntyre of BCGSB.
- The distribution, composition, textures, and intrusive relationships involving high-level, miarolitic leucogranite and associated porphyry phases in the Hallett Lake and Knapp Lake areas indicate that these intrusions are the closest plutonic analogues of the Ootsa Lake Group volcanic units (Sellwood et al., 1999).
- Similar plutonic rocks as well as aphanitic and porphyritic felsic intrusions at Uncha Mountain were shown to be clearly co-spatial and synkinematic with north-northeast-trending brittle faults and associated development of fracture cleavage (Barnes and Anderson, 1999). The orientations of the Tertiary faults and intrusions on Uncha Mountain suggest a rotation of the uniaxial extensional stress directions from northwest-southeast in the Hallett Lake area in the east to east-west at Uncha Mountain in the west.

Nechako River map area Quaternary geological mapping

Surficial mapping concentrated on the southwest and southeast quadrants of Nechako River map area and 93 F/12. The mapping verified aerial photographic interpretations, catalogued Quaternary stratigraphy, studied landslide hazards, and included collection of till samples for geochemical study. That work was done by A. Plouffe (GSC) and student assistant J. Bjornson (University of Ottawa), and by V. Levson (BCGSB), David Mate (University of Victoria), D. McClenagan (University of Victoria) and A. Stuart (University of Waterloo) and included the involvement of staff of the British Columbia Ministry of Forests.

Accomplishments

A. Plouffe and J. Bjornson mapped surficial geology and sampled till at a regional scale (approximately one sample per 25 km^2) in the eastern and central part of Nechako River map area. They collected a total of 131 till samples for geochemical analyses that will be completed on the clay-sized (<0.002 mm) and silt-plus-clay-sized (<0.063 mm) fractions. The samples were collected in the following NTS map areas: 93F/1, F/6, F/8, and F/9. Results of the 1996 and 1997 regional till-sampling programs will be published as two sets of coloured geochemical maps along with digital geochemical data (Plouffe, 1998a; Plouffe and Williams, 1998).

Two new surficial geology maps were published in 1998 (Plouffe, 1998b; Plouffe and Williams, 1998). With the combined effort of the BCGSB and the GSC, by the end of the Nechako NATMAP project, four new surficial geology maps at a scale of 1:100 000 will be available for the entire Nechako River map area.

Glacial striations were measured on a total of 53 bedrock outcrops, which included several sites that revealed more than one ice movement, and on some of these the age relationship was established. Quaternary stratigraphy was logged at a limited number of sites located in the Batnuni Lake, Van Tine Creek, and Entiako River valleys. A site located on the shore of Cheslalie Arm of Ootsa Lake was revisited by A. Plouffe and V. Levson to sample nonglacial sediments that predate the last glaciation. The site was first described by Levson et al. (1998) who reported a single radiocarbon date of 27 790 ± 200 B.P. (Beta-101017) on the fine organic detritus of the nonglacial sediments.

Fieldwork for two Bachelor's theses on Quaternary geology topics was completed during the 1998 field season. C. Huscroft (Huscroft and Plouffe, 1999) studied the Pleistocene lake sediments deposited in the area of Knewstubb Lake. She investigated the sedimentology of the glacial lake sediments and took a series of elevation measurements of the glacial lake outlets and sediments to reconstruct the deglaciation history. Her work will contribute to the regional study of the glaciolacustrine deposits of central British Columbia (Plouffe, 1997). Her thesis will be completed at the University of British Columbia under the supervision of M. Church. J. Bjornson completed a detailed investigation of ice-flow indicators (glacial striations, till fabrics, rat tail, flutes, drumlins, and crag and tail) for a 50 km^2 area located along the western margin of 93 F/11 NTS. He will compare ice-flow data obtained from micro- and macro-landforms and will reconstruct the ice-flow history of that region. His research will be conducted at the University of Ottawa, under the supervision of B. Lauriol.

Surficial geological mapping conducted by the BCGSB concentrated on the Tetachuck Lake (93 F/5) and Marilla (93 F/12) areas (Levson et al., in press). Surficial geology studies in this area are a continuation of work started in 1997 (Levson et al., 1998).

Highlights of the Nechako River surficial geological mapping for 1998 include

- Stratigraphic sections at Batnuni Lake, Van Tine Creek, and Entiako River valleys provide new information about the advance-phase paleogeography of the last glaciation.
- Preliminary results from ice-flow indicators show an east-northeast ice flow, followed by an eastward movement. Glacial striations, roches moutonnées, and erratics found in the Fawnie Range all indicate a general eastward ice movement. This new information suggests that the ice divide identified by Levson et al. (1998), which extended from the Babine Lake to the Ootsa Lake valleys during the last glacial maximum, probably never migrated as far easterly as the Fawnie Range.
- Anomalous westward ice flow during the Late Wisconsinan glaciation, recently described by Levson et al. (1998), and Stumpf et al. (in press) for the Babine Range and Hazelton Mountain area, was also found this field season on the west side of the Marilla area (93 F/12). This indicates that a Late Wisconsinan ice divide was located east of the Tweedsmuir area, subjecting that region to westerly ice flow and consequent west-directed glacial dispersal. Westerly flow was independent of large topographic barriers such as the Tweedsmuir, Babine, and Hazelton mountains and occurred when ice centres over the Hazelton and Coast mountains migrated eastward into the Interior Plateau. Evidence for westerly flow is most readily found in the western part of the map region and is absent in the east. Consequently, the effects of westward flow on geochemical dispersal are expected to rapidly diminish eastward.
- Westerly ice flow locally extended to the end of the last glaciation as indicated by preservation of paleoflow indicators at unprotected, low-elevation sites. These observations confirm that the maximum buildup of interior ice extended late into the last glaciation and that a topographically controlled, late-glacial, ice-flow phase was short-lived in this part of the Interior Plateau (Levson et al., 1998).

For monthly updates in Nechako NATMAP Project developments, see the project Newsletters posted on the Nechako project website (http://www.ei.gov.bc.ca/~natmap) during the life of the project.

ACKNOWLEDGMENTS

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Geological Survey of Canada Project 950036-02

Nechako NATMAP Project overview, central British Columbia, year four: part 2[1]

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Struik, L.C. and MacIntyre, D.G., 1999: Nechako NATMAP Project overview, central British Columbia, year four: part 2; in *Current Research 1999-A; Geological Survey of Canada, p. 79–84.*

Abstract: Part two of this two-part project overview summarizes magnetic and gravity studies; geochemical sampling of till, lodgepole pine bark, and earth gas; industrial mineral studies and site examinations; and Geographic Information Systems (GIS) applications and studies. For all activities, 16 university students assisted 25 government and university researchers this field season. New geoscience contributions include1) characterization of the geophysical and geochemical signatures of Endako Batholith and its deformation, 2) finding high background mercury in till and lodgepole pine bark north of Ootsa Lake in map NTS 93 F/03) digital terrain imaging of central British Columbia, 4) digital maps and data sets, and 5) generalized thematic geology of the Fort Fraser map area.

Résumé : La deuxième partie de cet aperçu de projet à deux volets décrit brièvement les études magnétiques et gravimétriques, l'échantillonnage géochimique du till, de l'écorce de pin de Murray et des émanations gazeuses dans le sol, l'étude des minéraux industriels et l'examen des sites, et les études et applications liées aux systèmes d'information géographique. Au cours de la présente campagne de terrain, 16 étudiants de niveau universitaire ont secondé dans leurs travaux 25 chercheurs gouvernementaux et universitaires. Les nouvelles contributions géoscientifiques sont entre autres : 1) la caractérisation des signatures géophysiques et géochimiques du Batholite d'Endako et de sa déformation; 2) la découverte de fortes concentrations de fond de mercure dans le till et dans l'écorce de pin de Murray au nord du lac Ootsa dans la région cartographique SNRC 93 F/ 3) l'imagerie numérique du terrain dans le centre de la Colombie-Britannique; 4) des cartes et fichiers numériques; et 5) la géologie thématique généralisée de la région cartographique de Fort Fraser.

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INTRODUCTION

This was the final year of fieldwork for the joint Nechako NATMAP project of the Geological Survey of Canada (GSC), British Columbia Geological Survey Branch (BCGSB), universities, and industry (Struik and McMillan, 1996; MacIntyre and Struik, 1998; Struik and MacIntyre, 1999). The project has encompassed more than 30 000 km^2 in central British Columbia (Fig. 1, 2, and 3). It is focussed on improving the quality and detail of bedrock and surficial geology maps to help resolve several geological problems. In particular the project addresses the following questions: 1) the extent and nature of Tertiary crustal extension, 2) Mesozoic compression and the manner of accretion of exotic terranes, 3) the geological and geophysical definition of the terranes, 4) the sequence of changing Pleistocene glacial ice-flow directions, and 5) the character and dispersion of glacial deposits.

This second of a two-part overview of the project for the 1998 field season summarizes research in geophysics, geochemistry, industrial minerals, and computer-based Geographic Information Systems (GIS). Part one of this overview dealt with the bedrock and surficial mapping that has relied so heavily on the studies reported here. These include magnetic and gravity studies; geochemical sampling of till, lodgepole pine bark, and earth gas; industrial mineral studies and site examinations; and Geographic Information Systems (GIS) applications and studies including construction and addition to the digital field-mapping databases, cartography of geological maps, internet GIS data sharing, surficial geology GIS data sets, analysis of RADARSAT and Landsat imagery, generation of Digital Elevation Models and creation of a general-interest geological map of the Fort Fraser map area (Hastings et al., 1998) (Fig. 3).

New geoscience contributions from these studies include1) characterization of the geophysical and geochemical signatures of Endako Batholith and its deformation, 2) finding high background mercury in till and lodgepole pine bark north of Ootsa Lake in map NTS 93 F/03) digital terrain imaging of central British Columbia, 4) digital maps and data sets, and 5) improved intellectual access to the geology of the Fort Fraser map area.

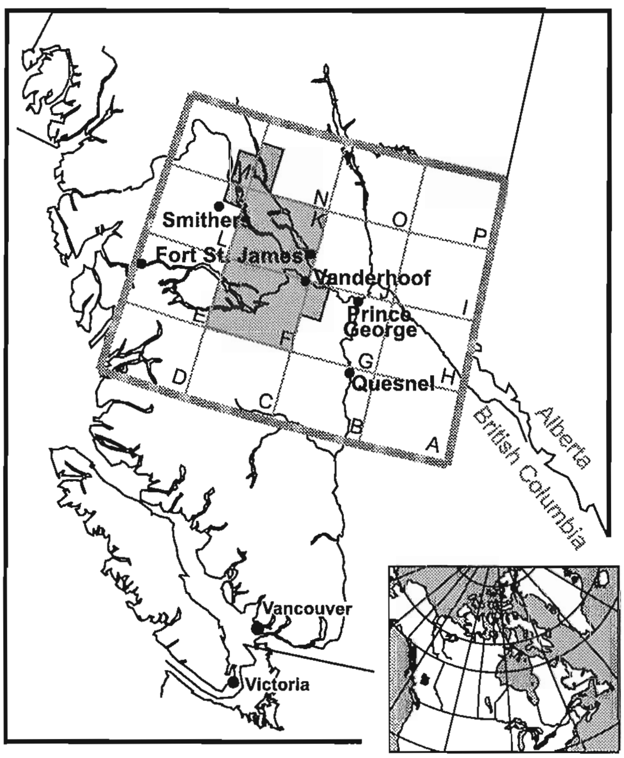

Figure 1. Location of the Nechako NATMAP project area within British Columbia. The Parsnip River (NTS 93) 1:1 000 000 scale map-sheet area and its 1:250 000 scale component map-sheet areas are shown for reference.

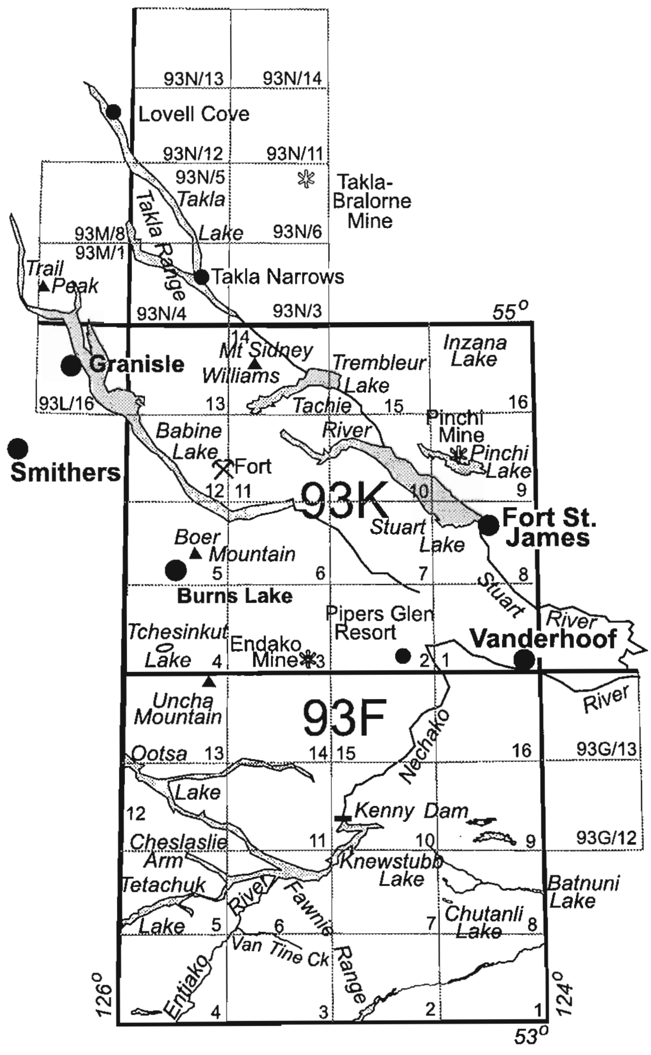

Figure 2. Reference map of geographic and NTS map locations mentioned in the text. See Figure 1 for the location of the Nechako NATMAP project area within central British Columbia.

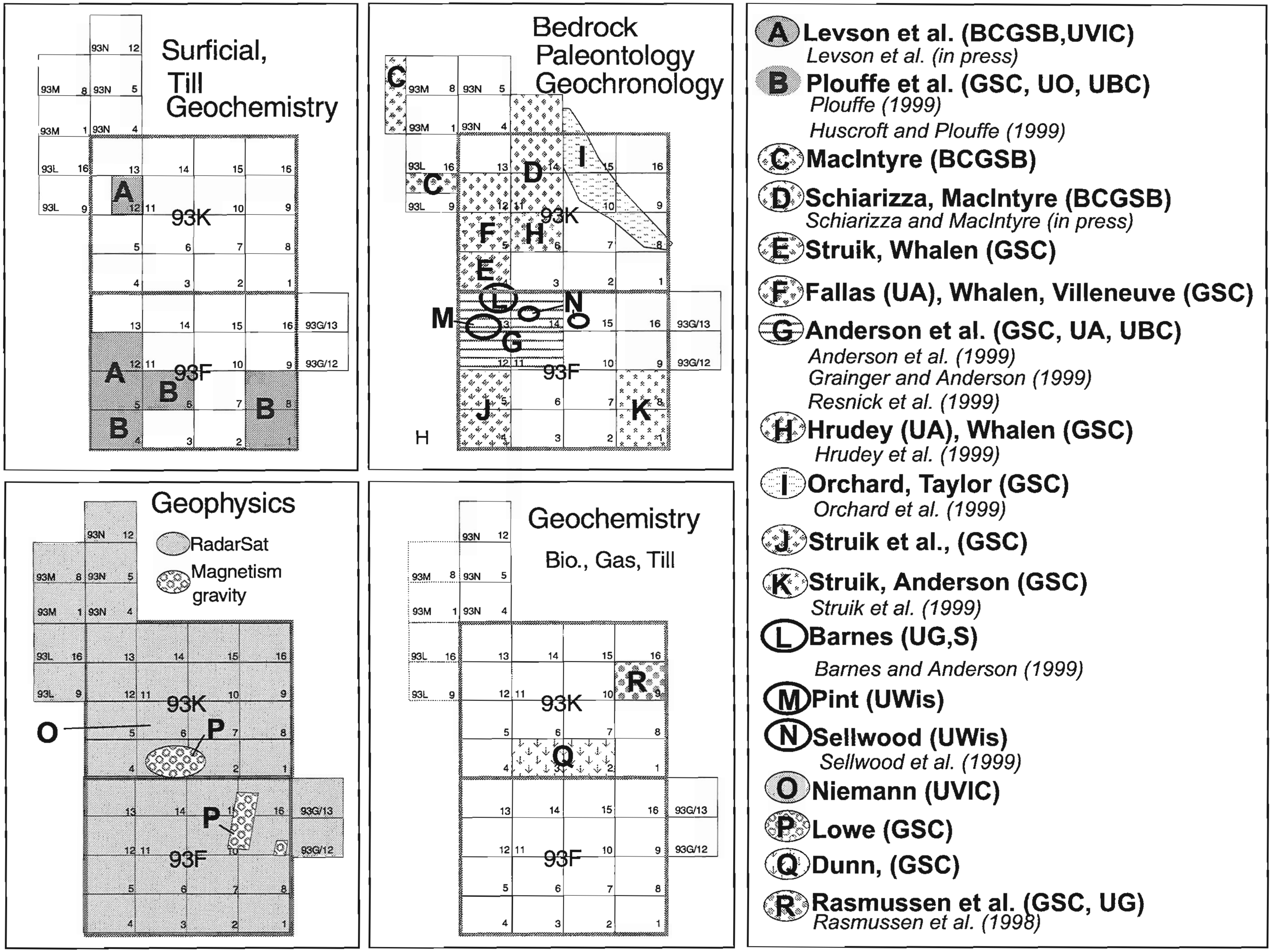

***Figure3**. Location of various Nechako subprojects active in 1998.*

This paper outlines research that is in many cases preliminary. References are given to more in-depth summaries in this volume and *Geological Fieldwork 1999* of the British Columbia Ministry of Employment and Investment. For others, the continuing research will lead to more comprehensive government and journal reports and maps. Analytical data is not reported in this paper.

OVERVIEW OF 1998 NECHAKO PROJECT RESULTS

Geophysical studies

In order to better constrain the geometry of Nulki Shear zone at depth, C. Lowe and J. Baker (GSC) extended gravity and magnetic traverses previously conducted across the structure (Lowe et al., 1998a). In addition, they undertook detailed measurements of the magnetic field and the magnetic susceptibility of exposed rocks within the Endako Mine to augment existing airborne-magnetic (Lowe et al., 1998a, b) and detailed paleomagnetic studies (Enkin et al., 1997; Lowe and Enkin, 1998). The magnetic data will be integrated with geochemical data to further explore the observed correlation between increasing molybdenum concentrations and decreasing magnetic susceptibilities (L'Heureux and Anderson, 1997). As a contribution to this work, magnetic-susceptibility and density measurements were taken on samples for a large part of the project area.

Geochemical studies

Biogeochemical surveys

C.E. Dunn (GSC), R. Scagel (Pacific Phytometric Consultants, Surrey, British Columbia), and a volunteer, D. Jost (Berne, Switzerland) conducted a reconnaissance-level, lodgepole-pine sampling program in the area surrounding the Endako Molybdenum camp (NTS 93 K/02, 93 K/03). The sampling extends 1996 and 1997 coverage throughout the northern half of the Nechako River map area. Samples were taken of the outer bark of lodgepole pine. The bark was collected from 218 sites at 2 km intervals along all driveable roads and trails. Preliminary data show extremely high molybdenum concentrations with up to 1.5% molybdenum in bark ash.

Till samples collected in 1997 in the northwestern quadrant of Nechako River map area had high background concentrations of mercury. To supplement that information, all the lodgepole-pine bark samples collected in that region (also 1997) were analyzed for mercury. The analyses show that the pine trees are taking up high background levels of mercury and corroborate the till data (Dunn and Hastings, 1998; Plouffe, 1999; Plouffe and Williams,1998).

Metals in the environment (MITE)

P.E. Rasmussen, C.E. Dunn, and A. Plouffe (GSC), and G. Edwards (University of Guelph) with four students: J. Kemp, L. Halfpenny, S. Wong, and E. Wong are working near the former Pinchi and Bralorne Takla mercury mines and at additional sites along the Pinchi fault zone. This work is part of the GSC 'Metals in the Environment' (MITE) initiative. Objectives of this project are to determine if an anthropogenic signature is detectable around the mercury mine sites, to establish criteria that could be used to distinguish between natural and anthropogenic metal enrichments, and to identify the forms and phases where metals are bound. Epiphytic moss and b-horizon soil samples were collected in 1996 and 1997 in these locations, and in 1998, A. Plouffe continued this work collecting samples of humus, b horizon, till, and glacial-lake sediments on two transects near the Pinchi mine. In addition, these orientation surveys were to find suitable sites for the in situ monitoring of mercury fluxes to the atmosphere, which was conducted in the summer of 1998.

Information on the natural air-surface exchange of mercury is relevant to risk assessors, in particular for apportioning exposure amongst natural and anthropogenic sources, and to provide a perspective for understanding releases from anthropogenic sources in the context of natural background variation.

The Pinchi mercury flux study is part of a larger survey of natural mercury emissions from representative geological settings across Canada (Rasmussen et al., 1998), a collaborative project between GSC, University of Guelph, and Atmospheric Environment Service (Environment Canada). Two methods for determining fluxes are used: the micrometeorological gradient method and the dynamic flux-chamber method. Both methods are coupled with Tekran Model 2537A cold-vapour atomic-fluorescence detectors. Time series measurements include wind speed and direction, net radiation, humidity, barometric pressure, air and soil temperature, and soil moisture. The focus of the current study is on the development of methods to obtain reliable measurements of air-surface exchange of mercury representative of natural and perturbed surfaces in the vicinity of the Pinchi fault zone, and on the understanding of factors causing temporal and spatial variation. In future, more portable methods are required to obtain spatially representative natural-emissions data in remote areas.

Lake-sediment geochemistry

Three regional lake-water geochemical surveys are being written up. These studies were undertaken in conjunction with earlier lake-sediment surveys in the southern Nechako, Pinchi Lake, and Babine Porphyry Belt areas. This data (Cook et al., in press), the first Geological Survey Branch release of regional multi-element lake-water geochemical data in British Columbia, will be available at the 1999 British Columbia and Yukon Chamber of Mines 'Cordilleran Geology and Exploration Roundup' meeting. Several other geochemical studies are also in advanced stages of completion. These include studies of molybdenum distribution in lake sediments adjacent to porphyry molybdenum deposits of the Endako region, and studies of contamination of organic lake sediments during sample preparation. Interior Plateau lake-sediment case-study results from areas such as Hill–Tout and Chutanli lakes are also nearing completion, as are regional geochemical compilations of stream-sediment, lake-sediment and till geochemical data from the Babine Porphyry Belt and the Pinchi fault zone areas.

Industrial minerals investigations

Z.D. Hora and G. Simandl (BCGSB) continued follow up on industrial-mineral and precious-stone sites previously known and newly reported during mapping of the Nechako project. Dimension stone, decomposed lapilli tuffs (for clays), ornamental and landscaping rock (basalts mainly), perlite, opal, and agate were investigated. In addition, the hypothesis connecting diamonds to subduction-generated and mantle-derived high-pressure rock types was explored.

Highlights of the 1998 mapping include:

- A fairly large area north of Mount Sidney Williams is underlain by soapstone altered from ultramafic rocks. The stone is massive, macroscopically free of pyrite, and is jointed in rectangular systems that break the rock into blocks of 1 cubic foot or more. The polished stone colour is mottled light green and grey. This stone has very good potential as carving material.
- The area of soapstone near Mount Sidney Williams also has outcrops of siliceous listwanite, locally very rich in bright green mica. The listwanite could provide an attractive facing stone. The area is very accessible.
- Rhyolitic pumiceous volcanic rock south of Burns Lake may have pozzolanic properties. It resembles material quarried in Nisconlith Creek area south of Quesnel, which was successfully used by a local ready-mix operator some 20 years ago (Hora and Hancock, 1995).

Geographic Information System development

S. Williams and N.L. Hastings (GSC) continued development of the Nechako Project digital point, line, and areal database and query system. This work produces and releases digital geological map and point data sets. In addition it contributes to the computer production of standard and thematic geological maps and reports.

Accomplishments

Work focussed on the digitization and cartography of geological maps, the addition of GIS data to an intranet GIS data-sharing system, generating a user-friendly geological map for the non-specialist (GEOMAP) for the Fort Fraser map area (Hastings et al., 1998), production of a CD-ROM of all digital surficial-geology data of the Fort Fraser and Manson River map areas (Plouffe and Williams, unpub. rept.); poster style multi-element publication of till geochemical data on coloured geology bases (Dunn and Hastings, 1998; Plouffe and Williams, 1998), release of digital field notes for the Fort Fraser bedrock-mapping component (Quat and Struik, 1998); and production of internet-readable Current Research Reports for the project. C. Lowe generated Digital Elevation Models for the project area from British Columbia 1:20 000 scale TRIM data. O. Niemann (University of Victoria) has continued work on the integration of the Digital Elevation Modelling (DEM) and RADARSAT thematic data for the Nechako project area. In turn, this work is being integrated with surficial geological mapping in the Nechako River map area.

Highlights from this year's GIS work include:

- Several new bedrock and surficial maps published as coloured 1:100 000 and 1:50 000 scale open files, and geochemical data sets (Dunn and Hastings, 1998; Struik, 1998a, b; Struik and Whalen, 1998; Wetherup, 1998; Plouffe and Williams, 1998).
- The MapGuide intranet GIS data-sharing system is now operational for project participants. We continue to aspire to have this same information available to the public.
- Several Current Research reports previously published for the Nechako project are now available for viewing on the WEB at the Nechako Project WEB site (http://www.ei.gov.bc.ca/~natmap).
- GeoMap Fort Fraser is complete (Hastings et al., 1998).
- Digital Elevation Models integrated with the geology and geophysics of the eastern Fort Fraser map area are completed (Lowe et al., unpub. rept.).
- The complete digital data set for the surficial geology of the Fort Fraser and Manson River map areas is ready to transfer to CD-ROM for publication this spring (Plouffe and Williams, unpub. rept.).

For monthly updates in Nechako NATMAP Project developments, see the Nechako Newsletters posted on the Nechako Project website (http://www.ei.gov.bc.ca/~natmap) during the life of the project.

ACKNOWLEDGMENTS

All project participants contributed to the success of this year's research and to this overview. Project funding comes directly through continuing GSC and BCGSB programs and the GSC NATMAP program. In addition, in-kind funding comes from the many universities listed throughout the text, and support from various mineral exploration companies working the area. Cathie Hickson provided a useful critique of the manuscript and Bev Vanlier helped in its production.

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Geological Survey of Canada Project 950036-02

Geology of the Taltapin Lake map area, central British Columbia[1]

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Hrudey, M.G., Struik, L.C., and Whalen, J.B., 1999: Geology of the Taltapin Lake map area, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 85–96.*

Abstract: The Taltapin Lake map area (93 K/6) is characterized by Permian to Jurassic Sitlika assemblage volcanic and sedimentary rocks, the Late Triassic–Middle Jurassic Taltapin metamorphic complex of mainly amphibolite and strongly foliated to gneissic diorite, and Jurassic diorite to granite plutons of the Stag Lake and Francois Lake suites. Tertiary Ootsa Lake and Endako groups blanket older units, and are vesicular andesites, and basalts. Ootsa Lake Group also contains dacite, rhyolite, and rhyodacite breccia. The Permo-Triassic mafic Volcanic unit, and Triassic-Jurassic Eastern clastic unit of the Sitlika assemblage appear distinct lithologically, metamorphically, and structurally from Taltapin metamorphic complex units. The Sitlika assemblage separates rocks of Cache Creek and Stikine terranes, hence Taltapin metamorphic complex is interpreted as a metamorphic equivalent of Stikine Terrane, rather than metamorphosed Cache Creek Terrane. The Taltapin metamorphic complex was deformed and metamorphosed prior to the Late Triassic. It was further metamorphosed and juxtaposed with Sitlika assemblage between the Late Triassic and Middle Jurassic.

Résumé : La région cartographique du lac Taltapin (93 K/6) englobe des roches volcaniques et sédimentaires permiennes–jurassiques de l'assemblage de Sitlika, le complexe métamorphique de Taltapin du Trias tardif–Jurassique moyen qui se compose principalement d'amphibolite et de diorite intensément foliée à gneissique, et des plutons dioritiques à granitiques jurassiques des suites de Stag Lake et de Francois Lake. Les groupes tertiaires d'Ootsa Lake et d'Endako recouvrent des unités plus anciennes et se composent d'andésites vacuolaires et de basaltes. Le Groupe d'Ootsa Lake renferme également des brèches à dacite, rhyolite et rhyodacite. L'unité volcanique mafique permo-triasique et l'unité clastique orientale triasique–jurassique de l'assemblage de Sitlika semblent être différentes des points de vue lithologie, métamorphisme et structure des unités du complexe métamorphique de Taltapin. L'assemblage de Sitlika sépare les roches du terrane de Cache Creek de celles du terrane de Stikine et, par conséquent, le complexe métamorphique de Taltapin est interprété comme étant l'équivalent métamorphique du terrane de Stikine plutôt que du terrane métamorphisé de Cache Creek. Le complexe métamorphique de Taltapin a été déformé et métamorphisé avant le Trias tardif. Il a été l'objet d'un métamorphisme plus poussé et a été juxtaposé à l'assemblage de Sitlika entre le Trias tardif et le Jurassique moyen.

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INTRODUCTION

Bedrock of the Taltapin Lake map area (NTS 93 K/6) (Fig. 1, 2, 3) was mapped in the 1998 field season as part of the regional Nechako NATMAP project (Struik and MacIntyre, 1999). This report describes field observations and preliminary geological interpretations.

GEOLOGICAL FRAMEWORK

Armstrong (1949) first regionally mapped the Fort Fraser area, and was followed by Kimura et al. (1980), who mapped the Taltapin Lake and surrounding areas. Work at a larger scale by Struik and Erdmer (1990) and Traub (1995) documented the metamorphic character and structure of rocks exposed along Babine Lake (Fig. 2).

The map area contains four main geologic groupings: 1) Sitlika Permo-Triassic volcanic and Triassic–Jurassic sedimentary assemblage, 2) Taltapin metamorphic complex, of mostly amphibolite and gneissic diorite, 3) Mesozoic diorite to granite plutons of the Stag Lake and Francois Lake plutonic suites that intrude 1 and 2, and an overlap of 4) Tertiary volcanic rocks of the Ootsa Lake and Endako groups. The Taltapin complex defines a belt of amphibolite-grade, multiply deformed, metamorphic rocks locally underlying rocks of the Takla and Hazelton groups (*see also* Schiarizza and MacIntyre, in press). Tertiary volcanic rocks presumably nonconformably overlie older plutonic and metamorphic rocks, and are in angular unconformity with older strata. Intermediate Cretaceous volcanic rocks exposed near the east end of Babine Lake, and near Taltapin Lake, are not included in the discussion. All units are tilted and translated by Eocene faults (Struik, 1993; Wetherup and Struik, 1996; Whalen et al., 1998).

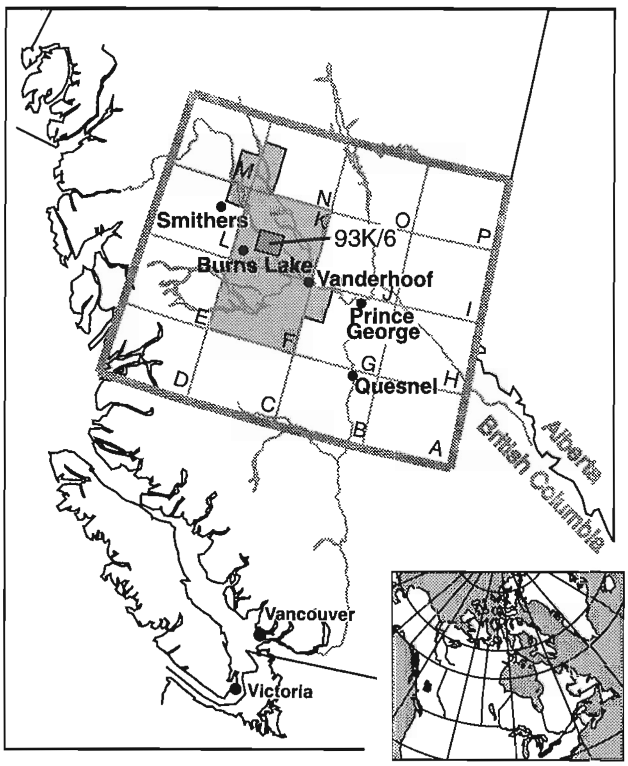

Figure 1. *Location of the Taltapin Lake map area (NTS 93 K/6) in British Columbia. The Parsnip River (NTS 93) map area is shown for reference.*

UNIT DESCRIPTIONS

Late Paleozoic-Mesozoic

Sitlika assemblage

Paterson (1974) first distinguished the Sitlika assemblage east of Takla Lake, approximately 100 km north of Fort St. James, from rocks of Cache Creek and Takla groups. Paterson described structurally and lithologically distinct argillite, mafic and felsic metavolcanic rock, and greywacke lying west of Cache Creek Group Trembleur ultramafic rocks, and east of Takla fault (*see also* Bellefontaine et al., 1995). Childe and Schiarizza (1997), Schiarizza et al. (1998), and Schiarizza (1998) further characterized and traced the Sitlika assemblage. The Schiarizza et al. (1998) classification will be used here, distinguishing a Permo-Triassic *Volcanic* unit, and an overlying Late Triassic–Jurassic *Eastern clastic* unit.

Volcanic unit (PTStv)

Sitlika volcanic rocks occur in a 2–3 km thick belt south of the east end of Babine Lake, along-strike with the newly defined Sitlika assemblage to the north (Schiarizza and MacIntyre, in press), defining a geographically distinct, prominent, northwest-trending ridge. They are metamorphosed to variable, greenschist-grade, basaltic, meta-tuff chlorite-sericite-schists, amphibole-chlorite-schists, and minor chlorite-amphibole schists, all with feldspar phenocrysts/porphyroclasts. The unit also contains less-schistose, mafic meta-lapilli tuffs with oblate, felsic volcanic, 1-2 cm clasts and spots of feldspar, and locally, more-massive intermediate flows preserving relic epidote and quartz clots (amygdules(?)). Subordinate metre-scale layers and augen of felsic metadacite and metarhyodacite occur within the mafic sequence. These felsic metavolcanic rocks are feldspar-phenocryst and agglomerocryst quartzofeldspathic schists and semi-schists.

Schistosity in Sitlika volcanic rocks in the Taltapin Lake map area typically dips moderately and consistently to the southwest, distinct from surrounding rocks (Fig. 3b). Zircon U-Pb dating of Sitlika volcanic rocks gave 258 +10/-1 Ma and 241 ± 1 Ma ages (Childe and Schiarizza, 1997), indicating Permo-Triassic volcanic and plutonic activity.

Eastern clastic unit (TJSts)

Sitlika sedimentary rocks outcrop in Taltapin Lake map area as isolated small exposures south of Babine Lake, and large exposures near the east end of Babine Lake. The unit contains metasiltstone, sandstone, slate, argillite and limy argillite, and minor marble and basaltic tuff. Well bedded, medium-grey-weathering metasiltstone, with coarser grained sandy laminae up to 0.5 cm thick, is well exposed on the north shore of eastern Babine Lake (Fig. 3, 4), as is subordinate marble with competent transposed layers. Five to ten metre thick layers of dark grey slate, brown-grey fine-grained basaltic tuff, medium-grey argillite, and minor limy argillite are found along the shores and south of Babine Lake. Volcaniclastic tan-brown sandstone is interbedded with slates and metasiltstone. Within the metasiltstone, beds are disrupted by microfaulting, and slightly contorted (Fig. 4). Fine-grained laminated rocks have moderately well developed slaty cleavage. Near the south shore of Babine Lake, massive, acicular, hornblende-porphyritic (0.5 cm) dacite is found, presumably as a dyke cutting the clastic unit. Bedding typically dips moderately to steeply northeast, and cleavage dips moderately southwest, similar to the Volcanic unit (Fig. 3b). Bedding is consistently right-way-up, based on cleavage association.

Schiarizza et al. (1998) described the Eastern clastic unit as unconformably, but stratigraphically, overlying the Sitlika Volcanic unit. However, little internal stratigraphy has been discerned due to paucity of continuous exposure. The age of the Eastern clastic unit has been constrained between upper Triassic and lower Jurassic (Schiarizza et al., 1998), partly by Late Triassic conodonts (M.J. Orchard, pers. comm, 1998).

Mesozoic

Late Triassic–Middle Jurassic

Taltapin metamorphic complex

Amphibolite (LTJSam). Amphibolite and biotite amphibolite are exposed throughout the map area, with several textural variations. Generally the amphibolite is fine grained, with elongate to acicular, dark green-black amphibole crystals defining foliation, and locally overprinted by hornblende porphyroblasts. In places the amphibolite is microcrystalline and banded by leucocratic mineral layers (Fig. 5). Outcrop-scale and smaller asymmetrical folds are seen in outcrop (Fig. 5), and are locally refolded by open folds of the same scale. Near the margins of the Middle Jurassic Stag Lake suite plutons, amphibolites are hornfelsed and metasomatized. Near the northern contact with Pinkut Pluton, amphibolites exhibit spectacular metasomatic textures, with 'log-jams' of megacrystic amphiboles (up to 10 cm) separating 10–20 cm thick bands of medium- to fine-grained amphibolite with blocky euhedral amphibole crystals (Fig. 6). Fine-grained amphibolite is cut by dykes of fine-grained dark (presumably Stern Creek phase) diorite.

Along the shore of Babine Lake, near to and including Silver Island (Fig. 7), the rocks show intense brittle and ductile shearing, and are highly altered and bleached (*see also* Traub, 1995).

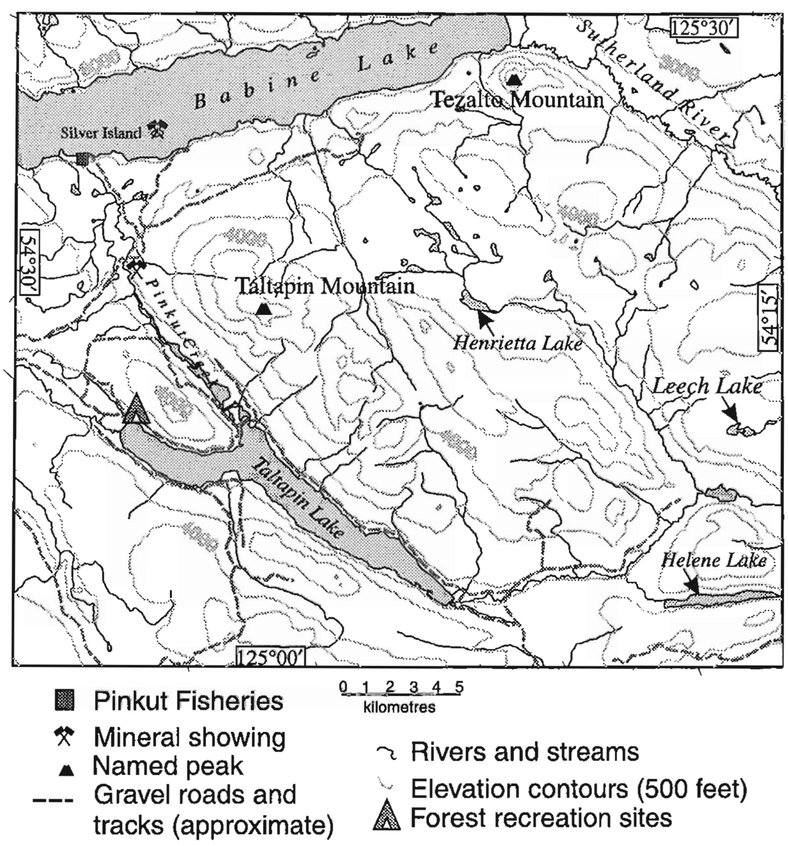

***Figure 2.** Geographic features, areas of mineralization, recreation facilities, and approximate location of forestry corridors in the Taltapin Lake map area.*

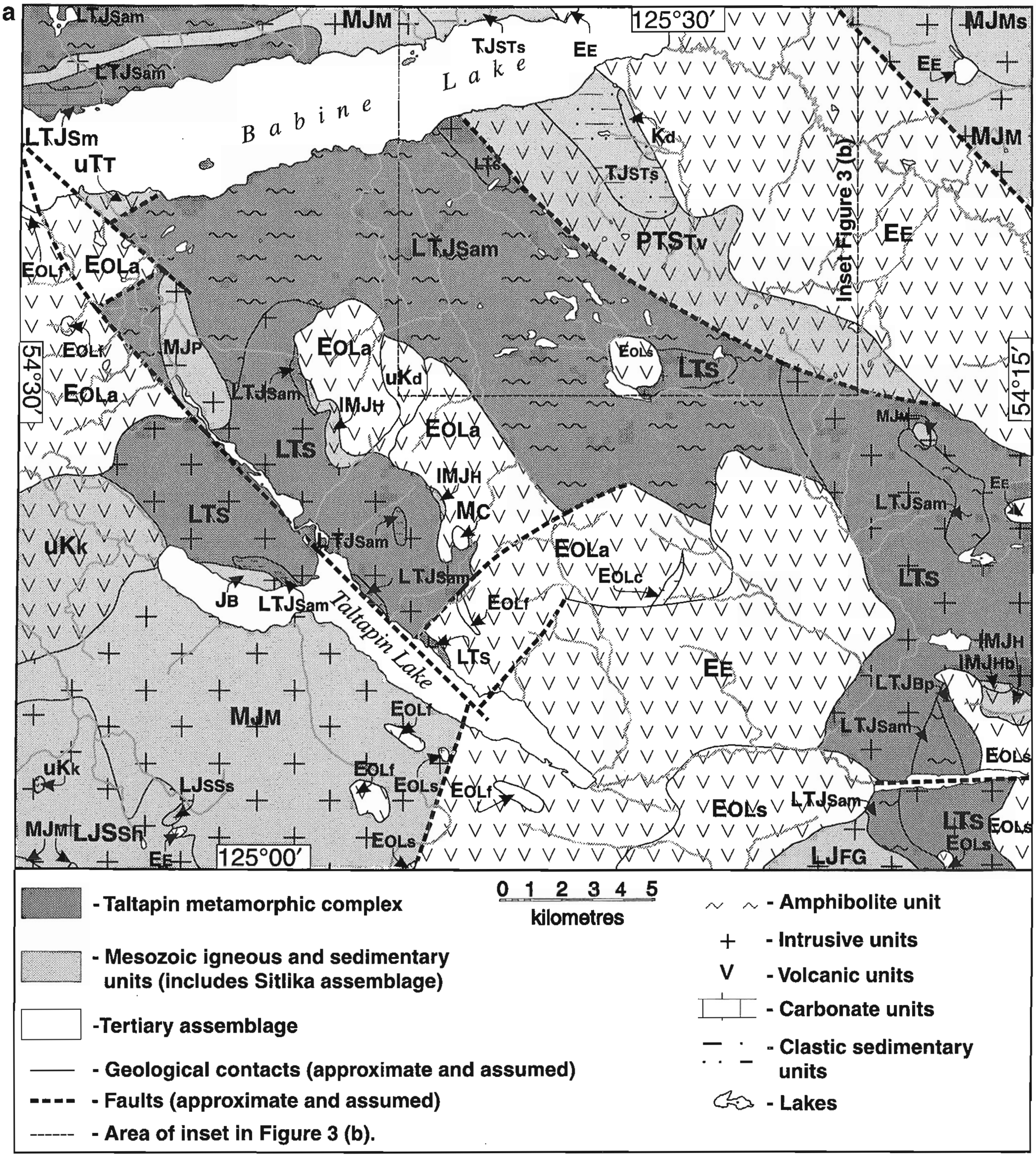

*Figure 3. **a**) Geology of the Taltapin Lake map area, and distribution of the Taltapin metamorphic complex, Mesozoic plutonic rocks, and Tertiary volcanic rocks. **b**). Structural elements of the Sitlika assemblage and surrounding Taltapin metamorphic complex amphibolite and Stern Creek diorite. Location of the map is shown as inset in Figure 3a.*

b

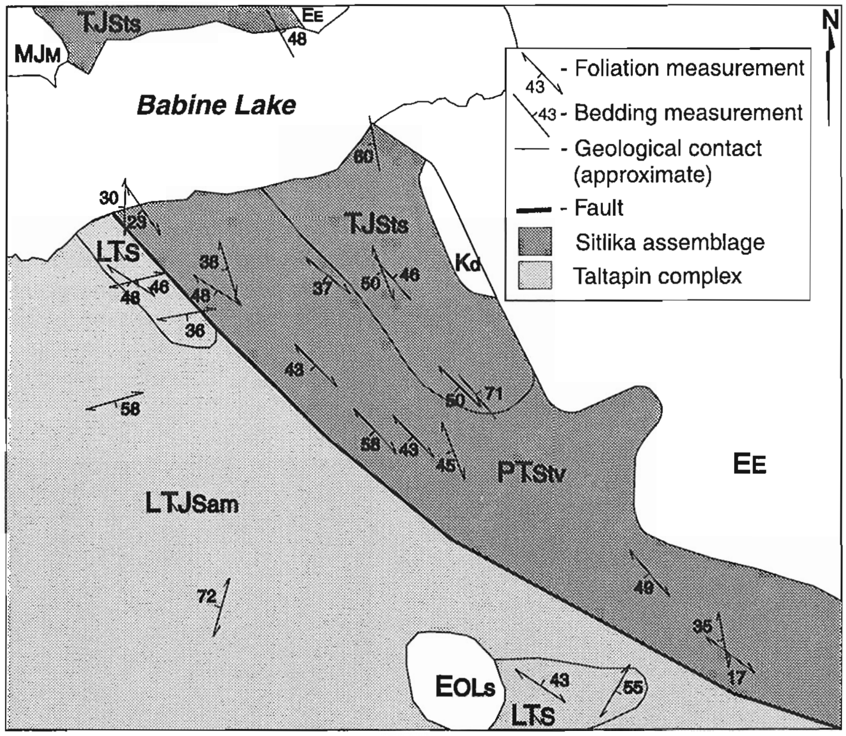

Figure 3 Legend

Tertiary

Miocene

| MC | *Chilcotin Group*: olivine basalt |

Eocene

| EE | *Endako Group*: andesite, basaltic andesite; flows, breccia, vesicular, amygdaloidal, tuff |

Eocene

Ootsa Lake Group (**EOL - EOLs**)

EOLf	rhyodacite, rhyolite; flows, tuff, locally flow banded; includes some felsic subvolcanic intrusives
EOLc	arkosic sandstone, coal
EOLa	andesite, vesicular, amygdaloidal, some plagioclase-phyric, tuff; minor basalt, dacite
EOLs	*Savory member*: dacite, rhyodacite breccia and minor andesite and rhyolite

Mesozoic

Upper Cretaceous

| uKk | *Kasalka Group*: plagioclase porphyry andesite |
| uKd | dacite, hornblende-plagioclase porphyry dacite, minor andesite |

Cretaceous

| Kd | dacite, locally with hornblende |

Late Jurassic

Francois Lake suite (**LJFG**)

| LJFG | *Glenannan phase:* biotite granite and granodiorite, porphyritic |

Sheraton suite (**LJSSh-LJSSs**)

| LJSSh | *Sheraton phase*: biotite-hornblende granodiorite to quartz diorite, subporphyritic |
| LJSSs | *Slug Lake phase:* hornblende diorite |

Middle - Late Jurassic

Stag Lake suite (**MJP - MJMs**)

MJP	*Pinkut phase*: muscovite tonalite
MJM	*McKnab phase*: biotite-hornblende diorite to quartz diorite (U-Pb 165+2/-1 Ma)
MJMs	*Sutherland subphase*: foliated biotite-hornblende diorite
JB	*Boer phase*: hornblende diorite to quartz diorite

Lower - Middle Jurassic

Hazelton Group (**lMJHb - lMJH**)

| lMJHb | basalt breccia |
| lMJH | *Greenstone:* feldspar-phyric greenstone, andesite tuff |

Triassic - Jurassic

Taltapin metamorphic complex (**LTJSm - LTS**)

LTJSm	*Marble:* marble and calc-silicate
LTJSam	*Amphibolite:* amphibolite; includes minor calc-silicate, quartzite, and diorite
LTJBp	*Butterfield pyroxenite:* serpentinized meta-pyroxenite

Late Triassic

| LTS | *Stern Creek phase*: foliated hornblende diorite, granodiorite gneiss |
| uTT | *Takla Group*: basalt; agglomerate, tuff |

Late Paleozoic-Mesozoic

Late Permian - Jurassic

Sitlika assemblage (**PTStv - TJSts**)

| TJSts | *Eastern clastic unit:* metasiltstone, argillite, slate, arkosic sandstone, limy argillite, limestone, basalt tuff |
| PTStv | *Volcanic unit:* feldspar porphyroclast-sericite chlorite schist, (quartz) chlorite schist, chlorite schist, amphibole chlorite schist, basaltic lapilli tuff, metarhyodacite, metadacite |

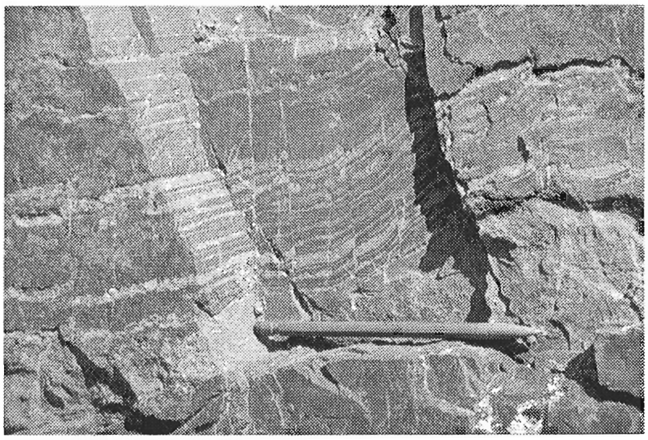

Figure 4. Contorted sandy bedding in Sitlika Eastern clastic unit on Babine Lake.

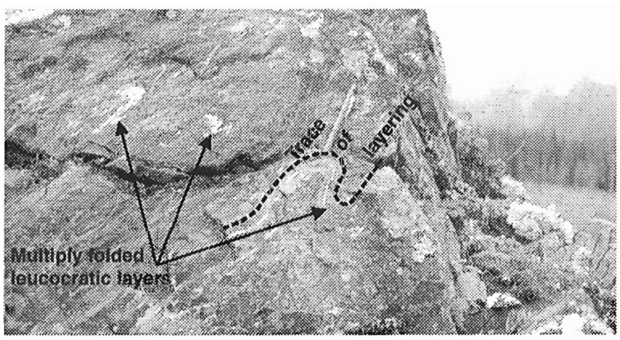

Figure 5. Asymmetric centimetre-scale folds made apparent by leucocratic layers in fine-grained amphibolite, near Helene Lake. Folds are openly refolded obliquely to first generation folds.

Minor metapyroxenite and serpentine are found in this broad shear zone mélange, with possibly metasomatic carbonate. Minor quartzite-metachert and compositionally banded calc-silicate interlayered with the dominant amphibolite are found along the shore. They are locally intensely folded, and are described by Traub (1995) and Struik and Erdmer (1990). Hornblende diorite cuts these fabrics along Babine Lake, as does Ootsa Group biotite-quartz rhyolite. Amphibolite of the Taltapin metamorphic complex is multiply deformed, locally with a broad F_2 overprint seen on the primary penetrative fabric, refolding centimetre-scale F_1 folds (e.g. Fig. 6, 8) (*see also* Traub, 1995). This polyphase deformation in Taltapin metamorphic complex is distinct from that of the Sitlika assemblage, which, save for slight crenulation, is characteriized by one penetrative, consistently oriented fabric (Fig. 3b).

Marble/calc-silicate (LTJSm). Marble is well exposed on the north shore of Babine Lake, near the northwest corner of the map sheet (Fig. 3). It is creamy white to grey, and has centimetre-scale resistant and recessive layers. The layers are interpreted as transposed compositional variations. They appear as intense disharmonic, asymmetrical, tight to isoclinal, centimetre- to outcrop-scale folds, with brittle shear cutting these ductile folds and layers (Fig. 8). Traub (1995) describes two generations of folding within the marble exposed on Babine Lake. Marble is locally medium grained and recrystallized, with well developed 1 mm calcite crystals.

Evergreen to grey calc-silicate exposed along Babine Lake in proximity to marble is characterised by transposed compositional layering, and variable silica content. The marble and calc-silicate are cut by thin epidote veins.

Figure 6. Megacrystic and medium- to fine-grained layers of metasomatic amphibolite near Pinkut Pluton.

Figure 7. Adit and equipment, bleached and sheared wall rock, and metapyroxenite boulders on Silver Island, Babine Lake.

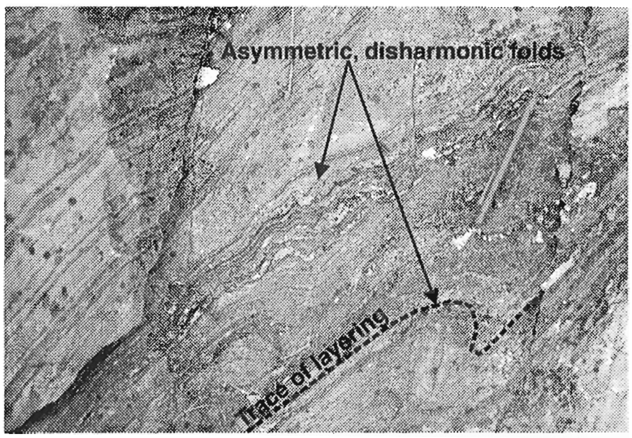

Figure 8. Asymmetric centimetre-scale folds in competent layers in marble on Babine Lake; east is to the right.

Stern Creek phase (LTS). Stern Creek phase rocks occupy a large area of the southeast corner of the study area, the ridges to the north and west of Taltapin Lake, and south of Babine Lake (Fig. 3). Stern Creek phase comprises grey- to dark-grey-weathering hornblende diorite, hornblende-biotite diorite and granodiorite, which is generally strongly foliated to gneissic. Throughout the map area the texture of the Stern Creek phase varies moderately from medium-grained orthogneiss with chalky, white-weathering plagioclase and blocky hornblende (Fig. 9), to mottled grey, fine- to medium-grained, foliated diorite with anastamosing thin, fine-grained, dark grey, hornblende-rich bands. North of Taltapin Lake, the fine-grained variant has a medium green tinge caused by epidote alteration. Stern Creek phase rocks are commonly found with fine-grained amphibolite lenses and layers running parallel to or oblique to foliation. North of Leech Lake (Fig. 2, 3), and on the ridge northeast of Taltapin Lake, Stern Creek phase foliated diorite is seen with fine- to medium-grained amphibolite, cut by small stocks and dykes of sugary-textured McKnab phase diorite to tonalite. Tertiary rhyolite dykes cut Stern Creek phase, as do Mesozoic granitic dykes in the eastern portion of the map. Uranium-lead zircon geochronology yielded Late Triassic ages for Stern Creek diorite (M. Villeneuve, pers. comm., 1996).

Butterfield metapyroxenite (LTJBp). Fine-grained, black, serpentinized metapyroxenite (ultramafic amphibolite) is exposed in the southeast corner of the map area, near Helene Lake (Fig. 2, 3). It is black to green-black on fresh surface, with local fine amphibole crystals in the aphanitic felty dark matrix. Locally it is thoroughly serpentinized, and in places has a dun-weathering metasomatic dolomitic rind. The rock is foliated, with microcrystalline tremolite and hornblende surviving where not pervasively serpentinized. This unit may correlate with the Butterfield phase intrusions of Schiarizza and MacIntyre (in press). Its relationship to other units of the Taltapin metamorphic complex is unclear, as no external contact relationships were observed.

Figure 9. Stern Creek orthogneiss intruded by unfoliated diorite, near Helene Lake.

Takla Group (uTT). Takla Group volcanic rocks are found well exposed along the south shore of Babine Lake near Pinkut Fisheries (Fig. 2, 3). These rocks comprise low-greenschist-grade metamorphosed basalt flows and basaltic agglomerate. Agglomerates have rounded, elongate to equant, dark-grey- to maroon-grey-weathering basalt clasts 0.5 to 15 cm across, some of which have quartz-filled vesicles. Flows are pyroxene- and feldspar-phyric, with some carbonate alteration. Given the relatively low metamorphic grade of these rocks, they are presumed to nonconformably overlie rocks of the Taltapin metamorphic complex, although this relationship was not directly observed.

Hazelton Group.

Undifferentiated volcanic rocks (*lmJH*) Hazelton volcanic rocks are found in isolated outcrops, nonconformably overlying Taltapin metamorphic complex rocks, and underlying Mesozoic–Tertiary volcanics north of Taltapin Lake, and in the southeast corner of the map area near Helene Lake (Fig. 2, 3). They are typically pervasively altered to greenstone, but locally appear to show relict brecciated texture, and are locally feldspar-phyric, and tuffaceous, with angular 1 mm plagioclase fragments.

Basalt breccia (*lmJHb*) North of Helene Lake (Fig. 2), greenstone basalt breccia is exposed nonconformably overlying Stern Creek orthogneiss (Fig. 3). Near the unconformity, which was not directly observed, the basalt is found with rounded gneissic blocks and elongate rounded amphibolite clasts 5 to 20 cm across. Several hundred metres farther to the south, an approximately 50 m high cliff of basalt breccia altered to greenstone is found, with angular 1–5 cm basalt fragments, and isolated pillow-like structures, 2 m across.

Boer phase (JB). Boer phase (e.g. Whalen and Struik, 1997; Whalen et al., 1998) is exposed near the north shore at the west end of Taltapin Lake. It is dark grey, medium-grained, equigranular and massive hornblende diorite with characteristic blocky euhedral hornblende. Plagioclase is dark grey, and weathers chalky white. The Boer phase is well exposed to the south (Whalen et al., 1998), and may be similar in age to McKnab-phase magmatism.

Middle-Late Jurassic

Stag Lake plutonic suite

McKnab phase (MJM). McKnab-phase plutonic rocks are extensive throughout the Fort St. James area (e.g. Whalen and Struik, 1997), south of Stuart Lake, and in the Endako map area (Whalen et al., 1998). The McKnab phase comprises medium-grained, equigranular biotite-hornblende-quartz diorite, and biotite–quartz diorite to hornblende-biotite tonalite varying from massive to moderately foliated (Fig. 3). Aligned biotite and hornblende define the fabric. Plagioclase ranges from 1 to 4 mm crystals, and constitutes 50–70% of the rock. Feldspar crystals are anhedral to euhedral, and slightly altered with sericite and lesser epidote. Quartz (5–30%) is interstitial, recrystallized, and anhedral. Hornblende (10–40%) typically occurs as stubby to elongate subhedral 1 to 3 mm crystals, or as laths or clumps, and biotite (1–15%) is pristine. Ellipsoidal, locally plagioclase-porphyritic, mafic enclaves are found throughout McKnab-phase diorites. Dykes of plagioclase porphyry microdiorite are seen cutting older units. Previous workers (Kimura et al., 1980; Whalen et al., 1998) distinguished between McKnab-phase and Taltapin-phase plutonic rocks on the presence of foliation (Kimura et al., 1980). However, field observations and available chronology indicate they are synonymous, thus the authors tentatively call them *McKnab* as described by Whalen and Struik (1997). The McKnab phase yielded 165 +2/-1 Ma. U-Pb zircon ages (Ash et al., 1993; M. Villeneuve, pers. comm., 1996). Ash et al. (1993) used the name *Shass* Pluton for these rocks after Armstrong (1949).

Sutherland subphase (MJMs). The Sutherland subphase of the McKnab phase is found north of Sutherland River, east of Babine Lake. In hand sample, the mineralogy appears the same as McKnab phase, comprising hornblende-biotite–quartz diorite with hornblende and biotite ranging from 10–15%, and recrystallized quartz interstitial to a foliated matrix of plagioclase. However, it exhibits distinct textural and hand-sample character with its strong foliation, defined not only by mafic minerals, but also by kinked and aligned brown-grey, medium-grained plagioclase laths. Sutherland subphase is dark grey-brown on fresh surface, and weathers grey. North of Sutherland River this phase is cut by aplite and basalt dykes (1–50 cm thick). Proximity to, and mineralogical similarity with, McKnab phase suggest that Sutherland represents a subphase of McKnab rather than a temporally and spatially distinct phase.

Pinkut phase (MJP). This plutonic phase is well exposed west of Pinkut Creek. It comprises massive, medium-grained, equigranular, creamy white-grey-weathering biotite-muscovite tonalite. Mafic minerals are generally absent, save for minor biotite. The presence of muscovite distinguishes Pinkut tonalite from other plutons in the area. Pinkut-phase biotite-muscovite tonalite is cut by basalt and rhyolite dykes of Endako and Ootsa Lake groups.

Sheraton phase (LJSSh). Sheraton phase (Fig. 3), comprises medium-grained to coarse-grained quartz monzonite to granodiorite, made porphyritic in places by potassium feldspar. Mafic phases include fine pristine biotite and stubby 1–3 mm hornblende. The rock is massive, and weathers medium grey with slight pink potassic alteration.

Slug Lake phase (LJSSs). The informal Slug Lake phase of the Stag Lake plutonic suite, a stock south of Taltapin Lake (Fig. 3), comprises medium-grey- to chalky-weathering, fine- to medium-grained equigranular hornblende-biotite diorite to quartz diorite. It is characterized in hand sample by its black acicular amphibole crystals (up to 7 mm long). Amphibole crystals are slightly altered to chlorite, but otherwise the rock is fresh, with medium grey plagioclase.

Francois Lake suite

Glenannan phase (LJFG). The Glenannan phase comprises massive, medium- to coarse-grained, potassium-feldspar-subporphyritic, mainly unaltered hornblende-biotite- and biotite-hornblende-granite to granodiorite. Potassium feldspar crystals are subhedral and blocky 7–12 mm laths, weathering salmon pink against the medium-grained creamy matrix. Some chlorite alteration occurs in the elongate 1–2 mm hornblende crystals, whereas biotite appears generally pristine as black flakes. Glenannan-phase granite cuts biotite amphibolite as fine-grained feldspar-porphyritic dykes near Helene Lake (Fig. 2, 3).

Tertiary

Eocene

Ootsa Lake Group (EOL)

The Ootsa Lake Group rocks have been described elsewhere as containing basal mafic members (Diakow and Koyanagi, 1988; Whalen et al., 1998). Subdivisions of the Ootsa Lake Group of Whalen et al. (1998) are accepted herein, with the caveat that some of this volcanism, particularly the more mafic and intermediate varieties, may in fact be Upper Cretaceous (N. Grainger, pers. comm., 1997).

Rhyolite/Rhyodacite member (EOLf). Ootsa Lake Group rhyolite to rhyodacite includes aphyric and quartz- , plagioclase-(±biotite-)porphyritic flows and tuffs, as well as massive, coarser grained possible subvolcanic equivalents, and dykes cutting older described units. These rocks weather chalky white to cream, and are massive to locally flow banded. South of Taltapin Lake (Fig. 3), rhyolite and rhyodacite are nonconformable on McKnab diorite, and are quartz- and plagioclase-phyric, with commonly smoky, 1 mm anhedral quartz blebs, chalky subhedral 1–4 mm plagioclase laths, and local pristine 1 mm biotite flakes.

Andesite member (EOLa). This unit consists of vesicular, medium brown andesite and minor dacite and basalt. The dacite has minor acicular hornblende phenocrysts, or 1 mm chalky white plagioclase laths. Andesites are typically aphyric, with chlorite-, quartz-, and clay-filled or lined, spherical to ellipsoidal vesicles. Locally, vesicles are up to 2–3 cm across in the fissile rock, which parts on a centimetre-scale-spaced fracture. The andesite weathers green against the maroon-brown matrix. At one exposure, quartz-phyric rhyolite is seen cutting basalt, with rhyolite breccia (basaltic and rhyolite fragments) proximal to the basalt.

On the ridge directly northeast of Taltapin Lake, including Taltapin Mountain (Fig. 2, 3), abundant andesites form vesicular, chestnut-brown-green- to maroon- or dark-grey-weathering flows with variable chlorite alteration. They are aphyric to 0.5–1 mm plagioclase-phyric flows, with minor ashy layered tuff. Plagioclase forms 1–3 mm crystals up to 5–10% of the volume, weathering white in the maroon-brown matrix. Few floating elongate hornblende crystals occupy less than 1% of the rock. At lower elevations on Taltapin Mountain these rocks are locally cut by dacite dykes.

Savory member (EOLs). Savory member rocks (Fig. 2, 3) are interlayered medium brown andesites and rhyodacite breccia, and plagioclase- and hornblende-phyric dacite. The dacites are commonly quite fissile, parting on a closely spaced (centimetre-scale) fracture cleavage. The breccias contain chlorite-altered andesite clasts similar in appearance to Ootsa Lake Group andesites (*EOLa*) described herein, flow-banded rhyolite clasts, and plagioclase- and hornblende-phyric dacite clasts (Fig. 10). Clasts are unsorted and subrounded to angular, equant to elongate, and range in size from 0.5–7 cm in a variably weathered matrix.

Sandstone Member (EOLb). A single exposure of coarse, well-sorted, tan-brown sandstone is derived from mafic volcanic rocks, and has coarse maroon basaltic clasts in the sandy matrix composed of feldspar-needle-phyric volcanic rock. Abundant carbonized wood fragments form up to 15% of the rock's volume.

Endako Group (EE)

Endako Group rocks are typically stacked, 6–10 m thick, shallowly or moderately dipping to horizontal flows of aphyric, aphanitic, vesicular, dark grey weathering andesites to basaltic andesites (Anderson, 1998; Haskin et al., 1998). A section at least 280–300 m thick is well exposed at Tezalto Mountain (Fig. 2, 11). Vesicles may be filled or lined with chlorite, quartz, or more characteristically oxide, or calcite. Andesites in the area adjacent to and including Tezalto Mountain are brecciated and northeasterly dipping, with glassy subangular and equant fragments ranging from 1 to 40 cm across in an aphanitic matrix (Fig. 12). Between some brecciated flows, massive aphyric 0.5–1 m thick flows are found. Flow tops in Endako Group andesites are commonly defined by oxidised

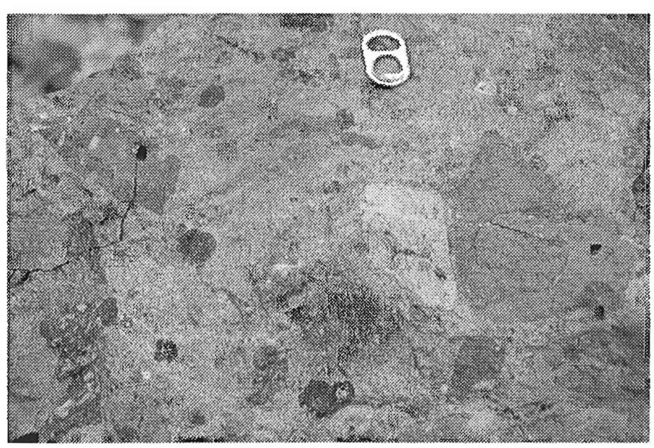

***Figure 10.** Subrounded andesite, rhyolite, and dacite clasts in Savory member rhyodacite, near Helene Lake.*

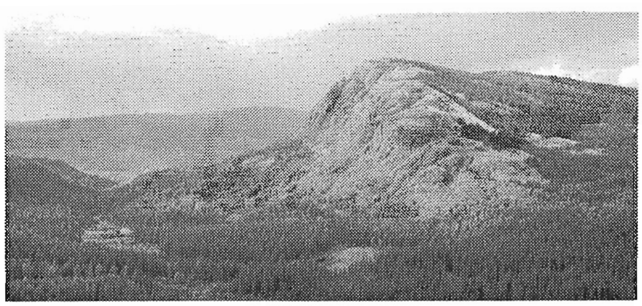

Figure 11. Tilted Endako Group andesites forming Tezalto Mountain (mountain is approximately 400 m high).

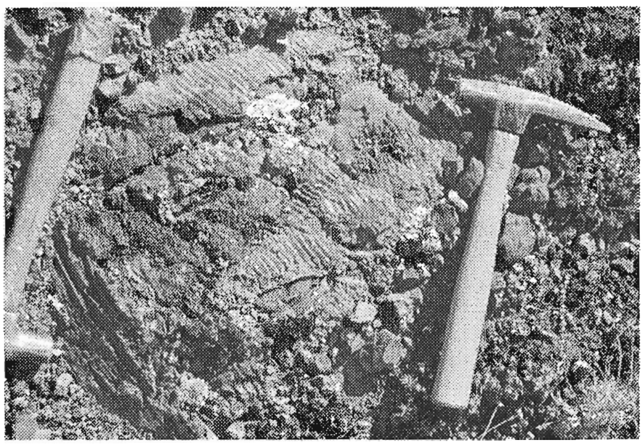

Figure 12. Columnar jointing in large clast, and surrounding angular equant fragments in Endako Group andesites on Tezalto Mountain.

frothy and rubbly zones approximately 1 m thick. Endako Group andesites are assumed to be in angular unconformity with other older sedimentary and volcanic rocks.

Chilcotin Group (MC)

Chilcotin Group basalts unconformably overlie other units throughout the Nechako Plateau as flat-lying, metre-scale thick flows. Little is found in the Taltapin Lake area, with the only extant outcrop being just north of Taltapin Lake (Fig. 3), consisting of columnar-jointed plagioclase-phyric basalt.

ECONOMIC GEOLOGY

Areas of mineralization (e.g. Energy, Mines and Resources Canada, 1977), are scattered within the Taltapin Lake map area. On Pinkut Creek, silver-lead-zinc mineralization (Armstrong, 1949) is found in an intensely altered shear zone, hosted by Pinkut pluton (Fig. 2, 3). Silver Island on Babine Lake (Fig. 2, 7) has altered, sheared, and bleached wall rock, altered intrusive rock, altered amphibolite, and serpentinized metapyroxenite containing quarter-sized sulphide blebs, exposed near previous workings (Fig. 7). Mineralization on Silver Island includes silver, lead, and zinc (Armstrong, 1949). Arsenopyrite-bearing muscovite-quartz veins cut Sitlika assemblage rocks on logging roads south of Babine Lake.

DISCUSSION

Taltapin metamorphic complex — protoliths, age, and uplift

Components of sedimentary protolith, mainly limestone, sandy limestone, and chert are likely for marble, quartzite-metachert, and calc-silicate exposed along the shores of Babine Lake. Struik and Erdmer (1990) considered the possibility that some of the abundant amphibolite was derived from calcareous rock, given that some amphibolite is interlayered with calc-silicate. However, beyond those exposures of metasediment with amphibolite along Babine Lake, the metamorphic complex within the Taltapin Lake map area comprises amphibolite and metaplutonic rocks. It is likely that much of this amphibolite has volcanic origin, possibly as basaltic flows.

The Taltapin metamorphic complex is probably not a metamorphic aureole about the margins of Mesozoic plutons, as Stag Lake suite magmatism served only to metasomatize and/or hornfels the fine-grained amphibolite. The Stern Creek phase is gneiss, and is therefore more likely part of the metamorphic complex. Furthermore, no systematic textural or metamorphic variations were observed in amphibolite coinciding with proximity to exposed Stern Creek plutons. The complex is interpreted, rather, as a regionally metamorphosed belt of multiply deformed rock. Presuming that less metamorphosed, less deformed, Takla Group rocks lie nonconformably on Taltapin metamorphic complex rocks, much of the metamorphism and deformation of the complex must have occurred prior to the Late Triassic. The Late Triassic Stern Creek phase is gneiss, thus further metamorphism and deformation of the complex is interpreted as having happened between the Late Triassic and Middle Jurassic (post-Stern Creek-to pre-McKnab-phase plutonism). Some metamorphism within the complex is post-deformational. Porphyroblastic hornblende overprints foliation, and marble is recrystallized with fine- to medium-grained calcite (*see also* Struik and Erdmer, 1990).

Struik (1993) described the importance of regional Eocene strike-slip faulting in the Canadian Cordillera. Wetherup (1997) and Wetherup and Struik (1996) detailed its role in unroofing the Vanderhoof Metamorphic Complex in the transfer zone of these regional dextral strike-slip faults. No evidence in support of a similar model for unroofing of the Taltapin metamorphic complex was found. Some exposed Sitlika Volcanic unit rocks have undergone relatively high greenschist-grade metamorphism, suggesting that later metamorphism affected both the Taltapin metamorphic complex and juxtaposed Sitlika assemblage units. Mesozoic thrust imbrication can be considered a possible mechanism for unroofing these metamorphic rocks, commensurate with amalgamation of Cache Creek and Stikine terranes.

Tectonic implications

The Sitlika assemblage is newly recognized in the Taltapin Lake area. Schiarizza and Payie (1997), Schiarizza (1998), and Schiarizza et al. (1998) have described the tectonic significance of this Permo-Triassic belt farther north, where the assemblage structurally underlies Cache Creek Group Trembleur ultramafite, and structurally overlies Stikine Terrane rocks. The presence of the Sitlika assemblage south of Babine Lake therefore suggests that the Taltapin metamorphic complex comprises metamorphosed Stikine Terrane rocks, rather than metamorphosed Cache Creek Group rocks, as previously mapped by Armstrong (1949), and tentatively by Struik and Erdmer (1990). The presence of Takla Group and Hazelton Group volcanic rocks nonconformably overlying these metamorphic rocks further supports this interpretation. It is not obvious what Stikine assemblage is metamorphosed to define the Taltapin metamorphic complex. The presence of subordinate marble and meta-chert in amphibolite suggests that part of the Lower Permian Asitka Group, comprising limestone, tuffaceous carbonate, chert, basalt, argillite, and rhyolite (Monger, 1977; Monger et al., 1991) may be a possible protolith.

Additionally, the Sitlika assemblage has been recognized as extending significantly to the south of its original definition by Paterson (1974), furthering the work of Schiarizza and Payie (1997), Schiarizza et al. (1998), and Schiarizza and MacIntyre (in press), and confirming the interpretations of Bellefontaine et al. (1995). However, no contact, thrust or otherwise, was found in the Taltapin Lake map area between the Eastern clastic unit and Cache Creek Terrane ultramafic rocks to the east (*see* Struik et al., 1997). However, the distinctions in structure and general metamorphic character between Sitlika assemblage and those Taltapin metamorphic complex rocks described herein (e.g. Fig. 3b) suggest disparate tectonic histories for the two packages. These disparate histories are pinned by 165+2/-1 Ma. (Ash et al., 1993; M. Villeneuve, pers. comm., 1996) McKnab-phase diorite north of Babine Lake (Fig. 3a). Rocks of the Taltapin metamorphic complex (Stikine Terrane) and Sitlika assemblage belt were thus juxtaposed at the latest by the late Middle Jurassic, possibly by the thrusting of Cache Creek Terrane over Stikine Terrane (Monger et al., 1978; Schiarizza et al., 1998).

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Carboniferous–Triassic conodont biostratigraphy, Nechako NATMAP project area, central British Columbia[1]

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Abstract: Fifty-seven new conodont collections from the Nechako NATMAP area contribute to a conodont biostratigraphic framework for the region. Most collections are from the Pope unit of the Cache Creek complex and are early Late Carboniferous (Bashkirian–Moscovian) to Middle Permian (Wordian). The most extensive carbonate buildup is Bashkirian–Moscovian, whereas latest Carboniferous to Permian limestone is much less common and Middle Permian buildups are known only in the north. The Sowchea clastic-volcanic unit is Late Permian to Late Triassic (Norian); it includes unique records of (?)Changshingian, Griesbachian, and Smithian fauna, and the first records of Middle Triassic Tethyan *Gladigondolella* in Canada. At two widely separated localities, breccia containing mixed conodont faunas show that Paleozoic and Triassic strata were reworked during or after the Late Triassic. Late Triassic conodonts are also reported from the Tezzeron unit and adjacent Takla Group.

Résumé : Cinquante-sept nouveaux assemblages de conodontes provenant de la région visée par le Projet de Nechako du CARTNAT ont permis de définir le cadre biostratigraphique des conodontes de la région. La plupart des assemblages ont été reconnus dans l'unité de Pope située dans le complexe de Cache Creek et s'échelonnent du début du Carbonifère tardif (Bashkirien–Moscovien) au Permien moyen (Wordien). Les calcaires construits les plus importants remontent au Bashkirien–Moscovien, alors que le calcaire du Carbonifère sommital–Permien est beaucoup moins abondant et que les calcaires construits du Permien moyen ne sont connus que dans le nord. L'unité volcanoclastique de Sowchea s'échelonne du Permien tardif au Trias tardif (Norien); elle renferme des assemblages uniques de faune du Changshingien(?), du Griesbachien et du Smithien, et les premières Gladigondolella téthysiennes du Trias moyen signalées au Canada. Dans deux régions très espacées l'une de l'autre, des brèches renfermant des faunes de conodontes mélangés montrent que les strates paléozoïques et triasiques ont été remaniées au cours du Trias tardif ou après. On a également reconnu des conodontes du Trias tardif dans l'unité de Tezzeron et dans le groupe attenant de Takla.

[1] Contribution to the Nechako NATMAP Project

INTRODUCTION

This report, the third on conodont biostratigraphy in the Nechako NATMAP project area, summarizes the results from the processing of 104 samples of carbonate and chert collected for microfossil analysis in the summer of 1997 from the Cache Creek complex and adjacent strata in the Fort Fraser (NTS 93 K) and Manson River (NTS 93 N) map areas of central British Columbia (Fig. 1). Fifty-seven samples yielded conodont collections and other microfossils were found in an additional seven (Table 1). This brings the total number of documented conodont collections from the region to 150. Further data is anticipated as a result of sampling during the summer of 1998, which largely completes the biostratigraphic program. The present summary is a prelude to a final report on conodont biostratigraphy of the Nechako project area.

GEOLOGY

The conodont collections recorded in this report come from Cache Creek Group, informally named Tezzeron unit, and Takla Group. Each of these units has correlatives or namesakes north and south in the Cordilleran Orogen (Gabrielse and Yorath, 1991; Silberling et al., 1992; Struik et al., 1998).

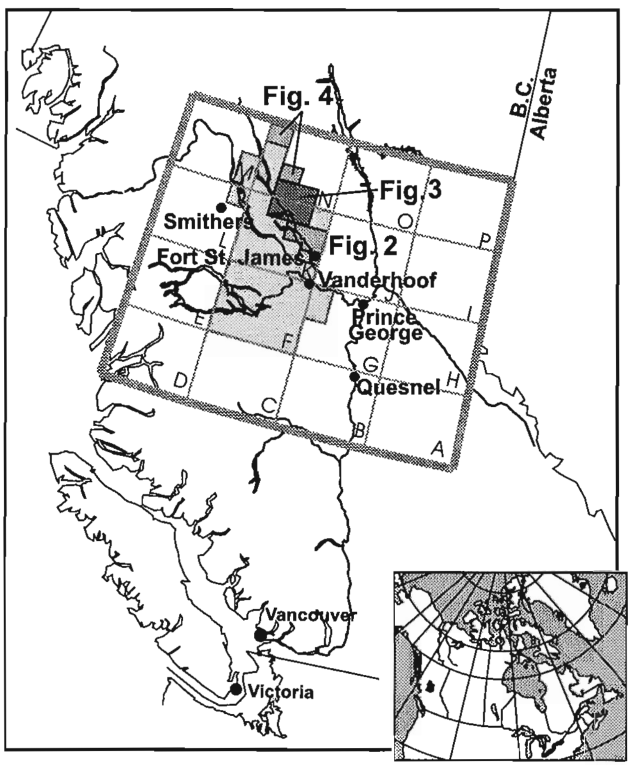

Figure 1. Location of the study areas shown in Figures 2–4 within the Nechako NATMAP project area. The 1:250 000 scale map areas of the Parsnip River (NTS 93) 1:1 000 000 scale map area are shown for reference.

The Cache Creek Group in central British Columbia consists mainly of siltstone, ribbon chert, limestone, ultramafite, basalt, and gabbro characteristic of an oceanic setting (Struik et al., 1998; Schiarizza and MacIntyre, in press). These rocks form thrust sheets imbricated during subduction under North America from the Early Triassic to Early Jurassic, and during collision primarily through the Early and Middle Jurassic. It is because of this structural imbrication that we here refer to these rocks in central British Columbia hereafter as a complex, rather than as a group in the classic stratigraphic context. The limestones and cherts which yielded the conodonts described in this report are from the informally named Pope and Sowchea units; each of which define various thrust sheets.

The lower Upper Carboniferous to Triassic Pope unit defines a northwesterly trending belt of elongate, probably separate thrust sheets of limestone and minor basalt and chert underlying the eastern part of the Cache Creek complex. Based on conodont fauna, the Pope unit can be divided into three distinct subunits: Necoslie-Mount Pope, Pinchi, and Kloch Lake. Although there are sedimentological differences between these units, here we concentrate mainly on the faunal distinction. For further information on the sedimentology see the work of Struik et al. (1996), Sano and Struik (1997), and Sano (1998).

The Upper Permian to Triassic Sowchea unit of siltstone, greywacke, mafic tuff, ribbon chert, and limestone is widespread and forms the lower structural levels throughout the Cache Creek complex. Limestone and chert from the Sowchea unit, which have yielded conodont fauna, generally come from isolated unnamed small exposures. An exception is the Whitefish Bay subunit that includes Middle and Upper Triassic limestone and limestone conglomerate southwest of Stuart Lake. In some places it is not clear that the limestone subunits should be included within the Sowchea unit, or whether they represent distinct thrust wedges or klippe.

The Tezzeron unit (Struik et al., 1998) consists of upper Triassic and Lower Jurassic greywacke, conglomerate, siltstone, slate, andesite tuff, and minor limestone. It primarily underlies the northeastern margin of the Cache Creek complex, and some scattered localities throughout that same region. It was previously included in the Cache Creek Group (Bellefontaine et al., 1995; Struik et al., 1998), and is here considered a separate overlap assemblage that became incorporated into the Cache Creek thrust complex. The unit is interpreted to have been deposited in a forearc setting, between the Cache Creek ocean to the west and the Quesnel Terrane island arc to the east.

Conodont fauna from the Tezzeron unit come from limestone beds that are gradational with the greywacke. These same limestone beds have yielded Triassic bivalves and ammonites (Armstrong, 1949; Paterson, 1973) that are the same age as the conodont faunas.

Takla Group of Quesnel Terrane lies to the east of Pinchi Fault, Cache Creek complex, and Tezzeron unit. In the area sampled for conodonts in Nechako project area, Takla Group

Table 1. Faunal composition and provisional age assignments of 1997 conodont collections from the Cache Creek complex and adjacent units, central British Columbia.

Map no. Field no. GSC loc. no.	Conodont taxa	Age (Geological unit)
93K/8 - Ft. St. James		
K8-23(1997) 97-OF-MP5-6A C-303478	*Idiognathodus delicatus* *Idiognathoides convexus* *Idiognathoides sinuatus* *Neognathodus* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K8-23(1997) 97-OF-MP5-15 C-303479	*Declinognathodus* sp. *Idiognathodus* sp. *Idiognathoides* sp. *Neognathodus* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
97-OF-CONG-1 K8-9(1995) C-303480	*Idiognathodus delicatus* *Neognathodus* spp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K8-9(1995) 97-OF-CONG-2 C-303481	*Diplognathodus ellesmerensis* *Hindeodus*? sp. *Idiognathoides* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K8-9(1995) 97-OF-CONG-3 C-303482	*Diplognathodus* cf. *ellesmerensis* *Hindeodus* sp. *Idiognathodus delicatus* *Idiognathoides* sp. *Neogondolella* sp. *Neospathodus* ex gr. *conservativus* *Neospathodus* ex gr. *homeri* *Neognathodus* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian and Early Triassic, Smithian-Spathian (PTCCl)
K8-24 97-OF-BAT-1 C-303515	*Declinognathodus*? sp. *Hindeodus* sp. *Idiognathodus* spp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCs)
K8-25 97-OF-SP-1 C-303518	*Adetognathus* sp. *Idiognathoides* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K8-25 97-OF-SP-2 C-303519	*Hindeodus* sp. *Idiognathodus delicatus* *Idiognathoides* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K8-25 97-OF-SP-3 C-303520	*Diplognathodus* cf. *ellesmerensis* *Gondolella*? sp. *Idiognathoides*? sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
93K/8 - Ft. St. James (cont.)		
K8-25 97-OF-SP-4 C-303521	*Diplognathodus oertlii* *Hindeodus* sp. *Mesogondolella* ex gr. *bisselli* *Neostreptognathodus* aff. *foliatus* *Sweetognathus* sp. ramiform elements	Early Permian, Artinskian (PTCCl)
K8-25 97-OF-SP-5 C-303522	*Diplognathodus oertlii* *Hindeodus* sp. *Mesogondolella* ex gr. *bisselli* *Neostreptognathodus pequopensis* *Sweetognathus whitei* ramiform elements	Early Permian, Artinskian (PTCCl)
K8-26 97-OF-S-MP-222 C-303525	*Diplognathodus* sp. *Idiognathodus delicatus* *Idiognathoides* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K8-26 97-OF-MP-222 C-303718	*Idiognathodus delicatus*	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
93K/9 - Pinchi Lake		
K9-19 97-SCB-1302B C-209073	*Streptognathodus* sp.	Late Carboniferous-Early Permian (PTCCl)
K9-9(1995) 97-SCB-1801A C-209903	*Neognathodus* sp.	Late Carboniferous, Bashkirian-Moscovian (PTCCl)
K9-20 97-SCB-B-1006B C-209926	ichthyoliths	Phanerozoic (TTl)
K9-21 97-SCB-3602A C-209935	radiolarians	Phanerozoic (TCCsv)
K9-22 97-SCB-3507E C-209937	*Epigondolella* ex gr. *bidentata* *Epigondolella* cf. *spiculata* *Norigondolella steinbergensis* *'Neospathodus'* sp. ramiform elements	Late Triassic, Middle-Late Norian (TCCsv)
K9-22 97-SCB-3507C C-209938	ichthyoliths	Mesozoic? (TCCsv)
K9-23 97-SCB-0203B C-209940	sphaeromorphs	Phanerozoic (TCCsv)

Table 1. (cont.)

Map no. Field no. GSC loc. no.	Conodont taxa	Age (Geological unit)
93K/9 - Pinchi Lake (cont.)		
K9-4(1995) 97-OF-BAT-2 C-303516	*Diplognathodus* sp. *Idiognathodus*? sp. ramiform elements	Late Carboniferous-Early Permian (PŦCCl)
K9-4(1995) 97-OF-BAT-3 C-303517	*Diplognathodus* sp. *Diplognathodus*? sp. *Gondolella* ex gr. *laevis* *Hindeodus* sp. *Idiognathodus*? spp. *Neognathodus* sp. *Streptognathodus*? sp. ramiform elements	Late Carboniferous, Moscovian (PŦCCl)
K9-24 97-OF-S-MP-250 (C-303524) 97-OF-MP-250 (C-303715)	*Hindeodus* sp. *Idiognathodus* sp. *Streptognathodus* sp. ramiform elements	Late Carboniferous-Early Permian (PŦCCl)
K9-25 97-OF-MP-203 C-303714	*Idiognathodus*? sp. ramiform elements	Late Carboniferous-Early Permian (PŦCCl)
93K/10 - Stuart Lake		
K10-4 97-SCB-1402B C-209095	*Idiognathoides*? sp. ramiform elements	Late Carboniferous (PŦCCl)
K10-5 97-SCB-1403B C-209096	ramiform elements	Ordovician-Triassic (PŦCCl)
K10-6 97-SCB-X-1005D C-209802	*Chiosella*? sp. *Gladigondolella* sp. *Neogondolella* sp. ramiform elements	Middle Triassic (ŦCCl)
K10-7 97-SCB-X-1006B C-209803	*Gladigondolella* sp. *Neogondolella* sp. ramiform elements	Middle Triassic (ŦCCl)
K10-8 97-SCB-0106A C-209909	*Neognathodus*? sp.	Late Carboniferous? (PŦCCl)
K10-9 97-SCB-H-2702C C-209924	*Neogondolella* sp. *Gladigondolella* cf. *tethydis* ramiform elements	Middle Triassic (PCCl)
K10-10 97-SCB-J-1805C C-209928	*Idiognathodus*? sp.	Late Carboniferous (PŦCCl)
93K/10 - Stuart Lake (cont.)		
K10-11 97-SCB-J-1804C C-209929	*Idiognathodus* sp. *Idiognathoides* sp.	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
K10-12 97-SCB-4102C C-209932	sphaeromorphs	Phanerozoic (PCCv)
K10-13 97-SCB-3501F C-209934	*Epigondolella* sp. *Norigondolella* sp.	Late Triassic, Norian (PŦCCl)
K10-14 97-SCB-H-4408A C-209946	*Metapolygnathus communisti* *M. nodosus* *M. primitius* *M. pseudoechinatus* ?*M. samueli* *Neocavitella*? sp. *Paragondolella*? sp. ramiform elements	Late Triassic, Late Carnian (ŦCCl)
K10-15 97-SCB-J-1802B C-209950	*Idiognathodus delicatus* ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
93K/15 - Inzana Lake		
K15-6 97-SCB-1405B C-209097	*Declinognathodus* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
K15-7 97-SCB-1406B C-209098	*Declinognathodus* sp.	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
K15-8 97-SCB-2101B C-209906	*Idiognathodus* sp. *Idiognathoides* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
K15-9 97-SCB-2210A C-209907	*Idiognathodus* sp. *Neognathodus* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
K15-10 97-SCB-H-1506D C-209918	'*Ellisonia*' sp.	Early Triassic? (ŦCCsv)

Table 1. (cont.)

Map no. Field no. GSC loc. no.	Conodont taxa	Age (Geological unit)
93K/15 - Inzana Lake (cont.)		
K15-11 97-SCB-2211A C-209941	*Hindeodus? sp.* *Idiognathodus* sp. *Idiognathoides* sp. *Mesogondolella* sp. ramiform elements	Late Carboniferous, Bashkirian-Moscovian (PŦCCl)
K15-12 97-SCB-4903B C-209943	*Metapolygnathus* ex gr. *nodosus*	Late Triassic, Carnian (UŦTt)
K15-13 97-SCB-H-1506A C-209945	sphaeromorphs echinoderms	Phanerozoic (PŦCCl)
K15-14 97-SCB-H-5808B C-209949	*Hindeodus* sp. *Neogondolella* sp. ramiform elements	Middle? Permian (PŦCCl)
93N/3 - Takatoot Lake		
N3-3(1997) 97-OF-FF-U46A C-303483	*Adetognathus* sp. *Hindeodus* sp. ramiform elements	Late Carboniferous-Early Permian (PŦCCl)
N3-2(1997) 97-OF-KO-1 C-303484	ramiform elements	Ordovician-Triassic (PŦCCs)
N3-2(1997) 97-OF-KO-2 C-303485	*Hindeodus* sp. ramiform elements	Carboniferous-Early Triassic (PŦCCs)
N3-2(1997) 97-OF-KO-3 C-303486	*Hindeodus* cf. *typicalis* ramiform elements	Permian-Early Triassic (PŦCCs)
N3-2(1997) 97-OF-KO-4 C-303487	ichthyoliths	Phanerozoic (PŦCCs)
N3-2(1997) 97-OF-KO-5 C-303488	*Hindeodus*? sp. *Neogondolella* sp. '*Stepanovites*' sp. ramiform elements	Late Permian (PŦCCs)
N3-2(1997) 97-OF-KO-6 C-303489	ichthyoliths	Phanerozoic (PŦCCs)
N3-2(1997) 97-OF-KO-7 C-303490	*Iranognathus* ex gr. *nudus* *Hindeodus* sp. '*Stepanovites*' sp. ramiform elements	Late Permian, ?Changhsingian (PŦCCs)
93N/3 - Takatoot Lake (cont.)		
N3-2(1997) 97-OF-KO-8 C-303491	*Diplognathodus* sp. *Hindeodus typicalis* *Neogondolella* sp. indet. ramiform elements	Late Permian (PŦCCs)
N3-2(1997) 97-OF-KO-9 C-303492	*Diplognathodus*? sp. *Hindeodus* sp. ramiform elements	Late Permian (PŦCCs)
N3-2(1997) 97-OF-KO-10 C-303493	*Hindeodus* sp. ramiform elements	Carboniferous-Early Triassic (PŦCCs)
N3-2(1997) 97-OF-KO-11 C-303494	ramiform elements	Ordovician-Triassic (PŦCCs)
N3-2(1997) 97-OF-KO-12 C-303495	ramiform elements	Ordovician-Triassic (PŦCCs)
N3-2(1997) 97-OF-KO-13 C-303496	*Neospathodus* ex gr. *bransoni* *Neospathodus* ex gr. *conservativus* *Neospathodus waageni* ramiform elements	Early Triassic, Smithian (PŦCCs)
N3-4 97-OF-K16 C-303499	*Hindeodus* sp. *Jinogondolella* ex gr. *serrata* ramiform elements	Late Permian, Roadian-Wordian (PŦCCl)
N3-5 97-OF-KELLY-8 C-303513	*Idognathoides*? sp. ramiform elements	Late Carboniferous? (PŦCCl)
93N/6 - Indata Lake		
N6-1 97-SCB-5104A C-209931	*Mesogondolella* sp. ramiform elements	Permian (PŦCCu)
93N/13 - Ogden Creek		
N13-1 97-OF-KELLY-2 C-303505	*Hindeodus* sp. *Neogondolella carinata* *Neogondolella discreta* *Neogondolella orchardi* ramiform elements	Early Triassic, Griesbachian (PŦCCs)
N13-1 97-OF-KELLY-4 C-303507	*Hindeodus* sp. *Gladigondolella* sp. ramiform elements	Early and Middle Triassic (PŦCCs)

is dominated by the Inzana Lake Formation (Nelson et al., 1991), composed of greywacke, andesite tuff, and minor limestone.

CONODONT BIOSTRATIGRAPHY

The oldest conodonts known from the Cache Creek complex in the Nechako project area date from near the base of the Bashkirian stage of the Late Carboniferous (=Pennsylvanian), whereas the youngest date from the Late Norian near the top of the Triassic. The total age range is much the same as that shown by initial sampling (Orchard and Struik, 1996; Orchard et al., 1997, Fig. 3) and has been extended only slightly by the discovery of the lower Bashkirian index *Declinognathodus noduliferus* from the Mount Pope trail and Pinchi Creek localities (Orchard et al., 1998). However, some significant gaps in the stratigraphic record have now been partly filled. Chief amongst these are new records of Lower Permian (Artinskian), Lower Triassic (Griesbachian), and Middle Triassic conodonts. Some of these collections contain conodonts of Tethyan affinity, notably Middle Triassic *Gladigondolella*. There is also new evidence of reworked carbonates. In total, the time represented by the conodont fauna can be divided into seven distinct intervals (Fig. 2), and the following discussion of the biostratigraphy will focus on those intervals.

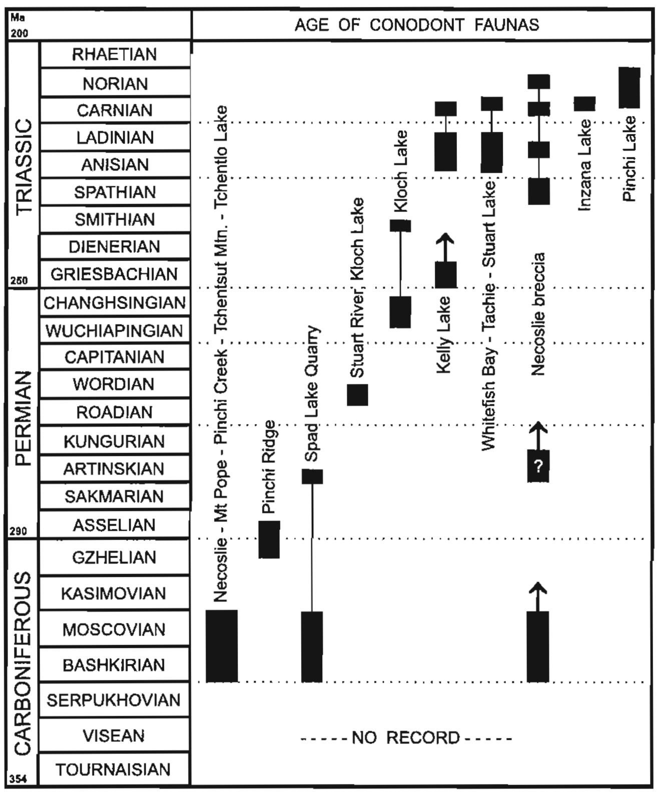

Figure 2. Ages of conodont faunas recovered from localities within the Nechako Plateau. The arrows indicate that the older conodonts have been reworked into younger strata.

Bashkirian–Moscovian, Upper Carboniferous

The predominant conodont assemblages found in limestones of the Pope unit in the Nechako project area are various associations of species of *Adetognathus, Declinognathodus, Diplognathodus, Gondolella, Hindeodus, Idiognathodus, Idiognathoides, 'Neogondolella', Neognathodus*, and *'Streptognathodus'*. The relative ages of these collections are under review, but all are typical of the Bashkirian and Moscovian stages of the Upper Carboniferous. These strata are the oldest part of the Pope unit and the only part that is identified throughout the length of the Cache Creek outcrop. Three broadly defined belts of the Bashkirian to Moscovian carbonates are punctuated by outcrops of younger limestones of the Pope unit.

The Mount Pope belt comprises many of the localities reported by Orchard et al. (1997). The belt extends from Mount Pope northwest of Fort St. James southeastward into McLeod Lake map area along the north side of Necoslie River (Fig. 3). New conodont collections of the Late Carboniferous are here reported from Mount Pope (K8-23, K8-26; these are locality numbers of Fig. 3, 4, and 5 and Table 1), the east side of Stuart Lake (K8-24, K9-19), Spad Lake quarry (K8-25), Necoslie (K8-9), and from Battleship Island (K9-4), where well preserved radiolarians are associated. To the immediate north and west of this belt, younger limestone units of Gzhelian–Asselian age occur, and within the belt a single locality of Artinskian turbidites occurs (*see* below).

The Pinchi Creek belt of Bashkirian to Moscovian limestone units, from which 14 new conodont collections are reported, extends from north of the Tachie Road in map area 93 K/9 (K9-25) through the Pinchi Creek quarry (Orchard et al., 1998, p. 104), northwest along the south side of the Pinchi Fault to near the northern edge of map area 93 K/10 (K10-5) and into the southern part of map area 93 K/15 (Fig. 4, K15-9). To the north of the Pinchi Creek belt (across the most southerly of the Middle Permian limestones) the Tchentsut Mountain-Tchentlo Lake belt of Upper Carboniferous limestones outcrops from the north side of Tchentsut Mountain (Orchard et al., 1998, K15-2, etc.) northwest through Kloch Lake (N3-3) in Manson River map area and as far north as N3-5 to the west of Tchentlo Lake.

Gzhelian–Asselian, uppermost Carboniferous–lowermost Permian

Conodonts from this younger suite of limestones of the Pope unit, first identified in the area east-northeast of Mount Pope, were described by Orchard et al. (1997, p. 100–101) as Pinchi fauna D. Abundant fusulinacean faunas collected by Hiro Sano from this area were studied by Lin Rui (pers. comm., 1998), who reported two early to late Asselian assemblages. Two new but poorly preserved collections from north (K9-24) and northwest (K9-19) of Mount Pope may correlate with this suite of limestones and demonstrate a general northward younging within the thrust panel (Fig. 3).

Artinskian, Lower Permian

Only a single locality within the Pope unit has produced definitive conodonts of this age. Spad Lake quarry (K8-25) to the east of Fort St. James (Fig. 2) has been studied in detail by Sano (1998), who informally named the strata outcropping there as the Spad Lake member of the Pope formation. Sano (1998) described lower, middle, and upper parts of the member. The lower and middle parts, exposed in the body of the quarry, include basaltic breccia interlayered with carbonate rocks, in part fragmented and dolomitized, and volcaniclastic rocks. The volcanic rocks decrease upsection. These strata have produced a Bashkirian to Moscovian fauna and constitute part of the Upper Carboniferous Mount Pope belt (*see* above).

The upper part of the member, exposed adjacent to the quarry entrance and in uncertain relationship with the other parts, consists of well bedded dolomite and limestone turbidites displaying Bouma sequences. Some clasts from the fine pebble-granule conglomerate at the base of one limestone bed are reported to contain abraded, probably reworked *Pseudofusulina* of Asselian age (Sano, 1998, p. 96). Conodonts from these turbiditic strata are younger than Asselian and, for the Cache Creek Group, totally new. They include *Diplognathodus oertlii, Mesogondolella bisselli, Sweetognathus whitei,* and *Neostreptognathodus* aff. *foliatus.* Whereas the first three species are well known in the Harper Ranch Group near Kamloops (Orchard and Forster, 1988), the last is closest to a species described from the Yoro Group of southern Japan (Igo, 1981) and has not previously been reported from North America.

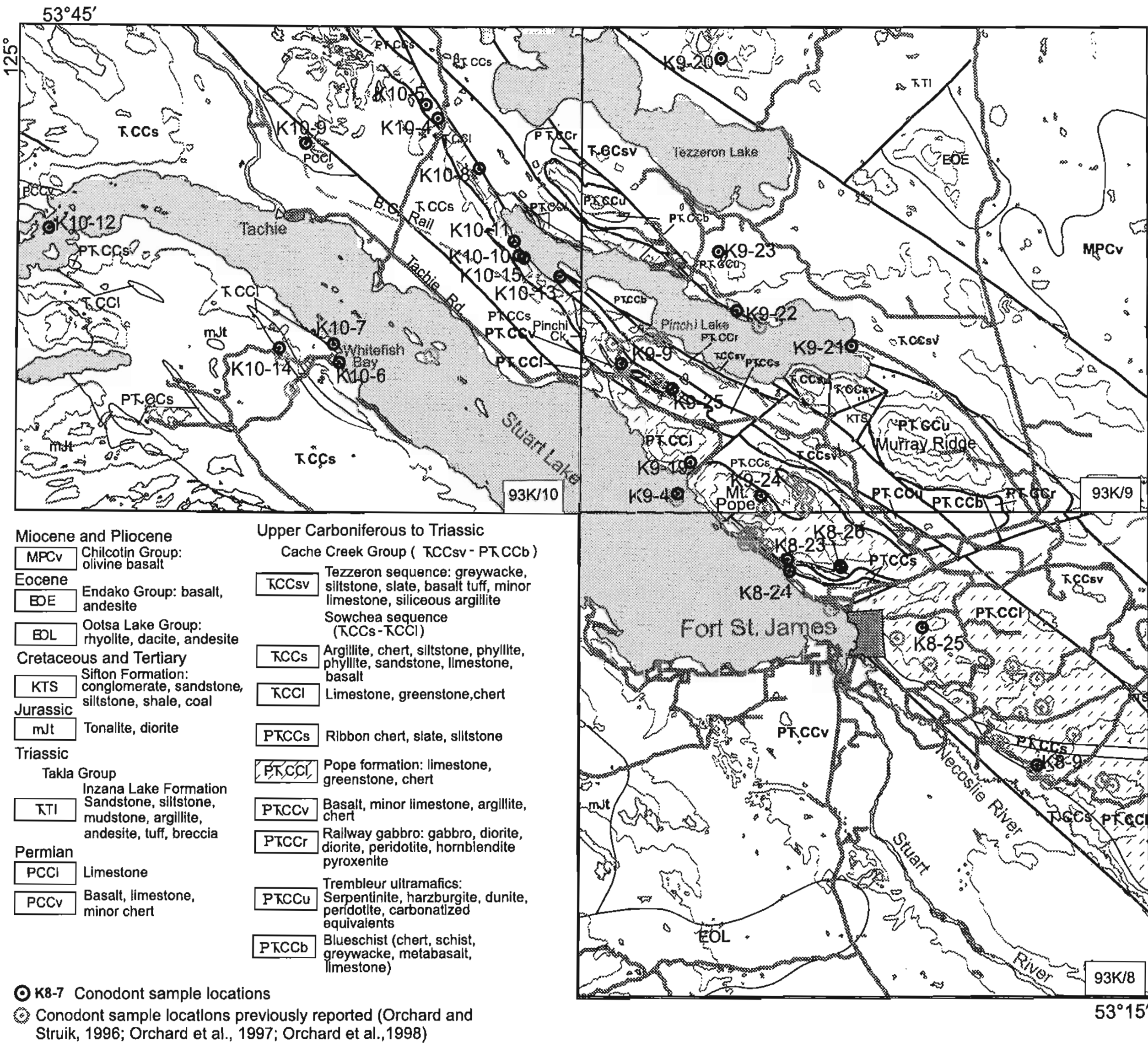

Figure 3. *Geology of Fort St. James area of Fort Fraser map area (NTS 93 K) with location of 1997 conodont sample sites. Previously reported localities are represented by screened symbols. Geology is after Bellefontaine et al. (1995) and Struik (1997, 1998).*

The suggested reworking of Asselian fusulinids into Artinskian turbidites implies that Asselian carbonate rocks, such as the limestone north of Mount Pope or its correlatives, were exposed and being reworked during the Artinskian. Coeval carbonate buildup sources for the Artinskian carbonate turbidites are unknown.

Roadian–Changshingian, Middle–Upper Permian

In general, Permian conodonts are not common in the Pope unit. This is due in part to unfavourable facies represented by fusulinid-bearing Permian carbonate rocks, but in the south it is a reflection of the predominantly Late Carboniferous age of the carbonate buildup. Permian massive carbonate rocks are far more common in the northern part of Fort Fraser map area northeast and east of Trembleur Lake and around Kloch Lake in Manson River map area (Armstrong, 1949; Fig. 3). A single outlier is identified north of Tachie (close to K10-9).

Two Permian sites from the area southeast of Tchentsut Mountain separate the Pinchi Creek and Tchentsut Mountain belts of Upper Carboniferous limestone (Fig. 3). Both the new site (K15-14) and the previously reported site (Orchard et al., 1998; K15-1) contain gondolellids that are probably mid-Permian. More diagnostic conodont elements occur in a sample from east of Kloch Lake (N3-4) where *'Jinogondolella'* species of Guadalupian age were found close to fusulinid limestone units dated as Wordian (Lin Rui, pers. comm., 1997). The same conodont group occurs in limestone units interbedded with basaltic flows on Stuart River (Orchard et al., 1997, p. 101; K8-15). The last locality and others where

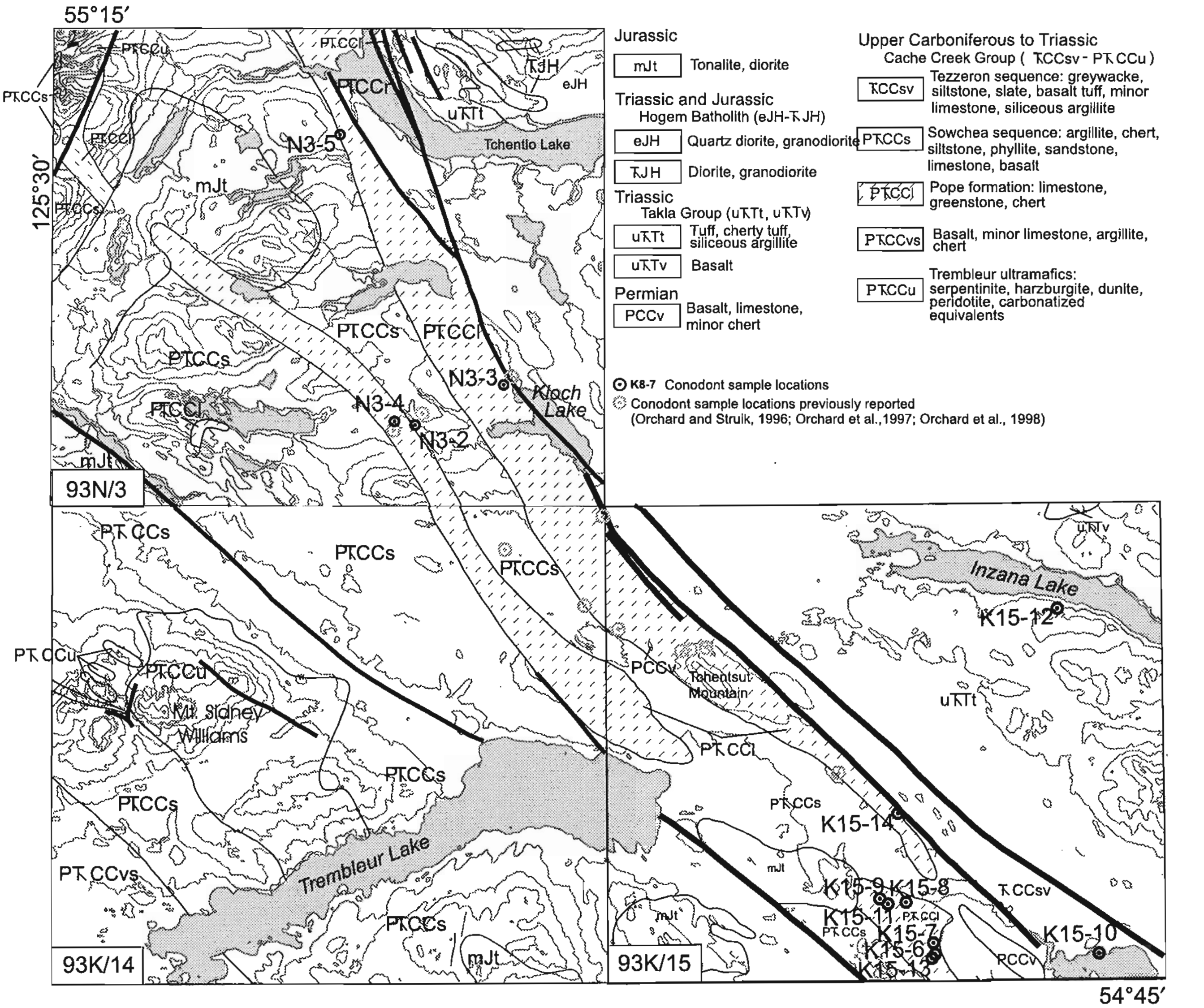

***Figure 4.** Geology of northern part of Fort Fraser map area (NTS 93 K) and southern part of Manson River map area (NTS 93 N) with location of 1997 conodont sample sites. Previously reported localities are represented by screened symbols. Geology is after Bellefontaine et al. (1995) and Struik (1998).*

Guadalupian chert is dated with radiolarians (Cordey and Struik, 1996) represent a pelagic environment that is broadly contemporaneous with the carbonate buildups to the north. The same appears true of a new collection (N6-1) recovered from a fault-imbricated chert sliver within Cache Creek ultramafic rocks in the Indata Lake map area (Fig. 5). There is no evidence at present that massive carbonate rocks of the Pope unit developed after the Wordian; all younger conodont collections come from the more clastic Sowchea succession.

The youngest Permian strata known from the Nechako project area lies to the east of Kloch Lake (Orchard et al., 1998, p. 104–105). Thorough sampling of this section (Fig. 4, N3-2) of the Sowchea unit produced additional small conodont collections of probable latest Permian age. The presence of *Iranognathus?* ex gr. *nudus, Hindeodus typicalis,* and/or fragments of *Neogondolella* with high and fused carinal nodes supports a very young Permian age for these strata, as does its proximity to Lower Triassic carbonate (*see* below).

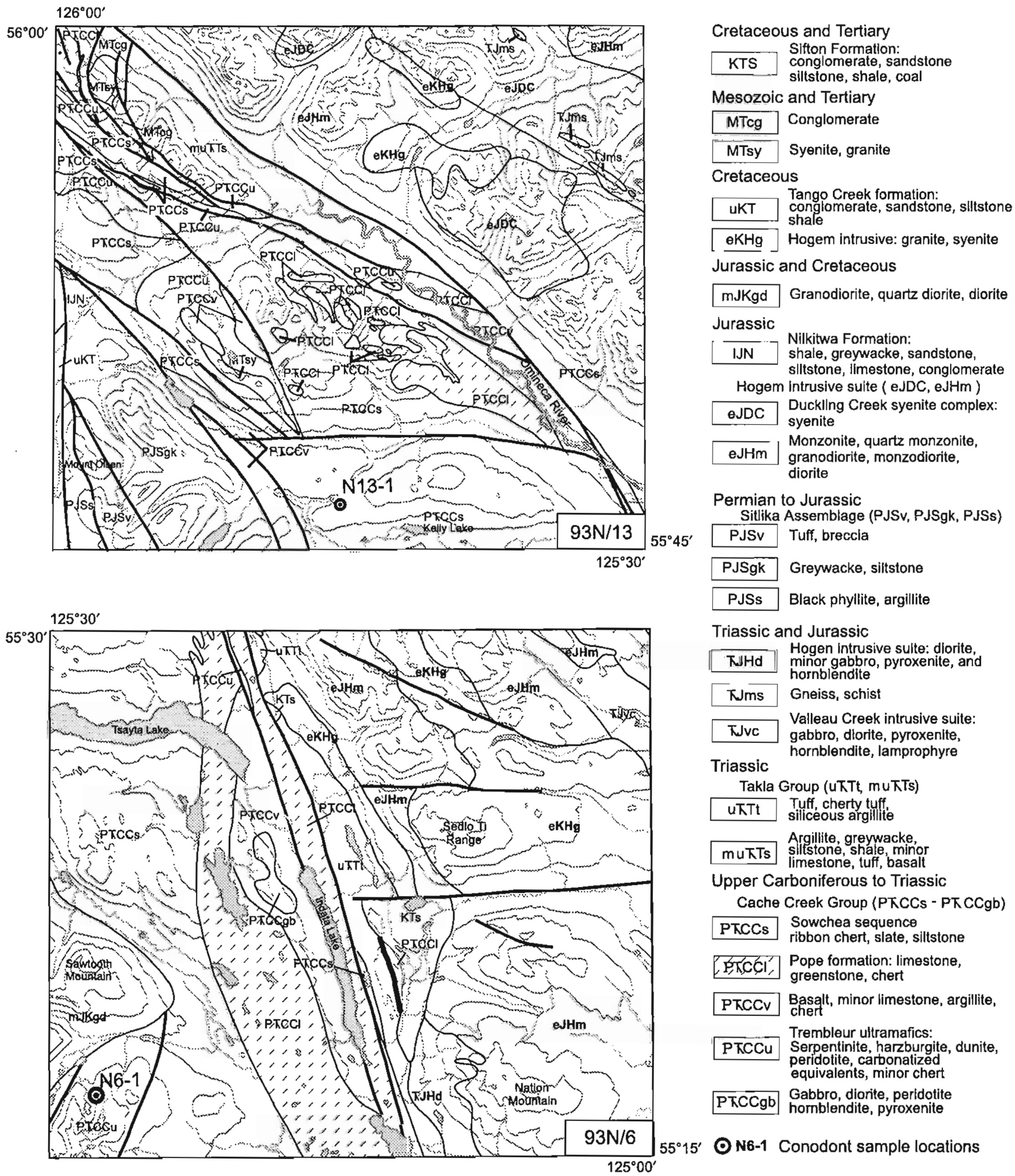

Figure 5. *Geology or parts of Manson River map area (NTS 93 N) with location of 1997 conodont sample sites. Previously reported localities are represented by screened symbols. Geology is after Bellefontaine et al. (1995).*

Griesbachian–Spathian, Lower Triassic

Although the basal Triassic has not been determined at Kloch Lake, evidence for Griesbachian strata is now known from near Kelly Lake in northern Manson River map area (Fig. 5, N13-1). This site was first sampled by British Columbia Geological Survey (BCGS) geologists in 1996. A single collection (GSC loc. C-208773) contained *Hindeodus parvus* and *Neogondolella carinata* of Griesbachian age, *Gladigondolella tethydis* of Middle Triassic age, and questionably a metapolygnathid of Carnian, Late Triassic age. An explanation for this anomalous association became apparent during a visit in 1997 when the small isolated outcrop was seen to be composed of recrystallized fragmental limestones. New samples were taken from both fragmentary and apparently nonclastic limestone. A collection recovered from homogenous limestone produced an unmixed Griesbachian fauna including several *Neogondolella* species, one of which (*N. discreta*) has recently been described for the first time from Spiti (Orchard and Krystyn, in press). This supplements the important index conodont *H. parvus* found earlier and establishes that Griesbachian sedimentation is a unique feature of the Cache Creek Terrane in the western Cordillera. Within the terranes, strata of this age have only been previously reported from the Marble Range of the type area of Cache Creek Group (Beyers and Orchard, 1991).

A second conodont fauna from Kelly Lake includes basal Triassic *Hindeodus* in association with *Gladigondolella*. This collection, which is similar to that of the original BCGS collection, came from a fragmental limestone and suggests that the Griesbachian limestone was reworked during the Middle Triassic or, based on the BCGS collection, the Late Triassic; an even later event cannot be ruled out. This is reminiscent of the interpretation for the Necoslie breccia (Orchard et al., 1998, p. 104) although the major source for Triassic reworking in that case was the Bashkirian to Moscovian limestone. The presence of *Gladigondolella* in these collections is also remarkable (*see* below).

East of Kloch Lake (Fig. 4, N3-2), the latest Permian succession is juxtaposed against dark recrystallized limestone that contains unidentifiable ammonoids. The limestone has now produced a large conodont fauna including several *Neospathodus* species (Table 1) that collectively prove an early Smithian age, probably equivalent to the Romunduri Zone of the ammonoid standard (Orchard and Tozer, 1997, 1998). This is also a unique fauna in Nechako project area, but again has parallels to the south where Smithian fauna has been described from the central belt of the Cache Creek complex (Beyers and Orchard, 1991). An isolated collection from the Tezzeron succession at the north end of Tezzeron Lake (Fig. 4, K15-10) may also be Early Triassic based on distinctive ramiform elements tentatively assigned to *Ellisonia*; these are similar to specimens found in the Kloch Lake Smithian fauna.

Supplementary conodont collections from the Necoslie limestone breccia within the Pope unit exposed on the roadcut north of Necoslie River are dominated by conodonts of Bashkirian–Moscovian age but rare (?)Smithian and Spathian elements (e.g. *Neospathodus* ex gr. *homeri*) confirm that Lower Triassic sedimentation also occurred in this southern area. These collections (Fig. 3, K8-9) also confirm the overwhelming Carboniferous content of the breccia, and the probable exposure of those carbonate rocks to erosion during the Triassic (Orchard et al., 1998). Carbonate breccia occurs elsewhere in Carboniferous outcrops of the Pope unit but none have yielded mixed conodont faunas. Some probably result from penecontemporaneous erosion in a shallow marine environment, but others may have a similar genesis to that at Necoslie; this cannot be excluded because the younger conodonts in the Necoslie breccia are rare.

Anisian–Ladinian, Middle Triassic

Middle Triassic strata are newly proven on both sides of Stuart Lake within the Sowchea unit. West of Whitefish Bay (Fig. 3, K10-6, K10-7) and north of Tachie (K10-10), conodont collections contain *Gladigondolella*, as do others from the limestone conglomerate at Kelly Lake. This genus is unknown in North America outside the Cache Creek Terrane and its southern equivalent the Baker Terrane in Oregon (Nestell and Orchard, 1991). *Gladigondolella* has also recently been discovered near Marble Canyon in the type area of the Cache Creek Group (sample collected by W.R. Danner). The genus ranges from the Spathian to the Early Carnian in Tethys where it is commonly dominant in samples from the Middle Triassic. The North American records attest to a truly Tethyan provenance for the Middle Triassic of the Cache Creek Terrane, as has been long argued for its Permian fauna (Monger and Ross, 1971). The extent of geographic separation of these rocks from North America in the Triassic is difficult to assess; their oceanic character rather than distant geographic separation may be an overriding factor in their composition. Nevertheless, *Gladigondolella* is not known from contemporaneous strata even in the most distal and deepest parts of the autochthonous Western Canada Sedimentary Basin.

Apart from the Kelly Lake occurrence, additional Middle Triassic conodont elements are questionably present in the Necoslie breccia. This further supports some contemporaneity in the unit and/or sources of the Kelly and Necoslie breccias. Middle Triassic conodonts in these breccias may be derived or they may represent early cave filling coeval with sedimentation of the Sowchea succession.

Carnian–Norian, Upper Triassic

The youngest conodont elements in the Necoslie and Kelly Lake breccias are probably Carnian, although they are very rare. They nevertheless imply that the processes of reworking, fissure- and cave-forming and -filling, are, at least in part, Carnian or younger. There may have been older intervals of reworking or cave filling, but it is clear that the sources of the Kelly Lake and Necoslie breccia differed. During the Late Triassic, Upper Carboniferous limestones were exposed at Necoslie whereas Early Triassic carbonates were exposed near Kelly Lake.

Several Upper Triassic conodont collections are newly reported in addition to those assembled as fauna G in Orchard et al. (1997). East of Whitefish Bay and the *Gladigondolella* localities, a diverse Late Carnian fauna (K10-15) occurs in a limestone pod of the Whitefish Bay subunit of the Sowchea unit (Fig. 2, Table 1). This fauna has direct correlatives in a collection reported previously from the western edge of Pinchi Lake (Orchard et al., 1997, K9-19) and a second collection newly reported from the Takla Group on the south side of Inzana Lake (Fig. 4, K15-12). All three contain *Metapolygnathus nodosus*. The Whitefish Bay collection supplements poorly preserved collections reported earlier (Orchard et al., 1997, K10-1, K10-3) that were broadly dated as Ladinian to Norian: apparently, both Middle and Upper Triassic strata are present in this area.

Two new collections from the east and west sides of Pinchi Lake are Norian. They are both mapped as Tezzeron unit and the eastern collection (Fig. 3, K9-22) is a well preserved Middle to Late Norian fauna; this supplements the undifferentiated Norian collection reported nearby by Paterson (1973) and Orchard et al. (1997; K9-13). The western Norian collection (K10-14) comes from limestone within a fine-grained greywacke succession caught between blue schist to the northeast and gabbro and basalt to the southwest. The Colour Alteration Index (CAI) of the conodonts of collection K9-22 is between 2 to 3, compared with 3.5 to 4.5 for other Triassic collections near Pinchi Lake, and more than 5 for most Paleozoic collections in the region. This points to a relatively low post-Triassic thermal regime for these rocks in the Pinchi Lake area. These Norian collections supplement the Norian collection reported from chert of the Sowchea unit on Stuart Lake (Orchard et al., 1997; K8-6).

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Geological Survey of Canada Project 950036

Bedrock geology of the Knapp Lake map area, central British Columbia[1]

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Anderson, R.G., Snyder, L.D., Resnick, J., Grainger, N.C., and Barnes, E.M., 1999: Bedrock geology of the Knapp Lake map area, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 109–118.*

Abstract: Fault-bounded panels containing widespread Mesozoic sedimentary and volcanic rocks, less common Eocene and Neogene felsic and mafic volcanic rocks, and uncommon Cretaceous and Tertiary porphyry and high-level felsic plutonic rocks underlie the Knapp Lake map area. Mesozoic stratigraphic units include: purple and green, heterolithic, plagioclase-phyric, andesitic, lapilli breccia and crystal tuff of the Hazelton Group; siliciclastic rocks of Bowser Lake (and/or possibly Skeena) Group; and Upper Cretaceous hornblende-plagioclase-phyric flows, tuff, and volcaniclastic rocks.

Eocene Ootsa Lake Group includes felsic crystal tuff, pyroclastic rocks, breccia and flows, and volcanic conglomerate. Important basal mafic volcanic rocks are difficult to distinguish from texturally and compositionally similar older Cretaceous or younger Eocene Endako Group mafic volcanic rocks where a stratigraphic context is absent.

Miocene Chilcotin Group olivine-clinopyroxene-plagioclase-phyric basalt occurs as columnar-jointed volcanic flows and necks distinguished by uncommon ultramafic nodules.

Eocene and younger northeast- and west-trending block faults dominate the map-scale structural style.

Résumé : Des panneaux limités par des failles et renfermant des roches volcaniques et sédimentaires répandues du Mésozoïque, des roches volcaniques mafiques et felsiques moins fréquentes de l'Éocène et du Néogène, et de rares porphyres et roches plutoniques felsiques de niveau crustal élevé du Crétacé et du Tertiaire se rencontrent dans la région cartographique du lac Knapp. Les unités stratigraphiques du Mésozoïque comportent des tufs cristallins et des brèches à lapilli violets et verts, hétérolitiques, andésitiques et à phénocristaux de plagioclase du Groupe de Hazelton; des roches silicoclastiques du Groupe de Bowser Lake (et/ou peut-être du Groupe de Skeena); et des roches volcanoclastiques, des tufs et des coulées à phénocristaux de hornblende et de plagioclase du Crétacé supérieur.

Le Groupe d'Ootsa Lake de l'Éocène comporte des tufs cristallins felsiques, des roches pyroclastiques, des brèches et des coulées, ainsi que des conglomérats volcaniques. En l'absence de cadre stratigraphique, il est difficile d'établir la différence entre les roches volcaniques mafiques basales importantes et les roches volcaniques mafiques de texture et de composition similaires plus anciennes du Crétacé ou plus jeunes de l'Éocène du Groupe d'Endako.

Des basaltes à phénocristaux d'olivine, de clinopyroxène et de plagioclase du Groupe de Chilcotin du Miocène se rencontrent sous la forme de necks et de coulées volcaniques à prismation caractérisés par la présence de rares nodules ultramafiques.

Des blocs faillés de l'Éocène et d'âge plus récent, de direction nord-est et ouest, dominent le style tectonique à l'échelle cartographique.

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INTRODUCTION

Ongoing revision of the Nechako River 1:250 000 scale geological map (Tipper, 1963), part of the Nechako NATMAP Project (Fig. 1; Struik and McMillan, 1996; Struik and MacIntyre, 1997, 1998), included mapping in the Knapp Lake map area (NTS 93 F/14; Fig. 1). Mapping in 1996 focused on the distribution of plutonic suites in the area (e.g. Anderson et al., 1997a; L'Heureux and Anderson, 1997) as part of a regional study of plutonic suites (*see* Struik et al., 1997; Whalen and Struik, 1997; Anderson et al., 1997b; Whalen et al., 1998). In 1997 and 1998, bedrock mapping concentrated on the Mesozoic and Tertiary volcanic and sedimentary rocks which flank the central plutonic massif. As in 1996, the present work builds on the excellent mapping and age-dating contributions by mineral exploration and provincial geological survey geologists in the area over the past 30 years (e.g. Kimura et al., 1980; Bellefontaine et al., 1995; Lane, 1995; Lane and Schroeter, 1997).

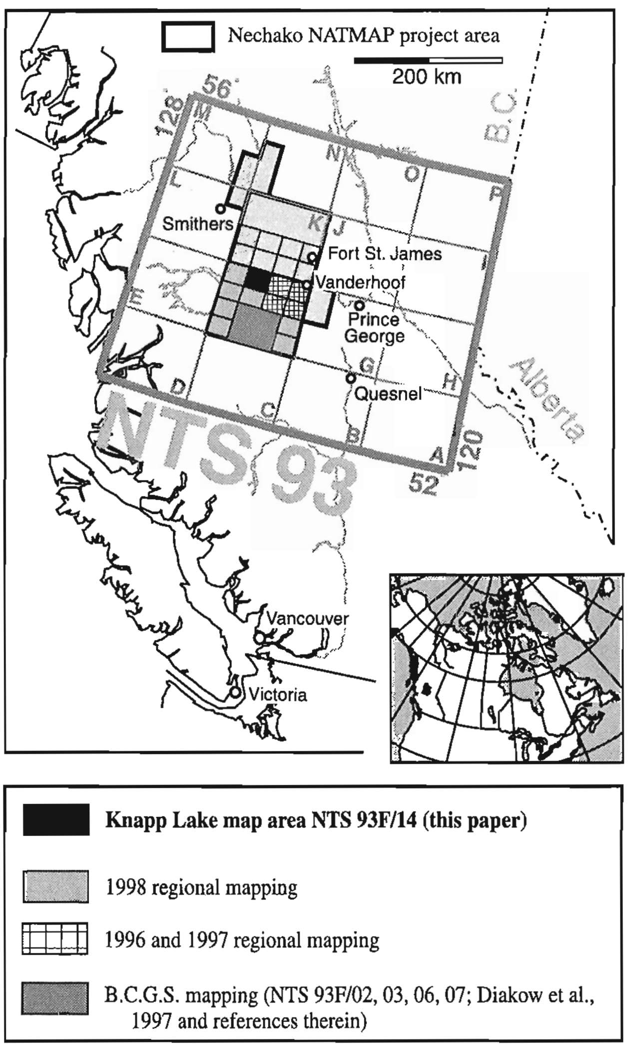


Figure 1. *Location of the Knapp Lake (NTS 93 F/14), Fraser Lake (NTS 93 K/02), and Endako (NTS 93 K/03) map areas within the Nechako NATMAP project area (shaded).*

This report summarizes descriptions of Mesozoic to Tertiary sedimentary and volcanic rocks and emphasizes the newly discovered stratigraphic members within Eocene Ootsa Lake Group, Neogene (?) Chilcotin Group volcanic rocks, and (?)Eocene intrusions in the area. Observed and inferred geological relationships between stratified and plutonic units suggest that small-scale as well as regional-scale block faults, for example, the Anzus Lake fault (Fig. 2), were important synvolcanic Eocene and younger structures.

PHYSIOGRAPHY, ACCESS, AND FIELD METHODS

The Interior Plateau physiography is characteristically low relief and entirely below treeline, although extensive logging is continually improving access to outcrop.

New data reported here were based upon six weeks work (45 traverses) in August 1997 and June 1998. Standard geological mapping techniques were supplemented by global positioning system measurements taken at each station, providing a lateral precision of 50–100 m (depending on number and orientation of satellites). Representative samples were collected for petrographic, mineralogical, $^{40}Ar/^{39}Ar$ age-dating, and geochemical studies. As well, magnetic susceptibility (m.s.) measurements were routinely obtained at each outcrop over a five minute period using a hand-held Exploranium KT-9 Kappameter (and are quoted in 10^{-3} SI units as an average of at least 5 measurements); these proved invaluable for delineating areas of alteration (m.s. <1). Specific gravity measurements are also underway on all hand samples. The database of magnetic susceptibility and specific gravity measurements will aid in the interpretation of potential field data (e.g. Struik and McMillan, 1996; Lowe et al., 1998).

GEOLOGY

Stratified rocks

The Knapp Lake map area is underlain by widespread Mesozoic sedimentary and volcanic rocks, less common Eocene and Neogene felsic to mafic volcanic rocks, and uncommon Cretaceous and Tertiary plutonic rocks (Fig. 2).

Lower and Middle Jurassic Hazelton Group (units lmJH)

Nonfossiliferous, maroon and green, fine- to coarse-grained volcaniclastic rocks typical of the Lower to Middle Jurassic Hazelton Group are recognized east of the informally-named 'Island' Lake and along part of the north shore of Francois Lake (Fig. 2). Near 'Island' Lake, brown to purple and green, heterolithic, plagioclase-phyric andesitic lapilli breccia is characteristic. Angular to round, mafic to felsic fragments reach 4 cm across and are matrix supported. Plagioclase-phyric andesite and lapilli tuff, dominant south of Anzus Lake, are intruded by the Cabin Lake pluton. South of 'Island' Lake, the strata are unconformably overlain by the

Ootsa Lake Group. The rocks are correlated with the Hazelton Group on the basis of similarities in weathering colour, volcanic facies, and composition of fragments and matrix to the Hazelton Group in the Hallett Lake (Anderson and Snyder, 1998; Anderson et al., 1998a) and Big Bend Creek (Anderson et al., 1998b) areas.

Middle and Upper Jurassic Bowser Lake Group (unit muJBL) and Cretaceous Skeena Group (unit lKs)

In the north-central part of the area, northeast of Binta Lake, Middle and Upper Jurassic Bowser Lake Group rocks, shown in earlier compilations (Bellefontaine et al., 1995; Williams, 1997; Fig. 2) were only locally revisited during the mapping. Tan-brown-weathering, tan to green pebble conglomerate and sandstone outcrop northeast and south of 'Island' Lake. The conglomerate is poorly sorted and matrix to fragment supported. Fragments are rounded, 0.5–2 cm, and comprise (most to least abundant): chert; aphanitic felsic to intermediate volcanic rocks; and local coarse-grained plagioclase porphyry, altered possibly pumiceous and minor amphibole-phyric volcanic rock. The sandstone is fine- to medium-grained and contains subangular feldspar, possible hornblende, and minor quartz crystal and rare felsic volcanic rock fragments. The abundance of intermediate composition volcanic fragments distinguishes the conglomerate from Bowser Lake Group conglomerate seen in the Hallett Lake area (Anderson and Snyder, 1998) and northern Nechako Range (Anderson et al., 1998b). As well, close spatial association of the unit with Upper Cretaceous hornblende-plagioclase porphyritic andesitic flow and volcaniclastic rocks of the Kasalka Group merits careful study to distinguish it from Lower Cretaceous Skeena Group siliciclastic rocks commonly associated with the Kasalka Group and Rocky Ridge volcanic rocks (e.g. Diakow et al., 1997; Bassett and Kleinspehn, 1997).

(?) Upper Cretaceous volcanic rocks (uKv)

Porphyritic, intermediate and felsic volcanic flow and tuffaceous rocks, possibly Late Cretaceous, are more widespread in eastern Knapp Lake map area than elsewhere in the northern Nechako River map area and are broadly cospatial with the Late Cretaceous Cabin Lake pluton and Holy Cross porphyry (e.g. Lane, 1995).

In the northeastern part of the map area, a widely exposed and very distinctive crystal-rich tuffaceous and flow rock unit defines a crude, east-trending belt across the area south of Francois Lake. It is generally dacitic to andesitic in composition and contains phenocrysts of plagioclase (10–35%), common amphibole (5–15%) which is characteristically oxidized and/or chloritized, and minor, local quartz and alkali feldspar in a grey groundmass with a dense appearance. Flow layering (Fig. 3) and common vugs are typical. The unit resembles the distinctive hornblende-bearing dacite distinguished west of Bungalow Lake and correlated as a subunit of the Ootsa Lake Group (Anderson and Snyder, 1998).

Associated with the crystal-rich tuffaceous unit is a columnar-jointed hornblende andesite that occurs commonly north of the tuff unit. Plagioclase phenocrysts, and particularly amphibole phenocrysts, are diagnostic; the amphibole is not everywhere abundant but locally is coarse-grained (up to 1 cm long). The unit strongly resembles a columnar jointed andesite porphyry in eastern Hallett Lake map area which was considered to be a sill unit structurally above deformed, felsic lapilli tuff and breccia (Anderson and Snyder, 1998).

Pale-green to green, andesitic to dacitic, biotite- and/or hornblende-plagioclase porphyry flow and volcaniclastic rocks are common in southeastern Knapp Lake map area. The unit is heterogeneous but is dominated by andesitic porphyry. Amphibole commonly exhibits rusty cores and plagioclase phenocrysts exhibit brown sericitic interiors. The composition, phenocryst mineralogy, texture, and alteration style of the andesitic rocks strongly resembles the Late Cretaceous Holy Cross porphyry (Lane, 1995; Lane and Schroeter, 1997) and the flows may be the volcanic equivalents of that intrusion (*see also* Anderson and Snyder, 1998). The andesitic unit is also difficult to distinguish locally from the mafic rocks which may represent the basal member of the Ootsa Lake Group.

Eocene Ootsa Lake Group (unit Eol)

Ootsa Lake Group (Fig. 2) in Knapp Lake area is more complex stratigraphically than seen elsewhere in the Nechako River map area. It includes important, basal andesitic volcanic rocks; volcanogenic sedimentary rocks; and felsic crystal tuff, pyroclastic rocks, breccia, and flows. Dacitic to rhyolitic subvolcanic intrusions are closely associated with the volcanic rocks. Nonetheless, the Ootsa Lake Group rocks are locally not easily distinguished from the felsic (?)Cretaceous tuffaceous rocks where exposure is poor.

The threefold subdivision of the Ootsa Lake Group is similar to that to the north in the Endako map area (Whalen et al., 1998; Struik and Whalen, 1998) and northeast in the Fort Fraser area (Struik, 1998). The rocks are closely associated with high-level, miarolitic leucogranite and porphyry intrusions (*see* below and Sellwood et al. (1999)).

The basal member is represented by red-brown- to tan-weathering, grey, heterogeneous aphanitic and amygdaloidal basaltic andesite to basaltic flows and breccia. Locally aligned, medium-grained, 'bladed' plagioclase phenocrysts in the mafic flows (Fig. 4) are distinctive, though rare, and decrease in abundance upsection. These flows resemble rocks correlated with the basal Ootsa Lake Group in the Hallett Lake map area (Anderson and Snyder, 1998; Anderson et al., 1998c) and elsewhere (Diakow et al., 1997). Elongate to round amygdules, 0.2–5 cm in size, account for 15–40% of the rock; widespread chlorite, iron oxide, epidote, calcite, and chalcedony, in order of increasing abundance, and uncommon but distinctive rose quartz, amethyst, and zeolite fill vesicles. Amethyst-bearing amygdules occur locally 2.5–3 km east of Trout Lake (Fig. 5). Isolated outcrops of

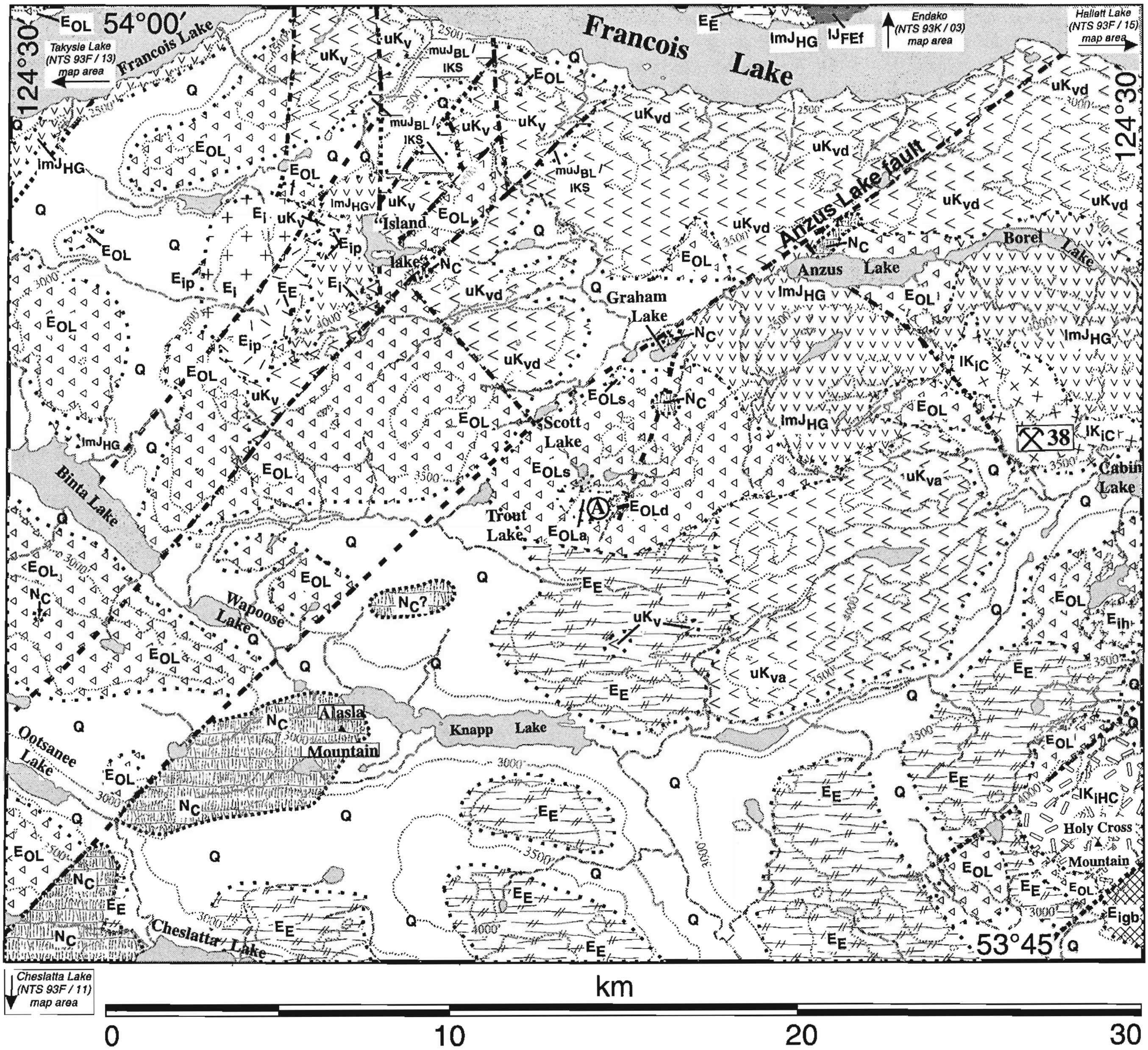


Figure 2. General distribution map of rock units and structures described in text (after Kimura et al., 1980; Williams, 1997; and this study).

aphanitic, amygdaloidal mafic flows included with the Ootsa Lake Group are difficult to distinguish from the (?) Upper Cretaceous volcanic unit or the Eocene Endako Group.

Volcanogenic sedimentary rocks (Fig. 6) also occur at or near the base of the Ootsa Lake Group and are heterogeneous, tan- to grey-brown-weathering volcanic conglomerate, grit, sandstone, and lesser siltstone and mudstone. The finer grained sedimentary rocks comprise tuffaceous, feldspathic sandstone, grit, and siltstone. Subangular to dominantly subrounded feldspar grains, aphanitic volcanic fragments and minor pumice occur in the generally poorly-sorted sandstone (Fig. 6a). The unit is locally moderately to well bedded (Fig. 6b; beds 2–15 cm thick and planar to curviplanar); bedding dips moderately (e.g. 30–45°) eastward. Large wood fragments (up to 10 cm long) and leaf fossils are locally abundant in the sandstone (Fig. 6c).

Felsic volcanic facies of the Ootsa Lake Group (Fig. 7) are heterogeneous and similar to that seen to the east in the Hallett Lake and Big Bend Creek areas to the east and southeast (Anderson and Snyder, 1998; Anderson et al., 1998a, b, c) and the Endako map area to the north (Whalen et al., 1998). They include dacitic to rhyolitic flows (Fig. 7a) with local moderately to steeply dipping flow-layering, crystal and lapilli tuff (Fig. 7b), breccia, and rare, weakly welded pyroclastic

Figure 2 LEGEND

Stratified rocks

Quaternary

Q — Pleistocene glaciofluvial and glaciolacustrine sediments.

Neogene

N_C — **Chilcotin Group?:** dark grey, vesicular basalt flows and volcanic centres; contains clinopyroxene, olivine and plagioclase megacrysts and ultramafic nodules

Eocene

E_E — **Endako Group:** vesicular, plagioclase-phyric basalt to andesite flow and volcaniclastic rocks; associated minor intrusions

E_{OL} — **Ootsa Lake Group:** rhyolitic and dacitic pyroclastic, volcaniclastic rocks;
Eola: amygdaloidal andesitic flow rocks;
Eold: hornblende porphyry intrusion;
Eols: volcanogenic sedimentary rocks

Upper Cretaceous?

uK_V — Porphyritic, intermediate and felsic volcanic flow and tuffaceous rocks; uKvd: dacitic, crystal-rich tuff; uKva: andesitic to dactic hornblende-plagioclase-phyric flows and breccia

Jurassic or Cretaceous

muJBL/ lK_S — **Bowser Lake or Skeena Group:** tan to green pebble conglomerate and hornblende- and plagioclase-bearing sandstone

Lower to Middle Jurassic

lmJ_{HG} — **Hazelton Group:** maroon and green, heterolithic fine- to coarse-grained volcaniclastic and epiclastic volcanic rocks; minor associated porphyry

Intrusive rocks

Eocene(?)

E_i — Miarolitic leucogranite and associated porphyry (Eip)

E_{igb} — Gabbro, diabase

E_{ih} — Hornblende-plagioclase porphyry

Late Cretaceous

lK_{iHC} / lK_{ic} — Holy Cross hornblende-plagioclase porphyry; lKic: **Cabin Lake pluton:** homogeneous, fine- to medium-grained, (hornblende-) biotite quartz monzonite

Late Jurassic

lJ_{FEf} — Francois subphase: fine- to medium-grained, (hornblende-) biotite quartz monzonite

SYMBOLS

- Geological contact (inferred)
- Block fault (approximate, inferred)
- Lakes
- Rivers and creeks
- Contours (contour interval: 500 feet)
- 38 ⚒ MINFILE locality and number
- Ⓐ Amethyst locality (east of Trout Lake)

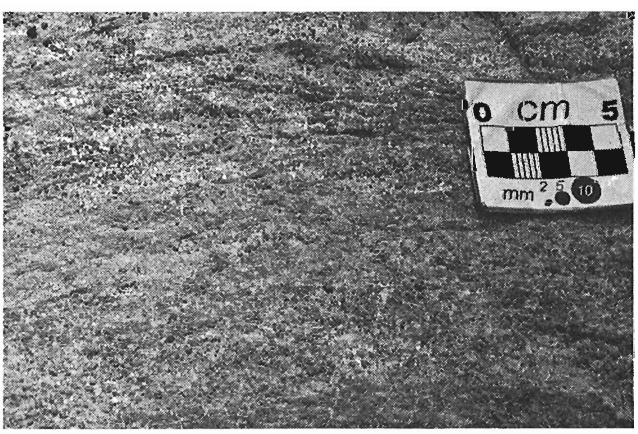


Figure 3. Weakly developed flow-layering in (?)Cretaceous crystal-rich flow rock.

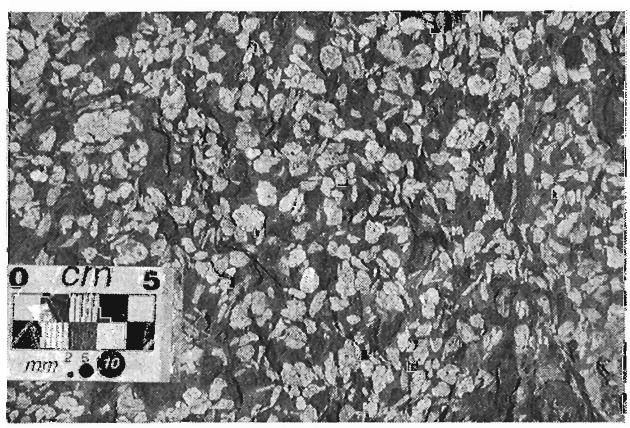


Figure 4. 'Bladed' plagioclase porphyry basalt is a distinctive, although scattered member of the Ootsa Lake Group.

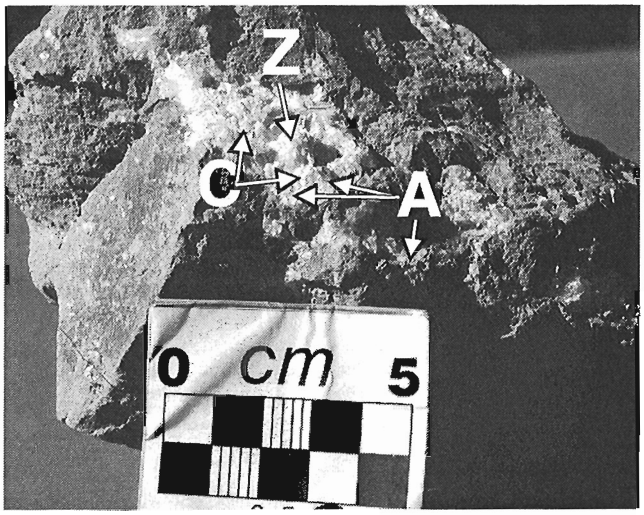


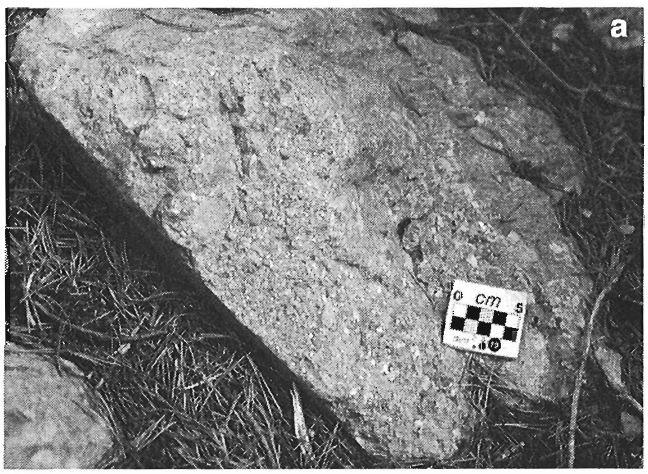
Figure 5. Mineral zonation in amygdule in basal Ootsa Lake Group andesite changes from early amethyst (A), later calcite (C), and late zeolite (Z) minerals (2 km east of Trout Lake).

rocks. Weathering and fresh surface colours are variable and include combinations of white, tan, pink, brown, orange, green, and grey. Most flow rocks are massive, but some are flow-layered and rarely spherulitic and amphibole-lineated. The rocks are commonly porphyritic and contain: 1–8 mm subhedral alkali feldspar (ranging from 1–20% (commonly 5–10%) of rock); euhedral, 0.5–3 mm biotite (1–10%); round, 1–4 mm quartz (<1–8%); acicular, 0.5–3 mm amphibole (1–5% (as much as 10–15%)); and subhedral to anhedral, 0.5–2 mm plagioclase (<1–5%). Locally biotite-alkali feldspar dacite strongly resembles the Hicks Hill and Savoury dacite subunits of the Ootsa Lake Group recognized to the north in the Endako map area (Fig. 7c; Whalen et al., 1998). Chloritization of the mafic minerals and common clay alteration of the felsic groundmass is typical.

Fragmental volcanic rocks include crystal and crystal-lithic lapilli tuff and breccia. Coarser-grained volcaniclastic rocks are matrix to fragment supported and contain subangular to subrounded, aphanitic to flow-banded volcanic rock, pumice, and tuff fragments (<1–60%; 0.1–1 cm).

Eocene Endako Group (unit Ee)

Brown-, grey-, and reddish-brown-weathering, light to dark grey, amygdaloidal basalt to basaltic andesite flow and volcaniclastic rocks of the Endako Group are most easily recognized



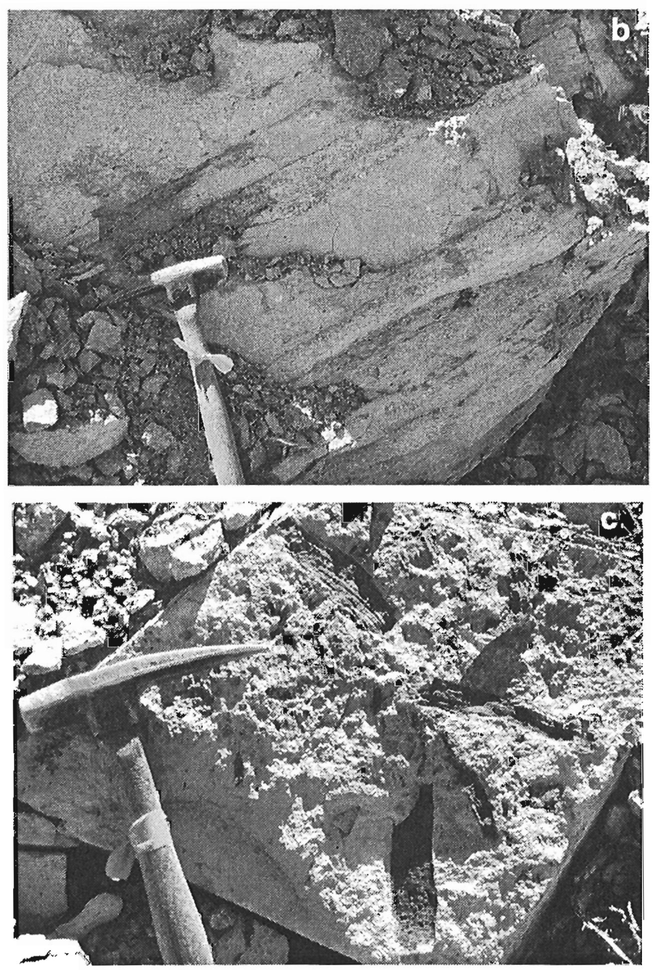


Figure 6.

*Ootsa Lake Group volcanogenic sediments: **a**) tuffaceous volcanic conglomerate; **b**) alternating beds of poorly sorted tuffaceous grit and conglomerate; **c**) tuffaceous grit with carbonized wood fragments. Hammer head is about 17 cm long.*

where they overlie felsic tuffaceous rocks of the Ootsa Lake Group (Fig. 2). Areas investigated include outcrops extending northeast from Binta Lake, and in the southeastern part of the map area, east of Knapp Creek. Aphanitic to commonly porphyritic, massive to flow-layered, fine-grained flows and minor breccia are typical. Flow-layering has various trends and dips 20°. Microphenocrysts include euhedral, locally glomeroporphyritic, 0.5–10 mm plagioclase microlites (5–40%); glassy, euhedral 1–5 mm clinopyroxene (trace to 5%); and rare olivine. Plagioclase and mafic minerals are locally altered to sausserite and to iron and manganese oxides. Amygdules are sparse to moderately abundant, round to elongate and 1 mm to 6 cm in size. Endako Group rocks in the Knapp Lake area resemble those described by Haskin et al. (1998) from Endako Group reference areas in the Hallett Lake, Big Bend, and Fort Fraser map areas.

Neogene (?) Chilcotin Group (unit Nc)

Medium-brown-weathering, black to dark grey, columnar-jointed, clinopyroxene-olivine basalt of the (?) Chilcotin Group occurs east of the Anzus Lake fault (east of Scott, Graham, and Anzus lakes corridor) and south of Knapp Lake at Alasla Mountain (also known as Alaska Mountain (Tipper, 1963)) as a volcanic neck (Fig. 2, 8a). The localities are described in detail by Resnick et al. (1999) and summarized here. The unit commonly contains microphenocrysts, megacrysts, and/or xenocrysts of olivine, plagioclase, and clinopyroxene. Fine- to medium-grained, 1–7 mm olivine phenocrysts account for 5–15% of the rock and are locally glomeroporphyritic; subhedral clinopyroxene is less than 1% to about 5% of the rock and 1–2 mm in size. Plagioclase-phyric varieties feature up to 5% fine- to medium-grained 4 mm plagioclase phenocrysts. Rare amygdules 0.5–1.5 cm across contain chalcedony and zeolite minerals.

Ultramafic nodules (Fig. 8b) are distinctive, round, 3–8 cm in size and comprise dunite to peridotite (lherzolite), locally containing apple green chromium pyroxene and spinel. At one site, near Alasla Mountain, a volcanic neck probably related to the Chilcotin Group mafic flows contains ultramafic nodules which are increasingly abundant with structural height.

Plutonic rocks

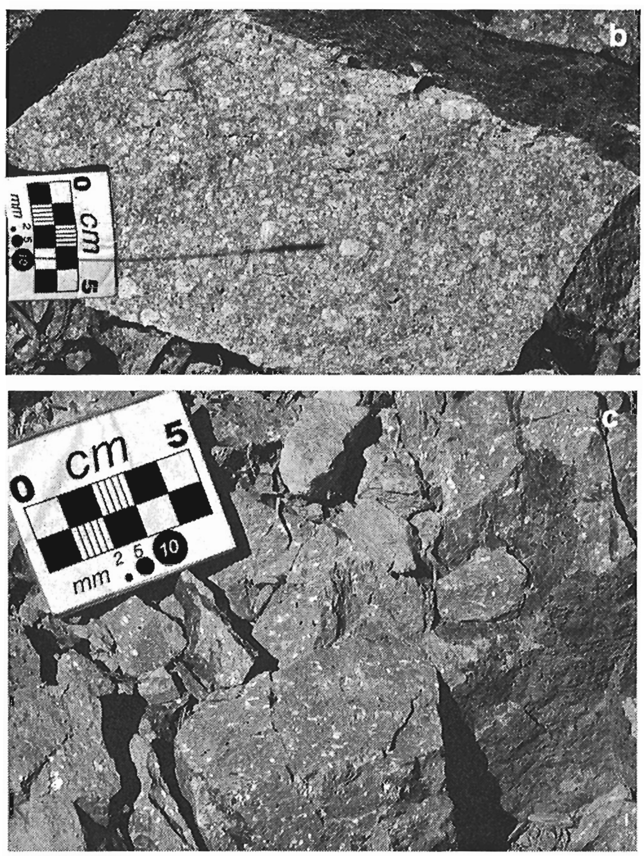
Compared with the Hallett Lake map area to the east, plutonic rocks are subordinate to stratified rocks in the Knapp Lake map area; however, representatives of the (?)Jurassic, Late Cretaceous and (?)Eocene suites recognized farther east are present (Anderson et al., 1997a, 1998d; Anderson and Snyder, 1998).

Late Cretaceous plutonic rocks (units lKi and lKic)

The Cabin Lake pluton (Fig. 2; unit lKic) is most extensive, and best exposed of the felsic intrusive rocks; it extends east into the Hallett Lake map area (Anderson and Snyder, 1998; Anderson et al., 1998a). It comprises pink, homogeneous to

Figure 7.

*Ootsa Lake Group felsic volcanic rocks **a**) rhyolitic porphyry with visible alkali feldspar (white) and quartz (grey) phenocrysts; **b**) dacitic crystal-lapilli tuff; **c**) weakly flow-layered biotite-alkali feldspar dacite resembles the Hicks Hill and Savoury dacite flows recognized to the north (Whalen et al., 1998).*



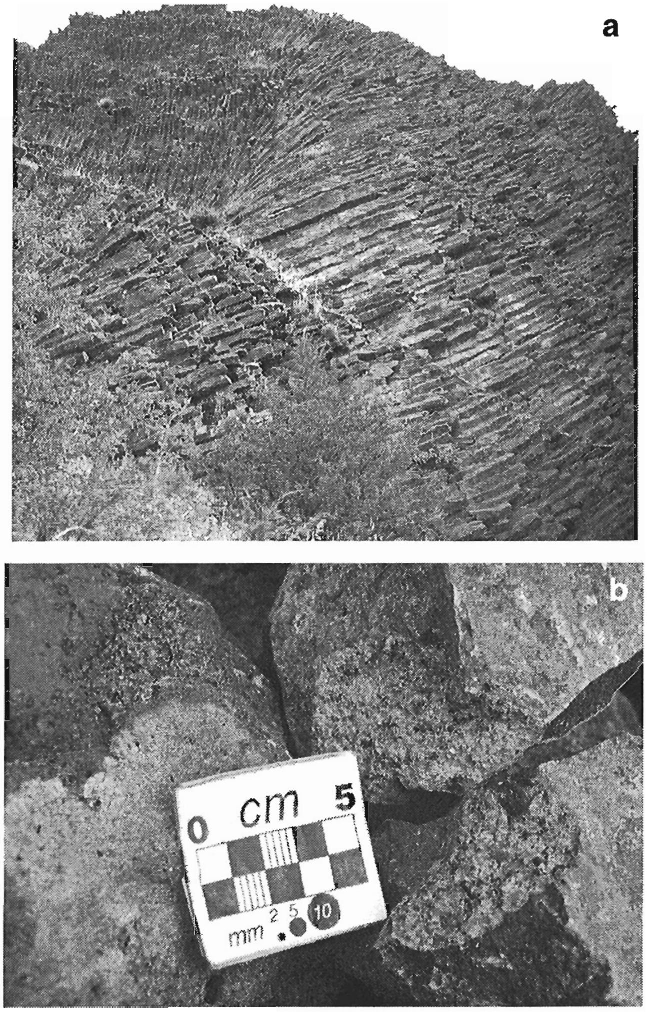


Figure 8. Localities on Alasla Mountain: ***a)*** *radiating columnar jointing in basaltic volcanic neck probably related to Neogene (?) Chilcotin Group flows;* ***b)*** *peridotite ultramafic nodules (above and to right of scale card) are characteristic.*

inclusion-bearing, fine-grained and equigranular (hornblende-)biotite quartz monzonite and quartz monzodiorite (Fig. 9). Inclusions are scattered, aphanitic and dioritic; mineral foliation is steeply dipping and rare. An unpublished K-Ar date of ca. 85 Ma reported by Kimura et al. (1980; *see also* Anderson et al., 1997a) for the pluton suggests that it may be part of the long-lived, mid-Cretaceous to Late Cretaceous (ca. 115–85 Ma) Fraser Lake plutonic suite (Anderson et al., 1997b, 1998d), and that it is coeval with and compositionally similar to mineralized Bulkley Suite intrusions 200 km to the west (e.g. *see* Lepitre et al. (1998) for summary). Scattered pyrite forms an accessory mineral; the CABIN showing (Ag-Pb-Zn-Cu; MINFILE number 93F038) is located within the pluton.

A distinctive dun-brown to grey to greenish-grey, unfoliated, seriate andesitic hornblende-plagioclase porphyry (unit lKi; Fig. 2) was first mapped by Lane (1995) in southwestern Hallett Lake area as an Upper Cretaceous volcanic unit (his unit Kv). New mapping has traced the unit west and south of his map area into the Knapp Lake and Big Bend Creek (Anderson et al., 1998b) areas (unit lKi, Fig. 2). Euhedral plagioclase and less common prismatic hornblende phenocrysts, the greenish-grey aphanitic groundmass, and common ferruginous alteration of the hornblende (and groundmass) are distinctive for the otherwise featureless, homogeneous porphyry (Fig. 10). In the southeastern Hallett Lake area, where contact relationships between the porphyry and siltstone of the Middle and Upper Jurassic Bowser Lake Group are better exposed, a number of features suggest that the porphyry is an intrusive rather than volcanic unit and post-dates the sedimentary rocks (Anderson and Snyder, 1998). A K-Ar date of 70.3 ± 3.0 Ma (R. Friedman *in* Lane and Schroeter, 1997) for the unit is correlative with similar Late Cretaceous intrusions (ca. 60-70 Ma; Diakow et al., 1997; L. Diakow, pers. comm., 1997) in the Chedakuz Creek map area (NTS 93F/07) to the south.

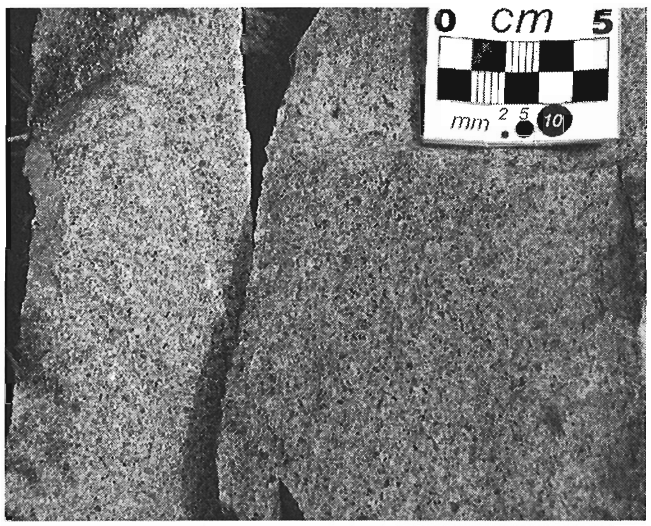


Figure 9. Fine- to medium-grained, unfoliated biotite quartz monzonite of Cabin Lake pluton.

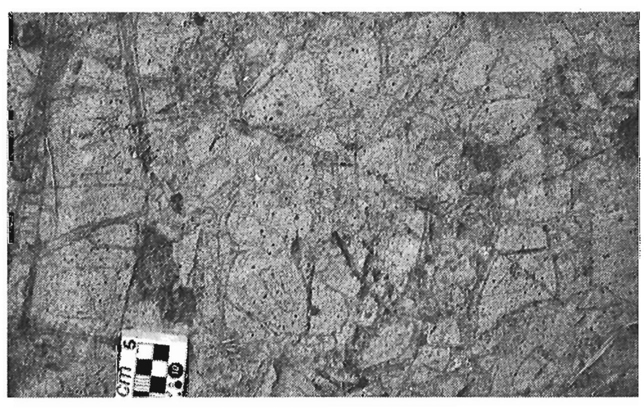


Figure 10. Ferruginous, leisegung banding and brecciation in hornblende-plagioclase Holy Cross Mountain porphyry.

(?)Eocene intrusive rocks (unit Ei)

Leucocratic, felsic (?)Eocene plutons and lesser subvolcanic porphyry intrusions occur in the north-central part of Knapp Lake map area (e.g. Sellwood et al., 1999). High-level phaneritic to hypabyssal monzogranite to rhyolitic intrusions are white weathering, homogeneous, fine grained, seriate to porphyritic, miarolitic, and locally contain amalgamated spherulites which define subvertical layers. Purple fluorite is a rare accessory mineral within the miarolitic cavities.

STRUCTURE

Northeast- and west-trending block faults of probably Eocene and younger age dominate the map-scale structural style (Fig. 2). An exception is a 'keystone' fault structure comprising north-northwest and north-northeast-trending block faults west and east of 'Island' Lake first recognized by Tipper (1963; *see also* Bellefontaine et al. (1995) and Williams (1997)). The faults separate an uplifted wedge-shaped block of Middle and Upper Jurassic Bowser Lake Group and (?)Cretaceous volcanic and related intrusive rocks from Eocene Ootsa Lake and Endako group volcanic rocks which flank them to the west and east. A northeasterly-trending fault extending from eastern Binta Lake to Francois Lake (Binta Lake fault) bounds the eastern side of the fault complex; another, subparallel fault extends northeast from Wapoose Lake to just west of Scott, Graham, and Anzus lakes (Anzus Lake fault).

The more complete stratigraphy of the Eocene Ootsa Lake Group and stratigraphic relationships between that unit and the Lower and Middle Jurassic Hazelton Group suggests less apparent stratigraphic throw across the Knapp Lake area faults than farther east in the Hallett Lake map area, where Middle Jurassic plutonic rocks overlain by a comparatively monotonous series of felsic crystal tuff, pyroclastic rocks, breccia, and flow-layered rhyolite flows are exposed along similar northeasterly-trending fault systems (Anderson et al., 1998a). The eastern fault systems are probably coeval with the Late Eocene Endako volcanic episode, which itself is coeval with final cooling of the Vanderhoof metamorphic complex. Brittle normal faults inferred in the Hallett Lake area are at least as old as and probably coeval and kinematically linked with extensional shear in the lower plate of the Vanderhoof metamorphic complex. Apparently the relative uplift along the northeasterly-oriented fault blocks decreased from east (i.e. Vanderhoof metamorphic complex) to west (Knapp Lake map area).

MINERAL OCCURRENCES

One mineral occurrence is known in the map area, the CABIN Ag-Pb-Zn-Cu showing (MINFILE number 93F038; Bailey et al., 1995), located about 2 km west-northwest from the western end of Cabin Lake (Fig. 2). It occurs within the Late Cretaceous Cabin Lake pluton which may be coeval with the well mineralized Bulkley suite farther west (e.g. Lepitre et al., 1998). The showing was not revisited during our fieldwork.

The abundance of olivine in the Neogene (?) Chilcotin Group and chromian pyroxene and spinel in the enclosed nodules, as well as amethyst amygdules in the basal andesite of the Ootsa Lake Group near Trout Lake, may be of interest to mineral collectors (G. Simandl, pers. comm., 1997).

CONCLUSIONS

Eocene stratified rocks closely resemble those to the north in the Endako map area (Whalen et al., 1998) but are difficult to distinguish locally from the more widespread Upper Cretaceous intermediate and felsic volcanic units. The comparative complexity of the Ootsa Lake Group (e.g. threefold Ootsa Lake Group stratigraphy and unconformable relationships between it and higher level strata than that recognized farther east), is believed to result from the distal position of the area relative to the tectonism involved in the formation of the Eocene Vanderhoof metamorphic complex (Wetherup, 1997) and related, widespread brittle faulting (Anderson et al., 1998a). Neogene (?) Chilcotin Group flows and a possible feeder volcanic neck at Alasla Mountain are distinguished mineralogically and by the presence of ultramafic nodules from the Eocene basaltic rocks.

Recognition of a possible felsic, sparsely mineralized, late Cretaceous pluton near Cabin Lake suggests that it may be a representative of the ca. 85 Ma, prospective Bulkley suite which is well described and well explored to the west.

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Geology of the Euchiniko map area, central British Columbia[1]

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Struik, L.C., Anderson, R.G., and Plouffe, A., 1999: Geology of the Euchiniko map area, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 119–128.*

Abstract: Euchiniko map area is a composite of the Euchiniko River (93 F/8) and Suscha Creek (93 F/1) map areas. The region was last glaciated during the Late Wisconsinan Fraser Glaciation that left important accumulations of glaciofluvial sand and gravel in the major valleys, and till in the higher areas. Rogen moraines might be present in the southern part of the region, which suggest an active ice retreat. Bedrock of the area has suffered at least four tectonic episodes since the Permian, involving the generation of the Triassic–Jurassic Takla and Hazelton Group volcanic arc; Cretaceous plutonism, volcanism, and compression; Eocene volcanism and extension; and Miocene volcanism and faulting or fault remobilization.

Résumé : La région cartographique d'Euchiniko englobe les régions cartographiques de la rivière Euchiniko (93 F/8) et du ruisseau Suscha (93 F/1). Elle a été englacée pour la dernière fois lors de la Glaciation de Fraser du Wisconsinien supérieur qui a laissé de vastes accumulations de sable et gravier fluvioglaciaires dans les principales vallées et de till dans les zones élevées. Des moraines de Rogen seraient présentes dans le sud de la région, ce qui indiquerait un recul actif des glaces. Le substratum rocheux a subi au moins quatre épisodes tectoniques depuis le Permien, dont la formation de l'arc volcanique de Takla et du Groupe de Hazelton du Trias–Jurassique, des manifestations plutoniques, volcaniques et de compression au Crétacé, le volcanisme et la distension à l'Éocène, et le volcanisme et la formation ou la remobilisation de failles au Miocène.

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INTRODUCTION

This work reports on new geological mapping of the Euchiniko River (NTS 93 F/8) and Suscha Creek (NTS 93 F/1) 1:50 000 scale map areas in central British Columbia (Fig. 1, 2). For the purpose of brevity within this report the area covered by the combined sheets will be called the Euchiniko map area. The region is part of the Nechako and Fraser plateaus (Holland, 1976) and is characterized by low relief with great expanses of rolling terrain with an average elevation of approximately 1100 m above sea level. The only prominent topographic feature is the Nechako Range, which flanks the western margin of the area. The region dominantly drains to the east through Euchiniko and Blackwater rivers.

GEOLOGY

The Euchiniko map area is underlain mainly by Pleistocene glacial deposits and Miocene basalts, and windows through these reveal Eocene and Mesozoic volcanic and volcaniclastic rocks and minor limestone (Fig. 2). The landforms appear to have formed during Tertiary uplift and erosion, and by the erosive and depositional action of Pleistocene Cordilleran ice sheets. To some extent the effusive outpouring of Eocene Endako Group and Miocene andesite and basalt has imparted some 'smoothing' of the topography. The Eocene rocks consist mainly of Ootsa Lake Group rhyolite and rhyodacite flows and fragmental deposits, and biotite-hornblende granodiorite, diorite, syenite, and granite. The Mesozoic sequence consists of Hazelton Group Jurassic mafic volcanic and volcaniclastic sedimentary rocks and minor diorite, and felsic volcanic rocks. Triassic limestone outcrops in one spot in southeastern Euchiniko map area.

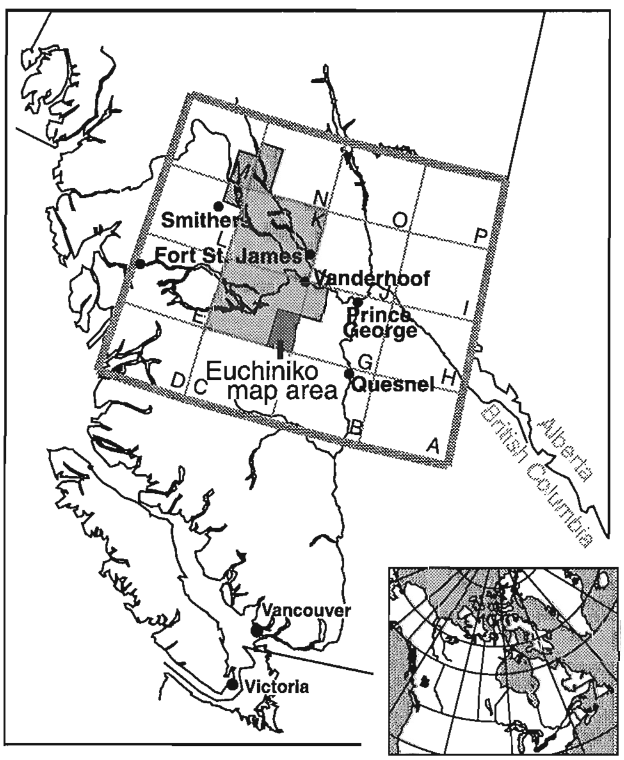

Figure 1. Location of the Euchiniko map area in central British Columbia.

Quaternary

The Euchiniko map area was last glaciated during the Late Wisconsinan Fraser Glaciation which has left great accumulations of glaciofluvial sand and gravel in the major valleys and till in the higher areas, important fields of glacial flutes, drumlins and crag and tails, and some ridges transverse to ice flow (Rogen moraines (?)) south of the Blackwater River. Macrolandforms (glacial flutes, drumlins, and crag and tails) and microlandforms (mini crag and tails, and striations) indicate that during the Fraser Glaciation, glaciers were predominantly flowing to the northeast and east-northeast. Easterly

Figure 2 LEGEND

Miocene	
Mv	basalt
Eocene	
EE	Endako Group: andesitic basalt
EOL	Ootsa Lake Group: rhyolite, dacite
Eg	syenite, granodiorite
Cretaceous	
Kv	andesitic greywacke, siltstone, slate
Kd	hornblende biotite diorite, granodiorite, syenite
Middle Jurassic	
Hazelton Group	
lmJH	undifferentiated mJHs to lmJHE
mJHf	rhyolite flows and tuff, greywacke
mJHs	greywacke, siltstone, arkose, rhyolite, chert conglomerate
mJHNc	Nagliko Formation: agglomeratic andesite, conglomerate
mJHN	Nagliko Formation: feldspar augite andesite flows and agglomerate
Lower and Middle Jurassic	
lmJHa	andesite agglomerate, greywacke
lmJHE	Entiako Formation: andesitic greywacke, conglomerate
Upper Triassic	
TRl	limestone
● 98-046	Location of section shown in Figure 3

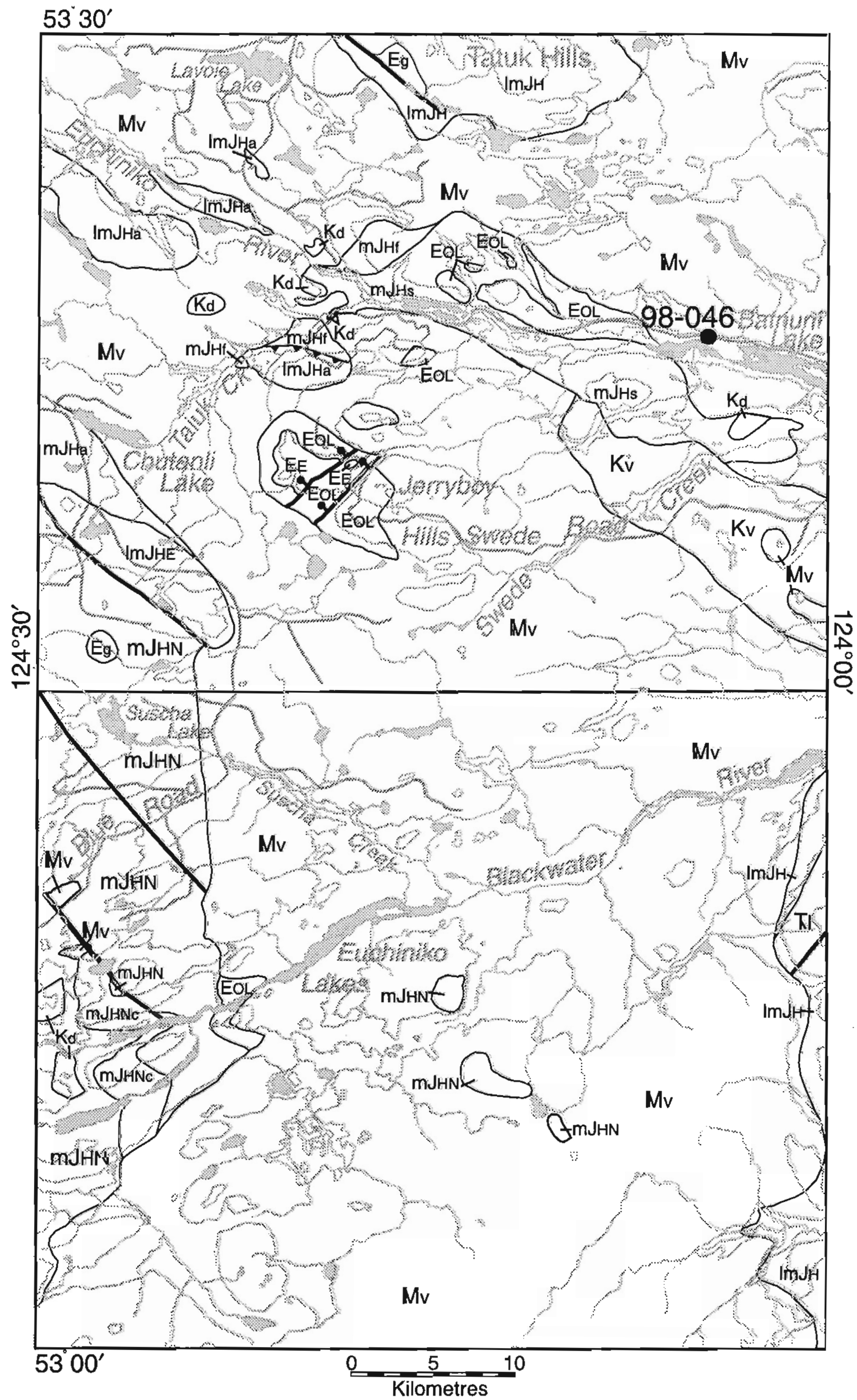

Figure 2. Generalized bedrock geology of the Euchiniko map area.

flowing ice derived from the Coast Mountains coalesced with glaciers derived from the Cariboo Mountains that resulted in general northeasterly ice-flow directions (Tipper, 1963).

Quaternary sediment exposures northwest of Batnuni Lake in the Euchiniko River valley suggest that a glacial lake might have formed in that valley during the advance phase of the last glaciation (Fig. 3). The regional significance of this glacial lake is still unclear because of poor and limited sediment exposure, but a glacial lake might have formed following the damming of Euchiniko River valley by advancing ice derived from the Cariboo Mountains. Ice retreat was generally from east to west, and as most of the region drains to the east, the drainage was opened at the ice front and no regional glacial lake formed during the retreat of glaciers. Some of the valleys, such as Suscha Creek valley, were in major part incised by glacial meltwater during the retreat phase of glaciers. Postglacial rock slides, some of which are still slightly active, have been noted in the Suscha Creek valley, and are thought to result from the readjustment of the steep valley walls abundantly eroded by glacial meltwater of the last glaciation. A series of ridges oriented transverse to the regional ice flow, and located east of Kluskus lakes and south of the Blackwater River, could be Rogen moraines (*see* Bouchard, 1989). If that is the case, these landforms might indicate that ice was at least partly actively retreating, as opposed to having solely disappeared by downwasting.

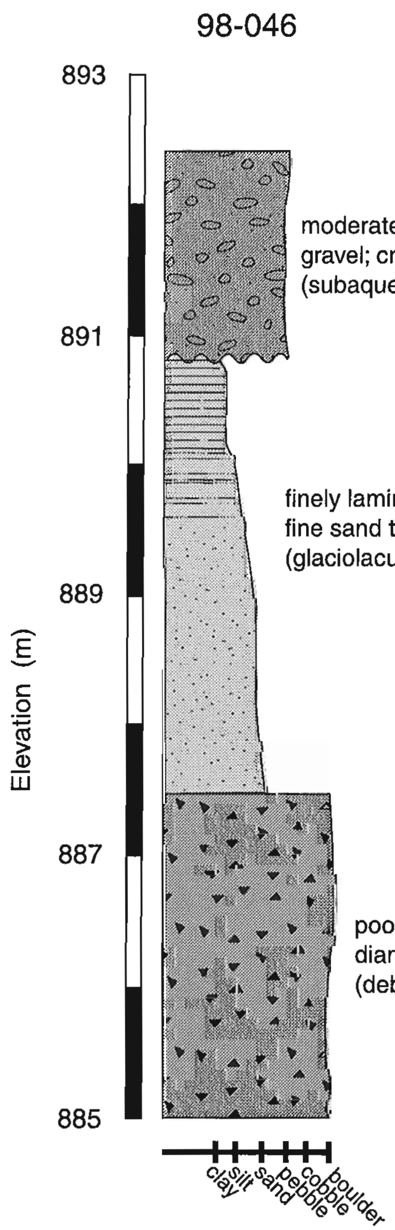

Figure 3. *Glaciolacustrine sediments overlain by Fraser Glaciation succession in the Euchiniko River valley, northwest of Batnuni Lake.* See *Figure 2 for section location.*

Miocene

Basalt interpreted to be mainly mid- to late Miocene underlies isolated centres in various parts of the Euchiniko map area. The basalt is mostly flat lying and consists of poorly exposed flows and eruptive centres. Generally, the rock has an aphanitic, dark matrix, locally with microcrystalline plagioclase, and contains microphenocrysts of olivine, pyroxene, and plagioclase. There appear to be three varieties: 1) dark, massive, and slightly to moderately vesicular, finely crystalline to aphanitic, 2) thinly laminated, moderately dark to grey vesicular, and 3) containing xenocrysts of olivine, pyroxene, and plagioclase minerals and ultramafic and intermediate composition crustal rocks. The xenocrystic variety is exposed to the west of the Tatuk Hills, around Hay Lake, northwest of the Euchiniko Lakes, where it also contains crustal fragments, and south of Batnuni Lake (Fig. 4). In the Jerryboy Hills the basalt is commonly a breccia with mainly pebble to cobble size clasts in a rusty weathering recessive matrix.

Peculiar to the Euchiniko map area are some widespread exposures of basalt that have a medium grey colour on fresh surfaces. In places this feature and associated vesicular texture are more characteristic of the Endako Group andesite.

Figure 4. *Xenocrysts of pyroxene and olivine in Miocene basalt.*

These basalt flows contain olivine phenocrysts, and in other parts of the Nechako NATMAP Project area the presence of olivine has been used to assign Tertiary basalts to the Miocene. The contradiction is not resolved in this preliminary report and the resolution will await results of geochemical analysis and isotopic dating. Here, all of the regionally distributed, flat-lying basalt is included in the Miocene. Some basalt eruptive centres and associated flows are confidently assigned to the Miocene and these will be described separately.

Columnar jointing, typical of the Miocene basalt elsewhere in the Nechako River map area (Fig. 1), is rare or poorly expressed in the Euchiniko map area. Flows are poorly exposed and therefore their thicknesses are undetermined. In other places to the north and northwest the Miocene basalts are generally from 5 to 20 m thick.

Miocene basalt (Mv)

A volcanic neck and associated lava flow(s)? are exposed approximately 1.5 km east of Lavoie Lake and this is one of the many extrusive centres recognized by Resnick et al. (1999). Its description is summarized from Resnick et al. (1999).

The volcanic neck is subcircular (350 m x 325 m), massive, and only rarely displays poorly formed, localized joints. Lava flows derived from the eruption are poorly exposed in roadcuts, distant from, and topographically below, the neck.

The basalt flow rocks include massive and vesicular varieties; both are dark grey to black and weather to a buff rusty-brown. The massive basalt occurs.5 km to the northeast of the neck, is dense, and contains up to 5% mantle and crustal xenoliths, and xenocrysts. Sampled mantle xenoliths comprise medium- to coarse-grained chromium-diopside-bearing lherzolite (24 samples), olivine megacrysts (1 sample), and pyroxenite (1 sample). Basalt 1 km to the south has 15–20% small vesicles (1–5 mm diameter).

South of Swede Creek, black basalt is typically fine grained, dense, massive and vitreous to vesicular, and sparingly olivine-phyric. Olivine makes up 1-2% of the massive varieties. Vesicles account for up to 25% of the rock, are irregular or flattened, and 4–10 mm in size. Steeply west-southwest-dipping fracture cleavage is also prominent.

A Miocene basalt eruptive centre occurs along the western margin of the Suscha Creek map area adjacent to, and southwest of, the Blue Road. The centre is northwest trending and is bounded on its southwestern end by a brittle fault zone traceable into Jurassic Naglico Formation country rocks, and is just northwest of the extrapolation of the northeast-striking Blackwater Fault (Diakow and Levson, 1997) into the map area.

The olivine basalt is light grey, fine grained, sparingly vesicular, and is dun brown on weathered surfaces. Phenocrysts (2%) are subhedral olivine (% and 4 mm), and comprise some or all of the following: pyroxene, plagioclase, magnetite and rare biotite(?), as accessory minerals. Xenoliths are distinctive (0.5–2 cm) and constitute up to 2% lherzolite mantle nodules and scarce granulite and plutonic crustal xenoliths.

The centre resembles the Cutoff Creek intrusive centre (NTS 93 F/10) in that both contain pyroxene and magnetite phenocrysts, but the eruptive centre has more abundant and diverse xenoliths. The more leucocratic and granular and less vitreous groundmass distinguishes this centre from others to the north (*see* Resnick et al., 1999).

Miocene or Eocene mafic rocks (Mv)

Northeast of Suscha Creek, continuous and discontinuous outcrop and subcrop of dun-weathering vesicular to amygdaloidal basaltic andesite and andesite are common. Typical of the rocks are the light-dun-brown-weathering, light to dark grey, massive to flow-layered, aphanitic to porphyritic flows and hyaloclastite. Flows are 30 cm to1 m thick (Fig. 5) and are rarely and crudely columnar jointed. Flow layering is on a millimetre to centimetre scale and rare; where it is locally steeply dipping and highly irregular (Fig. 6), a volcanic centre may be indicated. The sparkling groundmass is derived from subhedral to euhedral microphenocrysts of plagioclase (10–20% of the rock), clinopyroxene (10–15%) and

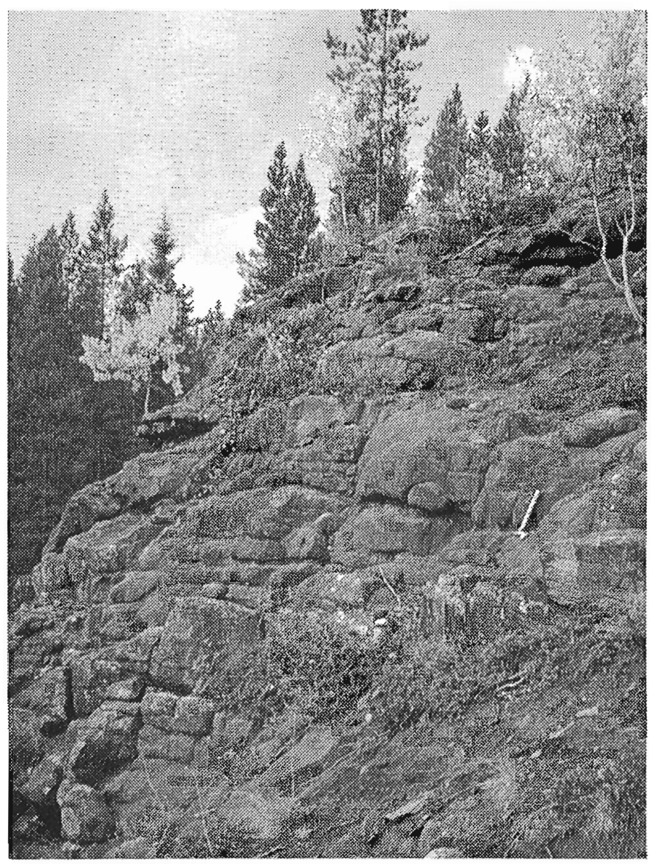

Figure 5. *Thin basaltic andesite flows at Suscha Falls.*

magnetite (less than 5%); and in places from frothy devitrified glass. Round to flattened, millimetre- to centimetre-scale vesicles constitute up to 25% of the rock.

Phenocryst mineralogy appears to vary with stratigraphic height in the subhorizontal sequence from Suscha Creek to the northeast. At the lowest stratigraphic levels, along Suscha Creek, olivine (2–5%) is significant, although subordinate to plagioclase (up to 20%) and clinopyroxene (10%) phenocrysts. To the northeast, and presumably upsection, sparse phenocrysts include plagioclase and lesser clinopyroxene. Locally, at higher structural levels, andesite to dacite contains rare biotite.

Basalt to andesite along Swede Forest Service Road (south of Jerryboy Hills) comprises tan- to reddish-tan-weathering, grey scoriaceous to massive, aphyric to olivine-phyric flows (Fig. 7). Flows are up to 5 m thick, and characterized by a massive medial portion and highly vesicular flow tops. Vesicles make up 25% of the rock and are elongate to locally flattened and aligned. Plagioclase (up to 30% of the rock and 2 mm in size) and localized olivine (1–3% of the rock and 2–4 mm in size) are the principal phenocrysts.

The scoriaceous nature, widespread olivine phenocrysts at lower stratigraphic levels, more leucocratic character and felsic composition, and rare biotite phenocrysts at higher stratigraphic levels distinguish these lava flows from Eocene Endako Group to the north closer to the reference area (e.g. Anderson et al., 1998; Haskin et al., 1998).

Figure 6. Thin, irregular flow layering at possible centre for basalt to andesite flows.

Eocene

Several units are interpreted to be Eocene based on their lithological correlation with units to the north and northeast in the Nechako River map area (NTS 93 F). These units include rocks of the Endako Group, Ootsa Lake Group, and various plutons.

Endako Group (EE)

Basalt of the Endako Group (Haskin et al., 1998) is interpreted to be present in one location in western Jerryboy Hills. Northwest of Euchiniko map area, the Endako Group has been dated as middle Eocene (51–45 Ma, Mike Villeneuve, pers. comm., 1998; Haskin et al., 1998). In Jerryboy Hills, basalt directly overlying rhyodacite of the Ootsa Lake Group is highly vesicular to massive and brecciated, rusty and olive weathering, and grey to dark blue-grey on fresh surfaces. The matrix is mostly microcrystalline plagioclase, and in places is aphanitic or devitrified glass. Phenocrysts include minor clinopyroxene and plagioclase. The vesicles are commonly lined with a light blue coating and in places contain coatings or are filled with zeolite.

Ootsa Lake Group (EOL)

The rhyolite, rhyodacite, and dacite are very similar to rocks of the Ootsa Lake Group (Anderson et al., 1998; Whalen et al., 1998) and the plutonic rocks resemble the Frank Lake Pluton (Wetherup, 1997).

The rhyolite has biotite, hornblende, plagioclase, and quartz microphenocrysts in a light grey to grey aphanitic, generally glassy, matrix. The biotite, hornblende, and plagioclase are generally euhedral. Textures include flow banding, breccia, and some mineral alignment. The dacite resembles

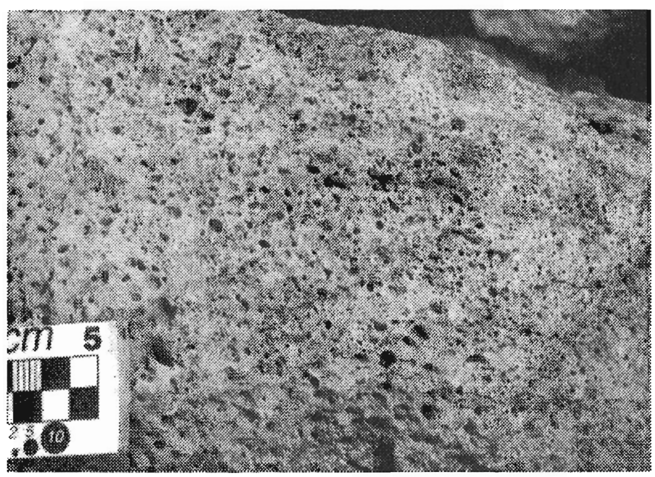

Figure 7. Vesicular, basaltic, andesite flow top in Endako Group-like rocks along Swede Road in Euchiniko River area (93 F/08).

the Hicks Hill dacite (Whalen et al., 1998) with its biotite, hornblende, and plagioclase phenocrysts (2–4 mm). The acicular hornblende crystal patterns form convoluted surfaces. Jurassic rhyolite and rhyolite breccia interlayered with Hazelton andesite tuffs and sedimentary rocks are not easily resolved from Eocene rhyolite when found in isolated outcrops.

Biotite diorite, granodiorite, and granite near Chutanli Lake is medium crystalline, equigranular, and resembles the Eocene Frank Lake Pluton of the Nulki Hills to the north. The Frank Lake Pluton has been dated by U-Pb systematics as 55 ± 0.5 Ma (M. Villeneuve, pers. comm., 1997). Medium-grained biotite syenite in western Tatuk Hills is interpreted to be Eocene by correlation with Eocene plutons to the southwest.

Cretaceous

Cretaceous rocks of Euchiniko map area consist of a sedimentary-volcanic unit and dioritic to granodioritic plutons. The ages of these units are interpreted from previous work by Tipper (1963) and by correlation with work by Diakow et al. (1997) to the west.

Sediment-volcanic unit (Kv)

Tipper (1963) assigned greywacke and various volcanic rocks exposed in northeastern Euchiniko map area to the Upper Cretaceous and Paleocene. Greywacke of this unit consists of fine- to medium-grained, homogeneous feldspathic sands in 3 to 6 cm beds. The beds are internally laminated in various colour shades, although the grain size appears to vary little. Where it does vary it shows grading and flame structures. In places the greywacke has ripple marks 3 cm in wavelength and 3–5 mm in amplitude (Fig. 8).

The volcanic rocks are mostly intermediate to mafic and have fragmental textures. Fragments (0.5–50 mm) consist of crystals of plagioclase, pyroxene, and various forms of rhyolite, dacite and andesite (some as shards). The andesite is recessive as the feldspathic matrix is mostly rotten.

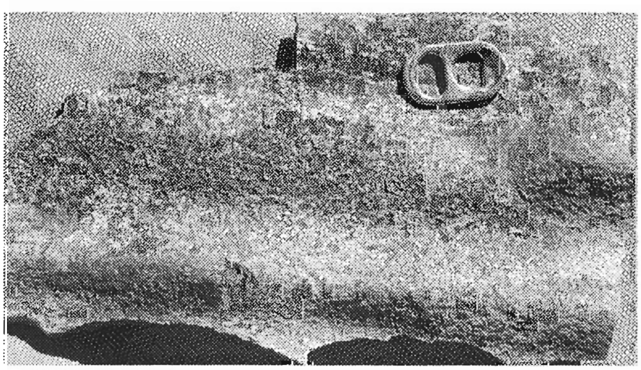

***Figure 8.** Ripple marks in Cretaceous greywacke.*

Plutons (Kd)

Diorite, granodiorite, and monzonite plutons and dykes scattered throughout the map area are interpreted to be Cretaceous, as they intrude Middle Jurassic Hazelton Group rocks and are similar to plutons described by Diakow et al. (1997) immediately to the west. Generally these rocks are hornblende bearing and minor biotite bearing, medium grained, equigranular, and have moderate to low magnetic susceptibilities. They are fresh to partially altered, unfoliated, and are locally intruded by basalt dykes.

Jurassic

Jurassic rocks of the Euchiniko map area consist of sedimentary and volcanic rocks of the Hazelton Group (Tipper, 1963). Adjacent to, and west of, the Euchiniko map area, Diakow et al. (1997) divided the Hazelton Group into the Entiako and Naglico formations, and we use those divisions here. In addition, Middle Jurassic and possibly younger sedimentary rocks are differentiated, as is a rhyolite unit and andesitic rocks distinct from the Naglico Formation of southwestern Euchiniko map area. The Naglico Formation is itself divided into two units to emphasize the distribution of conglomerates and the local structure.

Sedimentary unit (mJHs)

Chert-pebble conglomerate, chert sandstone, greywacke, and mudstone appear to be the youngest unit of the Jurassic sedimentary sequence. They may be in part younger than the Hazelton Group; perhaps part of the Bowser Lake Group.

Chert-pebble conglomerate, sandstone, greywacke, and mudstone beds are generally thin save for the conglomerates, which can be up to 2 m thick. At one locality, discontinuous biotite-quartz-porphyry rhyolite is interlayered with the mudstone, possibly as sills. Chert clasts consist of cherty tuff, jasper, and radiolarian chert in various shades of grey and light olive green. Locally, coal fragments are intermixed with the rounded to subrounded chert clasts. Those rocks are underlain by greywacke consisting of plagioclase sands with minor to less than 8% augite. It is thinly bedded with slates, and locally with arkosic sandstone and rhyolite tuff. The interlayered slates locally contain bivalve and ammonite fossils. Tipper (1963) reported a Bajocian age for these fossils.

Rhyolite unit (mJHf)

Rhyolite overlying the sedimentary unit is interpreted to be Jurassic rather than Tertiary as mapped by Tipper (1963). Rhyolite tuff and arkose beds within the sedimentary unit are interpreted to be the precursors to the rhyolite unit. The rhyolite consists of biotite-hornblende-plagioclase-phenocrystic, flow-banded flows north of the Euchiniko River, and fine-to medium-grained tuffs on Taiuk Creek.

Naglico Formation (mJHN-mJHNc)

The Naglico Formation is here differentiated into an andesite flow and tuff unit and an andesitic agglomerate and conglomerate unit that occurs within the flow and tuff unit.

Naglico Formation andesite (mJHN)

The Naglico Formation andesite tuff unit is very heterogeneous and is generally massive and maroon to greenish-grey weathering. Andesite crystal tuff and agglomerate form thick-bedded, massive units of interlayered augite-rich and plagioclase-rich beds. Bedding transitions are generally obscure gradations or channeling. Augite (2–8 mm, 3–15%) and plagioclase (1–6 mm, 5–30%) are mostly euhedral and floating in a fine-grained matrix of plagioclase and oxides (Fig. 9). In some places the plagioclase has been replaced with siderite, and/or epidote.

Three main varieties of the andesite are described here: an extensive and heterolithic clinopyroxene-phyric volcaniclastic facies, a minor but distinctive amygdaloidal andesite, and a rare epiclastic facies.

***Figure 9.** Crystal tuff texture in Hazelton Group Naglico Formation.*

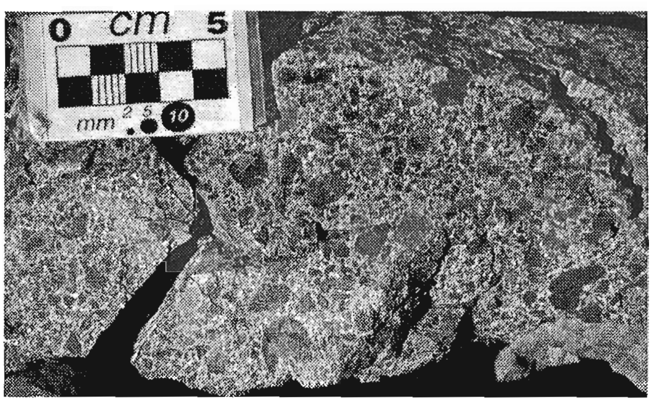

***Figure 10.** Hyaloclastite breccia in Naglico Formation along the Blue Road.*

Green-, purple- or dun-brown-weathering, clinopyroxene-bearing, laharic volcaniclastic rocks include coarse-grained, heterolithic, poorly sorted, volcanic breccia, conglomerate, and hyaloclastite (Fig. 10). Matrix-supported, lapilli- to boulder-sized (0.5 cm to 3 m) poorly sorted, angular to round, aphanitic to porphyritic fragments make up 10–40 percent of the rock (Fig. 11). Most to least common, they include basalt, andesite, and dacite compositions and occur in a poorly sorted clinopyroxene-bearing grit. Quartz monzodiorite plutonic fragments are rare and restricted to the coarsest grained deposits. The principal phenocryst phases, plagioclase, and less common clinopyroxene, make up typically 2–20 (and as much as 40) per cent of an andesitic tuff matrix; hornblende phenocrysts are rare.

Mottled grey and white, characteristically amygdaloidal, clinopyroxene-phyric andesitic lithic-crystal tuff occurs in a few places south of Suscha Lake (Fig. 12). Chloritized clinopyroxene phenocrysts are 2–4 mm in size and account for 1–3% of the rock. Irregular quartz- and/or calcite-filled

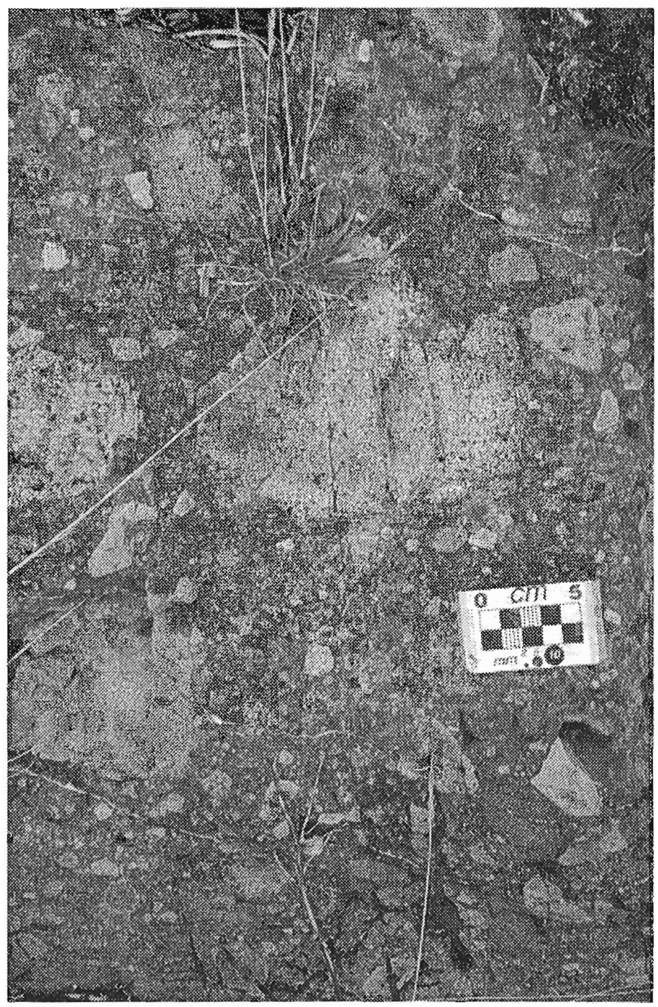

***Figure 11.** Laharic pebble to boulder volcanic breccia of Naglico Formation south of Blue Road. Small plutonic fragment to left of scale card.*

vesicles make up 10–25% of the rock. The rock is crumbly because of common irregular fractures and the groundmass is commonly rusty and/or altered to chlorite.

Thin-bedded, alternating brown- and white-weathering tuffaceous grit is rare and likely intercalated with chloritized clinopyroxene-bearing andesitic tuff. The volcanogenic sedimentary rocks comprise alternating 0.5–1 cm thick beds of immature, medium-grained, rusty brown, mafic and white feldspathic grit layers.

Naglico Formation agglomerate and conglomerate (mJHNc)

Agglomerate and conglomerate andesite has a matrix of augite and plagioclase sand, and the clasts consists of very fine-grained andesite tuff, plagioclase crystal tuff, and, locally, limestone or limy tuff. The clasts are mainly subrounded to subangular. The conglomerate unit lies within the crystal tuff unit and good examples can be found north of the Blackwater River in the western most part of the Suscha Creek map area (NTS 93 F/1).

Triassic

An area of rocks in southeastern Euchiniko map area was not visited during this remapping and the unit distributions as mapped by Tipper (1963) are included for completeness. This area includes volcanic rocks formerly mapped as Triassic Takla Group, and limestone formerly mapped as Cache Creek Group (Fig. 2). The Takla Group volcanic rocks have been reinterpreted as Hazelton Group following suggestions by H. Tipper (pers. comm., 1998), and the limestone has been left as an undifferentiated Triassic unit.

Figure 12. *Amygdaloidal clinopyroxene porphyry andesite of Naglico Formation on Blue Road.*

STRUCTURE

Fabrics

Most of the units in the Euchiniko map area show some degree of fracture or slatey cleavage although the Miocene basalt is generally massive or shows some exfoliation texture and extensive jointing related to cooling of the flows. Very little of the rock has a penetrative foliation, ductile shear, or flattening.

Faults

The most prominent faults in the map area dip steeply and strike northwest and northeast. Regional lineaments most commonly follow these directions. A single thrust fault was interpreted on Taiuk Creek.

Northwesterly striking faults west of Suscha Creek are characterized by distributed gouge zones locally hosting epidote and quartz veins. These faults are vertical to steeply dipping and their sense of motion was undetected. An example of these faults occurs along the southwestern end of Blue Road. There the fault zone has brittle fracture, closely spaced jointing, gouge zones, and irregular quartz and calcite veins and veinlets (Fig. 13). Gouge zones (60 cm wide) and closely spaced joints (5 cm spacing) are dominantly northwest trending and subvertical, or dip steeply southwest. Veins and veinlets are commonly irregular, but where planar trend north-northwest and are subvertical. The locality where the brittle deformation is most intense likely marks a brittle fault zone that extends to the northwest and bounds the southwestern end of the Miocene basaltic intrusive centre. The southeastern extent of the fault may be marked by its intersection with the northeast-striking Blackwater Fault recognized to the west by Diakow and Levson (1997). Pluton contacts in the Tatuk Hills and northwest of the Euchiniko Lakes follow these northwesterly trends.

Northeasterly striking faults were mapped in the Jerryboy Hills where the contact of the Ootsa Lake and Endako Group volcanic rocks is repeatedly down-dropped to the northwest.

Figure 13. *Veins (to left of figure) and gouge zones (to right) along brittle fault zone at southwestern end of Blue Road in the Suscha Creek map area (figure is 1.8 m tall).*

A northerly directed thrust fault is interpreted at Taiuk Creek, and places Hazelton Group andesite agglomerate and tuff onto the Hazelton Group rhyolite tuff and the Bajocian sedimentary sequence. The hanging-wall andesite tuff unit is broken by numerous gouge zones 3 to 10 cm thick that trend east-west and indicate top-to-the-north displacement.

Folds

Folds are most commonly displayed in the Hazelton Group rocks and are generally open and concentric. They are associated with an axial-planar cleavage that is slatey, or in most cases is a set of closely spaced fractures. Commonly the units show regional dips with no apparent association with fold hinges. Regional dips of Tertiary rocks appear to be the consequence of tilting in extensional fault panels.

DISCUSSION

The oldest event in the Euchiniko map area appears to be the deposition of Triassic limestone, thought to be part of Stikine Terrane. Subsequently, Jurassic rocks of the Hazelton Group define an island-arc assemblage recognized elsewhere in the western Cordillera (Gabrielse and Yorath, 1991). The thrust fault imbricating the Hazelton Group at Taiuk Creek, the Cretaceous plutonism and sedimentation are here amalgamated to represent a Cretaceous tectonic episode. From the information at hand, each of these structures and rocks may represent distinct structural and depositional events. The Tertiary represents a time of renewed volcanism and deformation. The Eocene Ootsa Lake and possibly Endako groups in the area, and the northwest- and northeast-striking faults are considered to represent a northwesterly directed extensional event (Wetherup and Struik, 1996; Wetherup, 1997). The Miocene basaltic eruptions are thought to have occurred during crustal stretching, although it is not clear in what form that tectonism took place. Anderson et al. (unpub. rept.) and Struik (1994) have indicated the association of Miocene basaltic eruptive centres with pre-existing northwest-striking faults. These may represent the reactivation of those faults during the Miocene.

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Geological Survey of Canada Project 950036

Bedrock geology of the Uncha Mountain area, northwestern Nechako River map area, central British Columbia[1]

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Abstract: Mesozoic and Tertiary strata and various high-level, Tertiary, aphanitic, porphyry and plutonic intrusions are recognized between Uncha Lake and Uncha Mountain (NTS 93 F/13 NW). Poorly sorted, poorly to moderately bedded epiclastic conglomerate, greywacke, and pebbly mudstone, and rare, chloritized, andesite flow rocks characterize the Lower to Middle Jurassic Hazelton Group. Fine-grained to aphanitic, leucocratic felsic porphyry, rhyolite, rhyodacite, and dacite, with associated autoclastic breccia and tuff, and rare andesite flows, constitute the Ootsa Lake Group. Tertiary intrusions include rhyolitic, dacitic, andesitic, basaltic, syenitic, and granitic compositions.

Faults define north-northeast-trending panels encompassing the stratified units and have imparted a penetrative and widespread fracture cleavage on all but the youngest units. This study emphasizes the importance of Tertiary faulting and associated small-scale deformation to the juxtaposition of Hazelton and Ootsa Lake groups rocks and to the localization of synkinematic, high-level aphanitic, porphyry, and miarolitic granite intrusions and hydrothermal alteration.

Résume : Des strates mésozoïques et tertiaires et diverses intrusions aphanitiques, porphyriques et plutoniques tertiaires de niveau crustal supérieur ont été reconnues entre le lac Uncha et le mont Uncha (SNRC 93 F/13 NW). Des conglomérats, grauwackes et mudstones à cailloux épiclastiques, mal classés et faiblement à modérément lités et de rares coulées d'andésite chloritisées caractérisent le Groupe de Hazelton du Jurassique inférieur à moyen. Le Groupe d'Ootsa Lake est constitué de dacite, de rhyodacite, de rhyolite et de porphyre felsiques leucocrates, à grain fin à aphanitique, de tufs et brèches autoclastiques associés, et de rares coulées d'andésite. Les intrusions du Tertiaire se composent de rhyolite, de dacite, d'andésite, de basalte, de syénite et de granite.

Des failles définissent des panneaux de direction nord-nord-est renfermant les unités stratifiées et donnent à toutes les unités, sauf les plus jeunes, une schistosité de fracture pénétrative et très répandue. La présente étude met en évidence l'importance de la fracturation au Tertiaire et de la déformation à petite échelle qui lui est associée sur la juxtaposition des roches des groupes de Hazelton et d'Ootsa Lake ainsi que sur la localisation des intrusions de granite miarolitique et de porphyre aphanitique de niveau crustal supérieur et de l'altération hydrothermale.

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INTRODUCTION

Regional-scale bedrock mapping and detailed topical studies continued in the northern half of the Nechako River map area in 1998 as part of the ongoing revision of the Nechako River 1:250 000 scale geological map (Tipper, 1963) under the Nechako NATMAP Project.

This detailed, baccalaureate study (Fig. 1) was initiated to examine the nature, correlation, and structural style of Mesozoic and Tertiary strata in an approximately 49 km^2 area between Uncha Lake and Uncha Mountain. At least three units were identified in earlier reconnaissance mapping (Tipper, 1963) and shown to be distributed in three north-northeasterly trending fault panels (from east to west): Upper Triassic and Lower Jurassic Takla Group; Middle and Lower(?) Jurassic Hazelton Group; and Paleocene(?), Eocene, and Oligocene Ootsa Lake Group. The age and nature of the bounding faults were poorly understood.

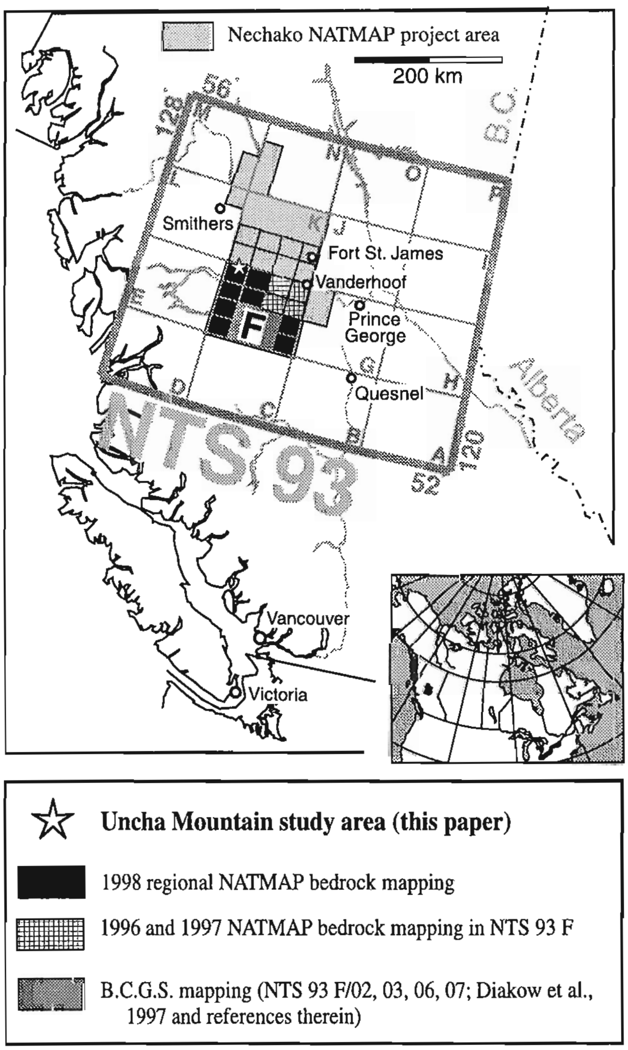


Figure 1. Location of study area and 1998 Nechako NATMAP bedrock mapping program.

Distribution of the units was unchanged, but the correlation of the Mesozoic strata was changed in subsequent compilations (e.g. Bellefontaine et al., 1995; Williams, 1997): Takla Group rocks were correlated to the Middle and Upper Jurassic Bowser Lake Group and the former Hazelton Group rocks were correlated to the Upper Cretaceous Kasalka Group.

Results of the new mapping reported herein emphasize the importance of Tertiary faulting and associated small-scale deformation to the juxtaposition of rocks of Hazelton and Ootsa Lake groups and to the localization of synkinematic, high-level, felsic, aphanitic, porphyry, and miarolitic plutonic intrusions and hydrothermal alteration.

PHYSIOGRAPHY, ACCESS, AND FIELD METHODS

The study area is characterized by low-relief Interior Plateau physiography and is entirely below the tree line. Access is principally via traverses on foot from maintained and abandoned gravel roads along the western part of the map area. The roads locally are only passable via all terrain vehicle.

New data reported here were based upon four weeks fieldwork, comprising 26 traverses in July and August 1998. Standard geological-mapping techniques were supplemented by global-positioning-system measurements taken at each station, providing a geographic precision of 50–100 m in station location (depending on number and orientation of satellites). Representative samples of units were collected for petrographic, mineralogical, and geochemical studies. Magnetic susceptibility (m.s.) measurements were routinely obtained at each outcrop over a five-minute period using a hand-held Exploranium KT-9 Kappameter and are an average of at least five measurements and reported in 10^{-3} S.I. units. Specific gravity determinations will be obtained for representative hand samples. The database of m.s. and specific gravity measurements for the samples will aid in the interpretation of potential-field geophysical data (Struik and McMillan, 1996).

GEOLOGY

Jurassic and Eocene stratified rocks and a variety of Tertiary intrusive rocks are recognized in the area, but are overprinted by widespread fracturing related to the development of map-scale, north-northeasterly trending brittle faults and localized hydrothermal alteration (Fig. 2).

Stratified rocks

Hazelton Group (unit lmJHs)

Rocks of the Hazelton Group (unit lmJHs) occur east of the north-northeast-trending Uncha fault and are generally maroon to grey, poorly sorted, poorly to moderately bedded, epiclastic volcanic conglomerate, greywacke, and pebbly mudstone. Changes in the unit from east to west include a change in colour from the typical maroon and grey to greyish-black, a transitional decrease in clast variation, and a younging of the sequence.

In all the lithofacies of the older sedimentary rocks in the east, the siliciclastic rocks are matrix to clast supported and contain 2–90% angular to rounded, granule- to cobble-sized clasts which increase to boulder size in the southeast. From most to least common, clast types are pale to dark grey aphanitic volcanic rocks, commonly showing quartz-filled microfractures and chloritic alteration (<60%); hornblende porphyry (up to 20–30%); chert and jasper (<25%); dark maroon fine-grained volcanic rocks (<15%); pale green fine-grained volcanic rocks (<10%); plagioclase porphyry (<5%); and minor black and buff pumice, bright orange lithic fragments, and granite. The greywacke and mudstone matrix is well to poorly sorted, consists of ash- to sand-sized grains, and is locally rich in subcentimetre-sized plagioclase, locally up to 15% chloritized hornblende, and minor broken quartz crystals. Most beds are chaotic and discontinuous, 10 cm to 1 m thick, and, in the northeast, exhibit rapid alternation of conglomerate, greywacke, and/or pebbly mudstone (Fig. 3a, 3b). Bedding dips shallowly to moderately to the north or northwest.

The overlying greyish-black epiclastic volcaniclastic rocks in the west resemble the sedimentary rocks in the east in clast abundance, rounding, and size, but the clast type is principally the pale to dark grey, aphanitic volcanic rock (commonly showing quartz-filled microfractures and chloritic alteration) and chert, with minor plagioclase porphyry (<5%) and quartz (2–3 mm, <1–5%). The dense, black matrix consists generally of ash-sized grains. The beds of interbedded conglomerate and greywacke (with rare nonplanar bedded mudstone), are <10–30 cm thick, chaotic and discontinuous, and generally less distinct and more poorly sorted than beds of same unit in the east. A shallow, high-energy depositional environment with rapid channel switching would account for the western unit. The beds dip moderately northwest.

Unit lmJHs in the west contains common, disseminated magnetite, which is responsible for the greyish-black colour and high magnetic susceptibilities (250 x 10^{-3} S.I.). Locally penetrative fractures dip steeply to the west-northwest. Pervasive chlorite alteration is common, as is epidote alteration of specific clasts and fracture coating.

To the northeast, along the southern shore of Francois Lake, the unit comprises maroon grey to greenish-grey, fine- to coarse-grained, heterolithic volcanic breccia, conglomerate, and tuffaceous sedimentary rocks. The volcaniclastic rocks are matrix-supported, and contain a subequal abundance of variegated aphyric rhyolitic, aphanitic to plagioclase-phyric andesitic, and amygdaloidal basaltic-andesitic volcanic rock fragments in a green tuffaceous grit matrix. Bedded rocks are rare, thin bedded (5–10 cm thick), and gently dip southeast and south-southeast. Locally massive and bedded rocks are intermingled nearly chaotically; many of the epiclastic units are likely laharic deposits.

The amygdaloidal andesitic fragments are particularly characteristic of Hazelton Group volcanic conglomerate seen regionally, and are also found in the flow rocks in the Middle Jurassic Naglico Formation in southeastern Nechako River map area (Diakow et al., 1997; Struik et al., 1999). The chert-poor, volcanic-rich nature of fragments in the volcanic conglomerate is dissimilar to well dated and described Callovian Bowser Lake Group conglomerate in the Nechako Range to the southeast (e.g. Diakow et al., 1997; Anderson et al., 1998a, b); similarly, the paucity of hornblende phenocrysts is dissimilar to Upper Cretaceous Kasalka Formation (Diakow et al. (1997); Diakow and Levson (1997) and references therein).

Hazelton Group (unit lmJHv)

Fine-grained andesite of the volcanic rocks of the Hazelton group (unit lmJHv) principally underlie a series of hills 5 km south of Uncha Mountain summit, and are dark grey to maroon and pale green (Table 1). Common vesicles and amygdules (10–50% of the rock) are variable, ranging from spherical to cigar shaped to flattened (2 mm to1 cm in size) within a hand sample. The unit is pervasively altered to chlorite, and exhibits sequential concentric in-filling of chlorite, epidote, and calcite in some amygdules. Quartz-filled amygdules are also fairly common. The plane of vesicle flattening dips moderately to the southwest. The stratigraphic relationships with the epiclastic volcanic conglomerate (unit lmJHs) were not observed.

Ootsa Lake Group (unit Eol)

Generally fine-grained, aphanitic, leucocratic, felsic porphyry, rhyolite, rhyodacite, and dacite with associated autoclastic breccia and tuff, and rare andesite flows, constitute the Ootsa Lake Group (*see* Table 1 for mineralogical compositions).

The Uncha fault (Fig. 2) separates texturally distinct varieties of the Ootsa Lake Group. West of the fault, flows are represented by flow-layered, spherulitic, lithophysae-bearing rhyolite and rhyodacite. Spherulites, up to 7 mm in diameter, constitute up to 50% of the rock and locally, lithophysae are abundant and up to 5 cm in diameter. These features may suggest that the rocks represent the upper portion of a cooling unit. Dacitic vesicular flows contain spherical to flattened vesicles, the latter defining planes which dip moderately to steeply to the northeast.

Autoclastic breccia with a rhyolitic groundmass of similar composition to the clasts is common west of the fault and contains 75–90%, angular, lapilli- to boulder-sized clasts of spherulitic and lithophysae-rich rhyolite (Fig. 4a). Fine-grained lithic fragments constitute 10% of the clasts in a few places. An andesitic flow on the northwestern border of the map area (site 1, Fig. 2) contains generally westerly trending plagioclase microlites. It is slightly amygdaloidal, with an unidentified white zeolite filling.

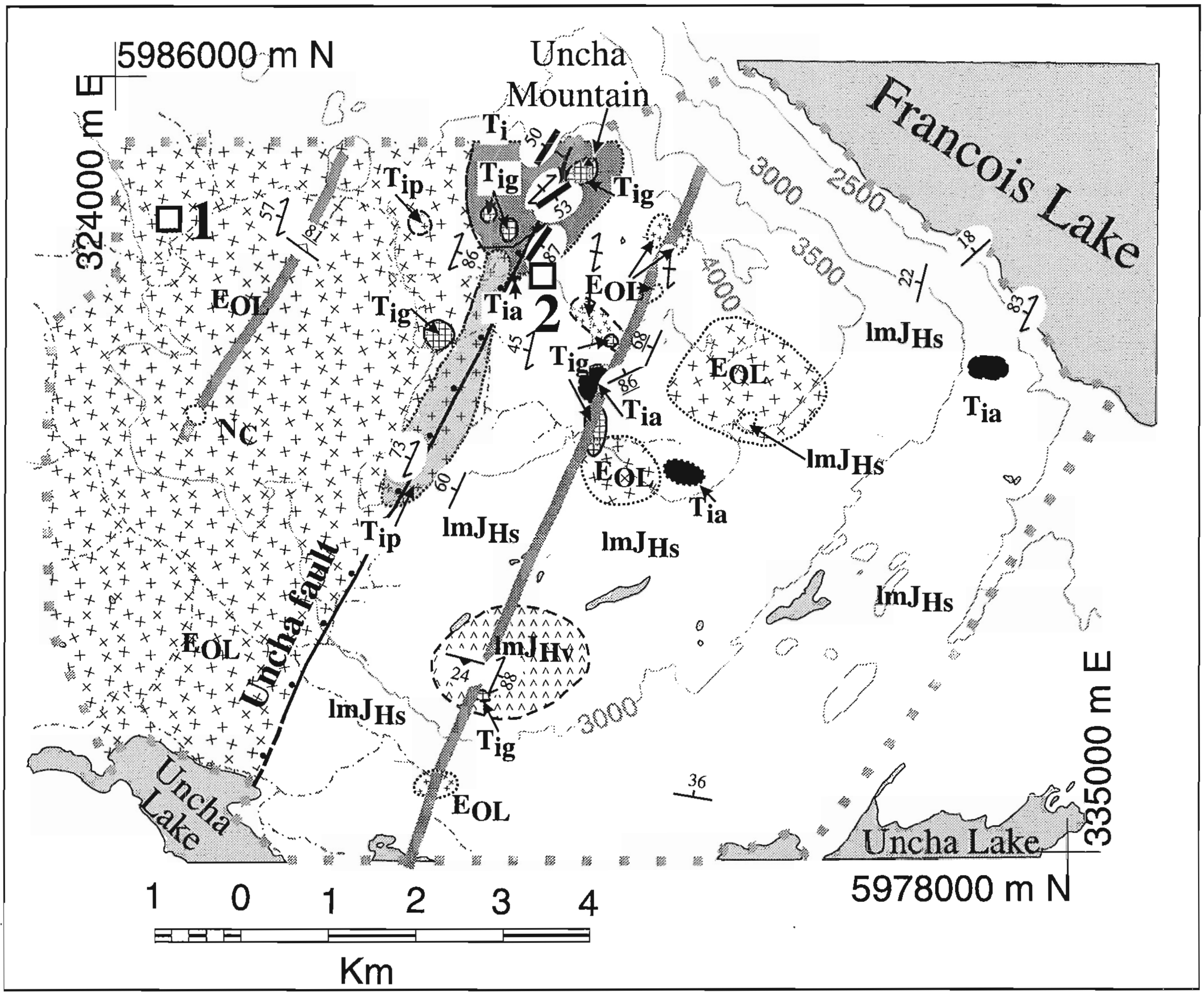


Figure 2. Geological map of the Uncha Mountain study area. Numbered sites are localities cited in text.

East of the fault, flow textures in the Ootsa Lake Group felsic volcanic rocks are less distinct. Spherulites are rare and lithophysae-rich rhyolite and autoclastic rhyolite breccia are absent east of Uncha fault. A tuffaceous member is also rare and only found at one location, in the south. The rhyolite dome 1 km southeast of the Uncha Mountain summit does have distinctive subvertical flow laminations (Fig. 4b) as do other scattered rhyolitic flows. The more massive texture of the porphyry and rhyolite to dacite east of the Uncha fault is interpreted to indicate a more basal position in a cooling unit. The interpretation of the more massive rocks as flow units in this area derives from the alignment of minerals and the orientation of contacts with adjacent strata.

Figure 3.

a) *Poorly-sorted, heterolithic, epiclastic volcanic conglomerate in eastern exposure of Hazelton Group (unit lmJHs);*

b) *Graded bedding in epiclastic volcanic conglomerate of Hazelton Group.*

LEGEND

Stratified Rocks

Neogene

Chilcotin Group(?)

N_C — dark grey, columnar-jointed olivine basalt

Lower Eocene

Ootsa Lake Group

E_{OL} — leucocratic, fine-grained, flow-layered rhyolite and rhyodacite flows with spherulites and lithophysae; less common massive to vesicular or amygdaloidal dacite flows; related autobreccia and tuff; minor andesite flows

Jurassic

Lower to Middle Jurassic

Hazelton Group

lmJ_{Hs} — maroon to greyish-black epiclastic volcanic conglomerate, greywacke, pebbly mudstone and tuffaceous sedimentary rocks; less heterolithic and more magnetite-rich in west

lmJ_{Hv} — dark grey to maroon to pale grey, locally vesicular or amygdaloidal, fine-grained andesite

fracture zone

fault: approximate, inferred; teeth on hanging wall of inferred normal fault

inclined bedding (45)

mafic dyke (unit T_{ib}) (45)

fractures: inclined, vertical (45)

mafic flow layering (45)

felsic flow layering (45)

Intrusive Rocks

Tertiary

T_l — pale grey, commonly featureless, aphanitic, fine-grained rhyolite to dacite; intense silicification commonly obliterated primary mineralogy

T_{ia} — dark to pale grey andesitic plagioclase porphyry dykes and massive units; locally highly chloritized and contains aligned hornblende

T_{ip} — dark grey to pale lilac-grey, fine-grained to medium- to coarse-grained, seriate to equigranular, miarolitic syenite, quartz syenite, granite and alkali-feldspar granite

T_{ig} — pale buff to pale greenish-white, fine- to medium-grained, equigranular alkali-feldspar granite

T_{ib} — rare, dark grey to dark brown, fine-grained, aphanitic to clinopyroxene-plagioclase-phyric basalt

SYMBOLS

limit of mapping

geological contact (approximate, inferred)

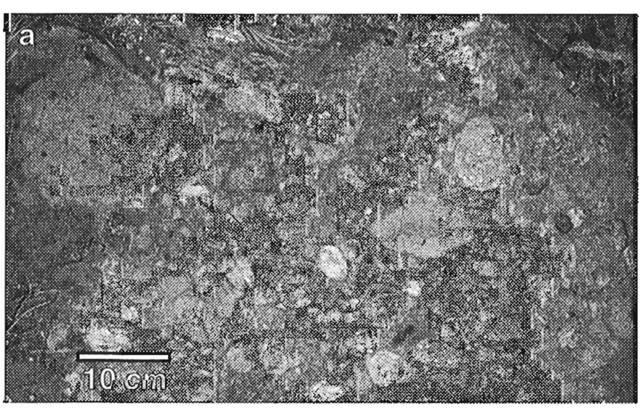
lakes

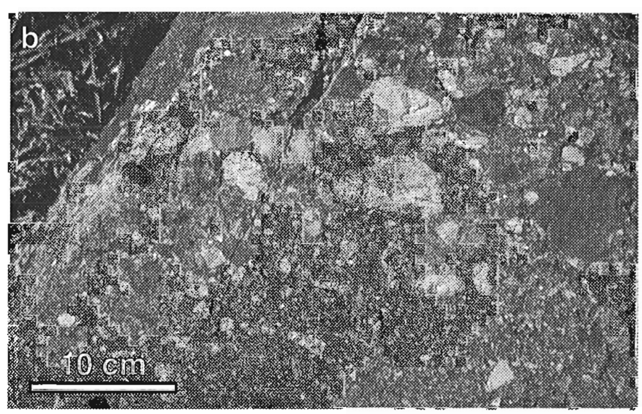
rivers and creeks

gravel roads

□1 — site described in text; site 2 is locality for Fig. 5a

Contour interval is 500 feet





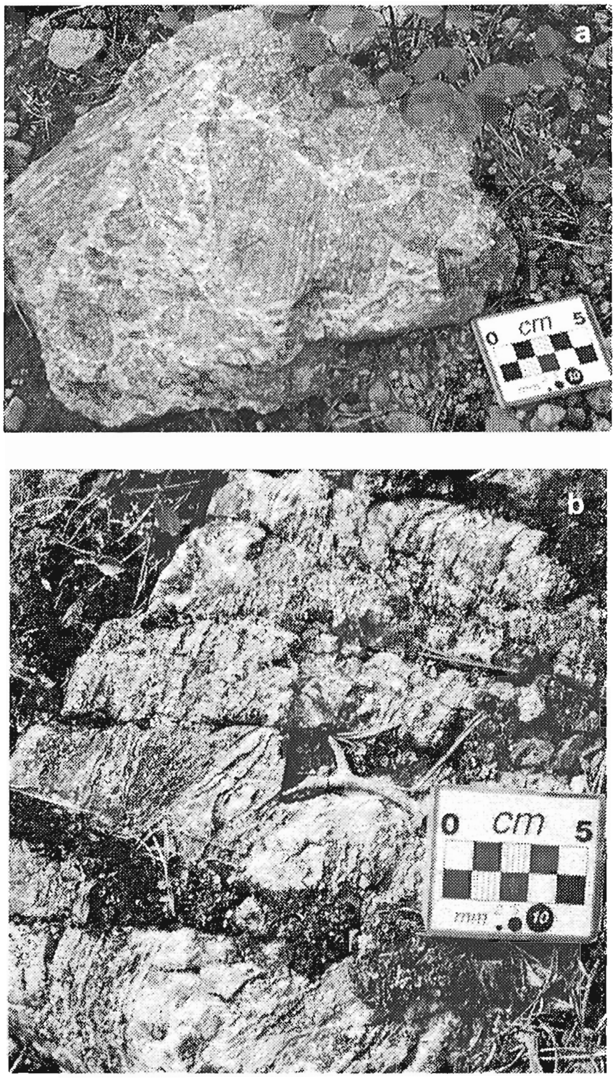


Figure 4. *a) Autoclastic rhyolite breccia of Ootsa Lake Group rocks west of the Uncha Mountain summit;* ***b)*** *Flow-layered rhyolite of the Ootsa Lake Group.*

Mineralization and alteration includes disseminated pyrite (1 mm, <1%) localized to the area around Uncha Mountain summit. Glass devitrification, sericite, iron oxidation, intense silicification, and locally pervasive chlorite are alteration products of the rock, locally attributable to hydrothermal activity, and are especially widespread east of the Uncha fault.

Chilcotin Group(?) (unit Nc)

Basaltic rocks tentatively correlated with the Chilcotin Group underlie a 40 m high, steep-sided hill to the west of the Uncha fault. Dark grey, columnar-jointed basalt contains plagioclase (as phenocrysts and microlites), clinopyroxene, and olivine phenocrysts in a dense, vitreous groundmass (Table 1). Physiographic expression, olivine phenocrysts, and groundmass character of the unit are particularly distinctive of Neogene volcanic rocks compared with the Eocene Endako Group (*see* Resnick et al., 1999 for discussion of regional correlation of Neogene volcanic rocks; Anderson et al., 1998a, b). Pervasive fracture planes define approximately 20 cm wide columnar-like joints and locally, the fractures are coated by pyrolusite. The unit is apparently unaffected by deformation localized along the fracture zone it straddles (Fig. 2).

Tertiary intrusive rocks

Undivided intrusive rocks (unit Ti)

Pale grey, generally featureless, aphanitic to fine-grained intrusive rocks widespread in the Uncha Mountain summit region are believed to be subvolcanic intrusions related to the Ootsa Lake Group rhyolite and rhyodacite (*see* Table 1 for mineralogy). Generally, the rock is textureless, and the local, weak to strong alignment of mafic minerals commonly provides the only indication of flow. An autoclastic breccia with angular clasts, 1 mm to10 cm in size, is common in areas of intense fracturing. The breccia may result from volcanic doming, associated with the emplacement of subsequent intrusions.

Unit Ti is commonly found in contact with, and structurally below, the greyish-black Hazelton Group epiclastic volcanic conglomerate (unit lmJHs) (*see* Fig. 5a and site 2, Fig. 2). The intrusive contact is angular, irregular, and discordant with the bedding of the epiclastic volcanic conglomerate. Black to dark green, aphanitic, magnetite-rich veins yielding high magnetic susceptibility values (323 x 10^{-3} S.I.) are associated with the contact. The veins, generally 10 cm wide and as wide as 1 m, are generally subvertical and trend northeast. The magnetite is believed to be remobilized from the epiclastic volcanic conglomerate (unit lmJHs).

Various locations provide evidence of intense hydrothermal silicification which often obliterates the intrusion's primary mineralogy. The high degree of silicification is especially visible where quartz and rare, poorly formed, millimetre-scale amethyst filled cavities in areas of autoclastic brecciation. Common quartz, uncommon calcite, and disseminated magnetite are also associated with veins and microfractures in these regions. Indistinct buff streaking of the rock is believed to represent the annealing of earlier fractures by silica-rich fluid influx.

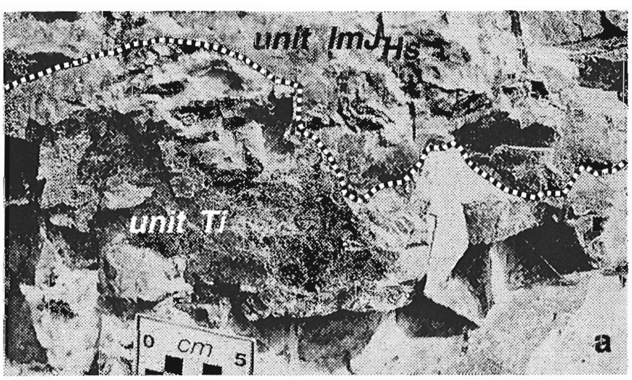
Figure 5.

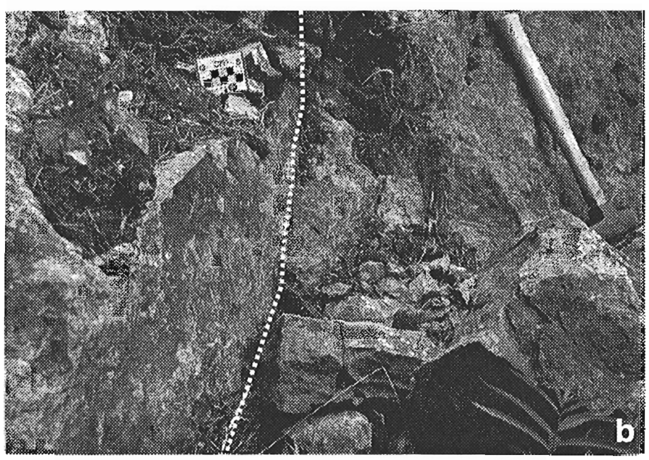
a) *Intrusive contact (dotted white line) between Tertiary felsic intrusion (unit Ti, below line) and Hazelton Group epiclastic volcanic conglomerate (unit lmJHs, above line) at Uncha Mountain summit (site 2, Fig. 2);*

b) *intrusive contact (vertical dotted line) between younger Tertiary granite phase (unit Tig, to left of line) and Tertiary felsic intrusion country rocks (unit Ti, to right of line) at Uncha Mountain summit.*

Table 1. Phenocryst mineralogy of selected units in the Uncha Mountain map area.

Unit	Minerals	Size (mm)	Abundance (%)	Texture
lmJHv	plagioclase	2–4	5–30	Subhedral to euhedral. Tabular; lath and microlite
	hornblende	1.5–3	2–10	Subhedral to euhedral
	biotite	1.5	1	Euhedral; fresh
Eol	potassium feldspar	1–10	up to 80, average 5–10	Subhedral to euhedral
	plagioclase	up to 10, average 1–5	up to 30, average 5–10	Subhedral to euhedral. Tabular; lath and microlite
	quartz	1–7	up to 20, average 5	Subhedral to euhedral
	hornblende	2–4	<10	Subhedral. Rare swallow-tail habit
	biotite	1–5	1–15	Subhedral
Nc	plagioclase	3–4	15	
	plagioclase microlites	1	5	
	clinopyroxene	1	<5	
	olivine	2	<2	
Ti	quartz	1–3	<1–10	Anhedral to euhedral to rounded
	plagioclase	5	<5	Subhedral
	-microlites	1–1.5	<5	
	hornblende	2–4	<5	Euhedral
	alkali feldspar	3	<1	
	magnetite	1	<1	
	biotite	1	<1	
Tia	plagioclase	5–10	50–60	Subhedral to euhedral. Bladed
	hornblende	1–3	<5–15	Local abundance. Rare alignment
	pyroxene	2	<1	
	pyrite		minor	
Tip	alkali feldspar	0.5–10	10–60	Subhedral to euhedral
	quartz	1–10	10–60	Anhedral to subhedral
	plagioclase	2–5	1–20	Subhedral to euhedral
	-microlites	1–1.5	<5	
	magnetite	1	1–5	
	hornblende	2–3	<1	
Tig	alkali feldspar	2–10	15–50	Anhedral to subhedral
	quartz	1–2	5–50	Anhedral to euhedral
	plagioclase	3	<5	Subhedral to euhedral to bladed
	unidentified mafic minerals	2–3	<1	Euhedral
Tib	plagioclase	1–4	5–15	
	-microlites	1–3	5	
	pyroxene	1–2	1–2	





On the southwest flanks of Uncha Mountain, an alkali feldspar granite (unit Tig) (*see* below) intrudes the highly fractured, pale grey, featureless rhyolite intrusion (Fig. 5b). The country rock has undergone contact metamorphism, resulting in a 2 cm zone of recrystallized feldspar and plagioclase phenocrysts, adjacent to autoclastic microbreccia distal to the contact.

Andesitic intrusive rocks (unit Tia)

Dark to pale greyish-green, highly chloritized, fine-grained, andesitic plagioclase porphyry of unit Tia (Table 1) intruded the contact between the epiclastic volcanic conglomerate (unit lmJHs) and pale grey featureless rhyolitic intrusion (unit Ti), 1 km south of Uncha Mountain summit. The rock also outcrops to the southeast, where it is structurally below the epiclastic volcanic conglomerate (unit lmJHs). Magnetite is disseminated throughout the unit and in veins crosscutting this and surrounding rocks. Common epidote and calcite, and localized high-temperature potassium-feldspar alteration occur in the intensely fractured areas. The fracture planes dip steeply west-northwest.

Undivided plutonic intrusive rocks (unit Tip)

Dark grey to very pale lilac-grey, fine to medium-coarse, seriate to equigranular, leucocratic hornblende-bearing syenite, quartz syenite, granite, and alkali-feldspar granite (Table 1) are distinctively miarolitic and closely associated with the north-northeast-trending Uncha fault. The intrusions strongly resemble other high-level felsic plutons farther east in Knapp Lake and Hallett Lake map areas (*see* Sellwood etal., 1999). Slightly elongate, 3–10 mm in length, miarolitic cavities which have a pale, 5 mm wide alteration haloes are fairly common, (5–15%). Minor disseminated magnetite is commonly associated with the cavities. Locally penetrative fractures, 3–10 cm apart dip steeply west-northwest and east-southeast.

Alteration products of the granitic rock are manifest in sericite and iron oxide with scattered chlorite, epidote, and celadonite. Silica-rich fluid influx is apparent locally by euhedral, fine-grained quartz crystals forming fracture coatings.

Granite intrusions (unit Tig)

Pale buff to pale greenish-white, fine- to medium-grained, equigranular, and leucocratic alkali-feldspar granite intrudes unit Ti on the southwestern flank of Uncha Mountain summit (Fig. 2, 5b) and has a close spatial and compositional relationship to unit Tip (Table 1). The high abundance of alkali feldspar and quartz occurs in rare aplitic phases to the south of Uncha Mountain summit. The granite is locally altered to sericite, patchy epidote, iron oxide, pyrolusite, and rare arsenopyrite.

Basaltic intrusive rocks (unit Tib)

Rare, dark-grey- to dark-brown-weathering, fine-grained, aphanitic to porphyritic basaltic dykes, strongly resembling the regional Endako Group flow rocks, occur near Uncha Mountain summit. They contain plagioclase phenocrysts, minor plagioclase microlites, and rare pyroxene (Table 1).

The dykes have sharp, discordant contacts with the pale grey, featureless rhyolitic intrusion (unit Ti) and the epiclastic volcanic conglomerate (unit lmJHs). The subvertical dykes are likely fault controlled as their trend parallels that of the principal fractures (Fig. 2).

STRUCTURE

The Uncha fault mapped in previous work (e.g. Tipper, 1963) apparently localized Tertiary intrusions (units Ti, Tia, Tip, Tig, and Tib), with associated hydrothermal alteration and veining. The elongate nature of the intrusions that run parallel to the Uncha fault (most apparent with unit Tip along the fault) suggests emplacement facilitated by extensional movement. A similar interpretation applies to the north-northeast-trending dykes of unit Tib at the Uncha Mountain summit, which are associated regionally with extensional rifting (Anderson et al., 1998a, b). All units in the map area, except the Chilcotin(?) Group basalt plug, have principal fracture orientations concordant with the north-northeast-trending Uncha fault.

There is a lack of any sense of movement, fault gouge, or mylonite accompanying the fractures. The fracturing is the brittle crustal response to movement on the fault. The Uncha fault, and the widespread planes of weakness resulting from intense fracturing associated with the faulting, has a long history as guides for broadly synkinematic intrusions.

Structural orientation of the Hazelton epiclastic volcanic conglomerate (unit lmJHs) suggests that the area east of the Uncha fault is a tilted block with a general dip to the northwest. There are no kinematic indicators to ascertain the sense of movement along the fault. However, the westward increase in dip magnitude of bedding orientations for unit lmJHs towards the fault may indicate a slight 'roll-over' of beds in the footwall by the transposition of the strata along the fractures.

Tertiary fracturing and intrusions

Fracture planes consistently strike 180–200° and dip 55–90° to the west and east (Fig. 6). Intensely fractured zones trend subparallel to the Uncha fault. Effects of processes localized along these zones are most apparent 2 km east of the Uncha fault, and involve Hazelton Group flow rocks (unit lmJHv), Tertiary flow-layered rocks (unit Eol), and various high-level Tertiary intrusions (units Tig, Tia) and hydrothermal alteration. An alignment of numerous Ootsa Lake Group flow-rock outcrops (unit Eol) and the Miocene Chilcotin Group basalt plug (unit Mc) 3 km west of the Uncha fault, also closely parallels the trend of the Uncha fault. The topographic features, hill ridges, valleys, and lakes on Uncha

Mountain are commonly aligned along this orientation, implying widespread fracturing. This implies that fracture-controlled emplacement of intrusions and erosion occurred over a long period of time.

ALTERATION AND MINERALIZATION

The long history of fracturing in this region has facilitated intense alteration of all the units, although some of the Ootsa Lake Group volcanic rocks and some of the related intrusions are least affected. No MINFILE localities are known to be located in the study area (Bailey et al., 1995).

Pervasive chlorite alteration is associated with every unit except the Ootsa Lake Group rhyolite (unit Eol). Epidote and/or calcite alteration, either pervasive or as fracture coatings, is similarly common, but restricted to the intensely fractured zones. Silicification is most intense in, but not restricted to, Tertiary intrusions in the northern part of the map area.

Disseminated and vein magnetite occurs in the greyish-black, Hazelton Group epiclastic volcanic conglomerate (unit lmJHs; Fig. 7) and the units in contact with it, particularly in the miarolitic cavities of the granite (unit Tip), and the pale grey, featureless rhyolitic intrusion (unit Ti). Such veining, together with the occurrence of pyrite (in various units) and amethyst (in unit Ti) are restricted to the summit of Uncha Mountain.

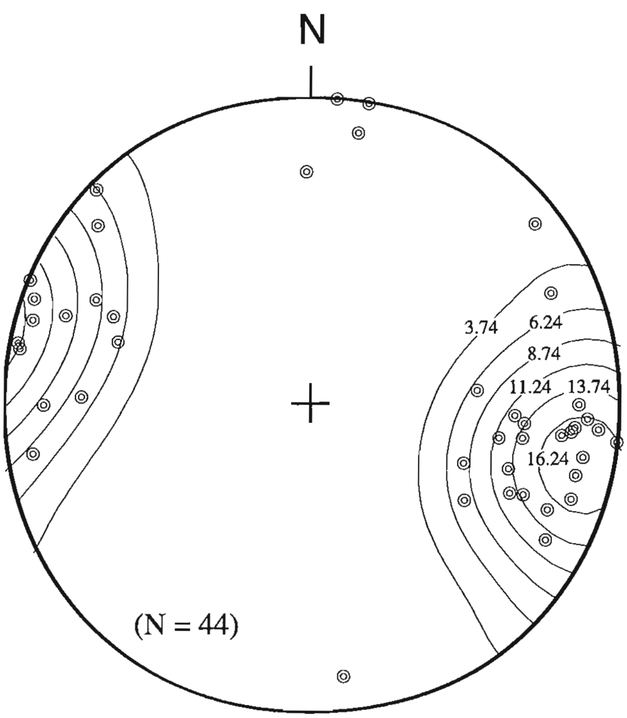


Figure 6. Equal-area stereonet of some structural data from the Uncha Mountain area: poles to fracture planes for all units in the Uncha Mountain area. Contours (at intervals 3.74, 6.24, 8.74, 11.24, 13.74, and 16.24) emphasize steep, north-northeasterly trending fracture cleavage.

CONCLUSION

Mesozoic and Tertiary strata and intrusions near Uncha Mountain have recorded a history of extensional Tertiary faulting and fault-related emplacement of felsic intrusions. The Uncha fault is apparently downthrown to the west where commonly felsic flow-top rocks of the Ootsa Lake Group occur, compared with more basal cooling units to the east. Displacement along the north-northeast-trending Uncha normal fault created regional widespread fracturing with a localized series of high-level felsic intrusions along fault-induced weak zones in the crust, and likely led to a significant steepening of the footwall strata east of the fault. The close association of Tertiary intrusive rocks with the north-northeasterly trending Uncha normal fault indicates a change in orientation of a component of Tertiary extension from northwest-southeast directed in the east (e.g. Anderson et al., 1998a, b) to a more west-northwest- and east-southeast-directed orientation near Uncha Mountain.

The disseminated magnetite in the Hazelton Group epiclastic volcanic conglomerate to the east of the Uncha fault was likely the source for numerous magnetite-rich veins close to Uncha Mountain summit, but neither the source nor the veins are believed to be of economic potential due to their limited extent. However, high-temperature potassium-feldspar alteration of the andesitic plagioclase porphyry (unit Tia) may suggest production of fluids within the temperature range required for hydrothermal ore deposition.

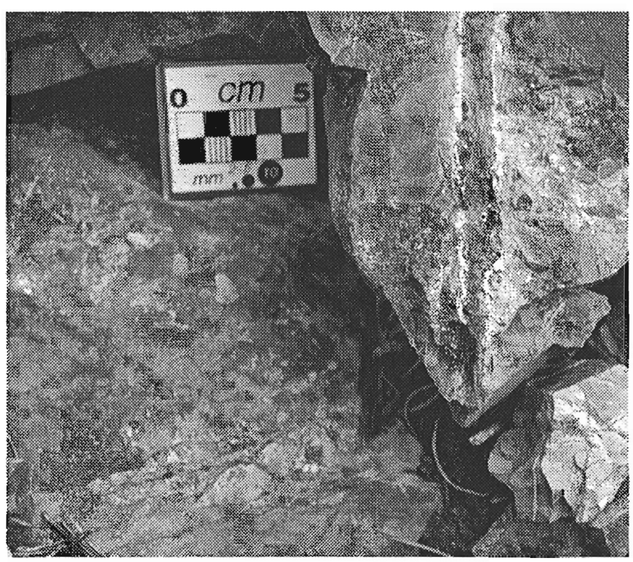


Figure 7. Mineralized veins in Hazelton Group epiclastic volcanic conglomerate (unit lmJHs).

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I (E.M. Barnes) would like to express my sincere thanks to the GSC, and especially Bert Struik, for allowing me to participate in the NATMAP project under the auspices of the GSC's Volunteer Program. It would have been impossible to undertake this work without the approval of Brian Bell of the University of Glasgow or the financial assistance of the estate of the late Jo Wylie; their backing is deeply appreciated. A sincere thank you to Tina Pint, Steve 'Rockman' Sellwood, Amber McCoy, Nancy Grainger, and Jonah Resnick for their excellent field assistance and calming influence through all the weather could throw at us, and to Lori Snyder for sharing her field experience. We appreciate the time spent by Dr. Howard Tipper, whose constructive review of an earlier version of the manuscript hopefully led to a better final version. Bev Vanlier is thanked for her digital preparation of the pre-press version. And finally, heartfelt thanks goes to the residents of Uncha Mountain and the near environs especially the Foot and Probst families for their assistance in rescuing various vehicular devices from the mud.

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Geological Survey of Canada Project 950036-04

Geology of the Eocene Ootsa Lake Group in northern Nechako River and southern Fort Fraser map areas, central British Columbia[1]

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Grainger, N.C. and Anderson, R.G., 1999: Geology of the Eocene Ootsa Lake Group in northern Nechako River and southern Fort Fraser map areas, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 139–148.*

Abstract: Eocene Ootsa Lake Group in northern Nechako River map area comprises variegated, flow-laminated rhyolitic flows and domes, crystal and lithic-crystal tuff, less common pyroclastic and autoclastic breccia, and minor dacite and andesite flows. Rotated rhyolite clasts, flow folding, vesicles, perlite and spherulites, and minor lithophysae and eutaxitic textures and phenocrysts of plagioclase, biotite, alkali feldspar, quartz, and rare hornblende are distinctive.

A local stratigraphy comprises basal hornblende-plagioclase porphyritic andesite with distinctive amethyst-bearing amygdules, medial flow-laminated rhyolite flow rocks and breccia, and upper felsic tuff and breccia. Distinct rhyolite ash-lignite beds mark the top of the unit and in addition to glassy quenched flow bases and reworking of lithic rhyolite tuff units, suggest local shallow-water environments.

The Dayeezcha Mountain, Henson Hills, and Mackenzie Lake study areas provide the most complete stratigraphy. Ongoing petrographic, geochronological, geochemical, and isotopic tracer studies will elucidate the age, correlation, composition, tectonic setting, and petrogenesis of the unit.

Résumé : Le Groupe d'Ootsa Lake de l'Éocène, dans le nord de la région cartographique de la rivière Nechako, comporte des coulées et dômes rhyolitiques bariolés à litage de flux, des tufs cristallins et cristallolithiques, des brèches pyroclastiques et autoclastiques moins abondantes ainsi que des coulées de dacite et d'andésite en quantités mineures. Des clastes de rhyolite hélicitiques, des plis ptygmatiques, des vacuoles, de la perlite et des sphérulites, des lithophyses et textures eutaxitiques en quantités mineures, ainsi que des phénocristaux de plagioclase, de biotite, de feldspath alcalin, de quartz et de rare hornblende sont caractéristiques.

La stratigraphie locale comprend à la base des andésites porphyriques à hornblende et plagioclase avec des amygdales à améthyste caractéristiques, puis des coulées de roches et de brèches rhyolitiques à litage de flux et enfin, des brèches et tufs felsiques. Des lits distincts de rhyolite à cendres et lignite marquent le sommet de l'unité et, avec les bases de coulées vitreuses figées rapidement et les unités de tufs à rhyolite lithique remaniées, suggèrent des milieux locaux d'eau peu profonde.

Les régions d'étude du mont Dayeezcha, des collines Henson et du lac Mackenzie offrent la stratigraphie la plus complète. Les études pétrographiques, géochronologiques et géochimiques et celles des marqueurs isotopiques en cours permettront de définir l'âge, la corrélation, la composition, le cadre tectonique et la pétrogenèse de cette unité.

[1] Contribution to the Nechako NATMAP Project

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INTRODUCTION

Eocene mafic and felsic volcanic rocks dominate the geology of northern Nechako River (NTS 93F) and southern Fort Fraser (NTS 93 K) map areas (e.g. Armstrong, 1949; Tipper, 1963; Bellefontaine et al., 1995; Williams, 1997). Paleogene Ootsa Lake and Endako group rocks were included in the Kamloops assemblage by Wheeler and McFeely (1991) and considered to represent a transtensional volcanic arc (e.g. Souther, 1991). Locally, the volcanic rocks are well known and dated (e.g. Struik et al., 1997; Villeneuve and MacIntyre, 1997; Anderson and Snyder, 1998; Anderson et al., 1998; Struik, 1998; Struik and Whalen, 1998; Whalen et al., 1998). Similarly, extensional tectonics coeval with some or all of the volcanism in the area is well documented (e.g. Wetherup and Struik, 1996; Wetherup, 1997, 1998). However, regionally, the felsic component of the Eocene magmatism, represented in the rocks of the Ootsa Lake Group, continues to be poorly known and understood. Moreover, the relationships amongst the sequence of magmatism and the timing and structural style of extensional tectonics remain unresolved.

Fieldwork undertaken in 1998 sought to better define the nature, timing, and petrogenesis of the Ootsa Lake Group and is the basis of a M.Sc. thesis by the senior author. This study will also contribute to two objectives of the Nechako NATMAP Project, 1) to test the hypothesis that the Eocene magmatic complex represents the tectonic and magmatic expression of an Eocene regional extensional event and 2) to improve our understanding of the potential for precious metal, epithermal and intrusion-related copper-gold and molybdenum deposits related to felsic magmatism (Andrew, 1988; Struik and McMillan, 1996).

PREVIOUS WORK AND STRATIGRAPHIC NOMENCLATURE

Previous and recent mapping first recognized the felsic volcanic Ootsa Lake Group in and around the study area (Armstrong, 1949; Tipper, 1955, 1963; Church, 1972; Kimura et al., 1980; Diakow et al., 1997; Struik et al., 1997; Wetherup, 1997; Anderson and Snyder, 1998; Anderson et al., 1998; T. Richards, pers. comm., 1998). The unit was first defined by Duffell (1959), who proposed the name Ootsa Lake Group for an Upper Cretaceous to late Oligocene series of mainly felsic flows with minor basalt, andesite, tuff, breccia, and rare conglomerate within the Whitesail Lake map area (NTS 93 E) to the west of the study area (Fig. 1). He correlated the unit with Eocene–Oligocene volcanic rocks, sedimentary rocks, and Upper Cretaceous or younger volcanic rocks of Armstrong (1949) within the Fort St. James and Fort Fraser map areas (Duffell, 1959). The Ootsa Lake Group was subsequently subdivided into rhyolite and andesite units within the Nechako River map area by Tipper (1955, 1963). Diakow and Mihalynuk (1987) refined the stratigraphy within the Whitesail Lake map area to include a sequence of basalt to rhyodacite flows and tuff.

Recent mapping, as part of the Nechako NATMAP Project (Fig. 1), has identified granitic to monzogranitic plutons associated with felsic and lesser intermediate to mafic units within the Ootsa Lake Group (Wetherup and Struik, 1996; Anderson and Snyder, 1998; Anderson et al., 1999). Distinguishing units within the Ootsa Lake Group from similar Cretaceous volcanic rocks has proven difficult (e.g. Anderson et al., 1999), as has making the distinction between mafic rocks of the Eocene Endako Group and the Neogene Chilcotin Group rocks within the map areas (e.g. Haskin et al., 1998; Resnick et al., 1999). Efforts to determine the internal stratigraphy of units within the Ootsa Lake Group are hampered by limited exposure which rarely reveals relationships between units and the integral, discontinuous nature of subunits (e.g. as thin and/or localized flows).

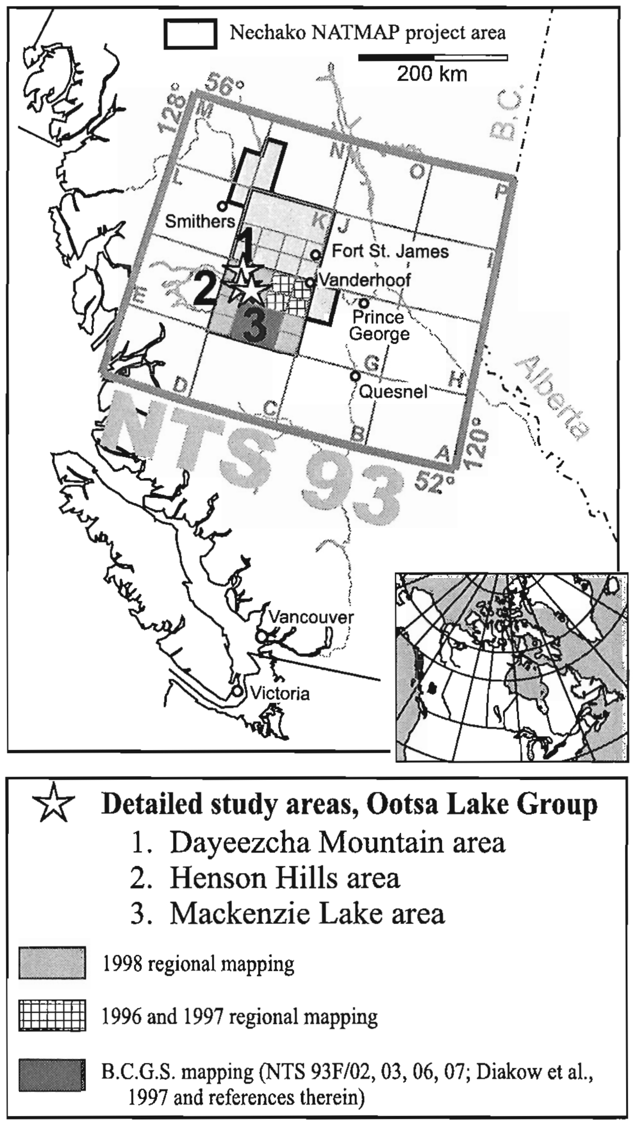

***Figure 1.** Location of study areas within Nechako NATMAP bedrock mapping area.*

Regional K-Ar age dates for the Ootsa Lake Group range from 54.0 to 47.6 Ma within the Fort Fraser and Nechako River map areas and from 55.6 to 47.4 Ma within the neighbouring Whitesail Lake (NTS 93 E) and Smithers (NTS 93 L) map areas (Fig. 2). Age dating within the Whitesail Range determined a significantly more restricted period of volcanism at 50 ± 1 Ma based on six age dates with only one anomalous date of 47.4 ± 2.7 Ma (Diakow and Koyanagi, 1988; Drobe, 1991). Similarly, recent Ar-Ar dating within the Hallett Lake map area (93 F/15) has identified a more restricted age range of Ootsa Lake Group volcanism ca. 53–51 Ma based on eight age dates (M. Villeneuve, unpub. data *in* Anderson et al., 1998).

The Ootsa Lake Group regionally has been characterized as a subalkaline to mildly alkaline and calc-alkaline series of rocks (Souther, 1977; 2 samples). Compositions in northeastern Nechako River map area are similar but show an additional bimodal and high potassium geochemical character (Anderson et al., 1998; 12 samples); rhyolite is silicic, enriched in the large ion lithophile elements and has rare-earth element (REE) patterns characterized by negative europium anomalies and light REE fractionation relative to heavy REEs.

Drobe (1991) concluded that the Ootsa Lake Group in the Whitesail Lake map area was likely formed from melting and mixing of lower crustal material with melts fluxed from the mantle, and further modified by fractionation. The model may not describe the Eocene magma generation within the Nechako River and Fort Fraser map areas because of the dissimilar nature of the volcanic rocks in the two areas. In addition, the genetic relationship of the Ootsa Lake Group magmatism with the local and preceding Late Cretaceous volcanic magmatism, nearby coeval Newman volcanism, coeval plutonic rocks, the subsequent Endako volcanism, and the regional Eocene extensional event (e.g. Souther, 1991; Struik, 1993; Wetherup and Struik, 1996; Wetherup, 1997) remains unclear.

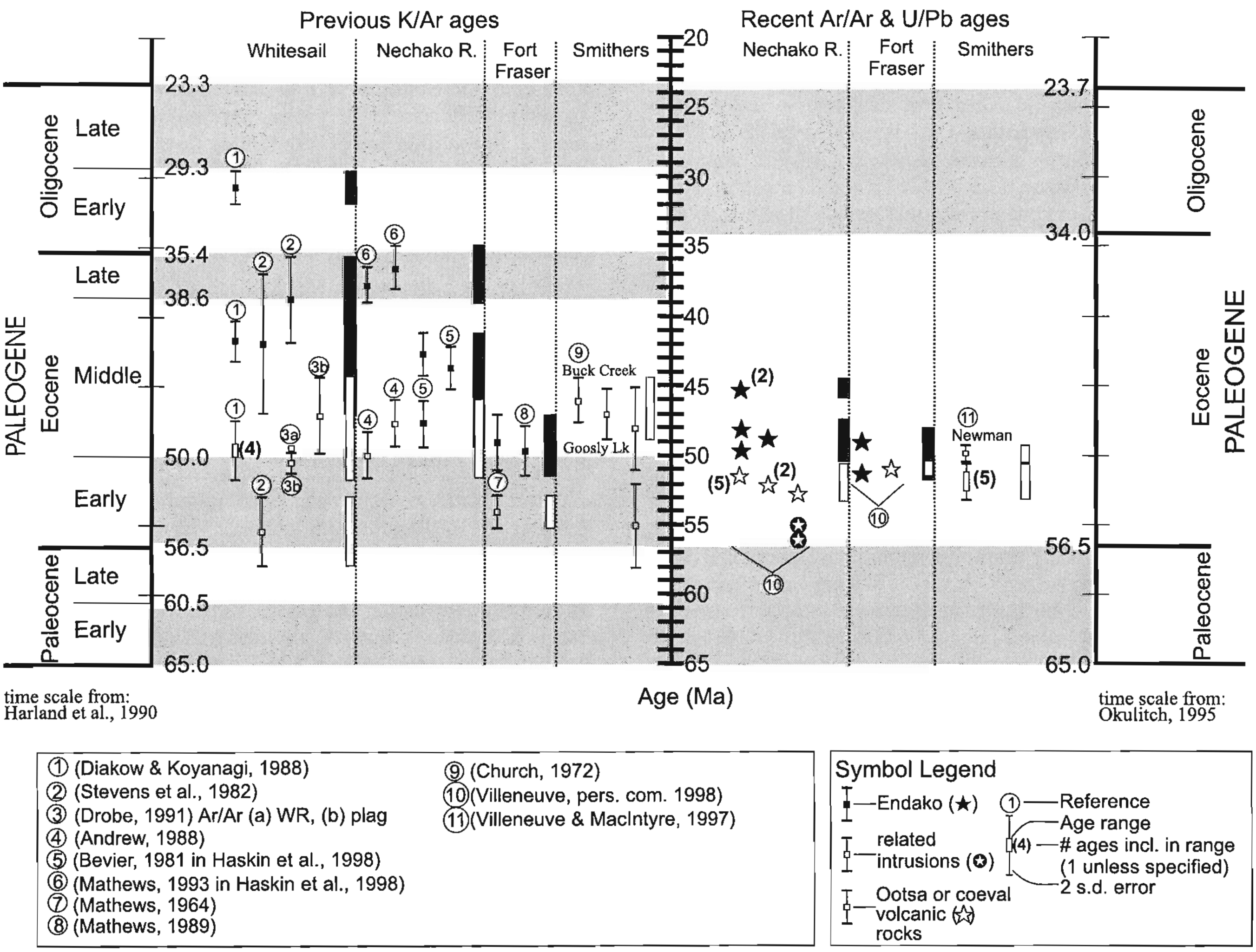

Figure 2. Regional age compilation for the Ootsa Lake and Endako groups and coeval intrusive rocks.

PHYSIOGRAPHY, ACCESS, AND FIELD METHODS

The study area is typical of the Interior Plateau, characterized by low-relief physiography, entirely below the treeline. Parts of the study area are accessible by provincial and municipal roads, but access is primarily via the regional network of logging roads and boat access from numerous lakes within the study area.

Thirty-six traverses were completed during June–August 1998 by the senior author to outcrops of Eocene rocks. Standard geological field mapping procedures were augmented by the use of global positioning systems to locate sites to within 50–100 m and the use of an Exploranium KT-9 Kappameter to obtain magnetic susceptibility measurements of units for correlation with potential geophysical data (Struik and MacMillan, 1996).

This report describes the composition and stratigraphy of the Ootsa Lake Group rocks observed regionally and within three study areas in the Nechako River map area. The following three areas of detailed study (Fig. 3) were chosen because they contained relatively extensive and continuous outcrop of units within the Ootsa Lake Group: 1) the Dayeezcha Mountain area in central-eastern part of Takysie Lake (NTS 93 F/13) and western Knapp Lake map areas (NTS 93 F/14), 2) Henson Hills area in north-central and eastern section of the Marilla map area (NTS 93 F/12), and 3) the Mackenzie Lake area, west-central portion of Cheslatta Lake map area (NTS 93 F/11). Samples were collected for additional studies at these sites and throughout the southern Fort Fraser and northern Nechako River map areas to provide regional coverage. Additional samples were collected from associated, presumably coeval, high-level plutons (e.g. Anderson and Snyder, 1998; Anderson et al., 1998; Barnes and Anderson, 1999; Sellwood et al., 1999).

Petrographical study, age dating, major and trace geochemical analyses, and isotopic tracer (Sr, Nd, Pb) studies are planned for subsets of the samples. Geochronological studies will involve U-Pb (on zircon) and/or Ar-Ar (on biotite) age dating to examine the timing, potential correlation, and duration of magmatic activity. A subset of samples collected for geochemistry will be analyzed for tracer isotopes, to investigate the role of crustal contamination in the origin of the Ootsa Lake Group. A suite of samples from the Newman volcanics (e.g. Villeneuve and MacIntyre (1997) and references therein) were also collected to compare their geochemical and isotopic compositions with the Ootsa Lake Group samples.

GEOLOGY

The Ootsa Lake Group consists of a heterogenous assemblage of felsic and less common intermediate volcanic flow and volcaniclastic rocks. The most abundant rock types described below characterize the regional distribution of the unit and the three study areas, Dayeezcha Mountain, Henson Hills, and Mackenzie Lake areas (Fig. 3), which themselves are distinguished stratigraphically.

Regional setting and composition of the Ootsa Lake Group

The regional geology of the northern Nechako River and southern Fort Fraser map areas is described by Struik et al. (1997), Wetherup (1997, 1998), and Anderson et al. (1998, 1999). The Ootsa Lake Group within the area is predominantly composed of rhyolite flows and domes, crystal and lithic-crystal tuff, pyroclastic and autoclastic breccia, and minor dacite and andesite flows. Approximately half of the Ootsa Lake Group consists of flows; subequal abundances of tuff and breccia are subordinate.

The predominant rock type is a generally red to white to grey, locally purple or green, flow-laminated rhyolite, which occurs as flows or less common domes and is widespread throughout the northern Nechako River map area. Outcrop-scale features include minor, locally rotated, rhyolite clasts (Fig. 4), primary flow folding, minor vesicles, perlitic or spherulitic textures, and minor lithophysae. Textures vary abruptly; for example, a unit may change from a flow-laminated rhyolite to rhyolite autobreccia within a few metres. Monolithic breccia containing flow-laminated clasts are generally found associated with rhyolite flows and domes. Generally the rocks are aphyric or sparsely plagioclase-phyric, and biotite, alkali feldspar, quartz, and/or rare hornblende are minor phenocryst phases.

Flow-layered or more massive rhyolite and rhyodacite flows also exhibit many of the same features in addition to microspherulites (Fig. 5) and locally abundant lithophysae. Flows are porphyritic (Fig. 6) to rarely aphyric. Several exposures of buff, flow-laminated rocks have black, glassy, perlitic flow bases (Fig. 7) which suggest the presence of shallow water at the time of extrusion.

Pyroclastic breccias are predominately unwelded to densely welded ignimbrite deposits, usually crystal rich, commonly containing lithic fragments and lesser portions of medium- to dark-grey pumiceous lapilli in a white to buff rhyolite, locally darker and glassy. Lithic fragments are angular, predominantly aphyric rhyolite and range in size from 1 cm to (more rarely) 40 cm. Black glass fragments are abundant in one locality. Autoclastic breccias are commonly moderately silicified and composed of flow-laminated rhyolite clasts (1–8 cm) in a slightly glassy, sparsely phyric matrix.

Rhyolite hyaloclastite is found on the west flank of Uncha Mountain (Fig. 8; *see also* Barnes and Anderson, 1999) and east of the Henson Hills area. Clasts are dark maroon to grey or black, glassy angular fragments of rhyolite, rarely exhibit a perlitic texture, and occur within a white to pale yellow rhyolitic matrix. Clast size varies from several centimetres up to 2 m at one locality. The most widespread type of breccia is a lapillistone with angular tuffaceous or flow-laminated rhyolite clasts in a glassy grey or tuffaceous rhyolitic matrix.

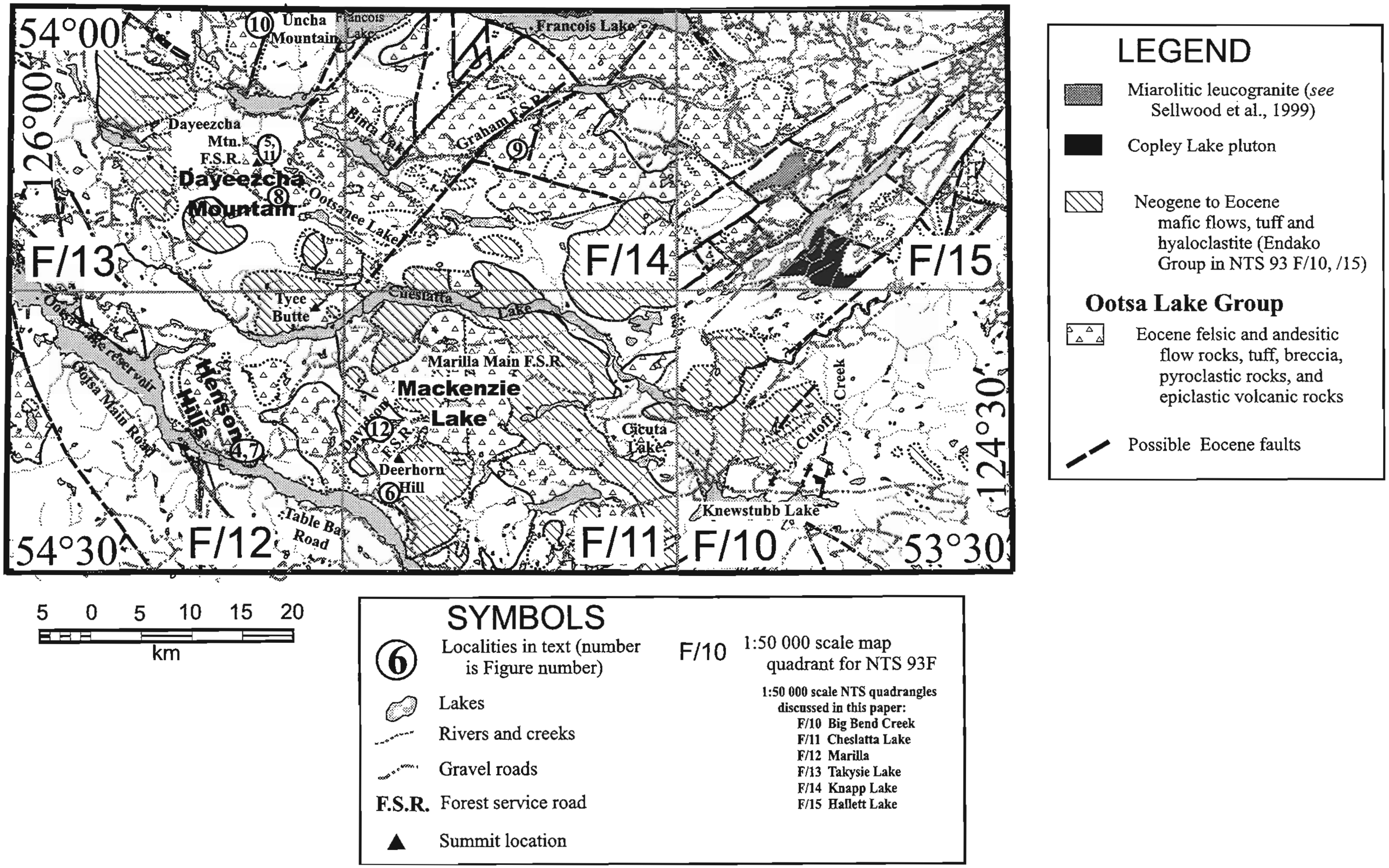

Figure 3. *Location of study areas mentioned in text (from Williams, 1997; Anderson et al., 1998; Barnes and Anderson, 1999; Sellwood et al., 1999; and R.G. Anderson, unpub. data, 1998).*

Similar units with a tuffaceous rhyolitic matrix and a more heterolithic clast assemblage are found in the Knapp Lake and Marilla map areas (93 F/14 and 93 F/12). Other distinctive types of breccia found regionally characterize the particular study areas described below.

Rhyolitic crystal tuff is generally 'punky' (i.e. friable, and commonly altered to clay) and may contain biotite, alkali feldspar, quartz, and/or plagioclase crystals. Tuff is generally unwelded to locally partly welded. Lithic crystal tuff resembles the crystal tuff, but contains sparse to abundant andesite or rhyolite clasts. Uncommonly, the lithic crystal tuff exhibits bedding, likely indicating reworking (Fig. 9), and in two localities was found to contain wood fragments. North of the Ootsa Lake reservoir, an erosional contact found between a crystal tuff and an underlying lithic breccia (Fig. 10) may represent an intraformational unconformity. At one locality, the bedded tuff appears to conformably underlie a green vesicular andesite flow with amethyst-calcite amygdules. The andesite member is interpreted to be the basal member of the Ootsa Lake Group within the study area (e.g. Anderson et al., 1999).

Distinct rhyolite ash-lignite interbeds are found at the Fraser Lake railway outcrop (Struik et al., 1997), Cheslatta Falls and Nautley Creek quarry localities (*see* Haskin et al., 1998 for location and details), and near Burns Lake (L. Struik, pers. comm., August 1998). The interbeds are commonly found immediately underlying basaltic andesite flows of the Endako Group and mark the top of the Ootsa Lake Group in these areas.

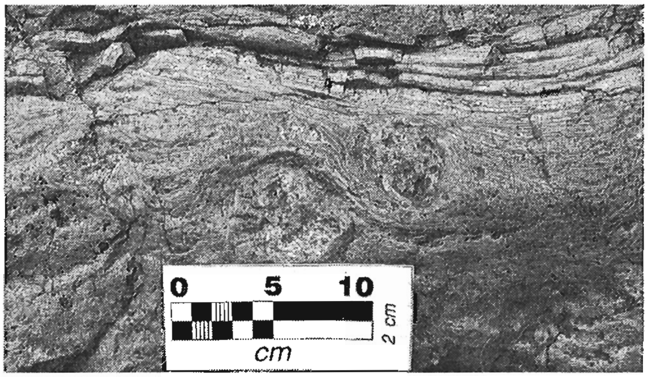

***Figure 4.** Flow-laminated rhyolite with rotated clasts on Marilla main forest service road, north of Ootsa Lake reservoir.*

***Figure 5.** Spherulites in rhyolite flow north of Dayeezcha Mountain.*

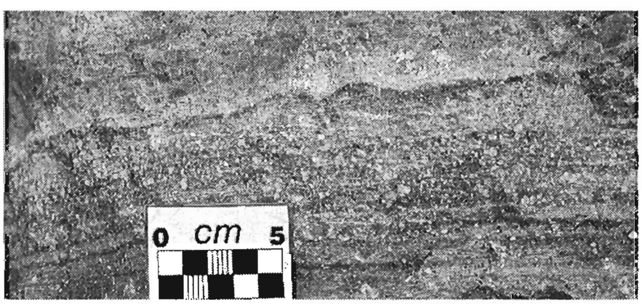

***Figure 6.** Flow-layered crystal-rich rhyolite near Deerhorn Hill.*

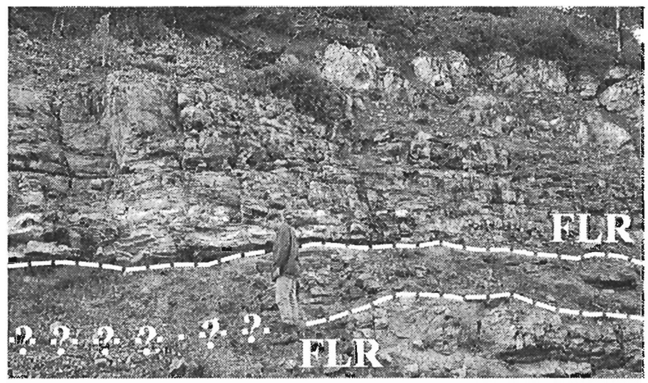

***Figure 7.** Flow-laminated rhyolite with black glassy perlitic flow base (to right of person) intercalated with flow-laminated rhyolite (FLR). Person is approximate 1.8 m high.*

***Figure 8.** Rhyolite hyaloclastite on Uncha Mountain.*

Dayeezcha Mountain area

Dayeezcha Mountain is a distinctive landmark and rises to an elevation of more than about 1170 m (3800 feet). It is underlain by a glassy, biotite-plagioclase-bearing, dacitic crystal ignimbrite containing partly welded clasts of flow-laminated rhyolite and tuffaceous rhyolite. Locally pyroclastic rocks include welded ignimbrite (Fig. 11), silicified green ash, tuffaceous rhyolite lapillistone, rhyolitic tuff, and crystal tuff.

Rhyolitic to dacitic flows interlayered with pyroclastic breccia and tuff occur in the immediate environs. Individual flows are 5–20 m thick. Flows contain spherulites, microspherulites, and/or lithophysae and common quartz, plagioclase, alkali feldspar, and biotite phenocrysts.

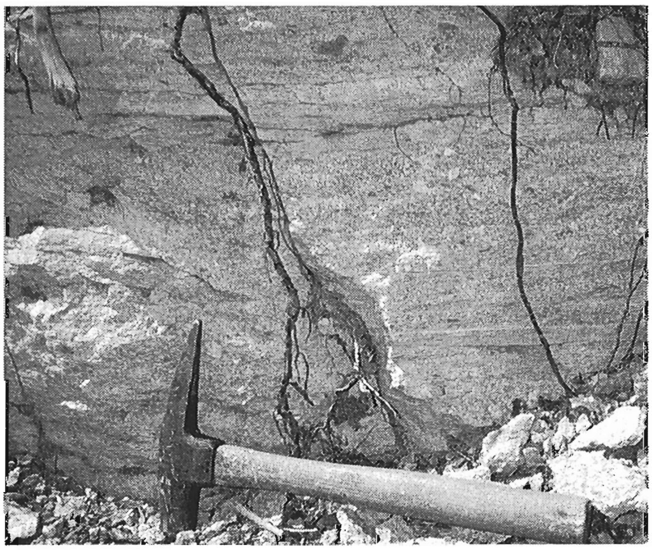

***Figure 9.** Bedded rhyolite crystal lithic tuff indicating likely reworking on Graham forest service road.*

***Figure 10.** Erosional contact between crystal rhyolite tuff and underlying lithic breccia at locality between Dayeezcha Mountain and Ootsanee Lake.*

Outcrops distal from Dayeezcha Mountain are predominantly white and red or light grey, flow-laminated rhyolite with local spherulites, vesicles, primary folding of flow laminae, and associated autoclastic breccia. Minor lithic tuff and flow-layered rhyolitic biotite-quartz-plagioclase porphyry flows are also distal from Dayeezcha Mountain.

Henson Hills area

Ootsa Lake Group rocks outcrop extensively in Henson Hills and are in fault contact with Lower to Middle Jurassic sedimentary rocks to the east and possibly unconformably overlain by a series of (hornblende-)plagioclase-phyric andesite, basalt breccia, and vesicular basalt flows to the west. From east to west across Henson Hills, a sequence of tuff, pyroclastic breccia, and flows occurs. Rhyolitic biotite-alkali feldspar-quartz porphyry crystal tuff is conformably overlain by a series of pyroclastic breccia units.

The pyroclastic breccia varies in content from rhyolite tuff clasts in a glassy matrix, and minor crystal ash layers, to a partly welded, rhyolite breccia with glassy, dark maroon to grey biotite rhyolite which locally contains green tuffaceous clasts. The nature of the contact between breccia and the flows is uncertain.

Flow units comprise flow-laminated rhyolite, some with black glassy flow bases up to 1 m thick. Some flows display primary folding. They are generally aphyric or contain sparse biotite, plagioclase, and/or quartz phenocrysts. Minor flow-layered, massive rhyolite and rhyodacite flows north of flow-laminated rhyolite contain vesicles, primary folding, sparse plagioclase and rare quartz and biotite phenocrysts, and rhyolitic clasts with minor perlitic textures.

A crystal-rich, rhyolitic ignimbrite which contains abundant coarse-grained biotite, quartz, and plagioclase phenocrysts underlies an area of 1.3 km^2 and at least 80 m of vertical exposure. The ignimbrite typically contains light grey, aphyric, tuffaceous rhyolite clasts but to the north becomes glassy and includes cleaved biotite andesite clasts. The unit may represent the site of an eruptive centre.

***Figure 11.** Pyroclastic welded breccia with chilled rims on clast shown on Dayeezcha Mountain Road.*

Mackenzie Lake area

Rocks of the Ootsa Lake Group within the Mackenzie Lake area are in fault contact with Jurassic Hazelton Group volcanic rocks. They may be locally overlain by Eocene or younger hornblende-bearing andesite flows, likely of middle to late Eocene age, and Neogene basalt hyaloclastite and pyroxene-olivine basalt. The Ootsa Lake Group assemblage within this area is typical: abundant flow-laminated rhyolite, flow-layered or massive rhyolite flows, crystal and lithic-crystal tuff, and tuffaceous rhyolite breccia. The last overlies flow-laminated rhyolite. A welded ignimbrite with eutaxitic texture (Fig. 12), which overlies a reversely graded sequence of green heterolithic tuff, characterizes the study area. Pyroclastic breccia is rare or absent in the area. At two localities, the green amygdaloidal andesite unit with minor amethyst-filled vesicles (Fig. 13) underlies glassy flow-layered and flow-laminated rhyolite.

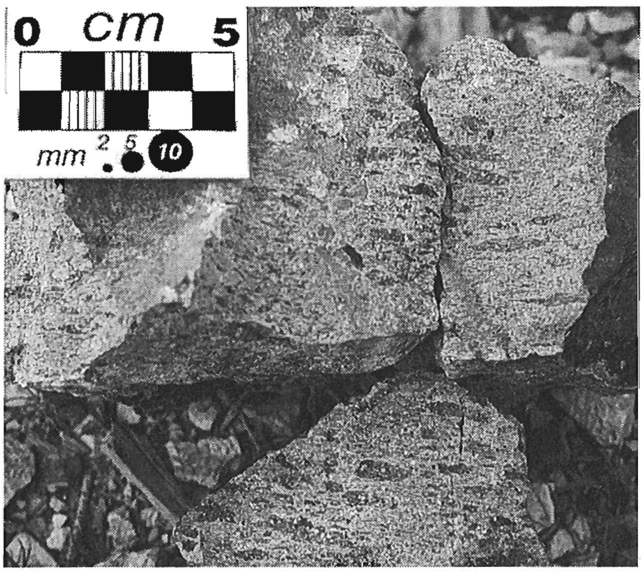

Figure 12. *Eutaxitic texture in welded ignimbrite on Davidson forest service road.*

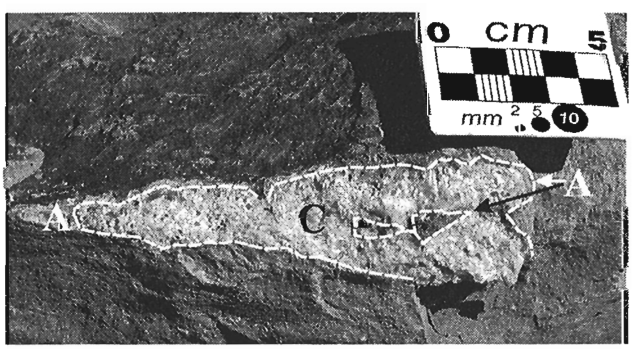

Figure 13. *Amethyst-bearing (A) and calcite-bearing (C) amygdules in hand sample of basal andesite unit from Graham forest service road. Dashed line marks contact between outer amethyst and inner calcite fillings.*

Plutonic rocks

Seriate or equigranular and miarolitic plutonic rocks and aphanitic to porphyritic hypabyssal intrusions make up at least three varieties of undated, commonly fault-bounded, felsic to bimodal intrusions which are co-spatial with the Ootsa Lake Group, and locally so strongly resemble the volcanic rocks in mineralogy and geochemical composition they are considered potentially cogenetic (Anderson and Snyder, 1998; Anderson et al., 1998; Barnes and Anderson, 1999; Sellwood et al., 1999). The most extensive and perhaps deepest level is the medium-grained, seriate, bimodal Copley Lake pluton which comprises biotite monzogranite, uncommon andesitic hornblende-plagioclase porphyry, and a variety of minor felsic porphyritic and intrusive breccia phases.

Possibly higher level but smaller plutons include leucocratic, fine- to medium-grained, equigranular granite to syenite with characteristic miarolitic cavities and associated porphyritic phases. The mineralogy and texture of the porphyry strongly resembles that of the nearby Ootsa Lake Group country rocks (Sellwood et al., 1999).

At Uncha Mountain, Tertiary faulting and associated small-scale deformation was important in the localization of synkinematic, high-level, aphanitic porphyry and miarolitic granite intrusions and hydrothermal alteration (Barnes and Anderson, 1999).

STRUCTURE

Flow-laminated rhyolite units throughout the study areas have dip magnitudes which range from 3–90°. Field evidence for synvolcanic faulting or fault control of volcanism is less obvious than that responsible for localizing younger Endako Group flows within the Big Bend Creek map area (NTS 93 F/10; Anderson et al., 1998) or higher level, cogenetic intrusions as at Uncha Mountain (Barnes and Anderson, 1999) and Hallett Lake map area (Anderson and Snyder, 1998; Anderson et al., 1998; Sellwood et al., 1999).

CONCLUSIONS

The Ootsa Lake Group within the northern Nechako River and southern Fort Fraser map areas mainly consists of felsic flows with tuff, pyroclastic breccia, and minor intermediate to mafic flows. Cospatial intrusions include aphanitic or porphyritic rhyolite, miarolitic leucogranite, and seriate biotite monzogranite.

The local development of thin lignite beds, black glassy quenched flow bases and reworking of some lithic rhyolite tuff suggest the presence of shallow water at the time of eruption and deposition.

The assemblage is distinct from that identified in the Whitesail Lake map area by Diakow and Koyanagi (1988) and Drobe (1991) which consisted of a series of generally more intermediate to mafic flows and tuff. Drobe (1991) suggested that the paucity of pyroclastic and epiclastic breccia in the Whitesail Range indicated little topographic relief existed during volcanism and that eruptions occurred onto a plateau. The differences in rock type and composition may be attributable to a different eruptive style, timing, structural setting, and/or magmatic source(s).

Further study will focus on establishing the relative timing of Ootsa Lake Group volcanism and related plutonism, and on obtaining and interpreting petrographic, geochronological, geochemical, and tracer isotope data to constrain the petrogenesis of the Eocene felsic magmatism. These data will enable comparison with other coeval volcanic rocks to better understand the distribution and nature of Eocene magmatism and its tectonic setting in central British Columbia.

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Geological Survey of Canada Project 950036-04

Geology of two high-level Tertiary granite plutons, northern Nechako River map area, central British Columbia[1]

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Sellwood, S.M., Snyder, L.D., and Anderson, R.G., 1999: Geology of two high-level Tertiary granite plutons, northern Nechako River map area, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 149–156.*

Abstract: Two high-level, felsic plutons in the northern Nechako River map area, suspected to be the plutonic equivalent to the Eocene Ootsa Lake Group felsic volcanic rocks, were mapped in detail and systematically sampled for geochemical and petrographic analyses and for U-Pb dating. Leucocratic equigranular granite to syenite with characteristic miarolitic cavities dominates over porphyritic phases with a variety of mineralogies and textures. Mesozoic to Tertiary country rock includes Middle Jurassic plutonic rocks, Lower to Middle Jurassic volcanic and volcaniclastic rocks, and Tertiary felsic volcanic rocks, suggesting a Tertiary age for the plutons. Field relationships and similarities in composition and texture with the Eocene Ootsa Lake Group volcanic and volcaniclastic rocks widely exposed in the Nechako River area suggest a genetic relationship. Ongoing geochemical, petrographic, and geochronological analyses will provide further information about the paragenesis, composition, age, and tectonic affinity of the plutons.

Résumé : Deux plutons felsiques de niveau crustal supérieur situés dans la partie nord de la région cartographique de la rivière Nechako, qui seraient le pendant plutonique des roches volcaniques felsiques du groupe éocène d'Ootsa Lake, ont été cartographiés dans le détail et échantillonnés systématiquement pour analyses géochimiques et pétrographiques et datation U-Pb. Des granites et syénites isogranulaires leucocrates contenant des miaroles caractéristiques, de compositions minéralogiques et de textures diverses, prédominent sur les phases porphyriques. Les roches encaissantes mésozoïques–tertiaires comprennent des roches plutoniques du Jurassique moyen, des roches volcaniques et volcanoclastiques du Jurassique inférieur à moyen et des roches volcaniques felsiques du Tertiaire, ce qui situerait l'âge des plutons dans le Tertiaire. Il existerait un lien génétique entre ces plutons et les roches volcaniques et volcanoclastiques du groupe éocène d'Ootsa Lake qui affleurent sur de vastes étendues dans la région de Nechako, à en juger par les relations observées sur le terrain et la similarité entre leur composition et leurs textures. Les analyses géochimiques, pétrographiques et géochronologiques en cours fourniront un complément d'information sur la paragenèse, la composition, l'âge et l'affinité tectonique des plutons.

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INTRODUCTION

Recent mapping conducted as part of the Nechako NATMAP Project (Fig. 1) has shown that Eocene (ca. 50 Ma) Ootsa Lake Group intermediate to felsic volcanic and volcaniclastic rocks are widespread throughout much of the region (Anderson et al., 1997; Diakow et al., 1997; Struik et al., 1997; Williams, 1997; Anderson and Snyder, 1998; Anderson et al., 1998; Whalen et al., 1998). Reconnaissance mapping in 1997 identified small felsic intrusions in the Hallett Lake (NTS 93 F/15) and Knapp Lake (NTS 93 F/14) map areas (Anderson et al., 1997; Anderson and Snyder, 1998; R.G. Anderson, L.D. Snyder, N. Hastings, S. Wetherup, R. L'Heureux, and L.C. Struik, unpub. map manuscript, 1998; Anderson et al., 1999). The intrusions were thought to be Tertiary, possibly associated with the Ootsa Lake Group, and were distinguished from the Mesozoic plutonic basement rocks in the region by their grain size, porphyritic nature, and miarolitic cavities. Nonetheless, the age, geological relationships, and composition of the Tertiary plutons are not firmly established. Other examples of these high-level plutons are widespread in the Nechako River area (e.g. in the Uncha Mountain area; Barnes and Anderson, 1999); this study is intended to provide a reference area for this style of plutonism.

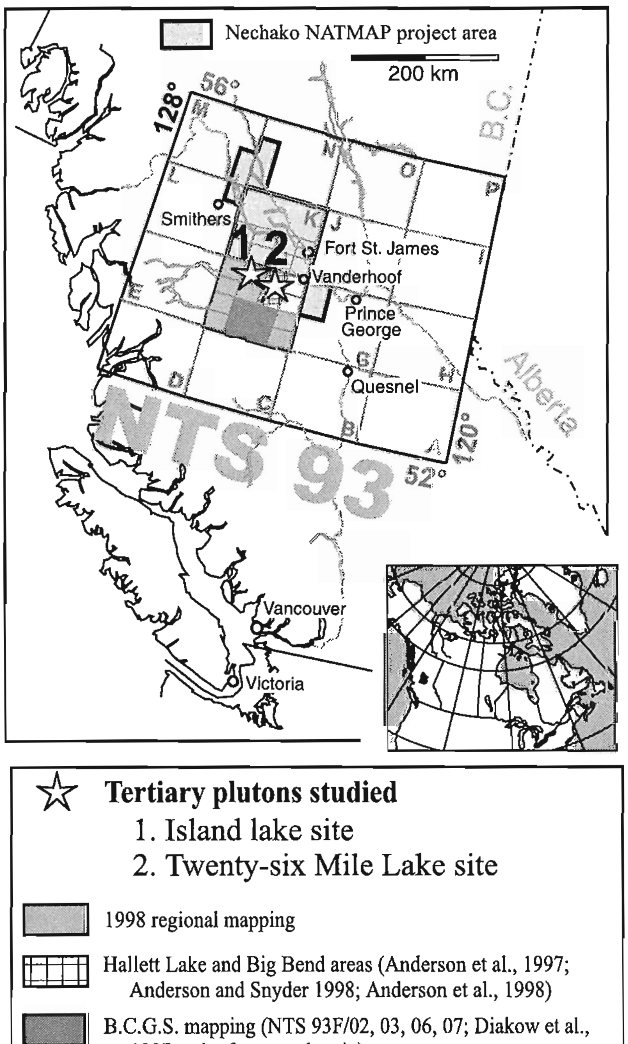


***Figure 1.** Location of the study areas in the Hallett Lake (NTS 93 F/15) and Knapp Lake (NTS 93 F/14) map areas within the Nechako NATMAP project area.*

This study presents results of recent mapping of two of these intrusions and study of their intrusive relationships, macroscopic textural evaluation, and internal variability. Samples were systematically collected for petrographic and geochemical analyses that are underway as part of a baccalaureate study.

The first of the two study areas is located west of Twenty-six Mile Lake near the centre of the Hallett Lake map area. The second is west of informally named 'Island' lake in the northwest part of the Knapp Lake map area (Fig. 1). Results of this study and follow-up U-Pb geochronology will more accurately define the nature and distribution of Tertiary magmatism within the Nechako NATMAP project area.

PHYSIOGRAPHY, ACCESS, AND FIELD METHODS

The study areas are heavily wooded and are typified by rolling low-relief Interior Plateau physiography. Numerous logging roads provided access but exposure is generally poor (approximately 5%).

New geological data presented here are derived from nine traverses completed during July 1998. Standard geological mapping techniques were supplemented by global positioning system measurements taken at each station, providing a geographic precision in station location of 50–100 m. Magnetic susceptibility (m.s.) measurements were routinely obtained at each outcrop over a five minute period using a hand-held Exploranium KT-9 Kappameter and are an average of at least five measurements. Representative samples were collected from each of the phases within the individual plutons for use in petrographic and geochemical studies as well as one sample from each pluton collected for dating by U-Pb methods.

GEOLOGY

Regional geology

The regional geological setting of the two study areas were given in Anderson et al. (1997) and Anderson and Snyder (1998) for the Twenty-six Mile Lake study area and by Anderson et al. (1999) for the 'Island' lake site. Bedrock in the Hallett Lake map area consists dominantly of Mesozoic intrusive suites which are unconformably overlain by Tertiary volcanic rocks of the Ootsa Lake and Endako groups. In Knapp Lake map area, Mesozoic intrusive rocks are subordinate to Lower to Middle Jurassic Hazelton Group

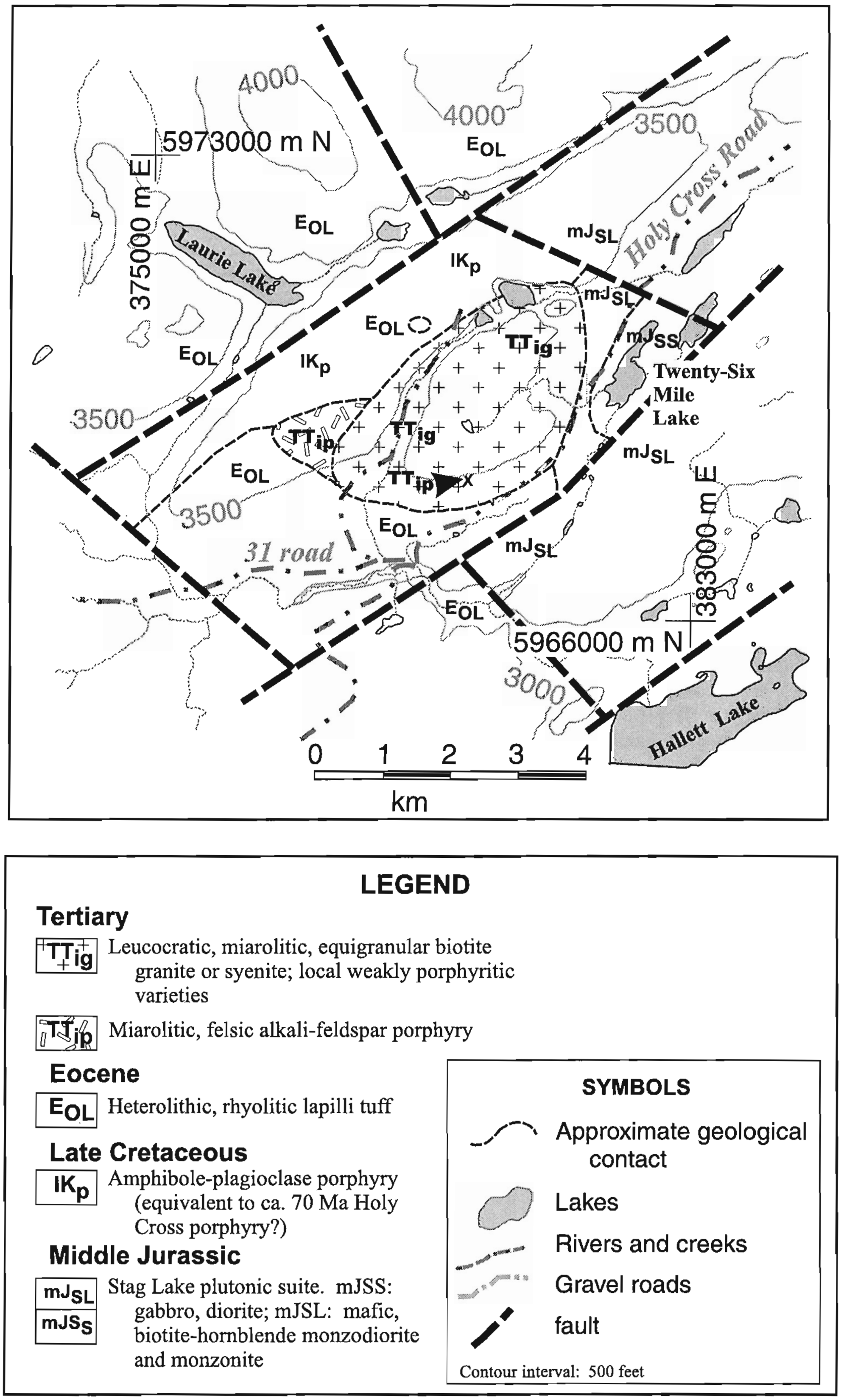


Figure 2. Geological map of the Twenty-six Mile Lake pluton in the Hallett Lake map area. Country rock geology from this study and R.G. Anderson, L.D. Snyder, N. Hastings, S. Wetherup, R. L'Heureux, and L.C. Struik (unpub. map manuscript, 1998).

volcanic and volcaniclastic rocks and possible Cretaceous volcanic rocks and these rocks are similarly overlain by a thin carapace of Tertiary volcanic rocks (Anderson et al., 1999).

Twenty-six Mile Lake site

The Twenty-six Mile Lake pluton underlies an area of approximately 9 km^2 in western Hallett Lake map area and consists of equigranular and a variety of porphyritic phases (Fig. 2). It intruded rocks of the Middle Jurassic Stag Lake-Twenty-six Mile plutonic suite (Anderson et al., 1997) to the east and northeast. To the northwest, the pluton intruded both amphibole-plagioclase porphyry of possible Cretaceous age and felsic crystal lapilli tuff of the Eocene Ootsa Lake Group. Lack of exposure south of the pluton precludes identification of the country rock, although felsic volcanic rocks of the Ootsa Lake Group are exposed a few kilometres away.

Pink, leucocratic, equigranular, medium-grained granite to syenite is the dominant lithology (Fig. 3). Grain size varies between 0.5 and 3 mm (average about 2 mm). Equant, subhedral plagioclase and alkali feldspar and anhedral quartz occur in subequal proportions. Locally, the granite is weakly porphyritic with elongate alkali-feldspar crystals reaching lengths of 4–5 mm, and, elsewhere, contains 1–3%, subhedral grains or anhedral clots of biotite 1–2 mm across. Sparse (1–3%), disseminated euhedral to subhedral, equant to elongate magnetite grains 1 mm in size also occur. The rock is generally fresh but locally is deeply weathered. Earthy, orange iron oxide is commonly associated with fractures and cavities.

Miarolitic cavities are characteristic of this equigranular granitic phase and vary in size and abundance (5–10%) throughout. The cavities are slightly elongate and range in length from 1 mm to 1 cm, but their size is uniform on an outcrop scale. Smaller cavities (1–4 mm) are typically completely filled with secondary minerals but larger ones (5–10 mm) are only partly filled. The secondary minerals are dominantly euhedral, alkali feldspar altered to clay, less common euhedral quartz, and rare muscovite. In outcrop, many of the miarolitic cavities are commonly rimmed by a zone of iron oxide.

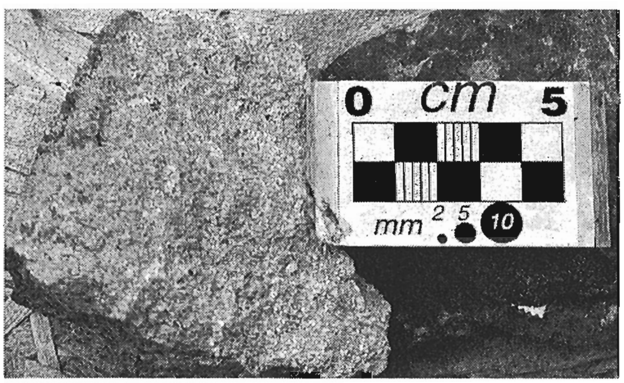


***Figure 3.** Hand sample (to left of scale card) of leucocratic, equigranular granite phase of the Twenty-six Mile Lake locality with characteristic miarolitic cavities.*

Three porphyritic rock units are spatially associated, and compositionally and texturally similar to the dominant equigranular granitic phase of the pluton. In the southern part of the pluton an isolated outcrop of porphyry comprises 10% subhedral alkali feldspar (2–4 mm), 10% square to rounded quartz (2 mm in size), and minor (1%) subhedral biotite phenocrysts (1–2 mm) in a pink, microcrystalline groundmass. Also in the southern part of the pluton is an areally more extensive porphyry phase composed of 15–20%, subhedral alkali feldspar (1–4 mm), locally with biotite cores, in a pink-grey aplitic groundmass (Fig. 4). A gradational contact was observed between this porphyritic unit and the equigranular granite.

Another porphyritic phase (unit TTip on Fig. 2) outcrops along the southwestern edge of the pluton. It is composed of 10%, subhedral, alkali-feldspar phenocrysts (1–3 mm in size) in a light purple groundmass. Miarolitic cavities, 1–2 mm across, are ubiquitous, although they form only a minor part (1–3%) of the rock.

Outcrops of this pluton are usually massive and structurally featureless. Structures within this pluton are limited to a scattered, south-southeast-trending vertical jointing with a spacing of 5 cm to 1 m. Locally, in severely weathered outcrops, a horizontal exfoliation fabric dominates.

Three rock units make up the country rocks. On the northwest side of the pluton an amphibole and plagioclase porphyritic andesite is exposed. This rock is compositionally and texturally similar to the Holy Cross porphyry to the southwest, dated at 70.3 ± 3.0 Ma (K-Ar by R. Friedman *in* Lane and Schroeter, 1997). The amphibole plagioclase porphyritic andesite is cut by a 1–2 m aplite dyke that may be related to the pluton.

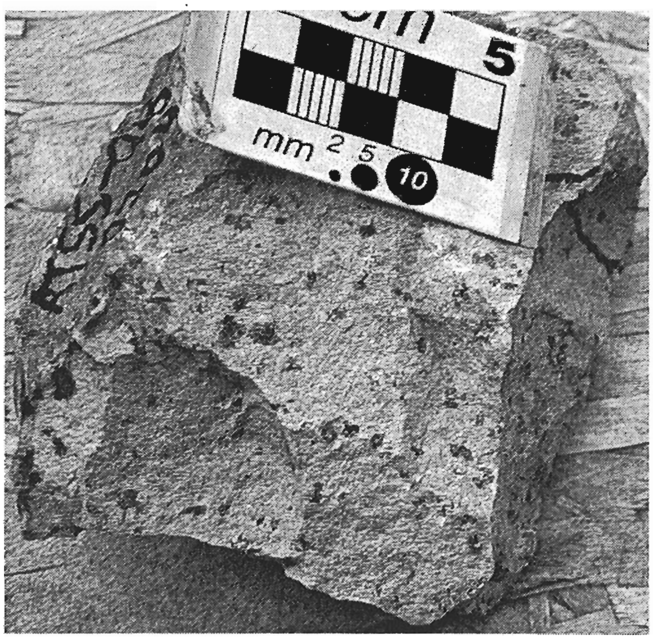
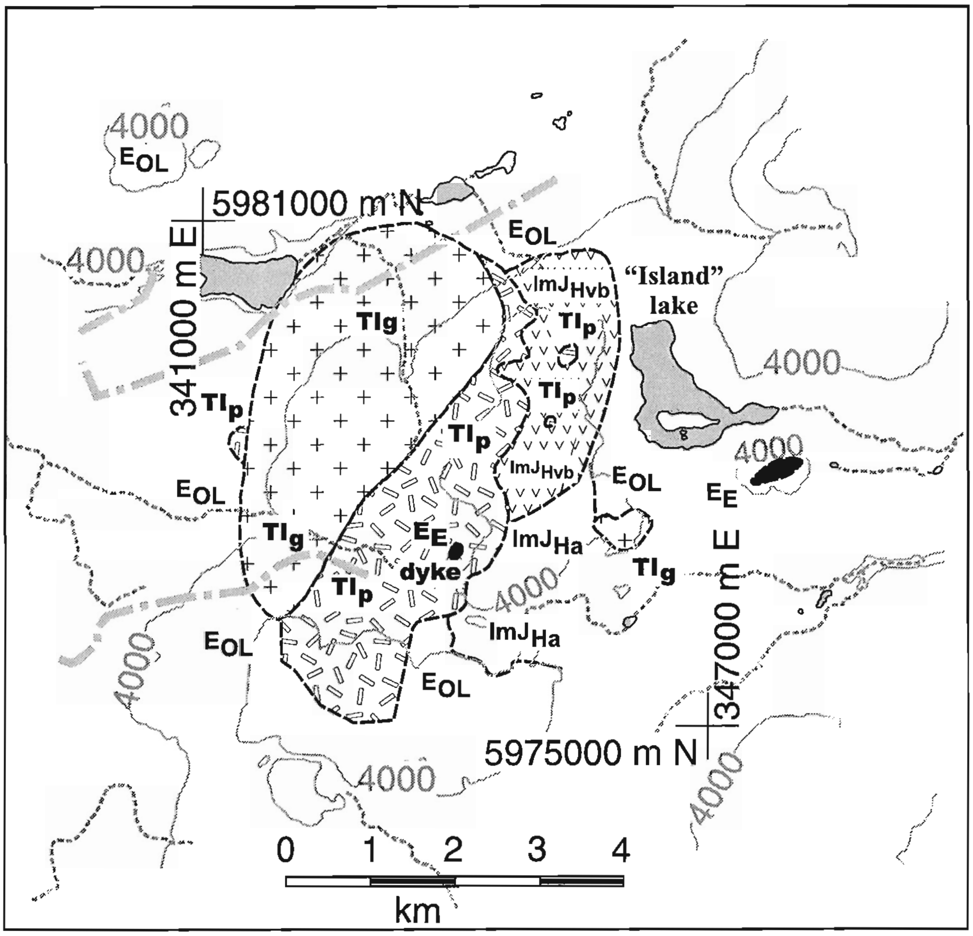


***Figure 4.** This porphyritic phase of the Twenty-six Mile Lake pluton is gradational with the dominant equigranular portion of the pluton. Phenocrysts are alkali feldspar cored by biotite.*



LEGEND

Tertiary

Eocene

Endako Group

EE (Olivine?) clinopyroxene-plagioclase phyric basaltic andesite flows and associated dykes

Island lake pluton

Tlg Pink, leucocratic, miarolitic, equigranular biotite granite or syenite; local weakly porphyritic varieties

Tlp Miarolitic, felsic alkali-feldspar porphyry

Ootsa Lake Group

EOL Flow-layered plagioclase or hornblende-phyric rhyolite and dacite; minor volcanic conglomerate

Jurassic

Hazelton Group

lmJHvb Volcanic breccia

lmJHa Plagioclase porphyry andesite

SYMBOLS

Approximate geological contact

Lakes

Rivers and creeks

Gravel roads

Contour interval: 500 feet

Figure 5. Geological map of the 'Island' lake pluton in western Knapp Lake map area. Country rock geology from this study and Anderson et al. (1999).

A mafic monzonite to monzodiorite occurs on the eastern side of the pluton. This unit is typically equigranular (grain size mostly 1–3 mm) and contains subhedral plagioclase, alkali feldspar, and amphibole (20–45%) as well as scattered, euhedral biotite (1–2 mm). Disseminated pyrite and fine grained dioritic xenoliths are typical. An aplite dyke intrudes this unit.

Ootsa Lake Group rocks can be found to the northwest of the pluton and comprise lapilli tuff containing 5–30% angular to subangular clasts of felsic and mafic volcanic rocks in a quartz-bearing tuffaceous matrix.

'Island' lake site

The 'Island' lake pluton underlies a 12 km^2 area west of 'Island' lake in the northwestern portion of the Knapp Lake map area (Fig. 5). To the east, this body intrudes volcanic and volcaniclastic rocks of the Lower to Middle Jurassic Hazelton Group and, to the west, volcanic and volcaniclastic rocks of the Ootsa Lake Group.

Highly weathered, pink, equigranular, medium-grained granite dominates the pluton (Fig. 6). Subhedral plagioclase and alkali feldspar and anhedral quartz occur in subequal abundances and range in size from 1–3 mm. Locally, alkali feldspar forms euhedral phenocrysts up to 4 mm across. The granite is leucocratic except for rare (1–3%) disseminated magnetite. Alkali feldspar is commonly altered to clay minerals and secondary epidote is a common alteration product of plagioclase.

Miarolitic cavities characterize the pluton and make up as much as 10% of the rock. The cavities are generally slightly elongate and range from 1–10 mm in length but are consistent in size at an outcrop. Secondary minerals which fill the cavities include euhedral alkali feldspar and quartz, subhedral magnetite, and rare fluorite. The cavities are typically rimmed with iron oxide.

A porphyritic phase, similar in composition to the granite phase makes up 40% of the pluton (Fig. 7). It is grey to white and typically consists of alkali feldspar and quartz phenocrysts in a felsic groundmass. Alkali feldspar forms 2–5 mm subhedral grains and comprises 5–25 % of the rock. Quartz is

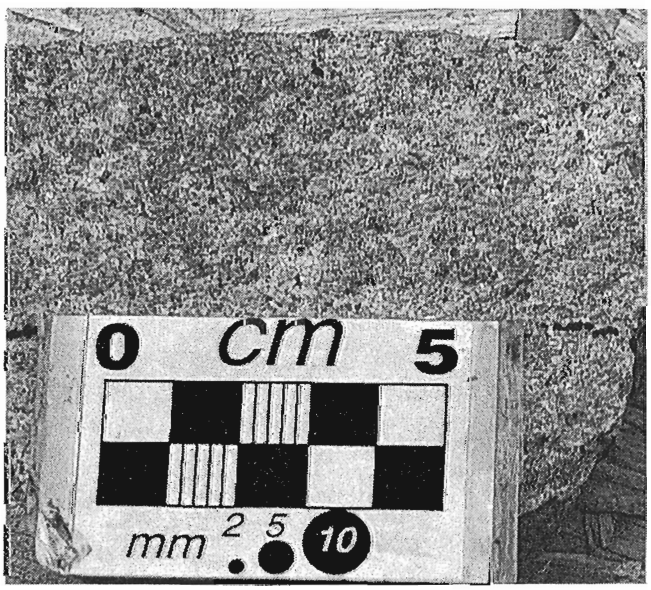


Figure 6. Hand sample of the leucocratic equigranular granite phase of the 'Island' lake pluton.

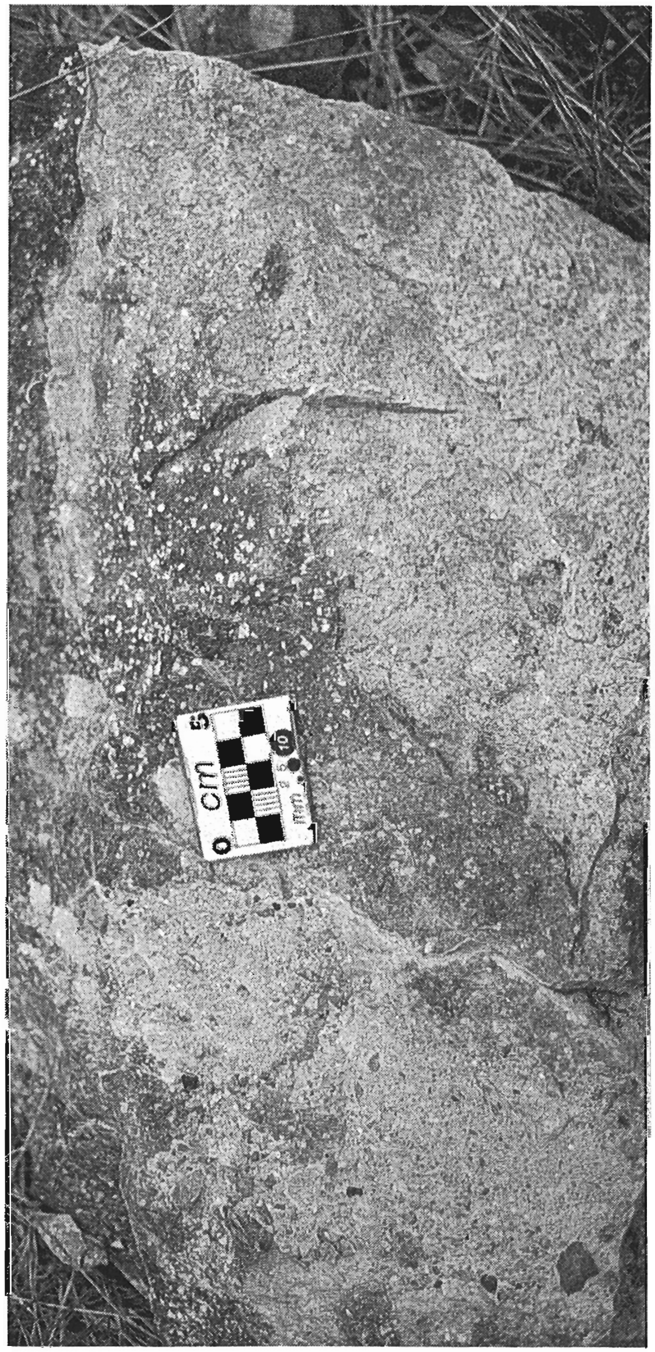


Figure 7. Outcrop view of the porphyritic phase of the 'Island' lake pluton. Phenocrysts are alkali feldspar.

typically found as subhedral grains (1–2 mm) and in 5–10% abundances. The groundmass is light grey in the freshest samples, but weathers to a light grey to white. Scattered, disseminated magnetite accounts for less than 3% of the rock.

The porphyritic phase of the granite is abundant on the eastern side of the pluton, where the pluton has intruded Lower to Middle Jurassic Hazelton Group volcanic and volcaniclastic rocks along a sharp but not fine-grained margin. A few granitic dykes, 1–5 m wide, are distributed up to 0.5 km from the contact. These dykes are mineralogically and texturally similar to either the equigranular phase or porphyritic phase of this pluton.

The generally massive nature of the pluton is disrupted only by a weak north-trending, subvertical fracture cleavage.

Mesozoic and Tertiary country rock units are recognized in this area. Hazelton Group rocks are typical of those found regionally (e.g. Anderson et al., 1999) and consist of aphanitic to plagioclase porphyritic andesite and volcanic breccia with abundant epidote and calcite alteration. Along the western and northeastern margins of the pluton, Ootsa Lake Group volcanic rocks are found in close proximity to the miarolitic granite. The volcanic rocks consist of aphanitic flow-layered rhyolite, hornblende- or plagioclase-phyric rhyolite and dacite and minor volcanic conglomerate. Layering is less than 1 cm thick and the rock has undergone intense clay alteration. Minor disseminated pyrite was observed.

In the southeastern corner of the pluton, an isolated outcrop of dark grey aphanitic basalt is found. Based upon the limited extent of outcrop and the known geological relationships in the area, this unit is interpreted as a dyke, possibly associated with the Eocene Endako Group.

CONCLUSION

Two compositionally and texturally similar felsic, possibly Tertiary intrusions in the Nechako River map area (the Twenty-six Mile Lake and 'Island' lake localities) intrude Mesozoic and Tertiary country rock including Middle Jurassic plutonic rocks, Lower to Middle Jurassic volcanic and volcaniclastic rocks, and Tertiary felsic and mafic volcanic rocks. The plutons consist dominantly of leucocratic, equigranular, miarolitic, medium-grained granite, but also contain minor porphyritic phases. Sparse biotite and magnetite are the only mafic minerals. The Twenty-six Mile Lake locality contains minor muscovite while the 'Island' lake locality contains rare fluorite and epidote alteration. These intrusive rocks are compositionally similar and spatially associated with felsic to intermediate volcanic and volcaniclastic rocks of the Eocene Ootsa Lake Group. Deformation in the plutons is limited to poorly developed joints.

The plutons are distinguished from the well studied, older plutonic rocks in the Nechako area by the presence of associated porphyritic rocks of similar composition and miarolitic cavities. The cavities indicate a shallow level of emplacement of a volatile-rich magma. Secondary minerals within the cavities include euhedral alkali feldspar and quartz with rare muscovite.

Geochemical analysis of representative samples collected from each of the plutonic phases is expected to accurately reflect the magma composition, define the geochemical character of the plutons relative to potential coeval volcanic rocks, and potentially discern the tectonic affinity of these plutons because there is no field evidence of contamination of these magmas (e.g. absence of xenoliths, homogeneous texture throughout).

ACKNOWLEDGMENTS

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Neogene basaltic flow rocks, xenoliths, and related diabase, northern Nechako River map area, central British Columbia[1]

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Resnick, J., Anderson, R.G., Russell, J.K., Edwards, B.R., and Grainger, N.C., 1999: Neogene basaltic flow rocks, xenoliths, and related diabase, northern Nechako River map area, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p 157–167.*

Abstract: Eleven remnant basaltic and diabasic volcanic centres, lava flow(s?), and a dyke related to Miocene(?) Chilcotin Group magmatism occur in the northern Nechako River map sheet (NTS 93 F). The centres are preserved as moderate topographic highs and range in area between 200 m^2 and 1 km^2. Well developed, vertical to subvertical columnar jointing is typical. Some centres erupted along pre-existing brittle fault systems. Related basalt lava flows unconformably overlie rare saprolite-grus horizons developed in granitic basement rocks.

The rocks are rarely amygdaloidal or vesicular and contain some or all of the following: megacrysts of olivine, pyroxene, plagioclase, and/or magnetite; xenocrysts of olivine and/or pyroxene; and phenocrysts of plagioclase, pyroxene, and/or biotite.

Xenoliths distinguish the centres and locally occur within lava flows. Mantle xenoliths include medium-grained lherzolite containing olivine, chromian diopside, orthopyroxene, magnetite, and spinel. Less common crustal xenoliths include gabbro, granite, and granulite. Both xenolith types exhibit millimetre- to centimetre-scale layering.

Résumé : Onze lambeaux de centres volcaniques basaltiques et diabasiques, une ou des coulées de lave et un dyke apparenté au magmatisme du Groupe de Chilcotin du Miocène(?) figurent sur la partie septentrionale de la coupure de la rivière Nechako (SNRC 93 F). Les centres sont conservés sous forme de hauteurs modérées et s'étendent sur 200 m^2 à 1 km^2. Une prismation verticale à subverticale bien développée y est typique. Certains centres ont fait éruption le long de systèmes de failles cassantes préexistants. Des coulées de lave basaltique associées reposent en discordance sur de rares horizons de saprolite-grus formés dans des roches granitiques du socle.

Les roches, rarement amygdaloïdes ou vacuolaires, renferment une partie ou la totalité des éléments suivants : mégacristaux d'olivine, de pyroxène, de plagioclase et/ou de magnétite; xénocristaux d'olivine et/ou de pyroxène; et phénocristaux de plagioclase, de pyroxène et/ou de biotite.

Les xénolites différencient les centres et se rencontrent par endroits dans des coulées de lave. Les xénolites mantelliques comprennent de la lherzolite à grain moyen renfermant de l'olivine, du chromdiopside, de l'orthopyroxène, de la magnétite et du spinelle. Les xénolites crustales, plus rares, contiennent du gabbro, du granite et de la granulite. Les deux formes de xénolites présentent une stratification millimétrique à centimétrique.

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INTRODUCTION

Regional-scale bedrock mapping and detailed topical studies continued in the northern half of the Nechako River map area in 1998 as part of the ongoing revision of the Nechako River (93 F) 1:250 000 scale geological map (Tipper, 1963) under the Nechako NATMAP program (Fig. 1).

The northern Nechako River map area is underlain by basaltic rocks formerly included in the Endako Group (Tipper, 1963). Recent results from the Nechako NATMAP program suggest that the Endako Group, as defined by Tipper (1963), comprises two distinct units: the Eocene Endako Group (e.g. Haskin et al., 1998; Anderson et al., 1998b), and the Miocene Chilcotin Group (e.g. Wetherup, 1997; Anderson et al., 1998a). Because of uncertainties in correlation (*see* below) and few reliable age dates, we refer to the unit as Neogene volcanic and related intrusive rocks. The occurrence of two crudely coeval, petrographically similar units within the map area poses a significant bedrock mapping problem warranting detailed field study to distinguish them.

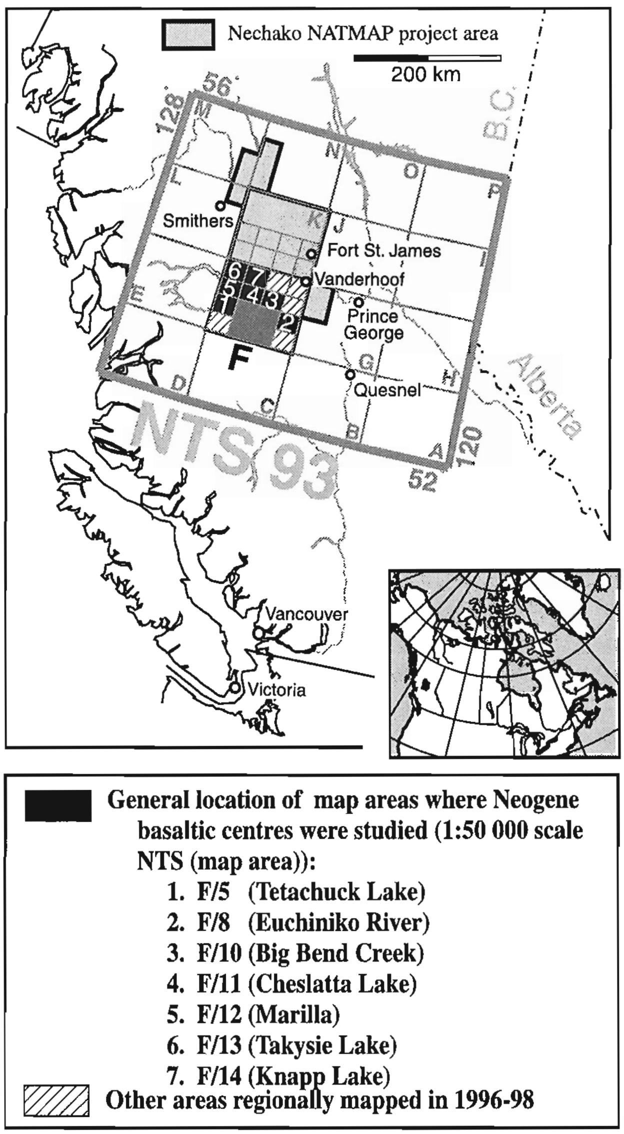

Figure 1. Location of study area and 1998 Nechako NATMAP bedrock mapping program.

This paper focuses on the Neogene basaltic rocks in the northern Nechako River map area. Included in this report are a revised field distribution of Chilcotin Group rocks (Fig. 2), descriptions of the individual field occurrences and rock types, and preliminary petrographic data. These results provide a basis for detailed petrographic, mineralogical, and geochemical studies. Future work will also include geochronological and isotopic tracer characterization of the xenoliths and host volcanic rocks. These studies will help to further distinguish the Eocene from Neogene basaltic units and permit comparisons with coeval(?) Chilcotin Group basaltic rocks studied to the south.

PREVIOUS WORK AND FORMAL UNIT DESIGNATION

Stratigraphic assignment of the basaltic rocks described in this article do not conform strictly to the formal designation of Chilcotin Group basalts defined to the south of the map area (Bevier, 1983a, b). However, based on detailed descriptions of basalts to the west (Woodsworth, 1979), northwest (Church, 1973), and northeast (Brearley et al., 1984) of the type sections, Mathews (1989) expanded the geographic distribution and age of Chilcotin Group basalts to include basalts of the late Oligocene (to the northeast) and early Miocene (to the west and northwest) (conventional K-Ar dates on whole rocks; Mathews, 1989). Very few geochemical analyses on whole rocks have been published for Chilcotin Group basalts in the central interior and few reliable age dates are available for the northern Neogene basaltic rocks.

PHYSIOGRAPHY, ACCESS, AND FIELD METHODS

The Nechako Plateau is an area of subdued topographic relief. Most of the region is below the treeline and covered by a dominantly coniferous sub-boreal forest. Bedrock geological mapping is hampered by the near continuous cover of vegetation and underlying Pleistocene till, glaciofluvial, and glaciolacustrine deposits. Intensive logging on the plateau provides excellent access to exposed bedrock along ridge lines, small buttes, and roadcuts.

Mapping was conducted through June, July, and August of the 1998 field season and included sampling the Summit Lake (Brearley et al., 1984) and Teapot Mountain localities in the Macleod Lake map area (NTS 93 J; Struik, 1994).

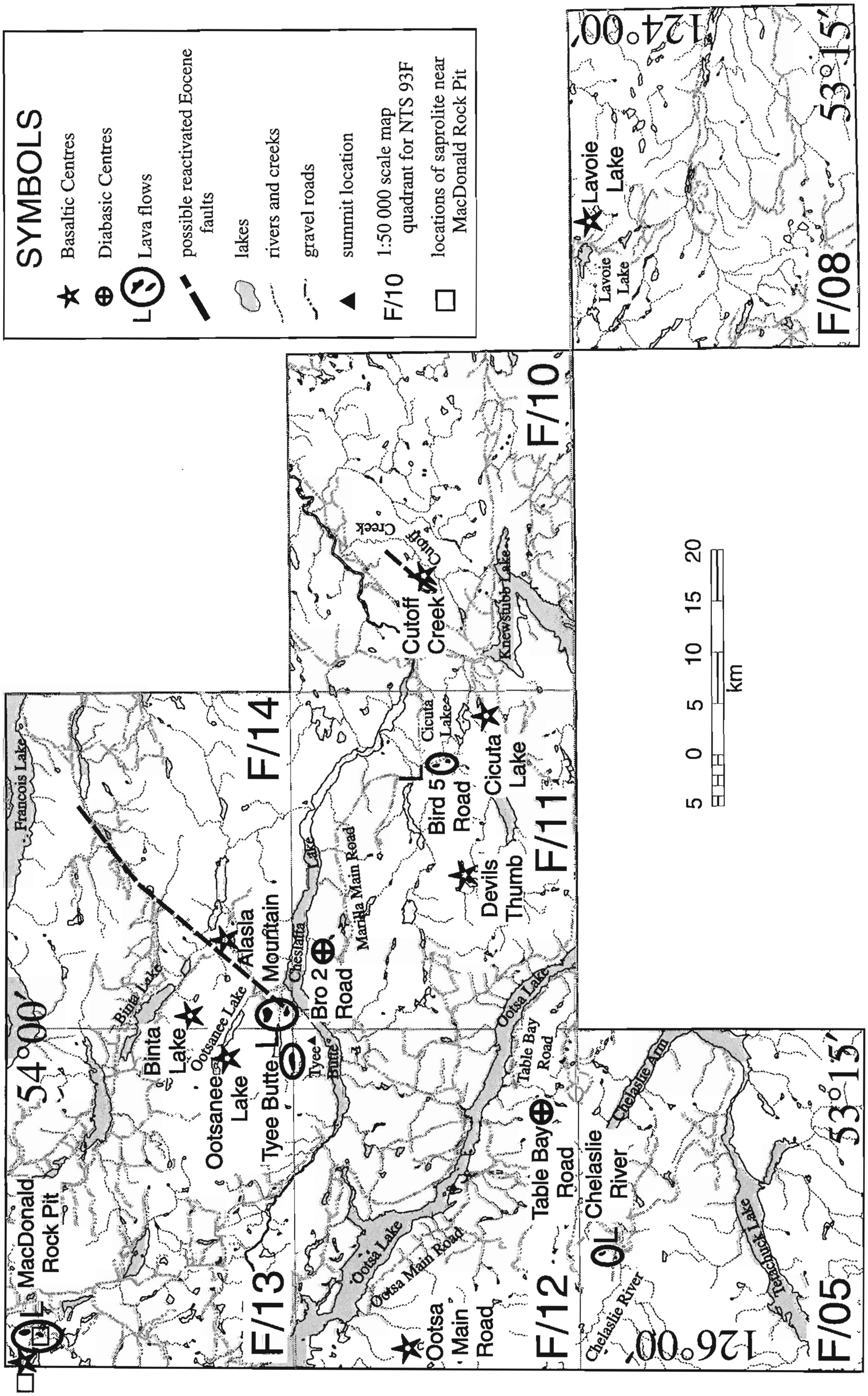

Figure 2. Locations described in text.

GEOLOGY

The centres are divided into diabasic and basaltic volcanic centres, based on properties summarized in the discussion section. Site descriptions follow this classification and are further organized by 1:50 000 scale NTS map area. Localities (Fig. 2) are named for dominant nearby geographic features (*see* Table 1). Diabasic and basaltic rocks are generally dark grey to black, and weather rusty brown to dark grey. Olivine xenocrysts are distinguished by disaggregation around ultramafic xenoliths, anhedral broken grains, and reaction rims indicating disequilibrium.

Diabasic centres

NTS 93 F/11 (Cheslatta Lake)

Bro 2 Road locality

Four hundred metres north of Bro 2 Road (Fig. 2), a diabasic centre 1 km in diameter crosscuts flow-layered rhyolite of the Ootsa Lake Group. The diabase displays well developed vertical columns between 1 and 3 m wide (Fig. 3). An identical intrusion occurs roughly 3 km to the southwest. The diabase is ophitic and contains phenocrysts of plagioclase and pyroxene (Table 1). Plagioclase is locally altered to epidote. No xenoliths were observed at this locality. Three hundred metres to the south, small outcrops of basalt of similar mineralogy are observed and are likely lava flows erupted from the centre.

NTS 93 F/12 (Marilla)

Table Bay Road locality

A circular, 1 km diameter diabasic centre crosscuts Jurassic Hazelton Group volcanic rocks 1 km east of a spur road (485 road) of Table Bay Road (Fig. 2). The diabase displays well developed, vertical columnar jointing. The diabase has an ophitic texture and contains phenocrysts of plagioclase, pyroxene, and olivine (Table 1). The diabase is generally fresh, but some plagioclase crystals are altered to epidote. No xenoliths were observed at this locality.

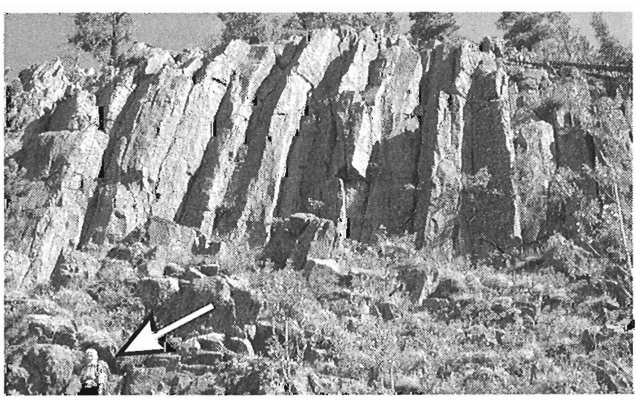

Figure 3. *Vertical columnar joints (1–3 m wide) in diabase (Bro 2 locality). Figure at bottom left is roughly 1.6 m tall. Exposure is approximately 30 m in height.*

Basaltic centres

NTS 93 F/5 (Tetachuck Lake)

Chelaslie River locality

North of the Chelaslie River (Fig. 2), a basalt lava flow (>10 m thick) unconformably overlies plutonic and volcanic basement rocks of Mesozoic age along a subhorizontal contact. The surface of the unconformity dips to the south, parallel to present topography. Lava flows may have been derived from volcanic centres topographically higher and to the north (e.g. Ootsa Main Road locality) assuming paleotopography in the Neogene was similar to the present. Plutonic and volcanic basement exposures at the same structural level as the nearby flow indicate that at least 10 m, if not more, of material have been removed after deposition of the lavas.

The basalt is dense. Locally ultramafic xenoliths within the basalt show evidence of disaggregation. Olivine xenocrysts and pyroxene phenocrysts are present in small numbers (Table 1).

The basalt contains between 1 and 5% exceptionally fresh xenoliths, and most samples contain mantle and crustal xenoliths. Three types of xenoliths include (in order of decreasing abundance) dark forest green, round (1–30 cm diameter), medium- to coarse-grained lherzolite (3–4%) composed of olivine, chromian diopside, black pyroxene, and magnetite; buff, small (1–2 cm in size), oval, fused felsic crustal xenoliths (1%) that are chalky, highly friable and have 1–3 mm reaction rims; and grey to dark grey, oval (1–5 cm long), medium-grained, hornblende-bearing granodiorite and quartz monzodiorite (1%).

NTS 93 F/8 (Euchiniko River)

Lavoie Lake locality

A volcanic neck and associated lava flow(s?) are exposed approximately 1.5 km east of Lavoie Lake (Fig. 2). The volcanic neck is subcircular, 350 m x 325 m in size, rising 100 m above the surrounding flat topography. The neck is massive and rarely exhibits poorly-formed, localized joints. Lava flows are poorly exposed in road cuts at a distance from and below the neck.

The basalt flows are dense and vesicular. Massive basalt occurs 0.5 km to the northeast of the neck and contains up to 5% percent mantle and crustal xenoliths and xenocrysts (Table 1). Distinctively fresh vesicular basalt (15–20 percent small vesicles, 1–5 mm in diameter) occurs 1 km to the south of the neck as common subcrop along logging roads.

Twenty-six mantle and eleven crustal xenoliths were collected from this site. Mantle xenoliths are round to ovoid and typically small (1–3 cm in diameter), but reach sizes of up to 12 cm. Rinds at the basalt-xenolith contact are preserved in xenolith cavities larger than 5 cm in width. Mantle xenoliths sampled comprise medium- to coarse-grained chromian-diopside-bearing lherzolite (24 samples), olivine megacrysts (1 sample), and pyroxenite (1 sample).

Table 1. Character of Miocene basaltic centres, northern Nechako River map area.

Location Name	NTS Map Sheet	UTM Easting	UTM Northing	Form	Shape	Dimension (plug) (m x m)	Vertical Relief (m)	Mineralogy 1	Mineralogy 2	Mineralogy 3	Texture	Xenolith Bearing
Chelaslie River	93 F/ 05	313264	5928315	basalt lava flow	NA	NA	NA	ol: xn? (1%; 1–2 mm; an)	ol: mg (<1%;15–30 mm; an)	py: ph (<1%; 1mm; eu)	dense	X
Lavoie Lake	93 F/ 08	412379	5926478	basalt volcanic plug	sub-circular	350 x 325	100	py: xn? (10%; 3 mm; an)	pl: mg (<1%; 10–15 mm; an)	mt: mg (<<1%; 5 mm; an)	dense + vesicular	X
Cutoff Creek	93 F/ 10	380505	5944585	basalt volcanic plug	sub-circular	300 x 250	90	px: mg (1–5%; 5-25 mm; eu-sub)	pl: mg (1-2%; 10 mm; sub)	mt: mg (<<1%; 12 mm; sub)	porphyritic + vitreous	X
Bird Road #5 1	93 F/ 11	361258	5943268	dyke and lava flow	NA	NA	NA	ol: xn (<1%; 3mm; an)			vesicular	X
Bird Road #5 2	93 F/ 11	360954	5943601	basalt lava flow	NA	NA	NA	none			aphanitic	X
Cicuta Lake	93 F/ 11	364328	5939695	basalt volcanic plug	oval	400 x 200	100	pl: ph (1%; <1 mm; eu)	ol: xn (1%; 4 mm; sub-an)	py: ph (<1%; 1 mm; an)	rarely vesicular	X
Devils Thumb	93 F/ 11	350528	5940567	basalt volcanic plug	circular	250 x 250	170	pl: ph (5%; 1–3 mm; eu)				X
Bro 2 Road	93 F/ 11	342370	5954724	diabase plug	circular	1000 x 1000	60	pl: ph (50–70%; 1–10 mm; eu)	py: ph (20–40%;1–3 mm; eu)		diabasic-ophitic	
Ootsa Main	93 F/ 12	303790	5948008	basalt plug	sub-circular	400 x 300	variable (up to 70)	ol: xn? (1%; 1–5 mm; an)			dense	X
Table Bay Road	93 F/ 12	325580	5934149	diabase plug	cicular	1000 x 1000	120	pl: ph (35-60%; 1–2 mm; eu)	py: ph (10–40%; 1–2 mm; eu)	ol: ph (1%; 1 mm; sub)	diabasic-ophitic	
North of Tyee Butte	93 F/ 12	332229	5958187	basalt? lava flow	NA	NA	NA	pl: ph (20-30%; 1–7 mm; eu)	ol: ph? (1–2 %;1–2 mm; sub)	bi: ph? (<<1%; 1 mm; eu)	vesicle infillings	X
Ootsanee Lake	93 F/13	332238	5963555	basaltic volcanic plug	sub-circular	150 x 200	100	pl: mg (25 %; 1–8 mm; sub)	py: ph (3%; 1 mm; eu)		vitreous + porphyritic	X
Macdonald Rock Pit	93 E/ 16	696043*	5985900*	basalt volcanic plug	oval	400 x 200	70	pl: ph (25%; 1–10 mm; eu)	ol: ph/xn? (1%; 1–15 mm; eu)	py: ph/xn? (1%; 1–6 mm, eu)	porphyritic + vitreous	
	93 F/ 13	306447	5983850	basalt lava flow	NA	NA	NA	pl: ph (1%; 1mm; eu)	ol: ph/xn? (<1%; 1 mm, eu)	py: ph/xn? (<1%; 1 mm; eu)	amygdaloidal and vesicular	
Alasla Mountain	93 F/ 14	344931	5964890	basalt volcanic plug	sub-circular	500 x 450	165	ol: ph+xn (5–15%;1–3 mm; eu-an)	mt: mg (1%; 5 mm; sub)		uncommonly amygdaloidal	X
Binta Lake	93 F/ 14	336325	5968537	basalt volcanic plug	oval	200 x 100	40	ol: ph (3%; 1–2 mm; eu)	ol: xn (1%; 3–5 mm; sub)		uncommonly amygdaloidal	X
Cheslatta Lake	93 F/14	337083	5958682	basalt lava flow	NA	NA	NA	pl: ph (35%:1–7 mm; eu)	ol: ph/xn? (5%; 1–2 mm; eu)		uncommonly amygdaloidal	

*UTM Zone 9 (all other values are UTM Zone 10)
NA: not applicable
Mineral table definitions:
Minerals: pl=plagioclase, py=pyroxene, ol=olivine, bi=biotite, and mt=magnetite
Origin: ph=phenocrysts, xn=xenocrysts, mg=megacrysts, ph/xn?=phenocryst or xenocryst (unknown)
Percentage of total rock: %
Length (mm): mineral axis of greatest dimension
Crystal form: eu=euhedral; sub=subhedral, an=anhedral

Crustal xenoliths are round and small (1–2 cm). Most samples are fused and highly altered precluding identification of textures and minerals in hand sample. The xenolith samples include medium-grained granulite (four samples), gabbro (three), granite (two), and two aphanitic samples. Reaction rinds around crustal xenoliths are uncommon.

NTS 93 F/10 (Big Bend Creek)

Cutoff Creek locality

North of Cutoff Creek (Fig. 2), a subcircular basaltic neck, 300 m x 250 m in size, rises 90 m above surrounding flat topography. Well developed columns within the basalt are 30 cm to 2 m wide, but average 65 cm. Subhorizontal columns sweep upwards from the base of the exposure becoming vertical and narrower upwards (Fig. 4). Northeasterly trending Pleistocene ice eroded and reshaped the plug, forming a streamlined drumlinized landform (Fig. 5). Locally the outcrop is highly weathered.

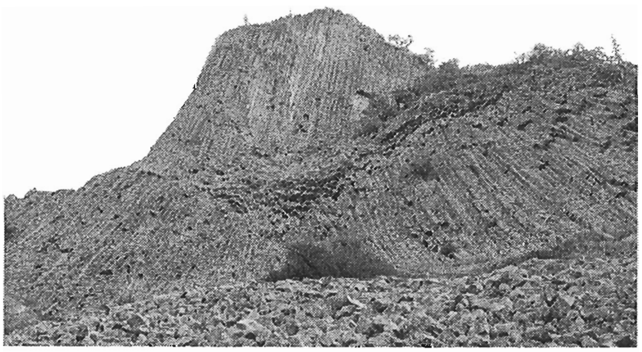

***Figure 4.** View to east of converging columnar jointing in basalt at Cutoff Creek locality. Columns are subhorizontal at margins of photograph and subvertical at peak. Exposure is approximately 70 m in height above talus pile.*

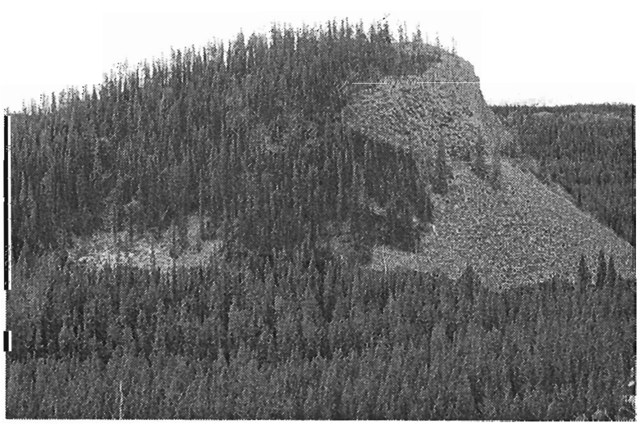

***Figure 5.** View south to glaciated form of Cutoff Creek locality. Exposure is approximately 70 m in height.*

The groundmass of the basalt is vitreous and dominantly aphanitic, but locally contains rare plagioclase microphenocrysts. Megacrysts of black pyroxene, plagioclase, and magnetite make up 1–3% of the basalt (Table 1).

Mantle xenoliths are rare (<1%) and only three samples were collected. They are round, 1–5 cm, medium-grained lherzolite containing olivine, chromian diopside, and orthopyroxene. Crustal xenoliths are also rare (<1%). Two layered crustal xenoliths were collected: one is 8 cm in diameter and contains a 2 cm thick magnetite-pyroxene layer between two 3 cm thick plagioclase layers. The other is fine grained and granular, and composed of a plagioclase layer bounded by 2 mm and 4 mm thick rims of magnetite.

As noted by Anderson et al. (1998a) the Chilcotin Group basalts outcrop in a linear geometry immediately southwest of the Cutoff Creek locality. Eocene volcanic rocks to the north are highly fractured and altered. A brittle fault parallel with other faults of the Nechako graben (Anderson et al., 1998a) separates the Endako from the Chilcotin Group basalts. Although the inception of the fault zone was probably Eocene, it is possible the Neogene centre was emplaced along the reactivated older structure.

NTS 93 F/11 (Cheslatta River)

Bird Road 5 locality

Eocene–Miocene pebble conglomerate is intruded by a 25 cm basaltic dyke and overlain by a basaltic lava flow along a secondary logging road (Bird Road 5) (Fig. 2). The conglomerate is light buff, poorly sorted, and oxidized. Clasts are well rounded, pebble size (4–15 mm), and composed of felsic and mafic volcanic rocks. The matrix is composed of poorly cemented sand-size particles.

The contact between the conglomerate and basalt lava flow is not exposed. Minor oxidation and an iridescent lining of vesicles characterize the lava flow. The lava flow contains 5 percent lherzolitic xenoliths (2 cm in diameter) and related xenocrysts (Table 1). Five xenoliths were collected from the lava flow.

At the sediment contact, the basaltic dyke is vesicular and oxidized. The interior of the dyke is dense and fresh, and contains 30%, 5–10 cm, round, medium-grained, chromian-diopside-bearing lherzolite nodules. The lherzolite has a pale green secondary alteration. Ten xenoliths were collected from the dyke.

A preliminary Ar-Ar date of mid-Miocene age (M. Villeneuve, unpublished data, 1998) was determined from a basalt sample collected from this site by D. Thorkelson (Simon Fraser University).

Cicuta Lake locality

A locality 500 m south of Cicuta Lake (Fig. 2) is underlain by an oval shaped volcanic neck 400 m x 200 m in size. Vertical columnar joints reach over 100 m in height. Columns range in width from 30–70 cm.

The basalt contains plagioclase phenocrysts, and rare xenocrysts of olivine and pyroxene (Table 1). A white unknown mineral partially fills rare vesicles (2 cm in diameter). The groundmass of the basalt is locally altered.

Twelve xenoliths were collected from this location: 10 ultramafic mantle xenoliths and 2 crustal xenoliths. Ultramafic xenoliths are common and make up 2–5% of the whole rock. Xenoliths are green, round to subround, and range in size between 1 and 7 cm. Xenoliths larger than 2 cm in size are preserved as cavities with rinds up to 1 cm thick of lherzolite at the xenolith margin. The mantle xenoliths are medium-grained lherzolite and dunite containing olivine and subordinate amounts of chromian diopside and orthopyroxene. Rare, white, lenticular, fused crustal xenoliths are 1–3 cm in size and friable.

Devils Thumb locality

The Devils Thumb (Fig. 2) is a dominant physiographic feature, 250 m in diameter, rising some 170 m above the plateau. Crude subvertical columnar jointing is continuous over 100 vertical metres. Penetrative, spaced fracture cleavage is planar and well developed at the millimetre to centimetre scale. No kinematic indicators occur on the cleavage surfaces. At the Devils Thumb the cleavage is oriented parallel to the long direction of columnar joints.

Phenocrysts of plagioclase occur within a vitreous groundmass (Table 1). The basalt is significantly more weathered than basalts at other localities. Exposures of basalt to the north and northeast contain 1–4 mm xenocrysts(?) of olivine.

Xenoliths are extremely rare (<<1%) at this site. The sole xenolith collected was an oval, 5 cm long, pale pinkish-yellow, medium-grained, vitreous, garnet lherzolite.

NTS 93 F/12 (Marilla)

Ootsa Main Road locality

Tipper (1963) identified a volcanic plug south of the Ootsa Main Road (Fig. 2). The plug is subcircular and 400 m x 300 m in dimension. It is poorly exposed on the north with modest relief (40–70 m) to the south. Well formed, vertical columnar joints in the basalt are 30–75 cm in width. Rhyolite of the Eocene Ootsa Lake Group occurs topographically below the neck, 100 m to the north. The groundmass of the basalt is friable and aphyric.

Samples collected from this site include thirteen mantle and one crustal xenoliths. Mantle xenoliths vary in size between 1 and 15 cm (Fig. 6), but an unusually large number are greater than 10 cm in size. The xenoliths make up 1–5% of the rock. Xenoliths larger than 5 cm are preserved as remnant cavities outlined by 2 cm thick lherzolite rinds along the basalt-xenolith contact. The xenoliths are medium- to coarse-grained lherzolite containing olivine, chromian diopside, and orthopyroxene. Disaggregated xenocrysts of olivine and chromian diopside occur locally. Crustal xenoliths are rare (<1%). The sole sample is 1 cm in diameter, altered and chalky in appearance. It contains quartz.

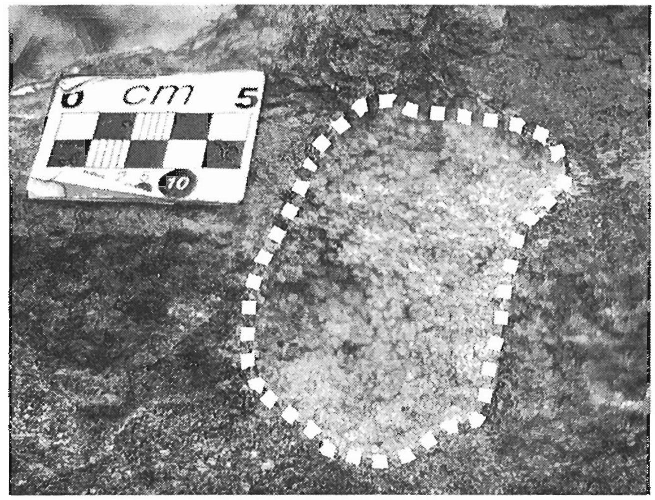

Figure 6. *A 10 cm cavity in basalt containing remnants of a lherzolite nodule (marked by white dashed outline).*

Locality north of Tyee Butte

North of Tyee Butte (Fig. 2) a 4 km long ridge of columnar jointed basaltic lava flow(s?) is exposed. The groundmass of the basalt is vitreous and contains plagioclase, olivine and biotite phenocrysts (Table 1), the latter suggesting a more intermediate composition. The basalt contains 3% lherzolite xenoliths up to 1 cm in size, olivine megacrysts, and common, fused crustal xenoliths.

NTS 93 F/13 (Takysie Lake)

Macdonald Rock Pit basaltic volcanic neck, lava flows, and associated saprolite horizons

Basaltic plugs and lava flows. South of Francois Lake, a small quarry (Macdonald Rock Pit) (Fig. 2) occurs at the base of a volcanic neck. A cliff face, approximately 70 m high, exposes subvertical continuous columnar joints 40–50 cm in width. To the east, associated lava flows are poorly exposed.

The basalt is porphyritic (Fig. 7) with plagioclase phenocrysts (Table 1) in a black vitreous groundmass. The basalt also contains minor phenocrysts(?) of pyroxene and olivine (Table 1), and olivine glomerocrysts.

To the east lava flow(s?) are poorly exposed and are less porphyritic than the neck (Table 1). A 5 m thick, dense, basalt lava flow, with poorly developed tortoise-back joints (McPhie et al., 1993) contains rare phenocrysts of plagioclase, pyroxene, and olivine within a vitreous groundmass. A 6 m thick vesicular to amygdaloidal basalt, locally pervasively oxidized, with minor black glass amygdules underlies the dense basalt.

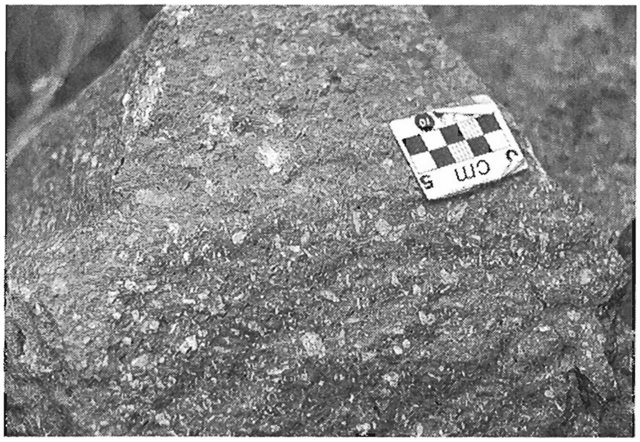

Figure 7. Plagioclase-phyric texture in basalt at Macdonald Rock Pit locality. White phenocrysts of plagioclase are 1 cm in long dimension.

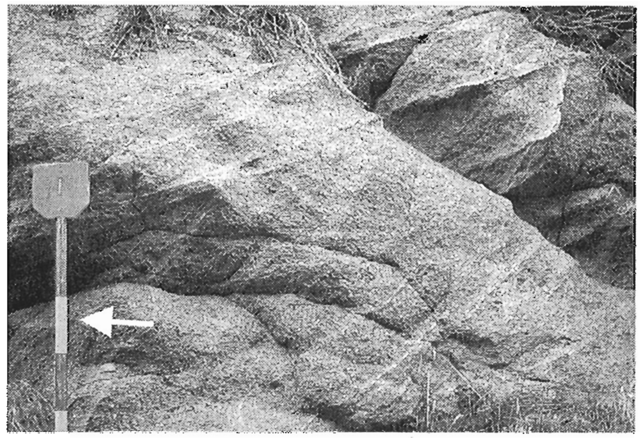

Figure 8. Isovolumetrically weathered saprolite of Clatlatiently Lake Pluton west of Macdonald Rock Pit. Smaller markers on Jacobs staff are 20 cm in length.

Saprolite and grus horizons. Saprolite horizons of granitic basement are exposed at two localities near the Macdonald Rock Pit neck. The horizons were preserved from erosion due to the basalt caps.

West of the Macdonald Rock Pit (Fig. 2), a 3 m thick, light buff-brown saprolite horizon is developed in the Clatlatiently Lake pluton, an alkali-feldspar-megacrystic syenite-monzonite. The exterior of the saprolite is light coloured and resistant to weathering, but its interior is dark and friable. Alkali feldspar megacrysts are resistant to weathering and stand out relative to the weathered groundmass. Undisturbed, irregularly oriented veins of quartz(?) up to 3 cm thick crosscut the pluton and indicate isovolumetric weathering (Fig. 8).

Another horizon occurs 4 km east of the plug (Fig. 2) where a 1.8 m thick basalt lava flow unconformably overlies a 3 m thick exposure of saprolite of the Clatlatiently Lake Pluton (Fig. 9). Boulder-size clasts (30 cm) of porphyritic basalt (similar to the Macdonald Rock Pit) occur within the lava flow. The lava flow is intensely oxidized near the unconformity surface.

NTS 93 F/14 (Knapp Lake)

Alasla Mountain locality

Alasla Mountain (Fig. 2) is the largest volcanic neck in the northern Nechako River map area, approximately 500 m x 450 m in dimension and has a relief of 165 m. The subdued landscape surrounding the neck is likely related to lava flows derived from the neck. At the base of the exposure, well developed, subvertical columnar joints, approximately 2 m wide, abruptly narrow to widths of 15–30 cm and dip subhorizontally to the southeast (Fig. 10). The neck was emplaced along an Eocene northeast-trending, brittle Anzus Lake fault system (Anderson et al., 1999).

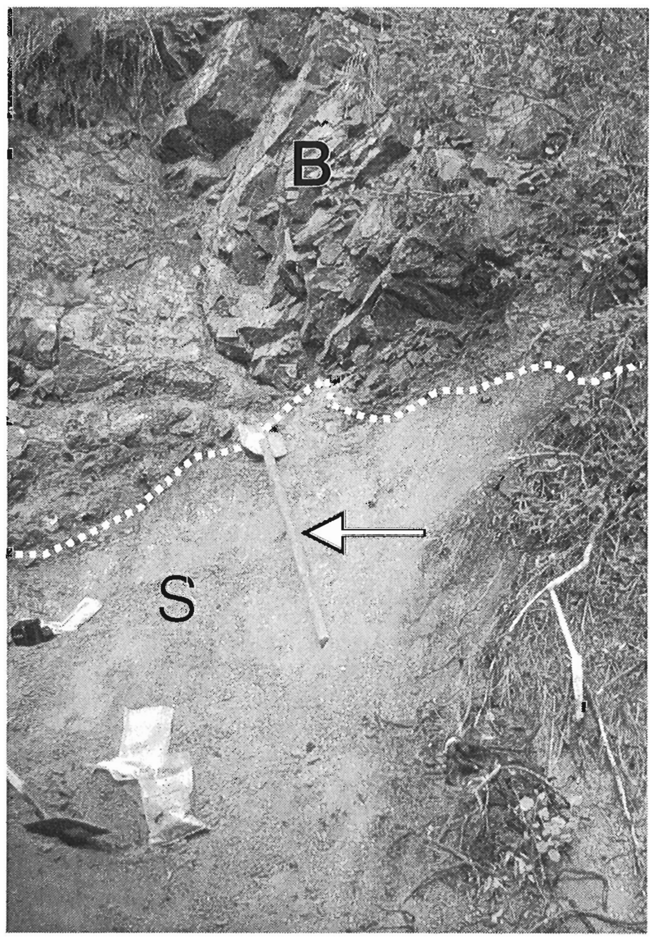

Figure 9. Basalt lava flow (B) unconformably overlying grus and saprolite (S) of Clatlatiently Lake Pluton 4 km east of Macdonald Rock Pit locality. White dashed line indicates the surface of the unconformity. Jacobs staff (1.5 m long see arrow) in centre of photograph for scale.

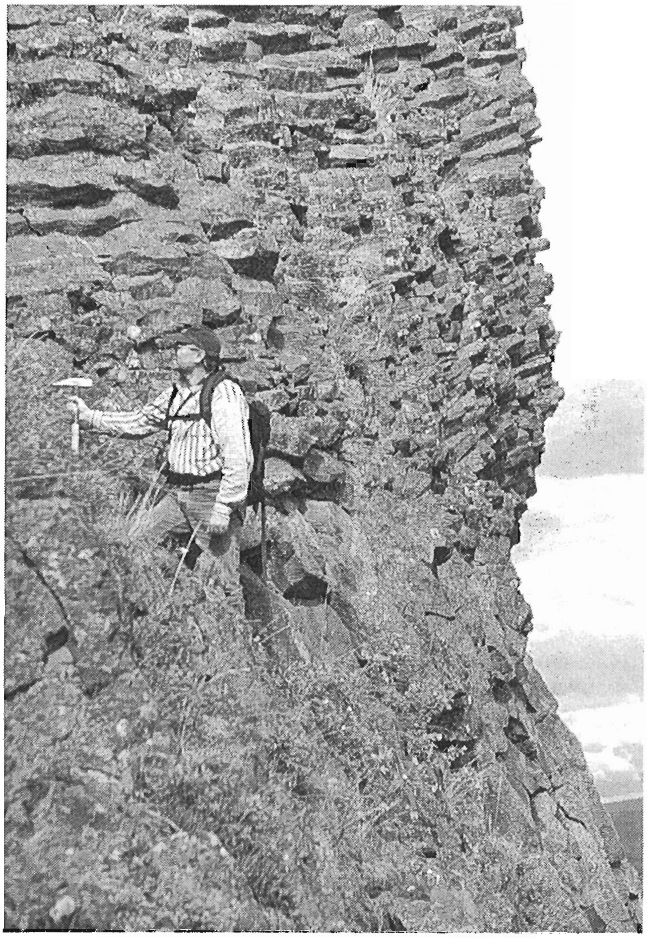

Figure 10. Abrupt change in orientation of columnar joints in basalt at Alasla Mountain. Figure (1.7 m tall) marks the abrupt change from vertical columns 2 m wide (bottom) and subhorizontal vertical, and thinner (25 cm wide) columns (top).

The basalt is dense, and contains olivine and minor magnetite (Table 1). Amygdaloidal basalt (10–15%, 1–6 mm amygdules, unidentified pale yellow mineral) occurs at the contact between the vertical and subhorizontal columnar joints (Fig. 10).

Approximately 46 xenolith and megacryst samples were collected from this locality comprising 44 mantle xenoliths and 2 crustal xenoliths. Round mantle xenoliths between 2 and 5 cm in size typically occur at concentrations around 1%. Rare xenolith cavities of greater size were observed. The most common xenoliths are coarse- to medium-grained lherzolite and minor dunite containing olivine, orthopyroxene, and chromian diopside. Two samples have discrete, millimetre- to centimetre-thick, chromian-diopside, orthopyroxene, and olivine layers. Olivine glomerocrysts and megacrysts are common, and both reach sizes up to 30 mm. Reaction rinds around crustal xenoliths are present.

Binta Lake locality

Four kilometres south of Binta Lake (Fig. 2), a small 200 m x 100 m, 40 m high volcanic neck crosscuts Eocene felsic volcanic rocks of the Ootsa Lake Group. Subvertical columnar joints are 10–50 cm wide and poorly developed in the medial part of the intrusion compared to the margin where they dip to the west. The orientations of columnar joints at this location resemble those at the Cutoff Creek location. From the margins to the interior of the centre, columns converge from subhorizontal to vertical.

The groundmass is aphyric with olivine phenocrysts and xenocrysts (Table 1). The basalt contains rare (<1%) amygdules (up to 20 mm in diameter) partially filled with a white, unidentified tetragonal mineral.

The neck contains between 2 and 5% xenoliths. Twenty xenolith samples collected include 15 mantle and 5 crustal xenoliths. Mantle xenoliths are round to oval and include dunite and lherzolite. Typical mantle xenoliths are 2–5 cm in diameter, but locally exceed 25 cm (Fig. 11). Xenoliths larger than 5 cm are highly weathered compared to smaller (<5 cm) unaltered xenoliths. The xenoliths are granular, fine to medium grained, and are locally in textural equilibrium (120° mineral grain contacts). They contain olivine, orthopyroxene, chromian diopside, and magnetite. A 3 cm diameter lherzolite sample contains planar, discrete, millimetre-scale layers of olivine, chromian diopside, and a composite layer of magnetite and orthopyroxene.

Round (1–3 cm in size) crustal xenoliths are poorly preserved and have been significantly altered in transport. The interiors of these xenoliths are chalky and friable. They are intermediate to felsic in composition and contain quartz, feldspar, and hornblende.

Cheslatta Lake locality

North of Cheslatta Lake (Fig. 2), a single 15 m thick lava flow of basalt is exposed. The uppermost 10 m of the basalt is dense and non-vesicular, and contains olivine (Table 1). A 5 m thick basalt with minor amygdules underlies the thicker unit.

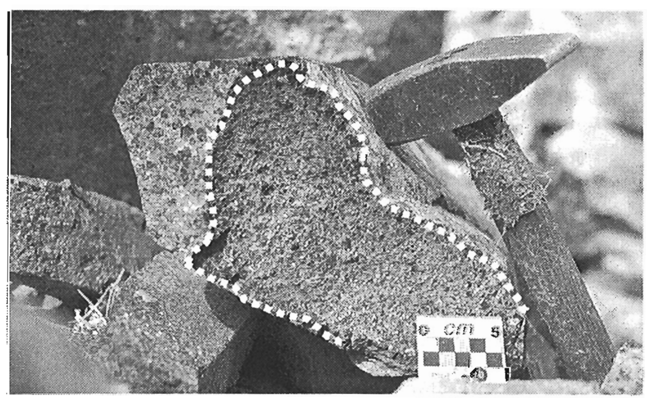

Figure 11. Rim of weathered lherzolitic xenolith cavity at Binta Lake locality (enclosed within dashed white line).

Well developed, penetrative, fracture cleavage occurs throughout the basalt in this area. The planar (rarely curviplanar) cleavage is spaced between 1 and 10 mm apart. No indicators of kinematic motion occur on the cleavage surface. Rarely it occurs associated with columnar jointing, and is formed parallel to the length of the columns.

DISCUSSION

Diabasic and basaltic volcanic centres

Diabasic and basaltic volcanic centres form prominent physiographic features of more than 50 m of relief in the northern Nechako River map area. Centres have well developed columnar jointing. Groups of centres are distinguished by grain size, widths of columnar joints, mineralogy, and xenolith abundances:

1. Diabasic centres at the Bro 2 Road and Table Bay Road localities are diabasic and ophitic in texture, and contain common pyroxene (Table 1). Columnar joints are large (1–3 m) and may indicate slower cooling rates than basaltic centres. No crustal or ultramafic xenoliths were observed at these localities. Lava flows do occur south of the Bro 2 locality but do not display the same textural characteristics of the diabasic centres. Other centres which lack these characteristics are basaltic centres, marking remnant volcanoes.

2. Basaltic centres at Alasla Mountain, Binta Lake, Cicuta Lake, Cutoff Creek, Lavoie Lake, Macdonald Rock Pit, and Ootsa Main Road are not diabasic (e.g. unlike Bro 2 and Table Bay Road localities). They have an aphanitic groundmass, thinner columnar joints (<1 m) indicating more rapid cooling rates. Within this group of centres two different types can be further subdivided:

   a. **Alasla Mountain type:** Alasla Mountain, Binta Lake, Cicuta Lake, Lavoie Lake, and Ootsa Main Road centres are characterized by abundant (>3% of total rock) ultramafic xenoliths. The groundmass is weathered, and in places friable. The basalt is also aphyric (not including xenocrysts from disaggregated xenoliths).

   b. **Cutoff Creek type:** Cutoff Creek and Macdonald Rock Pit centres are similar to Teapot Mountain (NTS 93 J/07) and have a vitreous groundmass with megacrysts (15 mm in diameter) of plagioclase. Cutoff Creek also contains megacrysts of orthopyroxene (similar to Teapot Mountain). The Cutoff Creek location is also similar to Teapot Mountain because it has significantly smaller concentrations (<1%) of mantle and crustal xenoliths. The Ootsanee Lake locality (see Fig. 2, Table 1) has similar characteristics to this type of centre (e.g. vitreous groundmass, plagioclase megacrysts, rare (<1% xenoliths)) and may be included within this type.

   c. **Anomalous centres:** the Devils Thumb locality is grouped within the basaltic centre group because it lacks a diabasic texture and contains ultramafic xenoliths. It lacks distinctive megacrystic assemblages (plagioclase and pyroxene) characteristic of the Cutoff Creek type centres, and lacks the proportion of xenoliths (1–3%) characteristic of the Alasla Mountain type centres. The Devils Thumb may indicate that a continuum exists within the basaltic centre group, and the Cutoff Creek and Alasla Mountain type of centres represent end members of this continuum.

Lava flows

Lava flows at Bird Road Number 5, Chelaslie River, Cheslatta Lake, and east of Macdonald Rock Pit are poorly exposed, thus true thicknesses and total number of flows are hard to evaluate. The Cheslatta River and Chelaslie River localities indicate that lava flows do reach thicknesses of at least 10–15 m. In the southwestern portion of the study area, three successive basalt flows are exposed containing ultramafic xenoliths (L.C. Struik, pers. comm., 1998). Lava flows may have flowed up to 4 km from the McDonald Rock Pit centre.

Within 100 m of some plugs, basement is typically well exposed topographically below the neck (e.g. Ootsa Main Road locality). This suggests that either lava flows erupted from these centres were not of significant thickness and/or that post-Neogene erosion was significant enough to remove a substantial amount of material.

CONCLUSION

Basaltic and diabasic centres related to eruption of Chilcotin Group basalt flows are widespread throughout the Nechako River map area. Centres are small and of moderate relief relative to the surrounding landscape. They display well developed columnar joints and commonly contain mantle and rare crustal xenoliths as well as distinctive megacryst assemblages.

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New data on till geochemistry in the northern sector of the Nechako River map area, British Columbia[1]

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Plouffe, A., 1999: New data on till geochemistry in the northern sector of the Nechako River map area, British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 169–178.*

Abstract: As part of the Nechako NATMAP Project, a regional till sampling program was implemented in central British Columbia, in Nechako River map area (NTS 93 F). Results are presented for the sampling completed in 1996 and 1997. Several sites with high gold concentrations (>15 ppb) in the silt+clay-sized fraction of till have been found, some of which are potential prospecting targets. Molybdenum concentrations in till are highest near the known molybdenum showings of the Nithi Mountain region. The central part of the study area is characterized by high barium levels in till, the source of which is uncertain. High cobalt concentrations measured west of Frank Lake pluton could be derived from a concealed mafic or ultramafic bedrock source. High mercury levels in the clay-sized fraction of till might reflect the presence of faults.

Résumé : Dans le cadre du Projet de Nechako du CARTNAT, on a mis sur pied un programme d'échantillonnage régional du till dans le centre de la Colombie-Britannique, dans la région cartographique de la rivière Nechako (SNRC 93 F). Les résultats des travaux d'échantillonnage menés en 1996 et 1997 sont présentés. Plusieurs sites ayant des concentrations d'or élevées (> 15 ppb) dans la fraction du till de la taille du silt et des argiles ont été reconnus, dont certains pourraient devenir des cibles d'exploration. Les plus fortes concentrations de molybdène se rencontrent à proximité des indices de molybdène de la région du mont Nithi. Le centre de la région à l'étude est caractérisé par des concentrations élevées de baryum dans le till, dont la source est inconnue. Les fortes concentrations de cobalt à l'ouest du pluton de Frank Lake pourraient provenir d'un substratum rocheux mafique ou ultramafique masqué. Les concentrations élevées de mercure dans la fraction du till de la taille des argiles pourraient refléter la présence de failles.

[1] Contribution to the Nechako NATMAP Project

INTRODUCTION

Regional till geochemical surveys were implemented by the British Columbia Geological Survey (BCGS) and the Geological Survey of Canada (GSC) in central British Columbia, in the Nechako River map area (NTS 93F), as part of the Canada British Columbia Agreement on Mineral Development (1991–1995) and the Nechako NATMAP Project (1995-2000). The objectives of these surveys are to determine the background metal concentrations in the surficial environment over various bedrock lithologies and to provide baseline information in support of mineral exploration. Regional till sampling was conducted in 1993, 1994, 1996, 1997, and 1998 by the BCGS in NTS areas 93 F/2, F/3, F/5, F/7, and F/12 (Levson et al., 1994). The GSC has led a till sampling program for the remaining of the Nechako River map sheet (1996 to 1998) and the purpose of this paper is to present and discuss geochemical results for the sampling completed in the northern sector of the map sheet in 1996 and 1997, during which a total of 411 till samples were collected. Results are discussed for selected metals of economic interest and for elements for which the natural concentration variability in till is closely linked to the bedrock geology.

PHYSIOGRAPHY, BEDROCK GEOLOGY, AND ICE-FLOW HISTORY

The northern sector of Nechako River map area is located in central British Columbia and lies within the interior system of the Canadian Cordillera (Holland, 1976) (Fig. 1). It includes two physiographic subdivisions: the Nechako Plateau and the Fraser Basin. Most of the area is part of the Nechako Plateau which is characterized by rolling hills with an average elevation of 1200 m a.s.l. The Fraser Basin is confined to the north-eastern sector of the map area and consists of a generally lower and flatter region than the Nechako Plateau. It is incised by Nechako River which drains to the east into Fraser River (Fig. 1).

The area is underlain by Triassic to Jurassic volcanic lithologies with minor sedimentary rocks which are intruded by a suite of Jurassic, Cretaceous, and possibly Eocene plutons. These rocks are covered in large parts by Eocene and Miocene basalt, andesite, and rhyolite with minor volcaniclastic rocks (Tipper, 1963; Anderson et al., 1997; 1998; Wetherup, 1997; Anderson and Snyder, 1998; Whalen et al., 1998). A moderate potential for mineralization exists in the area as suggested by the presence of Endako mine (porphyry molybdenum deposit) directly to the north of the map boundary and sporadic mineral showings of epithermal and porphyry type (Fig. 1), but mineral exploration is hindered because of the relatively thick cover of glacial sediments and the poor bedrock exposure.

The area was last glaciated during the Late Wisconsinan Fraser Glaciation. At the onset of the glaciation, valley glaciers first formed in the high regions of the Coast and Cariboo mountains located to the west and southeast of the study area, respectively. Following the coalescence of valley glaciers, glaciers predominantly derived from the Coast Mountains flowed generally easterly onto the interior plateaus and were locally deflected by topographic obstacles (Fig. 2). Easterly

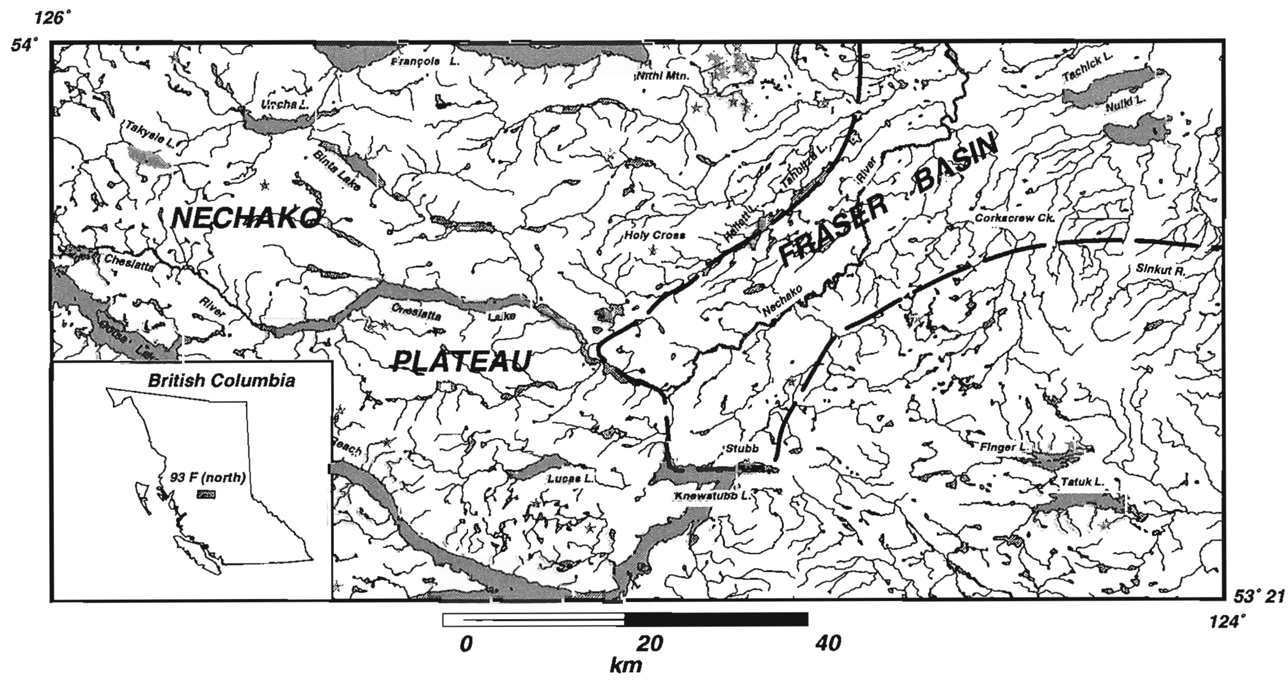

Figure 1. Physiographic subdivisions of study area (Holland, 1976). Mineral showings are depicted with a star.

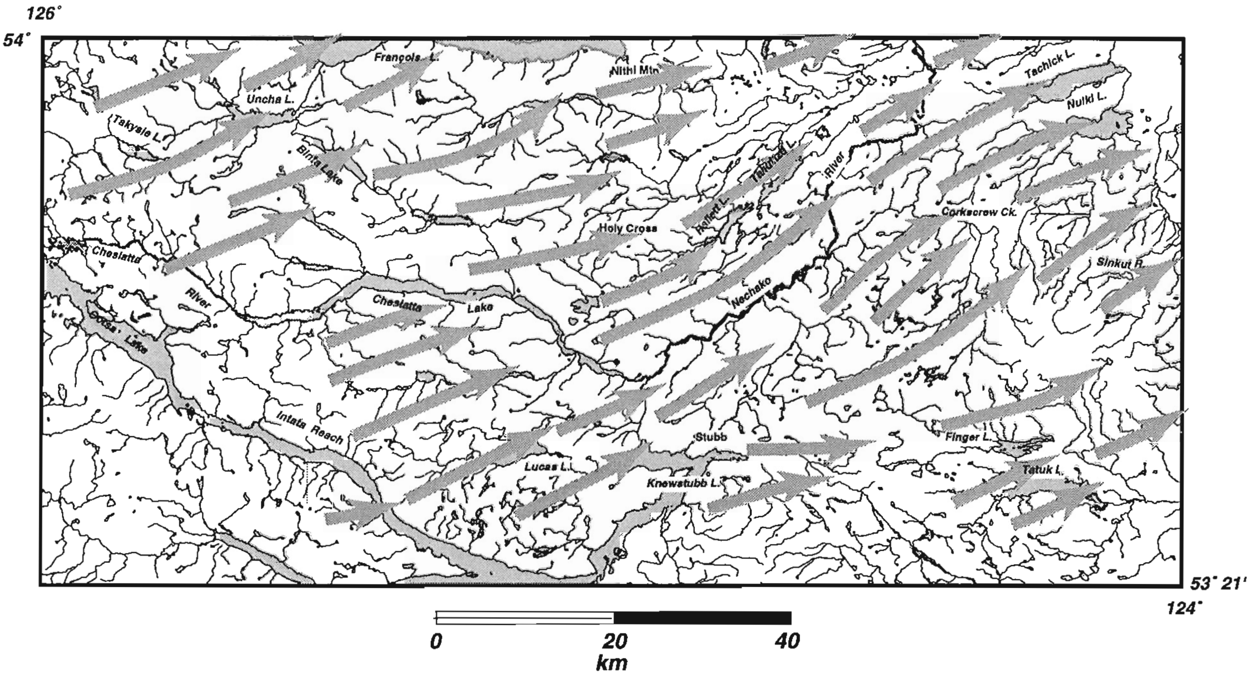

Figure 2. Generalized ice-flow directions (arrows) of the study area reconstructed from drumlins, crag-and-tails, flutes, and glacial striations (Plouffe, 1998b; in press; Plouffe and Williams, 1998).

flowing ice derived from the Coast Mountains was deflected to the northeast as it coalesced with glaciers originating from the Cariboo Mountains.

FIELD AND LABORATORY METHODS

Till samples were collected from roadside sections, natural river bank exposures, and hand-dug pits below the depth of most intense soil weathering, i.e. generally at a depth of 1 m. On bluffs with a height greater than 2 m, samples were collected at 1–2 m depth intervals to assess vertical compositional variations.

Geochemical analyses have been conducted on both the clay-sized fraction (< 0.002 mm) and the silt+clay-sized fraction (< 0.063 mm or -230 mesh) because of the well known enrichment of metals in the fine grain size fractions of till (*see* Shilts, 1975; 1984; DiLabio, 1982; Plouffe, 1997). The clay-sized fraction of till was separated by centrifugation and decantation in the GSC sedimentology laboratory following procedures outlined in Lindsay and Shilts (1995). The silt+clay-sized fraction was separated in the same laboratory by dry sieving. Both grain size fractions were analyzed for a suite of 32 elements by inductively coupled plasma-atomic emission spectrometry (ICP-AES) after an Aqua-Regia digestion. In addition, the clay-sized fraction was analyzed for mercury by cold vapor atomic absorption (CV-AA) which was preceded by an Aqua-Regia digestion, and the silt+clay-sized fraction was analyzed by instrumental neutron activation (INA) for gold plus 34 elements. Laboratory standards and duplicate samples were inserted within the sample set to monitor analytical precision and accuracy. Selected coloured maps of till geochemistry along with all geochemical results in digital form are presented by Plouffe and Williams (1998).

RESULTS

Gold

A detailed till sampling survey was completed by the BCGS at the Wolf gold-silver showing, located on the Nechako Plateau, 5 km south of the study area, to determine the length of the gold dispersal train in till (Levson and Giles, 1997). With a gold threshold concentration set at 15 ppb (threshold being defined as the concentration above which an indicator element is considered anomalous, Rose et al., 1979), which corresponds to the 90th percentile of the till samples from the region of the Wolf showing, the dispersal train extends 5 km down-ice from the mineralized zone (Levson and Giles, 1997). Therefore, for the northern sector of the Nechako River map area, the threshold for gold concentrations measured in the silt+clay-sized fraction of till is set at 15 ppb which corresponds to the 99th percentile (Fig. 3).

The median gold concentration in the silt+clay-sized fraction of the till samples from the survey area is 3 ppb with 45% of the samples yielding gold concentration below the detection limit of 2 ppb. The maximum gold concentration (50 ppb) was measured in till west of Tahultzu Lake (Fig. 3). High gold concentrations (≥ 15 ppb) are generally not located in the proximity of known gold prospects, the exception being gold levels in till near the Stubb showing which reach a

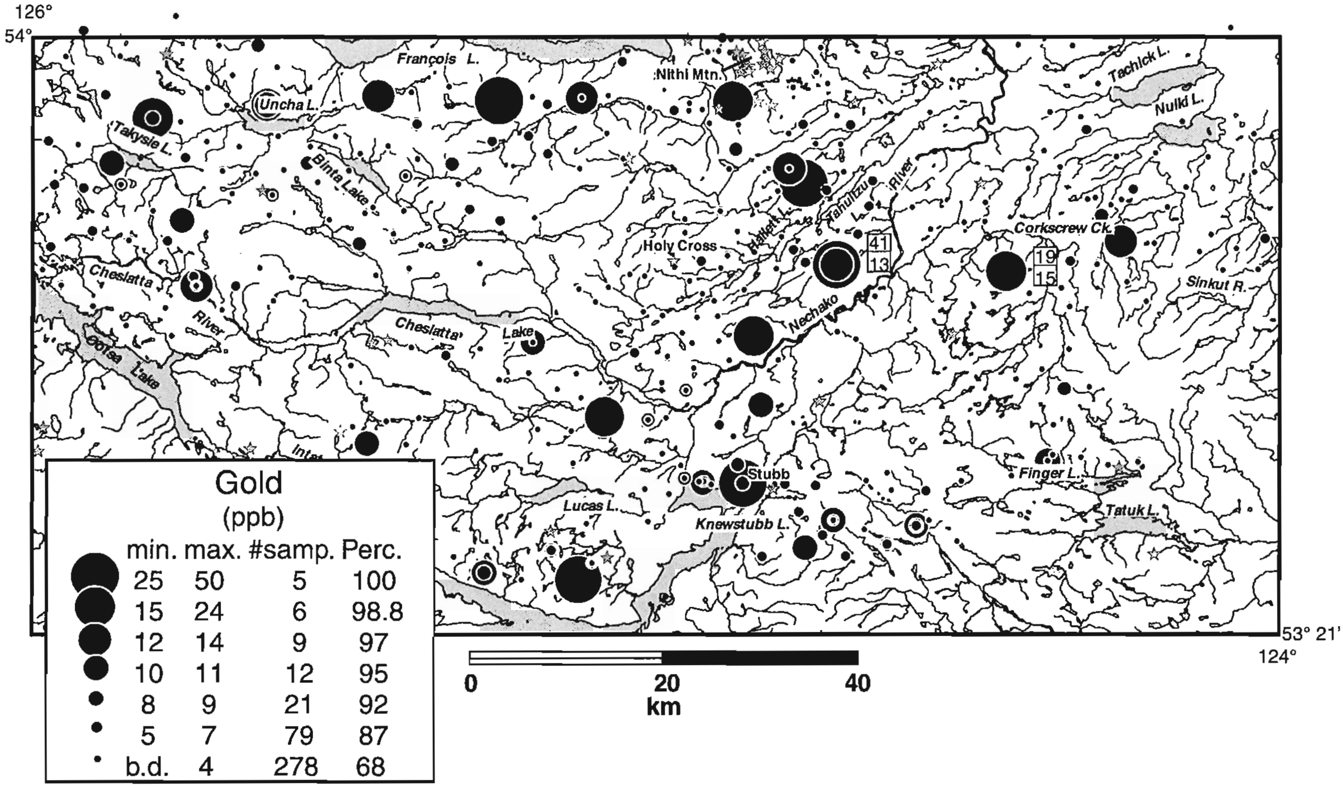

Figure 3. *Distribution of gold concentrations in the silt plus clay-sized fraction of till. Anomalous gold levels measured on sections are indicated in boxes with concentrations shown in their respective stratigraphic order. Mineral showings are depicted with a star. (b.d.: below detection limit).*

maximum concentration of 28 ppb. But even there, the high gold levels in till are located approximately 3 km up-ice from the showing which suggests that another unknown bedrock source for the gold might be present. Till samples are generally too far removed (> 5 km down-ice) from known mineralization to be expected to contain anomalous gold concentrations except for two till samples located less than 5 km down-ice from the Stubb showing which yielded gold concentrations below detection limit and 5 ppb (Fig. 3). Such low values at a short distance from the showing could be related to the heterogeneity of gold particles in till and a sample size not large enough to reflect mineralization or they could also be due to the small size of the mineralization which is not well reflected in till. The high gold level (29 ppb) measured in till due south of Lucas Lake (Fig. 3) is probably one of the most significant anomalies, because it is found in close association with high gold, arsenic, and antimony concentrations in a lake sediment sample (lake 3031 of Cook and Jackaman, 1994; Cook et al., 1997).

Profile sampling, which is the collection of till samples at different depths on prominent sections, revealed that gold levels are in most cases very similar within the same exposure. In fact most samples collected on sections returned gold concentrations below the threshold. However, two sections returned gold concentrations greater than 15 ppb (Fig. 3). On one of them, west of Sinkut River, both samples contain anomalous gold concentrations (19 and 15 ppb). On the other section, located south of Tahultzu Lake, both gold concentrations are significantly different (41 and 13 ppb) which might be related to a variation in till texture and provenance. At that site, a sandy till is overlain by a silty-loamy till. The sandy till is interpreted to be dominantly derived from the local Jurassic to Cretaceous intrusive bedrock, and the upper silty-loamy till reflects the more distal (1 km up-ice) fine grained volcanic rocks. Therefore, the high gold concentration (41 ppb) measured in the upper silty-loamy till is probably not derived from the immediate vicinity of the sampling site.

Even if gold analyses were conducted on 30 g samples of silt+clay-sized fraction, the precision of gold analyses is relatively poor, i.e. it averages ± 50% based on the analyses of 73 duplicates which had gold content that varied from below detection limit to 50 ppb (Fig. 4). Such poor analytical precision for gold is attributed to the small number and the heterogeneous distribution of gold particles in the sediment which is well known as the nugget effect (Harris, 1982). Furthermore, gold concentrations are near detection limit at which level analytical precision is known to be low (Thompson and Howarth, 1976). Consequently, any detailed follow-up survey on any of the high gold concentrations reported here should not be undertaken prior to testing the reproducibility of the values. This should be done by resampling till in the region of interest and conducting geochemical analyses on the same grain-size fraction. However, it can be presumed that an anomalous gold concentration reflects the presence of some gold in till at a site, even if the second analysis returns a low value.

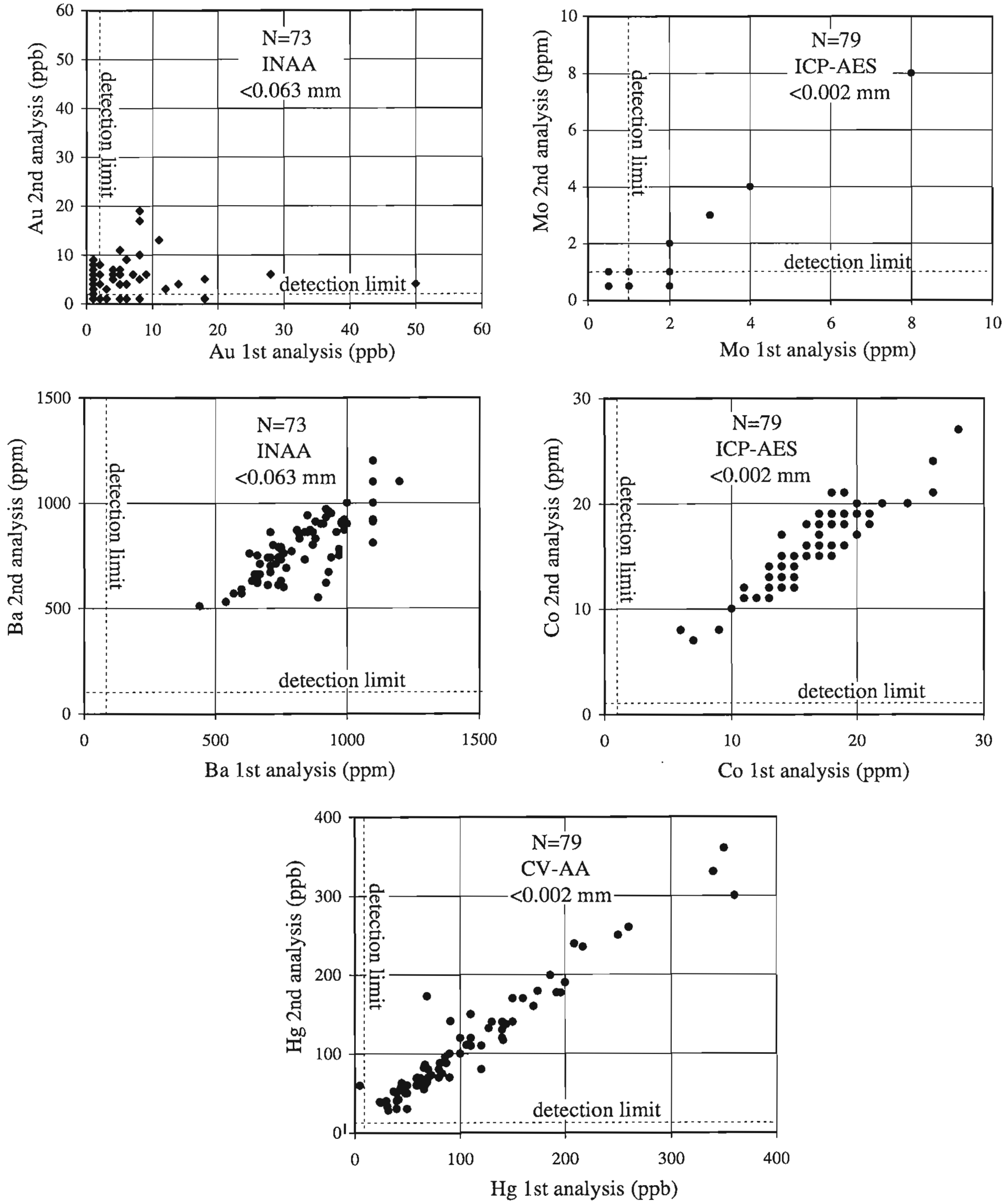

Figure 4. *Scatterplot of field and laboratory duplicate samples analyzed for gold, molybdenum, barium, cobalt, and mercury.*

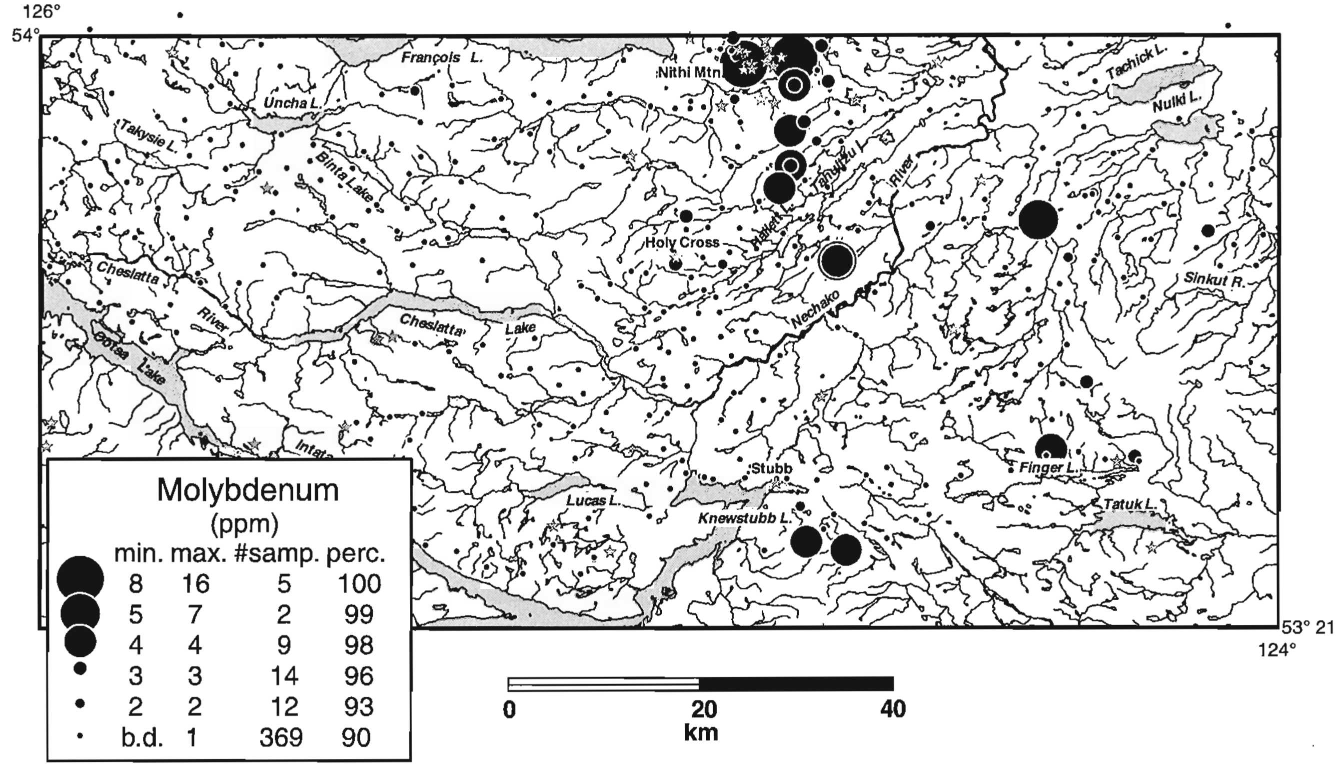

Figure 5. *Distribution of molybdenum concentrations in the clay-sized fraction of till. Mineral showings are depicted with a star. (b.d.: below detection limit).*

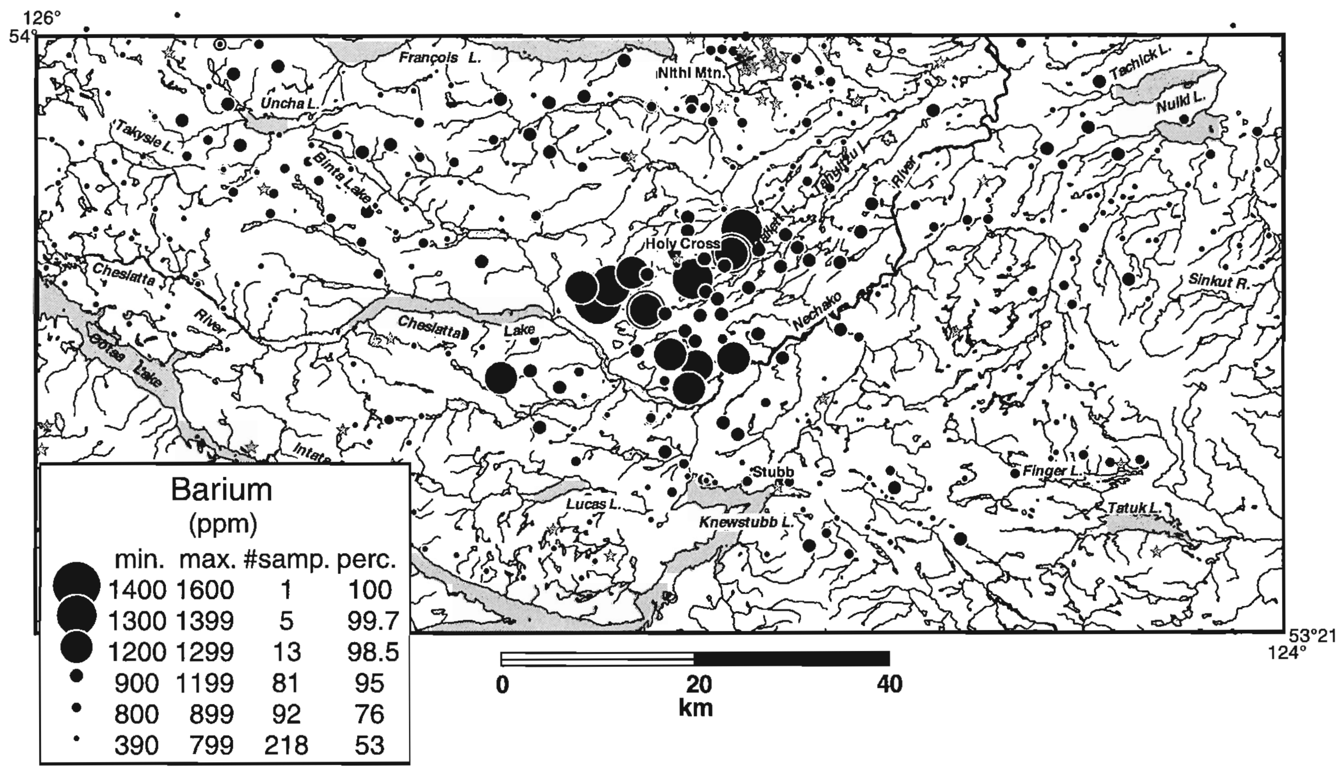

Figure 6. *Distribution of barium concentrations in the silt plus clay-sized fraction of till. Mineral showings are depicted with a star.*

Molybdenum

The presence of early Cretaceous plutonic rocks (Anderson et al., 1997; Anderson and Snyder, 1998) (host rocks of the molybdenum porphyry deposit at Endako mine) along with the occurrence of 12 molybdenum showings in the Nithi Mountain area (L'Heureux and Anderson, 1997) clearly suggest a high potential for molybdenum mineralization in the region.

Fifty-five per cent of the clay-sized fraction samples analyzed for molybdenum returned concentrations below the detection limit of 1 ppm. It follows that the median molybdenum concentration lies below the detection limit. The maximum molybdenum concentration as well as most of the highest concentrations have been detected in the Nithi Mountain area (Fig. 5). Significant molybdenum concentrations have also been measured in five small eutrophic lakes of that region (Cook, 1998). Two more anomalies probably deserve some attention given that high molybdenum concentrations in till do not seem to be present at large distances down-ice from the Nithi Mountain showings, and that directly down-ice from molybdenum mineralization in bedrock, molybdenum levels in till are slightly above detection limit (generally > 4 ppm and the detection limit for molybdenum determinations is 1 ppm). One of these sites is located southwest of Nulki Lake (5 ppm) and the other southeast of Hallett Lake (4 and 6 ppm). Because most of the measured molybdenum concentrations are close to the detection limit, analytical precision averages ± 27 % (Fig. 4).

Barium

Barite is often present as a gangue mineral within or in association with epithermal deposits (e.g. Sillitoe, 1993). Consequently, high barium concentration in till could be indicative of the presence of an epithermal system. The median value of barium concentrations measured in the silt+clay-sized fraction by instrumental neutron activation is 790 ppm, and no samples contained concentrations below the detection limit of 50 ppm. Although the barium concentrations show a normal distribution most of the high values are clustered in the vicinity of the Holy Cross gold epithermal prospect (Fig. 6). Several of the high barium concentrations are located up-ice from Holy Cross prospect. Therefore, the source of barium in this region is not solely the Holy Cross prospect, but it could be related to another source within the Takla Group or Hazelton Group volcanic and volcaniclastic rocks (Anderson et al., 1997; Anderson and Snyder, 1998), because most of the anomalies overlie these lithologies. The analytical precision on barium determinations averages ± 5% (Fig. 4).

Cobalt

Cobalt concentrations measured on the clay-sized fraction show a median value of 15 ppm and a maximum value of 38 ppm. Most of the high cobalt concentrations occur in a linear trend parallel to the western border of the Frank Lake pluton and directly above a shear zone mapped by Wetherup (1997) (Fig. 7). High cobalt concentrations in ash of lodgepole pine bark follow a similar trend (Dunn, 1998). Low percentages

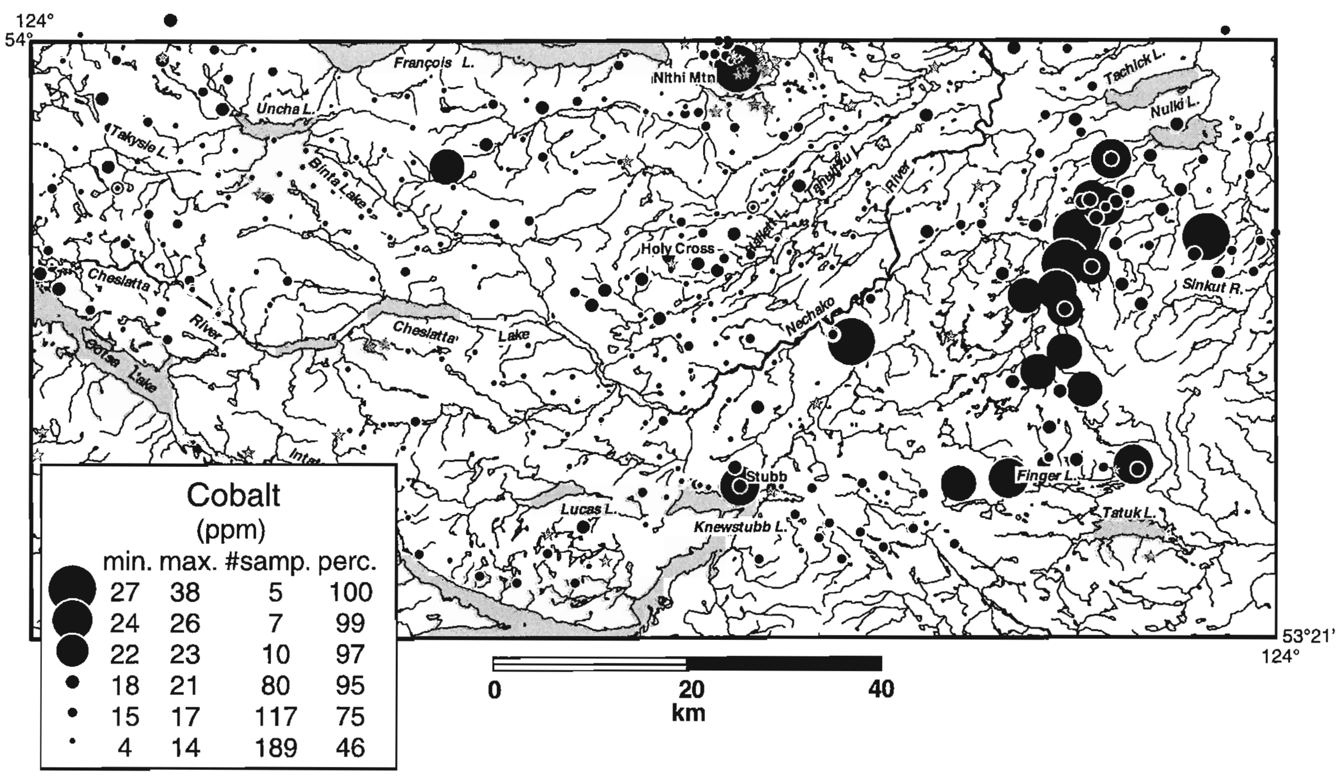

Figure 7. Distribution of cobalt concentrations in the clay-sized fraction of till. Mineral showings are depicted with a star.

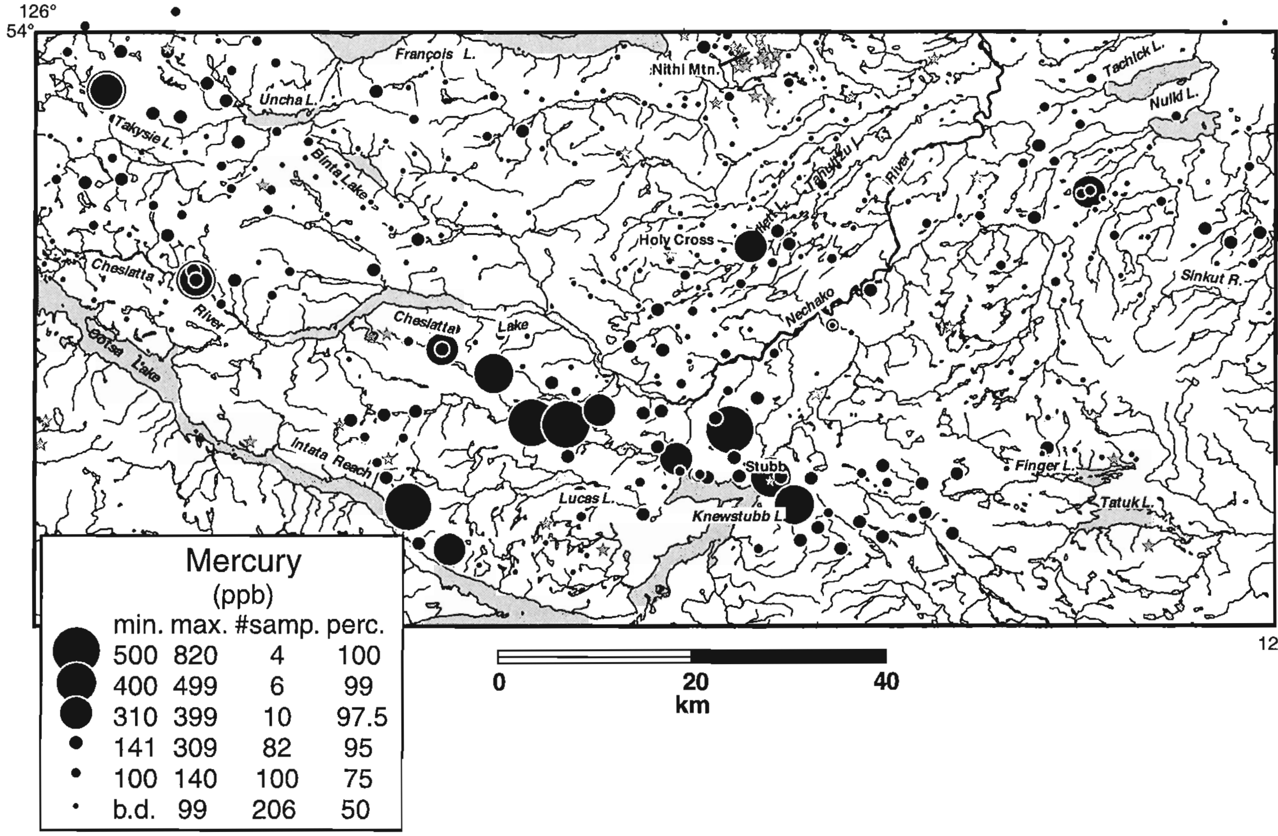

Figure 8. Distribution of mercury concentrations in the clay-sized fraction of till. Mineral showings are depicted with a star.

of ultramafic and mafic rocks were found in the pebble fraction of the till samples of that region and could be related to the source of high cobalt levels in till. The analytical precision on cobalt determinations averages ± 4% (Fig. 4).

Mercury

The median mercury concentration in the survey area is 98 ppb and the maximum value is 820 ppb. Only one sample had a mercury content below the detection limit of 10 ppb. Mercury is highly enriched in the clay-sized fraction of till down-ice from faults of the interior of British Columbia, such as Pinchi and Manson faults directly north of the study area (Plouffe, 1995a, b, 1998a). In addition, high mercury concentrations are known to be found in association with epithermal mineralization (Sillitoe, 1993) and therefore, mercury can be used as a pathfinder element in the search for such ore deposits. The elevated mercury levels in the Knewstubb Lake region are located in the vicinity of newly mapped faults and graben (Anderson, et al., 1998) which extend to the south in the adjacent map areas (Diakow and Levson, 1997) (Fig. 8). Some concealed mineralization located along the faults could be the source of the mercury in till. However, sample spacing is not dense enough to depict linear trend in geochemical anomalies parallel to the faults. High mercury values north and southwest of Lucas Lake could be related to the presence of faults or be indicative of concealed epithermal mineralization. The analytical precision on mercury analyses averages ± 8% (Fig. 4).

DISCUSSION

With the current availability of multi-element analytical packages in commercial laboratories, reports on regional till geochemistry contain a wealth of information applicable to mineral exploration and environmental geology. Often, there is a lack of interest devoted to regional till geochemistry because of the absence of anomalies or high metal concentrations within several adjacent till samples and because metal concentrations in till are not as high as in mineralized bedrock. Firstly, an isolated till sample with a high metal content could be significant because a geochemical glacial dispersal train can be a short entity (e.g. it can be a few hundreds of meters in the case of gold, *see* Plouffe and Jackson, 1995) and the sample density used in a regional survey generally exceed that length. Therefore, mineralization would be reflected by single-site anomalies, and it is very unlikely that two or more consecutive till samples would return anomalous metal concentrations. Secondly, even in areas very close to bedrock mineralization metal concentrations in till are in most cases lower than in bedrock because of the dilution effect, i.e. the incorporation and mixing of debris derived from unmineralized rocks and sediments which took place during glacial erosion, transport, and deposition. Thirdly, statistically it is more likely that a sample collected during a regional survey will fall within the 'tail' of a dispersal train, i.e. an area characterized by metal levels slightly above regional background, rather than the 'head' of train where concentrations are much higher (Shilts, 1976).

Identifying single or multi-element anomalies located in a geological setting associated with bedrock mineralization should be the first part of a selection process to differentiate between significant and insignificant geochemical anomalies in till. This should be done in consultation with published information on the bedrock geology, the regional geochemistry of lake sediments and plants, and regional geophysical data. Additional valuable information can also be found in assessment reports. The first objective of a follow-up survey should be to reproduce the metal values on the same grain-sized fraction of till, especially in the case of metals, such as gold, for which the analytical precision is known to be low. A denser sampling grid should be completed in the region of interest and evidence of mineralization should be looked for not only in the bedrock but also in boulders (boulder tracing) and smaller clasts.

Regional till geochemistry provides a means to evaluate variation in background metal concentrations in the surficial environment over large areas. From the environmental geology point of view, regions can be identified where potentially toxic metals (e.g. Hg) occur naturally in high concentrations, so that remobilization of metals by anthropogenic activities (e.g. building of roads, logging, etc.) can be avoided or at least mitigated. However, a better understanding of the mineralogical phases and forms where metals are held in the sediments is necessary to evaluate how easily can metals of concern be mobilized and if they could become bioavailable. Such research has been undertaken by the GSC as part of the new Metals in the Environment initiative (*see* http://www.nrcan.gc.ca/geos/index.htm). Finally, regional till geochemistry can provide data on spatial distribution of metal levels in the surficial environment for an environmental assessment prior to mining.

CONCLUSION

A few localities with high gold concentrations in till might represent significant mineral exploration targets, such as south of Lucas Lake. However, the values reported here should be reproduced prior to any extensive follow-up survey because of the poor reproducibility of gold analyses which is related to the well known 'nugget effect'. Most of the high molybdenum concentrations measured in till are located in the vicinity of known molybdenum showings and prospects of the Nithi Mountain area. Two other sites away from known molybdenum showings contain elevated molybdenum concentrations. The region around Holy Cross prospect is characterized by high concentrations of barium in till, the source of which is still uncertain. Finally, high cobalt concentrations west of Frank Lake pluton, directly above a shear zone, could be derived from a concealed mafic or ultramafic bedrock source, and the high mercury levels detected north and west of Knewstubb Lake could be related to the presence of faults. An understanding of the general geological setting (ice-flow history, bedrock geology, other geochemical and geophysical data) is crucial for the appropriate interpretation of till geochemical data.

ACKNOWLEDGMENTS

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Field investigations of glacial Lake Knewstubb of the Fraser Glaciation, central British Columbia[1]

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Huscroft, C. and Plouffe, A., 1999: Field investigations of glacial Lake Knewstubb of the Fraser Glaciation, central British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 179–184.*

Abstract: Glacial Lake Knewstubb was formed during the Late Pleistocene by the impoundment of glacial meltwater in the upper Nechako River drainage basin of central British Columbia. Approximately 60 km^2 of the Knewstubb Lake basin is covered with glaciolacustrine fine sand, silt, and clay. Stratigraphic and sedimentological studies of the glaciolacustrine deposits were conducted to define the deglacial history of the area. It is inferred that the regional topography and the position of ice fronts controlled the level of the glacial lake. As the ice receded, progressively lower outlet channels were exposed and the glacial lake level at any given time was limited by the elevation of the lowest open drainage channel.

Résumé : Le Lac glaciaire Knewstubb s'est formé au Pléistocène supérieur à la suite du piégage d'eaux de fonte de glacier dans la partie amont du bassin versant de la rivière Nechako, dans la Colombie-Britannique centrale. Du sable fin, du silt et de l'argile glaciolacustres couvrent environ 60 km^2 du bassin du Lac glaciaire Knewstubb. On a entrepris des études stratigraphiques et sédimentologiques des dépôts glaciolacustres afin de reconstituer l'histoire glaciaire de la région. On en déduit que la topographie régionale et la position des fronts glaciaires ont contrôlé le niveau du lac glaciaire. Au fur et à mesure du retrait des glaces, des exutoires ont été exposés à des niveaux de plus en plus bas et, à tout moment donné, le niveau du lac glaciaire était limité par l'altitude de l'exutoire libre le moins élevé.

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INTRODUCTION

New Quaternary geology mapping conducted as part of the Nechako NATMAP Project in central British Columbia has served to identify the presence of an extensive cover of glaciolacustrine sediments which occupy an area of approximately 60 km^2 in the Knewstubb Lake region of the upper Nechako River (Plouffe, 1998) (Fig. 1). This glacial lake, informally referred to as glacial Lake Knewstubb, developed at the end of the Late Wisconsinan Fraser Glaciation as a result of the blockage of the Nechako River by retreating glaciers. This report presents a description of the glaciolacustrine deposits and proposes a model for the deglaciation of the study area based on 1) airphoto interpretation of macrolandforms, 2) elevation measurements of landforms and deposits, and 3) stratigraphic logging of the sediments which includes the determinations of paleocurrent directions. Additional notes on the poor slope stability associated with fine-grained glacial lake sediments are briefly discussed.

PHYSIOGRAPHY

The study area lies within the Nechako Plateau which is characterized by rolling topography and rounded hills of low relief (Holland, 1976). Prior to the building of the Kenney Dam and the creation of Alcan's Nechako Reservoir in 1952 (Fig. 1, 2), the area formed part of the upper Nechako River watershed. The Kenney Dam is built to an elevation of 860 m and is located at the southern end of the Nechako Canyon such that the canyon, which was cut through 150 m of Eocene basalt (Anderson et al., 1998), is now occupied by an intermittent creek. Several sections of the Nechako Reservoir have received specific names and Knewstubb Lake represents the easternmost portion of the reservoir. Big Bend Creek, located in the eastern sector of the region, empties into Knewstubb Lake. The creek flows in a gently sloping valley from a drainage divide located at approximately 20 km from the mouth of the creek in Knewstubb Lake.

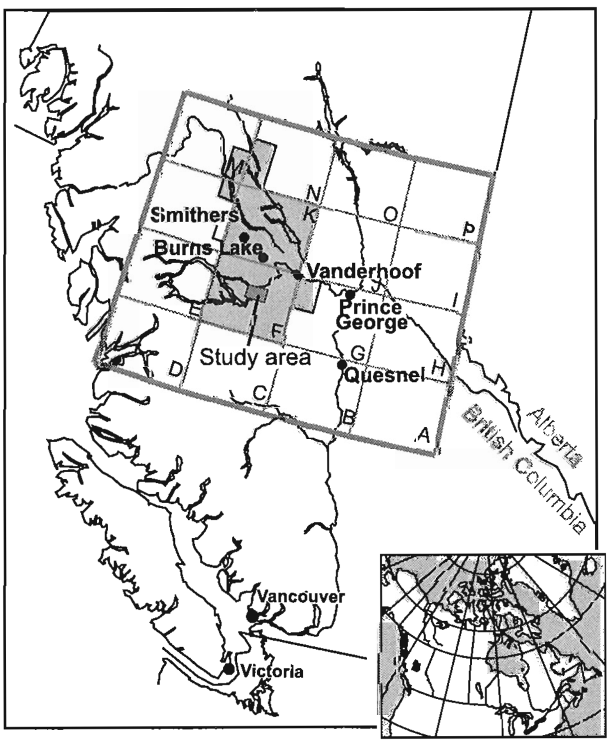

***Figure1.** Location of study area within the Parsnip River (NTS 93) map area.*

PREVIOUS STUDY

As part of a regional bedrock mapping project, Tipper (1963) provided important insight on the Quaternary geology of Nechako River map sheet (NTS 93 F). Fulton (1971), Tipper (1971), Clague (1981), Ryder et al. (1991), and Plouffe (1997) describe to various degrees the Late Pleistocene history of central British Columbia. These authors suggest that major ice lobes originating in the Coast and Skeena mountains flowed generally easterly on the Interior Plateau, and were deflected to the northeast as they coalesced with ice from the Cariboo Mountains. Deglaciation occurred in a general sense from east to west with topographic highs being deglaciated first, and stagnant ice remaining longest in valleys and basins.

Levson and Giles (1997) report the stratigraphy of bluffs located along the shore of Nechako Reservoir, to the south of the study area, and they comment on the presence of retreat-phase glaciolacustrine sediments in that region. The surficial geology map of the study area recently presented by Plouffe (1998) is the foundation for the field studies described in this report.

METHODS

Field investigations of the glaciolacustrine deposits included studies of their sedimentology, stratigraphy, topography, and internal sedimentary structures. Sections located along the Knewstubb Lake shoreline and forestry roads were measured and described using field criteria, including texture, stratification, and other sedimentary structures, to distinguish units. Figure 3 contains the best exposed and most representative of these sections. The elevation measurements were made with a Pennwalt altimeter by Wallace and Tiernan, with corrections being made for air-temperature variations. Measurements were generally made during stable weather conditions. All altimeter readings were referenced to a topographic benchmark on the Kenney Dam and are thought to be accurate to within 5 m. All reported elevation measurements are above sea level.

Paleocurrent directions were determined by measuring orientations of imbricated clasts and the migration direction of climbing ripples, trough crossbeds, and planar crossbeds. In several meltwater channels, where there was no sediment exposure, the channel gradient was used to determine paleocurrent direction. This procedure was applied in meltwater channels that are not occupied by significant modern streams and it assumes that if any regional isostatic rebound has occurred, it did not modify the local gradient of the meltwater channels.

DESCRIPTION, STRATIGRAPHY, AND INTERPRETATION OF GLACIOLACUSTRINE SEDIMENTS

The most prevalent glacial lake sediments are massive fine sand and silt beds, with a lesser amount of rhythmically laminated fine sand, silt, and clay couplets. The maximum number of couplets found in a single sequence was 28. The couplets are composed of silt grading to clay with abrupt transitions to the overlying couplet. Couplets are fining and thinning upwards in a regular manner. Fine-grained deposits were mostly horizontal but locally tilted, folded, and cut by high-angle normal faults (Fig. 4). Pebble- to boulder-sized dropstones, and gravel and diamicton lenses were repeatedly found within these deposits. Planar crossbedding, trough crossbedding, ripples, convoluted beds, and clay rip-up clasts were frequent structures in the coarser sediment. The fine-grained rhythmites and massive beds are often found in close association with stratified to massive sand and gravel, and diamicton interbeds and lenses. Finally, a medium to coarse sand and gravel deposit is often found capping the finer grained stratigraphy. Figure 3 contains the best exposed and most representative exposures of the sediment.

The maximum elevation at which glacial lake sediments were found was 975 m within the Big Bend Creek valley (Fig. 2). The maximum elevation of glacial lake sediments decreases to the west as determined from elevation measurements (Fig. 2).

The fine sand, silt, and clay are thought to have been deposited by a combination of rain-out and bottom flow, distally from any meltwater source in a glaciolacustrine environment. Following criteria established by Smith and Ashley (1985) and the sediment description given above, the rhythmites identified in the glacial lake sediment succession could reflect annual sedimentation (varves). Occasional dropstones are interpreted as being ice-rafted which indicate the presence of icebergs during the existence of the glacial lake. The massive and bedded sand and gravel units are inferred to have been deposited in proximity to the mouth of meltwater channels, possibly as subaqueous fans or deltas. Diamicton lenses and interbeds are thought to reflect debris flows (flow till)

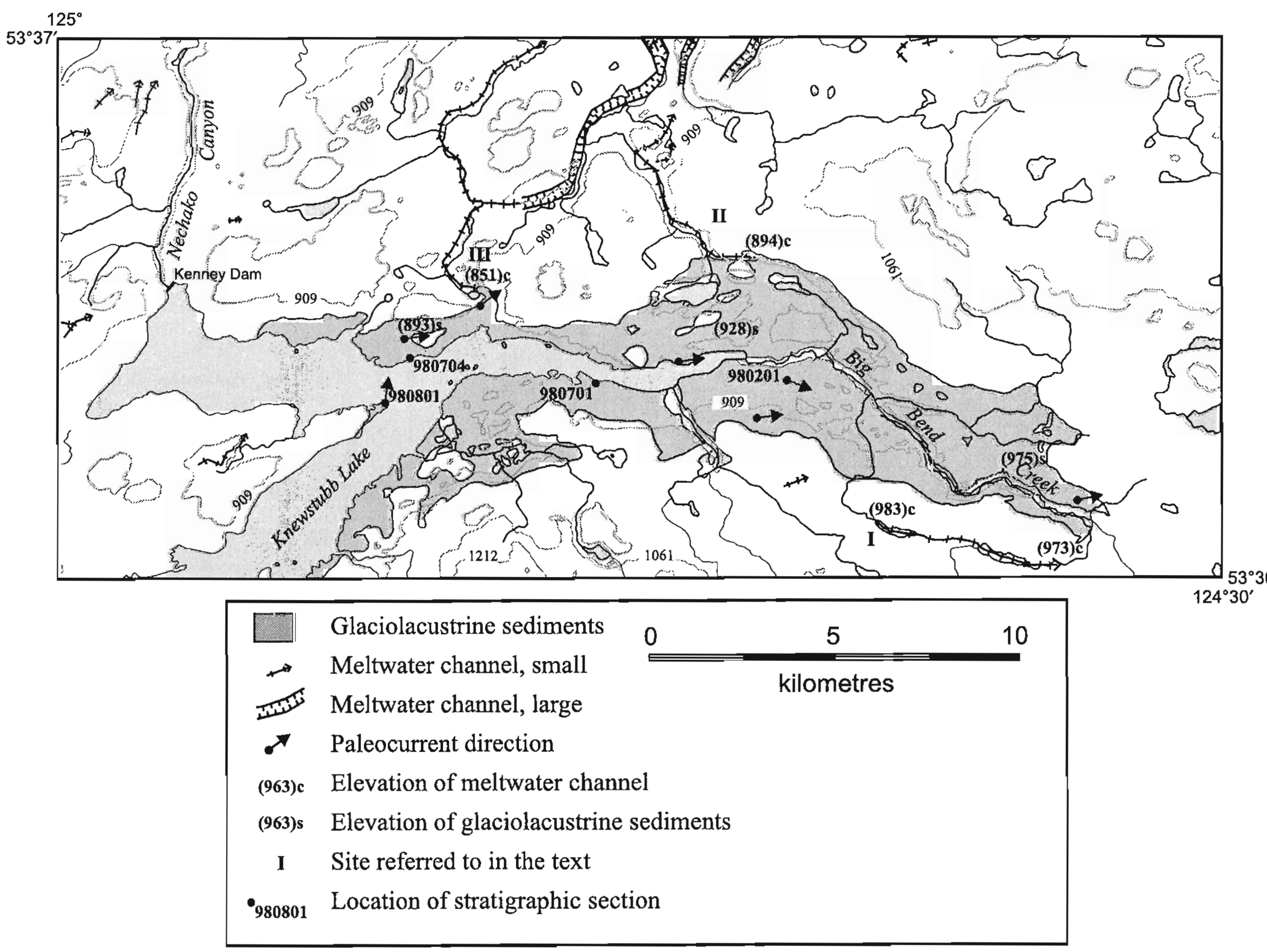

Figure 2. Distribution of glaciolacustrine sediments and meltwater channels modified from Plouffe (1998). Contour elevations are in metres (converted from feet) above sea level. Elevation measurements and paleocurrent indicators are new data part of this study.

possibly derived from local ice. While ice downwasted, subaqueous mass movements reworked deposits as the loss of support caused slumping. Post- and syndepositional deformation structures and the hummocky surface expression of the deposits suggest that sedimentation took place on dead ice or near the margins of the retreating glacier. The burial and subsequent melting of stagnant ice may explain the frequent lack of varves as year-round activity of sediment gravity flow processes may have disrupted any seasonal pattern. The coarse stratified sand and gravel unit capping the finer grained sediments was aggraded following the drainage of the glacial lake, during the establishment of a postglacial fluvial system.

As with other glacial lakes which occupied the Fraser Lake and Stuart Lake valleys north of the study area (Plouffe, 1997), no glacial lake strandlines were identified for glacial Lake Knewstubb. This is probably because of a combination of the following factors which were also noted by Plouffe (1997): 1) the forest cover hampers the identification of any shoreline features, 2) the glacial lake existed for only a short duration, 3) there was abundant fluctuation in the water level of the glacial lake as new outlets became open, and 4) at the maximum level reached by glacial Lake Knewstubb, the most common material reworked by the waves would have been a clayey till which is not easily eroded. On the other hand, the well developed beaches formed within 46 years since the reservoir level has been raised suggest that beaches could have formed within several decades if the glacial lake level dropped such that the waves were reworking the glacial lake deposits. The elevations of the northern outlets (see below) suggest that such a scenario did exist. Therefore, the absence of strandline may indicate that the northerly glacial lake drainage was short lived (less than 46 years).

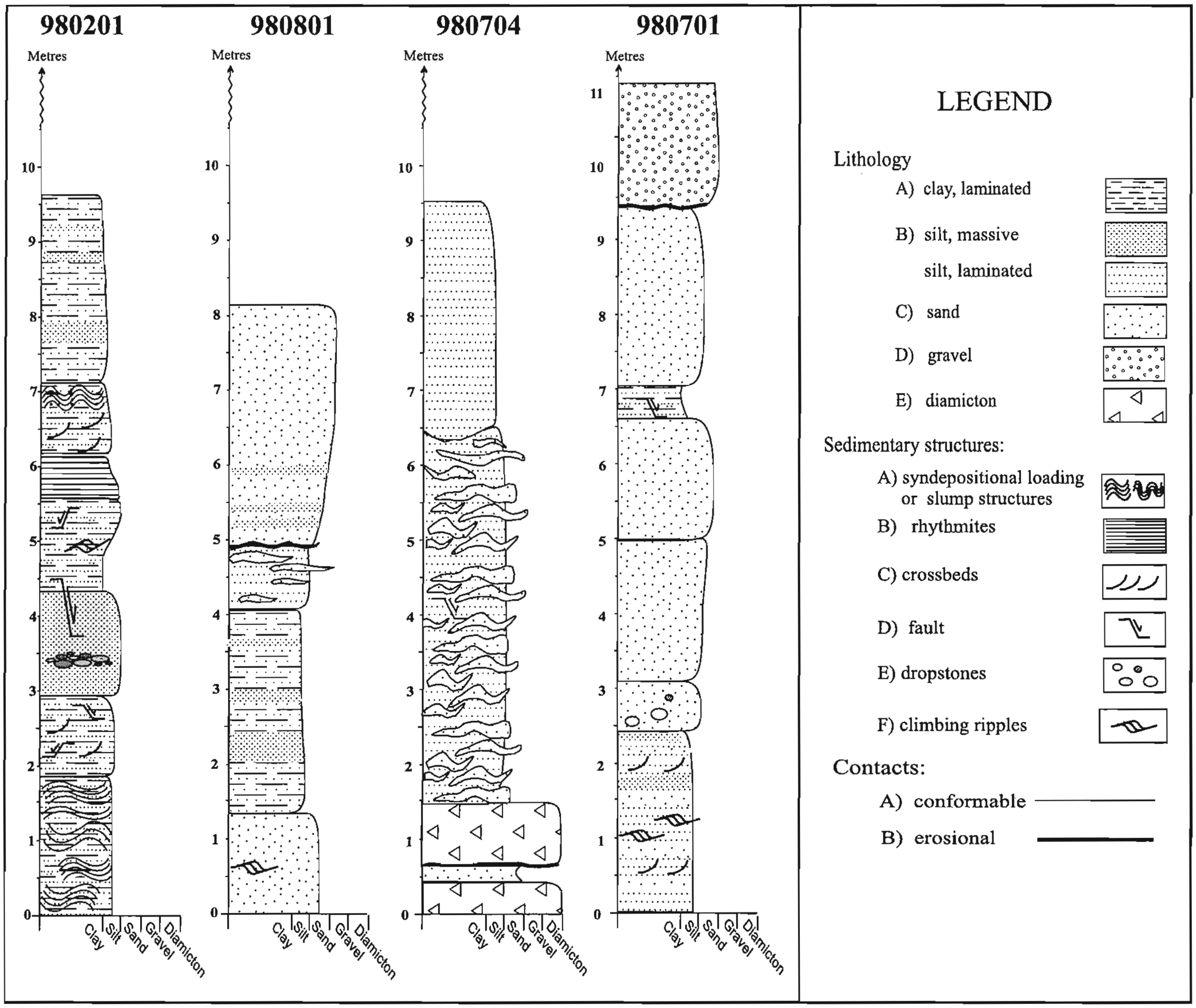

Figure 3. *Selected stratigraphic sections. Section locations are indicated on Figure 2.*

Figure 4. Photograph of folded laminations in glaciolacustrine sediments.

GLACIAL LAKE OUTLETS

A series of meltwater channels dominantly incised into till and locally into glaciolacustrine sediments are located in the higher hills surrounding Knewstubb Lake. These meltwater channels have been interpreted as the outlets that controlled the level of glacial Lake Knewstubb because the maximum elevation of glacial lake sediments is closely linked to the elevation of the channels. As ice retreated, and as lower ground became deglaciated, new outlets located at lower elevations became ice free which resulted in a drop of the glacial lake level. Two main sets of outlets have been identified: to the east and to the north.

Easterly drainage

In the Big Bend Creek region, glaciolacustrine sediments are found at a maximum elevation of 975 m. This measurement reflects a minimal estimate for the maximum level reached by glacial Lake Knewstubb. At this level, the glacial lake may have drained via a channel initiating at 983 m (Fig. 2; location I). This 250 m wide channel has a gradient towards the east and connects with the Big Bend Creek valley, 5 km to the east. Elevation measurements suggest that this meltwater channel was the controlling outlet of glacial Lake Knewstubb as long as Big Bend Creek valley was partly blocked by ice, sediments, or a combination of both. Big Bend Creek valley is thought to have been a second controlling outlet based on paleocurrent data collected to the east in the southeastern part of the glacial lake. The exact elevation of that outlet is unknown because it is difficult to estimate: 1) the amount of sediment erosion since the establishment of postglacial drainage and hence, 2) the elevation of Big Bend Creek valley floor at the time of existence of the glacial lake. However, it was probably slightly below 973 m, that is lower than the terminus of the meltwater channel at location I (Fig. 2).

Northerly drainage

Extending northward, beyond the study area, a number of incised meltwater channels are interpreted to have served as outlets to glacial Lake Knewstubb. Northeast of the Knewstubb Lake basin, at 894 m, the head of an approximately 15–40 m deep and 8 km long channel is cut in clayey till (location II; Fig. 2). To the west of this possible outlet, a second channel 20–40 m deep begins at 851 m (location III; Fig. 2). This channel system is approximately 13 km long, 150 m wide, and bifurcates several times. These channels were eroded by meltwater from glacial Lake Knewstubb.

INFERRED DRAINAGE HISTORY

During ice retreat, as outlets of glacial Lake Knewstubb became opened, progressively lower meltwater channels and branches within the same channel system became exposed. This caused the glacial lake level to lower and rendered former outlets inactive. Since the elevation of the southeastern channels are greatest, they are assumed to have initially drained glacial Lake Knewstubb while ice blocked northerly flow. As the ice retreated, the most easterly of the northern channels was exposed causing the abandonment of the southern outlets. Following further retreat of the glacier to the west, progressively lower channels were opened and the active outlet migrated westerly. This is corroborated with the maximum elevation of glaciolacustrine sediments which decreases to the west. During the higher phase of the glacial lake, its western portion was occupied by ice that prevented the deposition of glaciolacustrine sediments. When the western portion became deglaciated, the glacial lake level had dropped, and its level was controlled by a lower outlet. Finally, when the Nechako River became open in the vicinity of Kenney Dam, glacial lake Knewstubb drained completely.

Chronology

Due to the lack of datable organic matter found in the sediments associated with glacial Lake Knewstubb, no precise dating is available on the chronology of the creation or disappearance of the glacial lake. Based on radiocarbon chronological data presented by Clague (1981), the interior of British Columbia was deglaciated by 9.5–10 ka and by that time glacial Lake Knewstubb was completely drained.

ENGINEERING APPLICATION

Glacial lake sediments are often associated with poor slope stability conditions because of the low cohesion and strength of fine-grained sediments once saturated with water. Forestry roads within the study area are cut into lacustrine sediments and are prone to surface erosion and slumping. The beds of fine sand, silt, and clay often give rise to poor drainage conditions. Elevated pore pressures develop due to the dissimilar permeabilities of the layers, and create planes of weakness. In

Figure 5. View of the road cut in glacial lake sediments at Big Bend Creek. Extensive working has been completed at this site to mitigate the instability of the sediments. Arrow points at willow wattles.

several locations roads have been cut into folded sediments such that beds dip down slope and cause the hillsides to be particularly prone to failure. Sediments derived from the unstable road cuts end up clogging drains and creeks resulting in additional drainage problems and erosion. Efforts funded by Forest Renewal British Columbia to mitigate the instability of a road cut in the Big Bend Creek valley have included the construction of vertical cobble-lined channels for preferential drainage down the hillside, the installation of willow wattles to stop soil creep, the placement of various types of sediment traps near drains and creeks, and the reseeding of slopes (Fig. 5). In many cases, if mapping of surficial materials had been done prior to the building of roads, the glacial lake sediments could have been avoided.

CONCLUSION

The maximum elevation of glacial lake sediments and the elevation of the head of meltwater channels were used to reconstruct the glacial lake history of the area surrounding modern Knewstubb Lake. Stratigraphic and sedimentological studies suggest that the glacial lake was formed by the blockage of the northward drainage through Nechako River, by the retreating glacier. Initially the impounded water overflowed to the southeast. As ice retreated westward, drainage switched northward, and consecutively lower drainage channels were exposed along the northern shore of the glacial lake. The lowest outlet, at any given instance, controlled the level of the glacial lake.

ACKNOWLEDGMENTS

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Upper Triassic (Rhaetian) debris-flow deposits in the Sandilands Formation, Queen Charlotte Islands, British Columbia

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Abstract: Disrupted sedimentary-breccia deposits found locally within the Sandilands Formation of Queen Charlotte Islands are interpreted as debris-flow deposits, conformable within the stratigraphic succession of the formation. Similar conodont faunas have been obtained from strata in undeformed sedimentary blocks in the breccia deposits as well as from underlying, normally stratified beds, and are of Rhaetian (Late Triassic) age. This evidence indicates that slope failure and downslope transport of Rhaetian sedimentary clasts occurred after significant lithification of sediments had taken place. This is the first evidence of Rhaetian debris-flow deposits within the Sandilands Formation of Queen Charlotte Islands, although similar deposits are known from Vancouver Island. They may be genetically related to volcanic events in the terminal Triassic.

Résumé : Des dépôts de brèches sédimentaires disloqués observés localement dans la Formation de Sandilands dans les îles de la Reine-Charlotte sont interprétés comme des dépôts de coulées de débris, en concordance dans la succession stratigraphique de cette formation. Des faunes de conodontes similaires du Rhétien (Trias tardif) ont été trouvées dans des strates dans des blocs sédimentaires non déformés au sein des dépôts bréchiques, ainsi que dans des lits sous-jacents à stratification normale. Ces observations indiquent que les ruptures de talus et le transport descendant des clastes sédimentaires rhétiens se sont produits à la suite d'une lithification considérable des sédiments. Il s'agit de la première indication de dépôts de coulées de débris du Rhétien dans la Formation de Sandilands des îles de la Reine-Charlotte, bien que des dépôts similaires aient déjà été reconnus dans l'île de Vancouver. Ces dépôts sont vraisemblablement apparentés génétiquement au volcanisme de la fin du Trias.

INTRODUCTION

Upper Triassic strata are widespread on Queen Charlotte Islands, British Columbia (Fig. 1), extending from the northwest coast of the islands, near Sadler Point, to Kunghit Island at the islands' southern tip. The oldest Upper Triassic strata known on the islands include basalt flows and breccias of the Carnian Karmutsen Formation. These tholeiitic lavas are widespread across the islands and presumably formed in a rifted back-arc setting. The volcanic strata of the Karmutsen Formation are conformably overlain by carbonate and fine-grained clastic sedimentary rocks of the Kunga Group. This package includes a massive, shallow-water bioclastic limestone unit at its base, the Late Carnian Sadler Limestone, which is locally interstratified with volcanic flows of the upper part of the Karmutsen Formation. Conformably overlying the Sadler Limestone are thinly bedded, calcareous black shales and calcarenites of the Late Carnian–Late Norian Peril Formation, and, finally, siliceous shale, and tuffaceous siltstone and sandstone turbidites of the Sandilands Formation, which dates from the (Late Norian(?)–) Rhaetian to Sinemurian (Fig. 2).

The Triassic to earliest Jurassic litho- and biostratigraphy, and sedimentology, of Queen Charlotte Islands has been comprehensively described by Sutherland Brown (1968), Desrochers and Orchard (1991), Orchard (1991a), Carter (1991), and Haggart et al. (1995). The change in lithological composition seen though the Kunga Group, from shallow-water shelf carbonates of the Sadler Limestone to deep-water distal turbidites of the Sandilands Formation, has been interpreted to reflect a pronounced change in the depositional setting of Kunga Group strata. The massive bioclastic limestones formed in carbonate reefs associated with the back-arc volcanic complex of the Karmutsen Formation. Beginning in the later Carnian, however, fine clastic material of the Peril Formation introduced into the basin began to choke carbonate deposition, and the basin slowly subsided as clastic deposition increased. The stratigraphically highest parts of the Kunga Group, distal turbidites of the Sandilands Formation, reflect siliciclastic-dominated sedimentation in a deep-basin setting by the Rhaetian.

Details of the internal stratigraphy, lithofacies, and biochronology of the Sandilands Formation can be found in the references cited above. This paper documents an interesting breccia-bearing facies of the Sandilands Formation found on Oliver Islet, Queen Charlotte Islands (Fig. 1). This small island is the only known occurrence to date of this facies in the Sandilands Formation.

SEDIMENTOLOGY

Sandilands Formation strata on Oliver Islet are well exposed in the intertidal zone and dip moderately to near vertically to the south (Thompson and Lewis, 1990). Approximately 35 m of section outcrops on the island's western tip. Sedimentological features, such as basal scour and grading(?) in siltstones and fine-grained sandstones, and surface grazing traces, indicate that the section youngs southward. Much of the section consists of thinly to moderately bedded siltstone and fine-grained sandstone, both locally calcareous, as well as interbedded dark shale (Fig. 3a). Several thin, tuffaceous, siltstone beds are noted in the section. Grazing traces are often noted on the tops of shale beds, and specimens of the distinctive spongiomorph *Heterastridium* are also noted locally (Fig. 3b). Ammonoids, brachiopods, and bivalves are rare, but occasionally found on bedding-plane exposures of these strata.

Two breccia deposits are found within the Oliver Islet succession of normally stratified rocks (Fig. 3c). These polymictic breccia deposits are variable in thickness, with a maximum of approximately 4.5 m, typically have sharp bounding contacts with under- and overlying strata, and are conformable within the overall stratigraphic succession. The lower deposit can be seen to locally pinch out into undisturbed strata lateral to the breccia deposit, however.

The two breccia deposits contain both deformed and undeformed strata. Undeformed strata within the breccia deposits consist of irregularly shaped blocks (up to 0.8 m) of fine-grained sandstone, siltstone, and shale, generally showing original bedding (Fig. 3d). Deformed strata consist of a matrix of sheared silty shale or greywacke, often containing poorly sorted clasts derived from sedimentary deposits (Fig. 3e, f). Most clasts within the deformed strata are angular and composed of fine-grained sandstone, siltstone, and shale, but some are rounded and composed of massive, bioclastic limestone (Fig. 3e), a lithology typical of the older Peril Formation and Sadler Limestone. Within the breccia deposits, the blocks of undeformed strata exhibit sharp boundaries with the deformed strata.

BIOSTRATIGRAPHY

Two microfossil samples were collected in 1994 from the disrupted strata exposed on the southwestern point of Oliver Islet. One sample, from GSC loc. C-302270, was a composite from several bioclastic limestone clasts (Fig. 3e) within the upper debris-flow deposit. This sample contained a large and diverse microfauna of conodonts, ichthyoliths, foraminifers, ostracodes, microgastropods, microbivalves, and sponge spicules. A second sample, collected from a large nodule in dark stratified carbonates from strata immediately underlying the breccia of GSC loc. C-302270, was barren. An additional sample, from GSC loc. C-303650, was subsequently collected in 1997, also from the normally stratified beds, but underlying the lower debris-flow deposit. This collection produced a single conodont.

The conodont fauna from GSC loc. C-302270 contains 177 specimens of *Epigondolella* pectiniform elements and 28 relatively fragile ramiform elements representing the multielement apparatus of the former. All these elements are representatives of *Epigondolella* ex gr. *bidentata*, a group with a combined range of latest Middle Norian to Rhaetian (Orchard and Tozer, 1997). Taxonomic discrimination within this group has been attempted by Orchard (1991c, 1994),

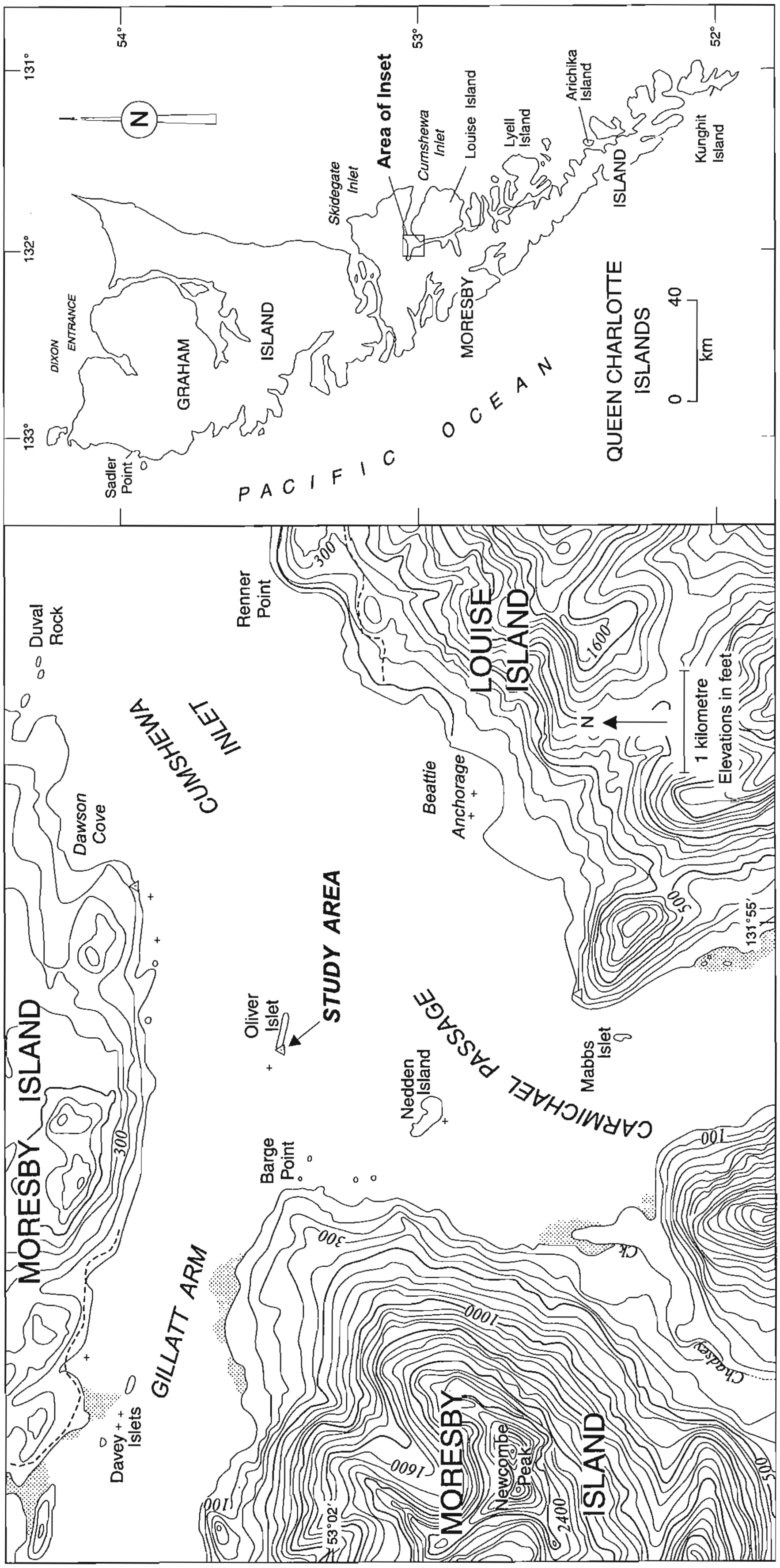

Figure 1. Map of Queen Charlotte Islands, British Columbia, showing location of study area.

SERIES	STAGE	SUBSTAGE	FORMATION	AMMONOID ZONE		CONODONT FAUNAS / ZONES
UPPER TRIASSIC	RHAETIAN		SANDILANDS	Choristoceras crickmayi		Mi. posthernsteini
				Paracochloceras amoenum		E. mosheri
	NORIAN	U	PERIL	Gnomohalorites cordilleranus		E. bidentata
		M		Mesohimavatites columbianus	IV	E. serrulata
					III	
					II	E. postera
					I	E. elongata
						E. spiculata
				Drepanites rutherfordi		E. multidentata
		L		Juvavites magnus		E. triangularis
				Malayites dawsoni		E. quadrata
				Stikinoceras kerri		M. primitius

Figure 2. *Litho- and biostratigraphic scheme of uppermost Triassic rocks, Queen Charlotte Islands (after Haggart et al., 1995). Conodont abbreviations are M. = Metapolygnathus, E. = Epigondolella, and Mi. = Misikella.*

who separated three species on the basis of relative platform dimensions: *E. bidentata, E. mosheri* (2 morphotypes), and *E. englandi*. Within the Oliver Islet collection from GSC loc. 302270, the majority of elements correspond to *E. mosheri*, as does the specimen from GSC loc. C-303650. There are also large specimens that resemble *E. englandi* and small growth stages that correspond to *E. bidentata* sensu stricto (Fig. 4). Variation in populations of *E.* ex gr. *bidentata* is complex and is the subject of ongoing study.

DISCUSSION

Large monospecific collections of *E. bidentata* sensu stricto appear to be more-or-less correlated with Upper Norian *Monotis*-bearing strata, equivalent to the Cordilleranus Zone. *Epigondolella mosheri* characterizes the next younger Amoenum Zone, based on ammonoid associations in the Gabbs Valley Range of Nevada (Orchard and Tozer, 1997) and the Tyaughton Group of the Cadwallader terrane in south-central British Columbia (Orchard *in* Umhoefer and Tipper, 1998). This species also occurs in superposition above *Monotis* both in the Bocock Limestone of Pine Pass in east-central British Columbia (Orchard, 1991c), and in the Sandilands Formation on Queen Charlotte Islands (Orchard, 1991a); it is also known from several other isolated localities in British Columbia (Orchard, 1991b) and as far away as Peru (Orchard, 1994), but is not known with certainty in Eurasia. *Epigondolella englandi* was first described based on faunas from the Lewes River limestones in the Laberge area of the Yukon, where it may co-occur with *E. mosheri*; the same association is evident elsewhere on Queen Charlotte Islands.
Data from British Columbia, Nevada, and Baja California (Orchard, 1998; Whalen et al., 1998) suggest that all three species of *Epigondolella* may extend through to at least the lower part of the ultimate Triassic ammonoid zone of *Choristoceras crickmayi*, although this evidence is partly indirect via association with the Tozeri Zone radiolarian zonal assemblage of Carter (1993). In summary, both the Oliver Islet breccia and matrix faunas belong to the *E. mosheri* Zone and are equivalent in age to the Amoenum, or possibly early Crickmayi, ammonoid zones. This places them in the Rhaetian Stage *sensu* Dagys and Dagys (1994).

The sedimentological relationships discussed above suggest that the Oliver Islet breccia deposits represent an exceptional situation in which debris-flow deposits resulted from slope failure and downslope transport of competent sedimentary blocks. Breccia deposits interpreted to represent downslope movement are sometimes noted in deep-water facies of the older, Norian Peril Formation on Queen Charlotte Islands, but this is the first example known to us of similar deposits within the Rhaetian part of the Sandilands Formation. The presence of Rhaetian fossils in limestone clasts within the Oliver Islet breccia deposits, as well as in bioclastic limestone of subjacent strata on the islet, indicates that Sandilands Formation strata were partially lithified prior to slope failure and subsequent downslope transport of the clasts.

On Vancouver Island, similar breccia deposits are well known around the Triassic–Jurassic boundary. Jeletzky (1976, p. 27 et seq.) described the Hecate Cove Formation of Quatsino Sound and noted its development elsewhere on the west coast of Vancouver Island. This pyroclastic and sedimentary unit includes slump breccias, and at the type section has a shelly fauna that was also determined as Rhaetian. At Mushroom Point, on the west coast of Vancouver Island (Jeletzky, 1950), limestone clasts from within the Hecate Cove Formation equivalents have also yielded Rhaetian conodonts of the *Epigondolella bidentata* group (M.J. Orchard, unpub. data).

Throughout Queen Charlotte Islands, coeval Rhaetian strata of the Sandilands Formation include well stratified siltstones and silty limestones, with less common micrite nodules interspersed with abundant thin interbeds of grey to tan tuffaceous shale and siltstone. These tuffaceous interbeds have been interpreted as reflecting an influx of ejecta derived

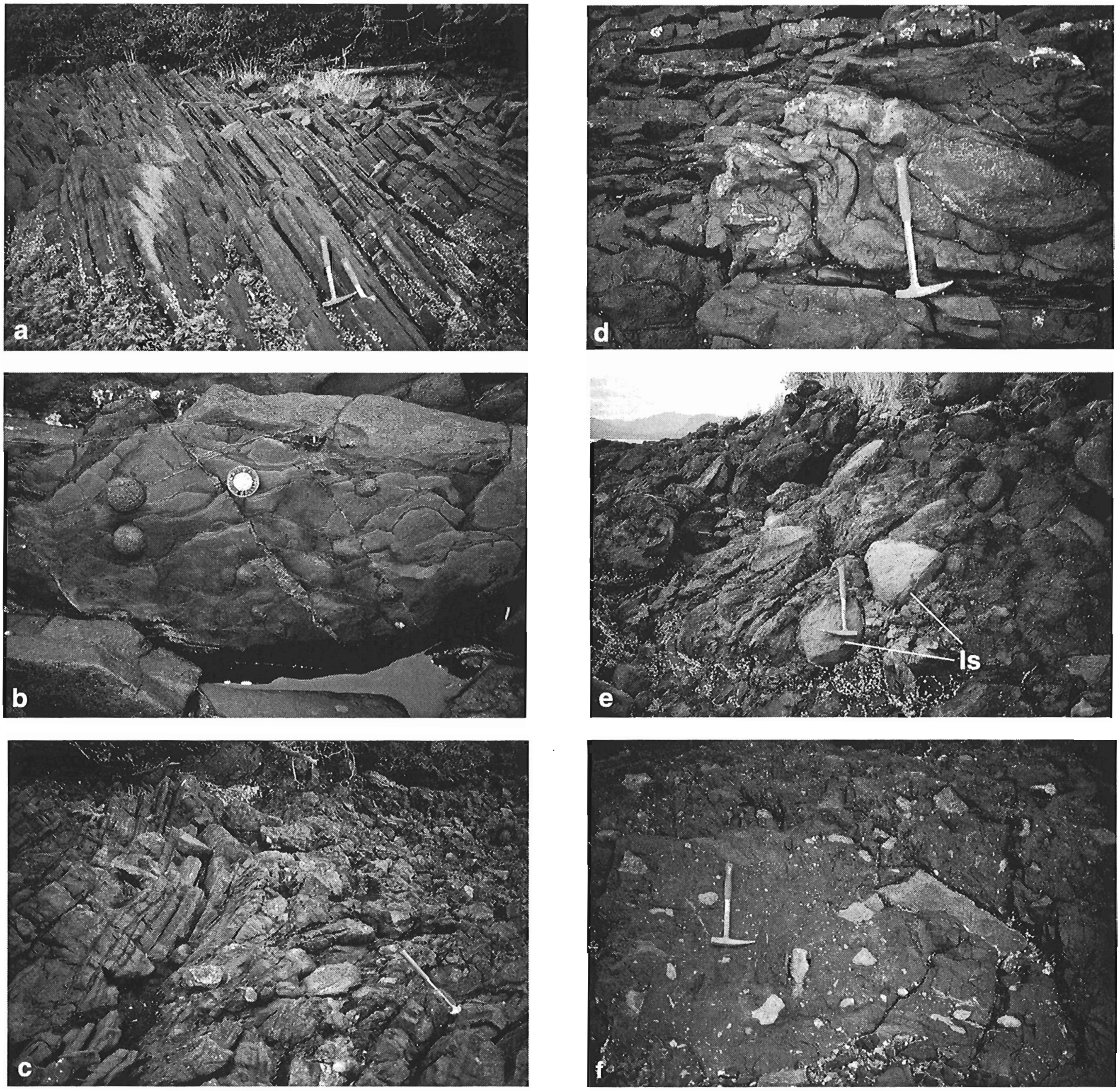

Figure 3. *Rock types present in the Sandilands Formation, Oliver Islet:* ***a)*** *thinly bedded black shale (dark) and calcarenite (light) beds; beds young to right of photograph;* ***b)*** *upper surface of calcarenite bed showing spherical and silicified Heterastridium;* ***c)*** *debris-flow deposit(s) overlain conformably by normally bedded strata (at left); note abundance of large clasts of concretionary, massive limestone;* ***d)*** *slump features associated with debris-flow deposit;* ***e)*** *large clasts of concretionary, massive limestone within debris-flow deposit; ls = concretionary, massive limestone clasts;* ***f)*** *less-competent matrix of debris-flow containing clasts of massive limestone and black shale.*

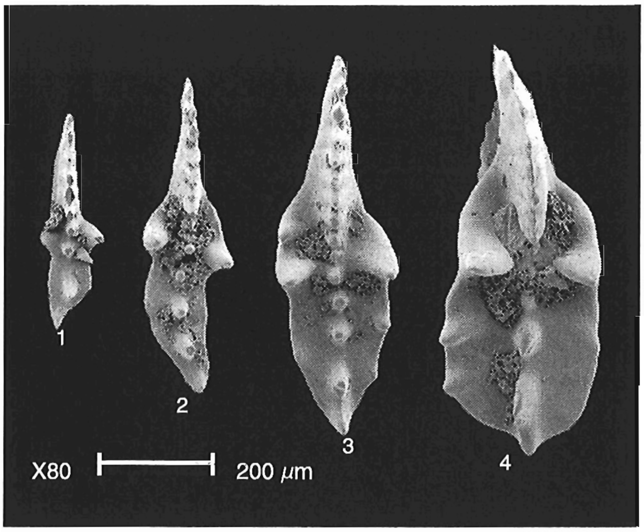

Figure 4. Epigondolella ex gr. bidentata Mosher from GSC loc. C-302270. 1. GSC 101776, small growth stage corresponding to E. bidentata Mosher; 2. GSC 101777, typical specimen of E. mosheri Kozur & Mostler, Morphotype A Orchard; 3. GSC 101778, E. mosheri, transitional to Morphotype B Orchard; 4. GSC 101779, Large growth stage, E. aff. englandi Orchard.

from a distant volcanic source that came to rest in a deep-water slope or basin setting (Cameron and Tipper, 1985). It has been suggested previously that the tuffaceous volcanic facies of the Sandilands Formation on Queen Charlotte Islands may represent a genetic linkage with the older part of the Lower Jurassic Bonanza Volcanic Group on Vancouver Island (Cameron and Tipper, 1985; Haggart and Tipper, 1994), although the known age of the Queen Charlotte Islands deposits was considered to predate significantly the age of Bonanza volcanism on northern Vancouver Island. However, recent advances in dating of volcanic deposits within strata of the Harbledown and Parson Bay formations, underlying the Bonanza Group on northern Vancouver Island, have confirmed that volcanism initiated in that area during the Late Triassic as well (G. Nixon, pers. comm., 1998). The stratigraphic and geographic proximity of Rhaetian volcanic deposits with Bonanza volcanic rocks on northern Vancouver Island suggests that the former represent a much more proximal setting of Late Triassic Insular Belt volcanic activity. Rhaetian slump deposits of northern Vancouver Island and Queen Charlotte Islands may reflect renewed uplift of the region, associated with this volcanic activity.

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Ductile shear zones and an Eocene unconformity between Kalamalka Lake and Oyama Lake, Vernon map area, British Columbia

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Abstract: A high-grade paragneiss assemblage intruded by a variety of plutonic bodies is exposed east of Kalamalka Lake in the Vernon area. The assemblage includes biotite-sillimanite schist, calc-silicate, marble, calcareous quartzite, amphibolite, and is inferred to be Neoproterozoic to Early Paleozoic. A granodiorite pluton and a heterogeneous diorite/granodiorite body truncate the foliation in the paragneiss. A ductile shear zone more than 20 km long and several hundred metres thick postdates the plutons. It is characterized by shallowly west-plunging stretching lineation, synkinematic sillimanite, and hanging-wall-down sense of shear. Isolated erosional outliers of dacite inferred to be Eocene rest unconformably on the high-grade rocks. At one location, a dacite flow directly overlies a regolith developed in mylonitic biotite-sillimanite schist. At several other localities, dacite breccia contains randomly oriented foliated gneiss clasts.

Résumé : Un assemblage de paragneiss fortement métamorphisé que recoupent divers massifs plutoniques affleure à l'est du lac Kalamalka dans la région de Vernon. Il est composé de schiste à biotite et à sillimanite, de marbre à silicate calcique, de quartzite calcaire et d'amphibolite et son âge présumé s'échelonne du Néoprotérozoïque au Paléozoïque précoce. Un pluton de granodiorite et un massif hétérogène de diorite et de granodiorite ont tronqué la foliation du paragneiss. Une zone de cisaillement ductile de plus de 20 km de longueur et de plusieurs centaines de mètres d'épaisseur est postérieure aux plutons. Elle se caractérise par une linéation d'étirement plongeant faiblement vers l'ouest, par de la sillimanite syncinématique et par un cisaillement dans le sens descendant du toit. Des buttes témoins isolées d'âge supposé éocène reposent en discordance sur les roches intensément métamorphisées. À un endroit, une coulée dacitique repose directement sur un régolite qui s'est développé dans du schiste mylonitique à biotite et sillimanite. À plusieurs autres endroits, des brèches dacitiques renferment des clastes de gneiss folié à orientation aléatoire.

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INTRODUCTION

To the southeast of Vernon, in the Vernon map area (Fig. 1), occurs a thick succession of high-grade metamorphic rocks, which Thompson and Daughtry (1996) correlated with the Neoproterozoic Monashee Group of Jones (1959). The succession is bounded on the west by the Okanagan Valley, which has been interpreted to be the locus of the Okanagan Valley detachment fault; a crustal-scale ductile shear zone which is proposed to have stripped low-grade Paleozoic and Mesozoic metasedimentary and volcanic cover rocks from high-grade metamorphic rocks of the Shuswap metamorphic complex during middle Eocene time (Tempelman-Kluit and Parkinson, 1986; Bardoux, 1993). The detachment model was based upon geological relationships in the Kelowna area, approximately 80 km south of Vernon, where amphibolite-grade mylonitic gneisses are overlain by lower-grade Mesozoic and Paleozoic volcanic and metasedimentary rocks and Eocene volcanic strata (Tempelman-Kluit and Parkinson, 1986). Similar mylonitic gneisses are exposed on the east side of Kalamalka Lake near Vernon. A renewed study focus on the distribution of shear-zone fabrics in the Vernon area has yielded geological evidence which suggests that a modification of the extension model is necessary (Thompson and Daughtry, 1994, 1996, 1997).

Mapping in 1997 along the east side of Kalamalka Lake within high-grade metamorphic rocks outlined a ductile shear zone at least 20 km long and several hundred metres thick, with hanging-wall-down displacement (Erdmer et al., 1998). The shear zone deforms a thick paragneiss succession intruded by a granodioritic pluton inferred to be Middle Jurassic. Fieldwork in the summer of 1998 focused on the east side of Kalamalka Lake (Fig. 2) with emphasis on ductile shear zones.

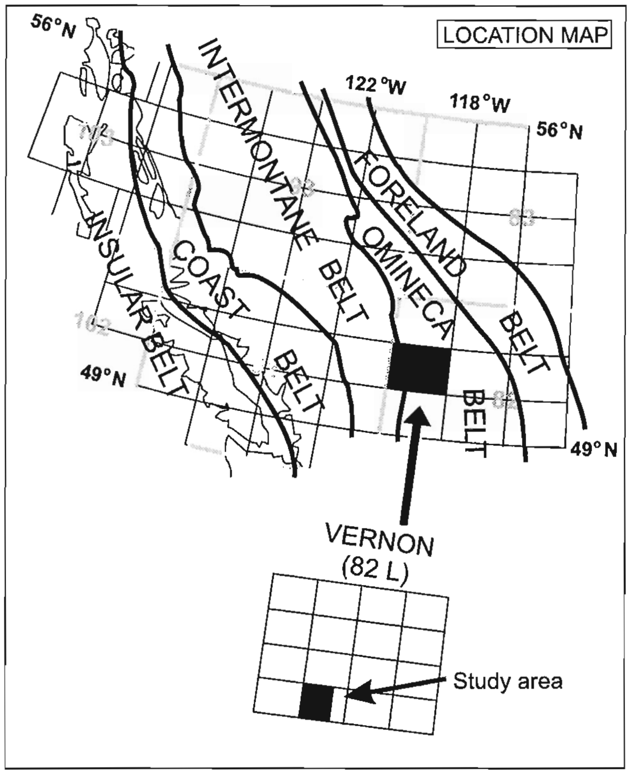

Figure 1. Location of the Vernon map area within the NTS grid, and outline of the geological-morphological belts of the Canadian Cordillera after Wheeler et al. (1991).

DESCRIPTION OF UNITS

High-grade assemblage

Amphibolite, amphibole schist, feldspar-quartz schist

This heterogeneous unit occurs south of Vernon, and includes a range of rock types including amphibolite, hornblende-biotite-plagioclase schist, biotite-hornblende-plagioclase schist, and plagioclase-quartz schist. Garnet is present in pelitic biotite-rich layers locally. Grain size is medium to coarse, and all rock types are strongly foliated. Transitions from one rock type to another are generally gradational and compositional layering is parallel to schistosity.

The heterogeneity of this assemblage suggests that it is a succession of mixed pelitic and mafic volcanic rocks and/or possibly dykes, metamorphosed to amphibolite grade. Thompson and Daughtry (1997) and Erdmer et al. (1998) assigned this unit to the Neoproterozoic and (or) Early Paleozoic miogeoclinal succession of the Silver Creek Formation.

Biotite-sillimanite schist

One of the dominant rock types in the map area is medium- to coarse-grained biotite-sillimanite-plagioclase-quartz schist. Locally, other rock types include amphibolite, plagioclase-quartz schist, and quartzite. Contacts between rock types are sharp and parallel to the foliation. Coarse-grained quartz-feldspar or feldspar pegmatites are common, and may be aligned with the schistosity or cut across it. Pegmatites are generally tens of centimetres in thickness, but may exceed 1 m. Schistosity is commonly wavy at the outcrop scale. The schist is garnetiferous locally, and coarse-grained sillimanite is commonly visible in biotite-rich layers; fine-grained fibrous sillimanite is present almost everywhere. Thin, discontinuous layers of quartzofeldspathic migmatite are common and parallel to schistosity. In many outcrops, particularly around Cosens Bay, migmatite bands have been disaggregated in a brittle to ductile fashion, resulting in centimetre-sized rounded boudins or augen that weather positively on foliation-parallel surfaces.

This unit is inferred to be a sequence of primarily pelitic sediments with minor mafic flows or transposed dykes, metamorphosed to amphibolite grade. On the basis of correlation with the Monashee Group, the succession, like the amphibolite unit, is inferred to be Neoproterozoic to Early Paleozoic.

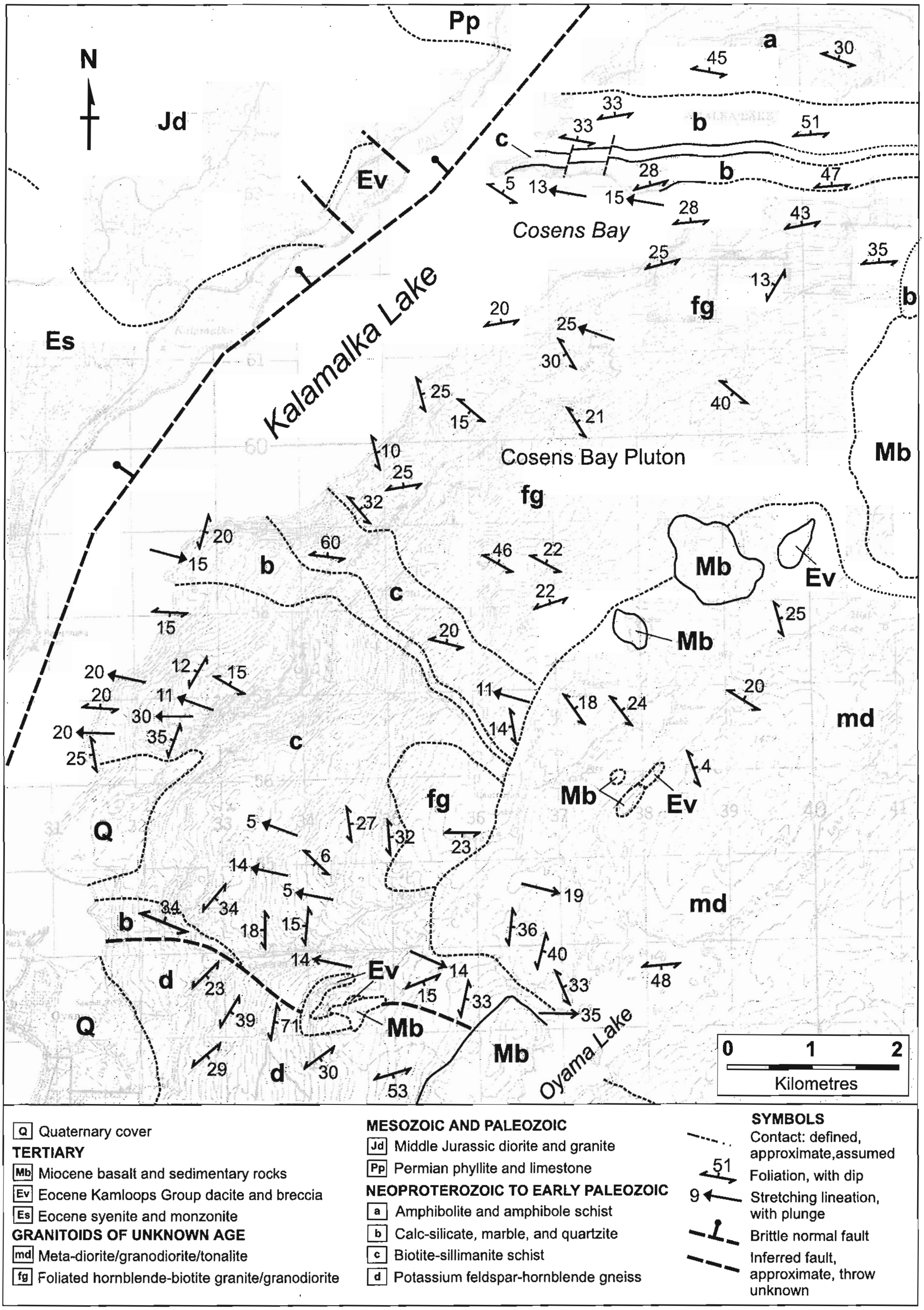

Figure 2. Geological map of the area east of Kalamalka Lake, central Okanagan Valley. Data are from this study and previous mapping for the Vernon Project. Topographic base is NTS 82 L/3, 1:50 000 scale map.

Calc-silicate, marble, calcareous quartzite

Calc-silicate, marble, and calcareous quartzite are interlayered with biotite-sillimanite schist and form the dominant rock type in three areas along the east side of Kalamalka Lake. At Cosens Bay, the unit is several hundred metres thick and forms resistant cliffs which jut out from surrounding topography and can be traced east towards Deep Lake. Calcareous quartzite dominates the assemblage. The mineralogy locally includes quartz, calcite, diopside, grossular garnet, plagioclase, hornblende, and biotite. Compositional layering is parallel to foliation and contacts are sharp. Pegmatite in biotite-sillimanite schist also cuts this unit and is largely parallel to foliation. Pegmatite and more siliceous layers are commonly boudinaged into discontinuous lenses with elongated and wispy tails.

This unit is interpreted to be a succession of quartz-rich clastic rocks, impure limestone, and minor pelite metamorphosed to amphibolite grade. The contact of calc-silicate with biotite-sillimanite schist is assumed to be a transposed stratigraphic contact.

Hornblende-biotite granodiorite/granite (Cosens Bay Pluton)

This unit outcrops along the northeast side of Kalamalka Lake for several kilometres and can be traced up-slope to the east onto the Thompson Plateau. It is characterized by homogeneous, medium- to coarse-grained, foliated hornblende-biotite granodiorite to granite, although in places it is quartz poor and is quartz diorite. The contact between granodiorite and biotite-sillimanite schist is parallel to foliation and difficult to place, as the granodiorite is strongly foliated along its margins and is mineralogically similar to the schist. The contact has likely been transposed during formation of the foliation. Away from its margins, the granodiorite is less foliated, and it is unfoliated at the centre of the pluton. The amount of biotite varies locally. Foliation is wavy on the outcrop scale. Numerous quartz-feldspar veinlets are present and are generally parallel to schistosity, although post-deformation veins and pegmatites are also present.

Several foliation-parallel layers of granodiorite are found within biotite-sillimanite schist on the north shore of Cosens Bay, which Erdmer et al. (1998) interpreted on the basis of compositional similarity to be transposed dykes or sills sourced from the main pluton. A sample of this unit is being processed for U-Pb zircon dating at the University of Alberta.

Potassium feldspar–hornblende gneiss

At the south end of Kalamalka Lake, there is a sharp contact between the paragneiss succession described above and a heterogeneous hornblende–potassium feldspar granitic gneiss. The gneiss contains little or no biotite. The unit is characterized by multiple phases of granitic veining and pegmatite, many of which are aligned parallel to foliation. The foliation is wavy and irregular on the outcrop scale. Layers of coarse-grained amphibolite up to several metres thick are common. Original mafic minerals in many outcrops of this unit have been pervasively altered to epidote and chlorite. Some outcrops have a bleached appearance, likely the result of silicification and/or sericitization. Many outcrops near the sharp contact with sillimanite-biotite schist are also brecciated and fractured.

The multiple generations of veining, the gneissosity, and the alteration indicate that this unit has a strain history which differs from that of the paragneiss to the north. A sample is currently being processed for U-Pb zircon dating to test the hypothesis that it is old basement.

Meta-diorite/granodiorite/tonalite/granite

To the east of Kalamalka Lake, a strongly heterogeneous multiphase intrusive body was mapped. The irregular and patchy distribution of the individual phases makes it difficult to map them separately, and all phases are commonly present at a single outcrop. The unit is generally weakly foliated, and strongly foliated only at the margins. The oldest phase, on the basis of crosscutting relationships, is medium- to coarse-grained hornblende diorite, hornblende quartz diorite, or amphibolite. It is locally strongly to weakly foliated and hosts plagioclase veinlets parallel to foliation. It forms a minor component of the unit, yet is present at most outcrops. It occurs most commonly as isolated elongate blocks or inclusions within other phases, commonly up to several metres in length.

The next younger phase is medium- to coarse-grained hornblende granodiorite to tonalite, which composes most of the unit. This unit may be strongly foliated to unfoliated and commonly hosts inclusions of diorite. Where both the granodiorite and diorite phases are foliated, foliations may be locally parallel, but are more commonly discordant. Foliation is commonly wavy at outcrop scale. The contact between granodiorite and diorite is generally sharp, but is locally a diffuse, gradational compositional change. The granodiorite locally resembles the Cosens Bay pluton, but is much more heterogeneous and lacking in biotite.

The youngest phase on the basis of crosscutting relations is medium- to coarse-grained hornblende granite. Its distribution is irregular. It is locally the only phase present at an outcrop, or is completely absent. It is generally weakly foliated to unfoliated. The contact between granite and granodiorite may be sharp or compositionally gradational. Numerous phases of quartz-feldspar veins and pegmatite are common, and range up to tens of centimetres in thickness. Some veins and pegmatites are deformed while others postdate the last episode of deformation.

The relation of this multi-phase igneous body to the Cosens Bay pluton to the north is unclear.

Granite

Numerous small stocks and sills of granite cut biotite-sillimanite schist, calc-silicate, and the Cosens Bay Pluton. These may be loosely grouped into two categories: lineated and non-lineated. Non-lineated granite is typically medium to fine grained, biotite bearing, and weakly foliated. Two bodies of this variety outcrop along Kalamalka Lake, one within biotite-sillimanite schist and the other in calc-silicate. Granite clearly truncates schistosity in the host unit; numerous other similar intrusions occur on the west side of Cougar Canyon. The other variety of granite is also biotite bearing, but displays a strong lineation defined by rodded quartz and feldspar grains. This granite is common within biotite-sillimanite schist immediately north of Oyama Creek. Samples of granite which intrude the biotite-sillimanite schist unit are being analyzed for U-Pb dating.

Low-grade assemblage

Eocene volcanic rocks/conglomerate

Volcanic strata and minor conglomerates, correlated with the regionally extensive Kamloops Group of Eocene age, rest unconformably on high-grade metamorphic rocks as isolated erosional outliers. Most of the succession is massive green-grey dacite. The dacite lacks deformation and metamorphism.

An erosional remnant of the Eocene succession occurs directly west of Oyama Lake (Fig. 2). In a road cut along the Oyama Lake road, massive dacite flows and volcanic breccia overlie a regolith developed in biotite-sillimanite schist. The loosely coherent, ochre to brown regolith is several metres thick and grades downward into foliated and lineated mylonitic biotite-sillimanite schist. Within the regolith, foliation in angular schist clasts up to several tens of centimetres across has the same orientation as in the underlying bedrock. Foliation and lineation in the underlying schist are discordant with the base of the dacite. The top few centimetres of the regolith are a slightly darker brown colour, interpreted to result from baking by the lava. The contact is a sharp, undulating surface with tens of centimetres of relief. The present orientation of the contact is steeply dipping at 70–80° to the west.

Approximately 400 m north of the roadcut exposure of the regolith, massive dacite is underlain by volcanic breccia at least 5 m thick. The breccia contains abundant angular to rounded clasts of mylonitic gneiss and dacite up to boulder size enclosed in a dacitic matrix. Gneiss clasts are strongly foliated and randomly oriented. The contact between breccia and overlying massive dacite flows is undulatory, with several metres of relief.

The contact between Eocene rocks and underlying metamorphic rocks is also exposed 1200 m northwest of King Edward Lake. In this outcrop, flows of massive dacite overlie a conglomerate of rounded hornblende-granodiorite clasts. The contact between conglomerate and the underlying hornblende granodiorite is not exposed; however, granodiorite occurs several metres away. The granodiorite is fresh and is not mylonitized.

Another breccia inferred to be Eocene is exposed 1 km north of Oyama Lake. The basal contact is not exposed. The breccia contains clasts of hornblende granodiorite in an undeformed dacite matrix.

Tilting associated with Eocene normal faulting may have occurred, but its extent is unclear, as the volcanic rocks lack any indicators of the paleo-horizontal. The present-day contact between Eocene strata and their basement west of Oyama Lake clearly truncates the fabric in basement rocks and dips 70–80°, which may indicate an equal amount of rotation of the volcanic strata. A sample of massive dacite from this locality is being processed for U-Pb dating.

Miocene volcanic and sedimentary rocks

Miocene flood basalts and sedimentary strata are preserved in erosional outliers above high-grade basement rocks, much like Eocene rocks, although they are more widespread. They commonly cap topographic highs and locally overlie Eocene volcanic strata. Basalt is dark and fine grained, with small plagioclase and/or olivine phenocrysts visible in hand specimen. Locally, flows are vesicular, and vesicles are locally filled with zeolites. Columnar jointing is common in the basalt. The Miocene basalt layers have undergone little or no tilting since deposition.

STRUCTURE

The high-grade metamorphic rocks on the east side of Kalamalka Lake record several episodes of deformation. On the basis of synkinematic metamorphic mineral growth, foliation in the amphibole schist, biotite-sillimanite schist, and calc-silicate units is inferred to have developed under peak metamorphic conditions (i.e. migmatization). The Cosens Bay pluton truncates foliation and hosts inclusions of schist, and thus postdates this metamorphic event. The oldest foliation in the heterogeneous diorite/granodiorite unit may be of the same age, as the unit contains younger discordant foliated phases.

All units of the paragneiss succession, the Cosens Bay pluton, and the margins of the heterogeneous diorite/granodiorite unit display a stretching lineation in many outcrops. The lineation is defined by streaky rodding of quartz grains and parallel alignment of coarse synkinematic sillimanite. The lineation consistently plunges between 0 and 20°, and trends between 260 and 280°. Near Oyama Lake, the lineation commonly plunges gently to the east. The Cosens Bay pluton and the heterogeneous diorite/granodiorite unit lack strong foliation except near their margins. The Cosens Bay pluton is also lineated near its margins, suggesting that foliation developed at the same time as lineation.

Shear-sense indicators including winged porphyroclasts, C-S fabrics, and domino structures in outcrop consistently record a top-to-the west sense of shear. In biotite-sillimanite schist near Cosens Bay, a strong lineation is present in many outcrops and coarse, lineation-parallel sillimanite is clearly visible in hand sample. Recrystallization of mineral grains during deformation appears to have been the dominant process of fabric development. Bands of leucocratic migmatite have been disaggregated during shear, forming rounded and boudinaged feldspar porphyroblasts on foliation surfaces. Intrafolial folds are common in biotite-sillimanite schist and the calc-silicate. The hinges of these folds are interpreted to have passively rotated during later simple shear.

At the south end of Kalamalka Lake, deformed rocks record more cataclastic deformation and less recrystallization. Strong stretching lineations are less common and grain-size destruction appears to have been dominant. Rounded and winged feldspar porphyroblasts are enclosed in a dark, fine-grained cataclastic matrix. This deformation persists eastward, from the south end of Wood Lake within the biotite-sillimanite schist unit to Oyama Lake.

South of Oyama Creek, biotite-sillimanite schist is in sharp contact with potassium feldspar– hornblende gneiss. Foliation changes orientation across the contact and the gneiss shows no evidence of pervasive shearing. This change, together with the distinct characteristics of the gneiss described above, suggest that the contact between the two is structural rather than primary. This is supported by the fractured and altered nature of the gneiss near the contact, suggesting brittle faulting.

DISCUSSION

The high-grade metamorphic assemblage east of Kalamalka Lake records two episodes of deformation. The peak event imprinted the paragneiss succession with pervasive foliation and preceded the emplacement of the Cosens Bay Pluton. Foliation in the pluton may be related to stretching lineation associated with formation of the ductile shear zone as the lineation lies in the foliation plane. The shear zone is continuous for at least 20 km along strike. The zone does not continue into the gneiss complex to the south and must change orientation and/or level of depth. Eocene dacite rests unconformably on basement gneiss and is not in the hanging wall of a crustal scale detachment zone, as proposed in the Kelowna area (Tempelman-Kluit and Parkinson, 1986; Bardoux, 1993). The lack of evidence of an Eocene detachment in the Okanagan Valley near Vernon is consistent with the findings of Thompson and Daughtry (1994, 1996) who reported the presence of a granitic body which appears to bridge the Okanagan Valley south of Wood Lake, and has yielded preliminary U-Pb ages of 161.7 ± 2.9 Ma and 162. ± 8 Ma (weighted mean of two determinations) (Thompson and Daughtry, 1996). Thompson and Daughtry (1996) also noted the presence of biotite-feldspar-quartz schist in a roadcut along the west side of Wood Lake, which places high-grade rocks in the hanging wall of the proposed Okanagan Valley detachment. This evidence, coupled with the Eocene regolith, suggests that a Middle Eocene detachment fault separating low-grade cover from high-grade basement rocks is not a viable model for the Vernon area.

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Geological Survey of Canada Project 930036

Transition from Neoproterozoic to Triassic stratigraphy, Silver Star Mountain, Vernon map area, British Columbia

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Unterschutz, J., Erdmer, P., Thompson, R.I., and Daughtry, K.L., 1999: Transition from Neoproterozoic to Triassic stratigraphy, Silver Star Mountain, Vernon map area, British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 199–204.*

Abstract: Rocks of the Neoproterozoic Silver Creek Formation, rocks possibly correlating with the Lower Paleozoic Tsalkom, Sicamous, and Eagle Bay formations and referred to here as the 'middle unit', and rocks potentially correlating with the Triassic Nicola Group form part of a complex fold structure north of Vernon, British Columbia.

The boundary between ancestral North America and what is thought to be the accreted Quesnel Terrane traverses the area. In the south, this boundary separates staurolite- and andalusite-bearing Triassic strata from underlying sillimanite-bearing schist of the Silver Creek Formation. Detailed mapping revealed that the contact may be transposed depositionally (i.e. stratigraphic). In the north, amphibolite-grade rocks with inferred upper and lower stratigraphic contacts separate Neoproterozoic from Triassic rocks. There is no evidence of a tectonic contact between any of the mapped units.

Résumé : Les roches de la Formation de Silver Creek du Néoprotérozoïque, qui pourraient être mises en corrélation avec les formations de Tsalkom, de Sicamous et d'Eagle Bay du Paléozoïque inférieur et qui sont désignées «unité médiane» dans la présente, et des roches susceptibles d'être mises en corrélation avec le Groupe de Nicola du Trias font partie d'une structure complexe formée par plissement au nord de Vernon, en Colombie-Britannique.

La frontière entre l'Amérique du Nord ancestrale et ce que l'on considère comme étant le terrane accrété de Quesnel, traverse la région. Dans le sud, elle sépare des strates triasiques à staurotide et à andalousite du schiste à sillimanite sous-jacent de la Formation de Silver Creek. Une cartographie détaillée indique que le contact pourrait être stratigraphique. Dans le nord, des roches du faciès des amphibolites aux contacts stratigraphiques supérieur et inférieur présumés séparent les roches du Néoprotérozoïque de celles du Trias. Il ne semble pas avoir de contact tectonique entre les unités cartographiées.

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INTRODUCTION

The contact between autochthonous ancestral North American stratigraphy and an assemblage of sedimentary, volcaniclastic, and volcanic rocks interpreted to be part of a displaced and accreted terrane called Quesnel transects Vernon map area (NTS 82 L, Fig. 1) in an east-southeast direction. Terrane maps and regional structural cross-sections show this boundary as a crustal-scale thrust fault with more than 200 km of west-to-east overlap, juxtaposing a 30 km thick block of crust on top of pericratonic North American crust (Varsek and Cook, 1994; Monger and Nokleberg, 1995; and references therein). The nature of this contact in south-central British Columbia is not well described or defined. Recent work by Thompson and Daughtry (1996, 1997) suggests that the boundary separating Quesnel Terrane rocks from pericratonic North American rocks is stratigraphic, negating the existence of a tectonic contact and making Quesnel Terrane rocks part of pericratonic North America.

The principal aim of this study is to examine the stratigraphic, structural, and metamorphic character of Neoproterozoic, Paleozoic, and Mesozoic strata to test the hypothesis that Quesnel Terrane rocks stratigraphically overlie pericratonic North America. This is part of a regional mapping program that aims to link rock assemblages marginal to the Monashee complex with those adjacent to the Okanagan Valley. A regional study of the pericratonic rocks is presented in an accompanying report (Erdmer et al., 1999).

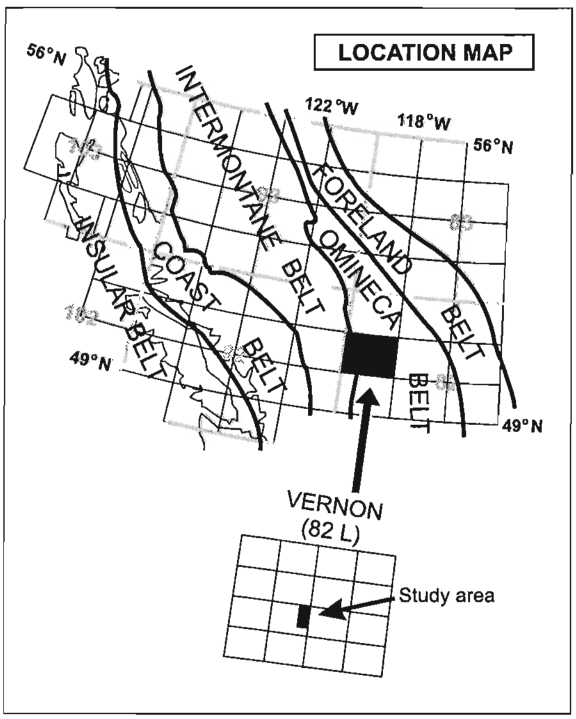

Figure 1. Map showing the location of the Vernon map area (82 L) and of the study area.

Fieldwork in 1998 covered an area bounded by the Okanagan Valley on the west (Fig. 1), the Trinity Valley on the east, and the towns of Enderby to the north and Vernon to the south. This area is referred to as the Silver Star Range in this report.

UNIT DESCRIPTIONS

The mapped area (Fig. 2) contains three distinctive lithological units. Lowermost is quartzofeldspathic schist of the Silver Creek Formation (Read and Okulitch, 1977). It is overlain by the 'middle unit', an informally named succession consisting of amphibolitic schist, marble, felsic to mafic tuff, and quartzite-cobble metaconglomerate. The uppermost map unit is a carbon-rich sequence of dark schist and argillite belonging to the Upper Triassic Nicola Group and/or the Slocan Group.

Silver Creek Formation

The Silver Creek Formation is inferred to be part of the Upper Proterozoic to Lower Paleozoic miogeoclinal succession of ancestral North America (Read and Okulitch, 1977). The dominant rock type is quartzofeldspathic biotite- and amphibole-rich schist locally with muscovite, garnet, and sillimanite. The Silver Creek Formation is commonly distinguished by its rusty-weathering character.

Within the study area, greater than seventy percent of the Silver Creek Formation is biotite-rich schist, with garnet and sillimanite present in approximately half of the occurrences. More than one generation of biotite is visible in many localities. Early biotite is foliation parallel whereas later biotite forms clots and porphyroblasts overgrowing foliation.

Fine- to coarse-grained calc-silicate and calcareous schist, locally with diopside and tremolite, form a small percentage (<5%) of the Silver Creek succession. These form layers varying from centimetres to up to 20 m in thickness. Garnetiferous muscovite schist forms less than one per cent of the succession, occurring in discontinuous layers 2–30 cm thick. Migmatite is common in the succession, forming 1–10 m thick layers that are most often parallel to schistosity.

Granite pegmatite is common and occurs as 5 cm to 3 m thick tabular bodies that cut across regional schistosity. It is massive, consisting of quartz, feldspar, muscovite, and in some instances garnet. At least two groups of pegmatite intrusions can be observed based on crosscutting relationships.

Fine- to medium-grained granite intrudes the Silver Creek Formation throughout. Accessory minerals include garnet, muscovite, biotite, and hornblende. The granite is more abundant in the southern portion of the mapped area, where evidence of in situ melting is ubiquitous. Some granite bodies are strongly foliated and lineated while others are massive, recording pre-, syn-, and post-tectonic emplacement.

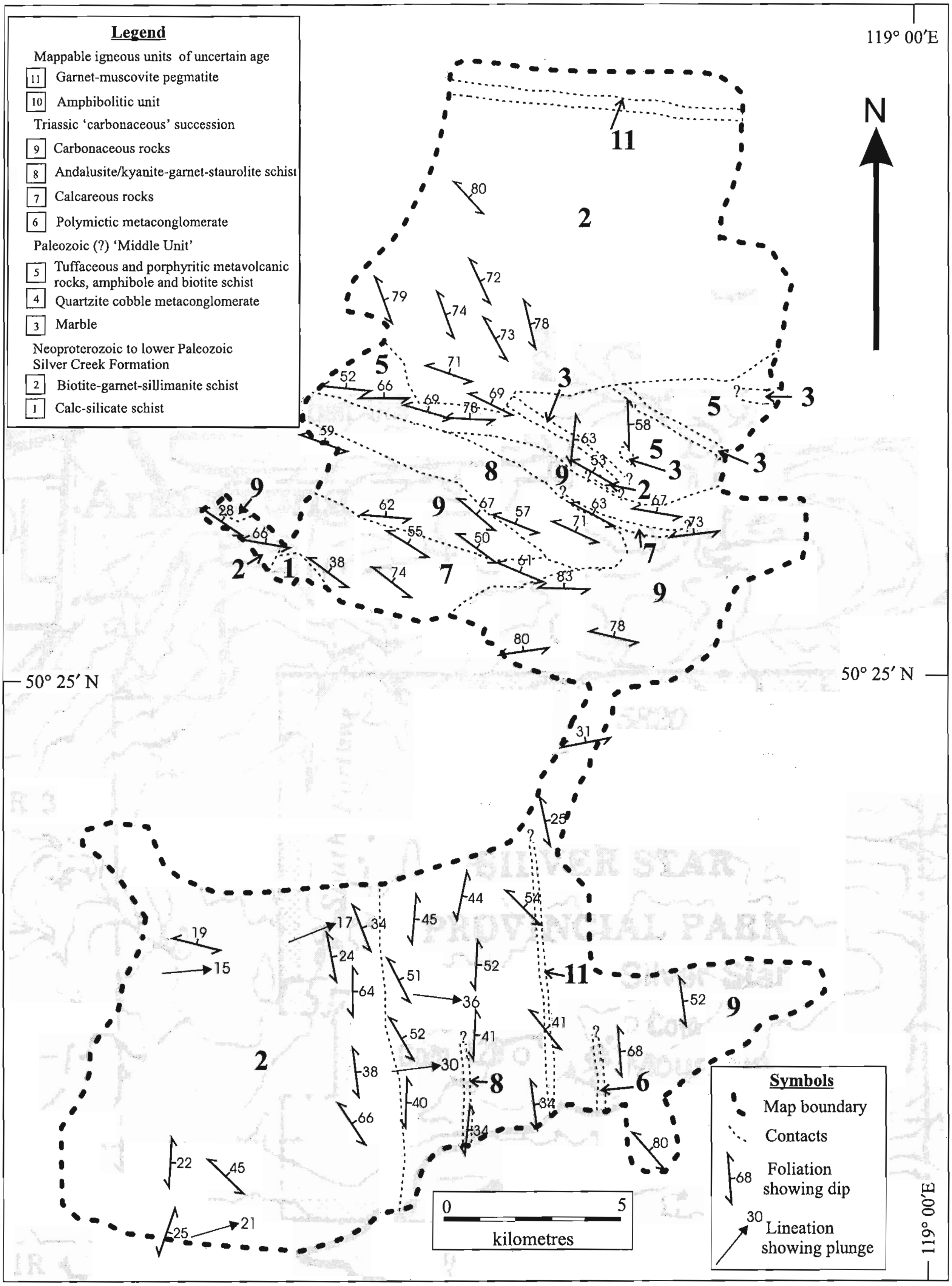

Figure 2. Geological map of study area, and the Silver Star region east of Armstrong, British Columbia. Source of topographic base is NTS 82 L, Vernon (1:250 000 scale) map sheet.

Middle unit

The 'middle unit' outcrops only in the northern part of the study area, where it overlies the Silver Creek Formation (*see also* report by Erdmer et al., 1999). The unit consists of tuffaceous, ignimbritic, and porphyritic metavolcanic strata, stretched quartzite-cobble metaconglomerate, marble, amphibole schist, biotite schist, and pelitic to semipelitic units interlayered at centimetre to metre scale. Both Jones (1959) and Read and Okulitch (1977) recognized the potential correlation of this unit with the Lower Paleozoic Tsalkom Formation, and Thompson and Daughtry (1998) suggested expanding the correlation to include the Middle Paleozoic Sicamous and Eagle Bay formations.

In the western part of the study area, talc-rich layers occur within mica and amphibole schists along Kendry Creek. They are interlayered with biotite- and amphibole-rich schist, calcareous schist, and quartzite layers. Farther east, the unit consists of tuffaceous and porphyritic intermediate metavolcanic rocks, marble, interbedded calcareous and biotite- and amphibole-rich quartzofeldspathic schist, biotite- and amphibole-rich schist, argillite, and quartzite-cobble metaconglomerate.

The marble is foliated, well banded, grey to white, and coarsely crystalline. Three resistant layers 50–100 m thick were mapped, two of which can be traced for 2–3 km. Internal grey and white layering is visible at scales varying from 1 cm to 10 m.

The ignimbrite units are heterolithic and contain clasts. One of the felsic units has a biotite- and amphibole-rich matrix and contains flattened clasts 1–3 cm long and 0.5 cm thick aligned in the foliation. A biotite-rich porphyry unit with distinctive green mica aggregates and interbedded layers of amphibole-rich schist is also present.

Triassic strata

Both the 'middle unit' (in the northern part of the study area) and the Silver Creek Formation (in the southern part) are overlain with evident disconformity by the Triassic 'carbonaceous unit'. It was first suggested by Read and Okulitch (1977) that these rocks in the Silver Star area correlate with the Triassic Nicola Group. Thompson and Daughtry (1998) suggested a correlation with the Triassic Slocan Formation to the east, implying that Nicola Group and Slocan Formation rocks accumulated in the same depositional basin.

Triassic strata within the area consist of carbonaceous mudstone, siltstone, and sandstone, volcanic tuffs and flows, marble, and conglomerate that have been metamorphosed to low to medium grade. An homogeneous resistant pale green amphibolitic unit mapped within this succession appears to be conformable with the surrounding foliation. It may be a flow or an intrusive body. It is hornblende-phyric, possibly after augite, and may correlate with augite porphyries typical of the Triassic rocks in other localities.

The strata are dominated by argillite, include staurolite schist, and may contain porphyroblasts of biotite, garnet, and rarely muscovite. The porphyroblasts are euhedral and grow across the tectonic fabric, a relationship consistent with post-deformational static metamorphism. The succession includes two distinctive horizons in addition to the amphibolitic unit, that can be traced for a distance of 2–3 km along strike. One is black calcareous argillite that weathers platy to friable. The other is staurolite schist, locally with andalusite, biotite, and garnet, having a silver sheen and exhibiting coarse foliation.

Outside the study area, primary structures are preserved in a few locations within the Triassic strata, including crossbedding in metasandstone and metasiltstone, and fossil boring traces in a metamudstone unit that allow facing direction to be determined. Some beds retain laminations and fine-scale grading.

There are several layers of metaconglomerate in the Triassic succession, four of which occur within the Silver Star Mountain ski area. The metaconglomerates are either matrix or clast supported; most clasts are pebble to cobble sized, rounded to angular; clast compositions include mafic schist, quartzite, and biotite schist. One granite pebble was observed. During thin section analysis a carbonate clast containing a fusilinid fossil was discovered within a layer of metaconglomerate.

Intrusive and extrusive bodies

Jones (1959) was the first to recognize granite and pegmatite bodies in the Silver Star Mountain region and named them the Silver Star intrusions. While he recognized their pre-, syn- and post-tectonic nature, he suggested a common origin and timing of intrusion based on their similarity of composition. He pointed out that most of the 'Silver Star pegmatites' are concordant with schistosity, and suggested an in situ source for them.

Post-tectonic intrusions of granite and granodiorite, as well as ultramafic dykes, and felsic to mafic dykes of inferred Eocene to Miocene age were observed cutting schistosity. There are several varieties of granite, including some containing phenocrystic muscovite or biotite, or tourmaline and diopside. A felsic dyke of inferred Eocene age with calcite-filled vesicles intrudes a small fault of unknown displacement along Fortune Creek (Fig. 2). At one locality along the Abbott Creek Road, which branches from the Silver Star Road, basalt of inferred Miocene age was observed draping across mylonite in the Silver Creek Formation.

CONTACT RELATIONSHIPS

The contact between the Silver Creek Formation and the overlying 'middle unit' is not exposed. While the location of the contact can be determined to within metres in some areas, an outcrop containing this contact was not seen.

The contact between the 'middle unit' and overlying 'carbonaceous' Triassic succession is exposed in at least one location along a forest road at the headwaters of Kendry Creek, at elevation 1540 m, 5 km due east of Armstrong. It is marked by a change in rock type, from volcanic-dominated to carbon-rich, fine-grained, sedimentary rock. It is inferred, by the sharp nature of the change, to be a transposed disconformable depositional contact. This contact contains no evidence of being originally tectonic, although it has suffered some strain (*see* report by Erdmer et al., 1999).

In the southern part of the study area, the Triassic succession directly overlies the Silver Creek Formation with disconformity, and the 'middle unit' is absent. The contact is exposed in the Sovereign Lake ski area on Silver Star Mountain. It is placed there in a 100 m thick zone that consists of units that could be assigned to either the overlying or underlying successions. Biotite- and amphibole-rich schist, silver muscovite schist, garnetiferous carbon-rich meta-argillite, quartz-rich carbonaceous rocks, diopside- and tremolite-rich calc-silicate rocks, and micaceous quartzite are interlayered at scales of 30 cm to 4 m. Another change defining the transition is the progressive disappearance of granitic bodies upward. Granite intrusions are rare, and pegmatite is virtually absent (one of the rare outcrops of pegmatite within the carbonaceous argillite occurs just above the transition, near the warming hut at the cross-country ski area).

The transition from Silver Creek Formation to Triassic strata is also exposed along Fortune Creek east of Armstrong. There, the width of the transition is estimated at between 100 and 200 m. A sequence of rocks occurs that does not clearly belong to either the overlying or underlying assemblages, and consists of biotite- and amphibole-rich schist, carbonaceous argillite, marble, quartz-rich carbonaceous rocks, quartz-rich biotite and amphibole schist, diopside- and tremolite-rich calc-silicate rocks, calcareous carbon-rich argillite and biotite- and amphibole-schist, and micaceous quartzite. There is a significant increase in the quartz in this transitional assemblage upward, as layers of quartz that have been boudinaged in many places on scales of 2 mm to 1 m become prevalent. The decrease in granite bodies and disappearance of pegmatite seen in the Sovereign Lake transition is echoed in the Fortune Creek transition.

STRUCTURE AND METAMORPHISM

Structural data and outcrop patterns suggest the presence of a map-scale northeast-plunging synform defined by the layering. Triassic strata within the northern limb of the inferred structure preserve inverted trace fossils. Additional mapping is planned to test this hypothesis.

Peak metamorphic grade varies from sillimanite in the Silver Creek Formation to staurolite in Triassic rocks. The 'middle unit' is inferred to be at staurolite grade, but from hand-sample scale observation, mineral assemblages can only be assigned unequivocally to garnet grade.

The Silver Creek Formation at the outcrop scale displays a consistent schistosity, and folds with amplitude and wavelength from centimetres to metres. Veins of quartz and feldspar cut schistosity; some are folded and extended along the axial surfaces of folds. A crenulation of the main schistosity is present in some outcrops. Quartz-rich horizons are commonly boudinaged, forming boudins on a scale of 1–50 cm long.

Regional deformation and metamorphism imposed tectonic fabrics on the Silver Creek Formation, the 'middle unit', and the Triassic strata. The units are folded on the map scale. The growth of static staurolite and garnet in the Triassic strata, and of garnet in the 'middle unit', records a metamorphic event subsequent to folding. A stretching lineation, expressed as rodding of quartz and feldspar in foliated granite cutting Triassic and Silver Creek Formation rocks, is visible locally in the southern part of the area.

A zone of mylonite and cataclasite occurs in the southeast corner of the mapped area within the Silver Creek Formation; excellent exposures occur along the Abbott Creek Road. The thickness and extent of this zone have yet to be determined, but are both at least several hundred metres. Broken and winged feldspar porphyroblasts between 0.5 and 4 cm in diameter are common within a schistose to finely ground matrix. Stretching lineation is defined by rodded quartz and feldspar grains plunging to the east. Sillimanite fibres form a crude linear fabric aligned in the direction of stretching. The mylonite fabrics and synkinematic sillimanite are similar to those described by Erdmer et al. (1998) south of the mapped area, and discussed by Glombick et al. (1999).

Two metamorphic events appear to have caused partial melting of the Silver Creek Formation. The first event, interpreted here as a result of burial, was responsible for the development of migmatitic layers and likely the early growth of sillimanite. Subsequent to cooling, these migmatite layers underwent deformation in discrete subparallel zones, resulting in mylonite and cataclasite development and synkinematic, subparallel sillimanite growth. Migmatitic layers also occur that have not been affected by mylonitization, and may have been coeval with or slightly later than the ductile strain. We suggest that some of these layers of partial melt intruded upward, cutting across the contact with overlying Triassic rocks, and forming at least some of the post-tectonic granite bodies above the contact (Silver Star intrusions of Jones (1959)).

The 'middle unit' is folded at centimetre to metre scale in places, and has a consistent planar fabric in others, although foliation is not always measurable. There is no change in schistosity orientation across the contact between the Silver Creek Formation and the 'middle unit'. However, metamorphic grade decreases from sillimanite in the Silver Creek Formation to inferred staurolite in the 'middle unit'. Metaconglomerate within the 'middle unit' displays flattened quartzite clasts in a pelitic matrix (*see* Erdmer et al., 1999). The clasts are stretched, defining a lineation trending 064° and plunging 54°. The matrix of the conglomerate contains dark maroon garnet that postdates deformation. The 'middle unit' reached garnet-zone metamorphism at least.

The Triassic metasedimentary strata are dominantly argillaceous and fissile, with well developed cleavage and joint surfaces in many areas. There is no change in foliation attitude across the contact with the Silver Creek Formation and the 'middle unit'. Secondary biotite has developed in some parts of the Triassic strata during deformation, and forms a mineral lineation on cleavage planes, which, notably in the south part of the area near the mylonite zone, is parallel to stretching lineation in both granite bodies and the mylonite zone in the underlying Silver Creek Formation. Typically, foliation has a consistent orientation in these areas; mesoscopic folds can be observed at the outcrop scale in a few locations.

Some of the layers within the 'carbonaceous' map unit are at staurolite-andalusite(-kyanite) grade, identifiable by that mineral assemblage occurring together with garnet as static overgrowths across foliation. We speculate that diagnostic minerals have not developed within other Triassic rocks, particularly those interbedded with and underlying the staurolite-grade rocks, because the included carbon may have acted as a metamorphic buffer, inhibiting growth. There is a contrast in metamorphic grade between the sillimanite-grade Silver Creek Formation and the staurolite-grade 'carbonaceous unit', but there is no change in apparent grade between the 'middle unit' and the Triassic rocks. While it is evident that parts of the Triassic succession are at staurolite grade, it has yet to be determined if this applies to the entire succession, which appears to be less deformed at higher stratigraphic levels. One explanation suggested to account for the metamorphism is heat from the Silver Star intrusions of inferred Mesozoic age (Jones, 1959).

DISCUSSION AND FUTURE WORK

It is unclear how the Silver Creek Formation was brought to surface to allow for deposition of the younger rocks. Mapping in the Silver Star region did not reveal evidence of a structural contact between the Silver Creek Formation, nor of the 'middle unit' with the overlying Triassic 'carbonaceous unit'. Contacts are sharp or mixed gradational, consisting of interlayering of rocks typical of upper and lower successions, which may result in part from transposition due to later strain. We suggest that a disconformity separates the Triassic carbonaceous rocks from underlying units.

By sampling clasts from conglomerate within the Triassic succession, we hope to ascertain the provenance of the succession, and test the hypothesis that Nicola Group (Quesnel Terrane) sedimentary rocks were derived from, and deposited onto, the outer margin of ancestral North America. The Silver Star intrusions, both foliated and unfoliated, and metamorphic rocks will be examined for datable minerals. The dating of the pegmatite and foliated and unfoliated granite bodies is planned to constrain the age of the stretching lineation. Geothermobarometric analysis is currently underway for sillimanite-garnet-biotite assemblage rocks within the Silver Creek Formation and andalusite-(possible kyanite)-garnet-staurolite assemblage rocks of the Triassic succession. This is part of a systematic investigation of the number of metamorphic events, of which strata were affected by which events, and of the physical conditions of each metamorphism.

Future fieldwork will extend eastward and focus on defining the nature of the contact between the Triassic succession and underlying units, and the contact between the 'middle unit' and the Silver Creek Formation.

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Pericratonic Paleozoic succession in Vernon and Ashcroft map areas, British Columbia

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Erdmer, P., Thompson, R.I., and Daughtry, K.L., 1999: Pericratonic Paleozoic succession in Vernon and Ashcroft map areas, British Columbia; in *Current Research 1999-A; Geological Survey of Canada, p. 205–213.*

Abstract: Ductilely deformed and metamorphosed pericratonic rocks of inferred Early Paleozoic age overlie the Neoproterozoic-Eocambrian Silver Creek schist in the Vernon map area along an apparent stratigraphic contact. Permian (Harper Ranch Group) and Triassic (Nicola Group and Slocan Formation) strata overlie the pericratonic succession along an unconformable depositional contact. The pericratonic succession, long recognized to include amphibolitic schist, marble, and quartzite, includes in addition to these a distinctive metaconglomerate, and forms a robust regional marker. The tripartite regional stratigraphy and its inferred Proterozoic or older depositional basement cross the Okanagan Valley without apparent offset, and persist for at least 100 km westward, as far as the Nicola horst. The pericratonic succession underlies rocks presently assigned to the Quesnellia terrane at this latitude.

Résumé : Des roches péricratoniques vraisemblablement du Paléozoïque précoce qui ont subi une déformation ductile et un métamorphisme reposent sur le schiste de Silver Creek du Néoprotérozoïque–Éocambrien dans la région cartographique de Vernon, le long d'un contact stratigraphique manifeste. Des strates du Permien (Groupe de Harper Ranch) et du Trias (Groupe de Nicola et Formation de Slocan) recouvrent la succession péricratonique le long d'un contact sédimentaire discordant. La succession péricratonique, reconnue de longue date comme étant composée de schiste à amphibole, de marbre et de quartzite, comprend également du conglomérat métamorphisé distinctif et constitue un solide marqueur régional. La stratigraphie régionale tripartite et son supposé socle sédimentaire protérozoïque ou plus ancien recoupent la vallée de l'Okanagan, avec absence apparent de rejet, et s'étendent au moins sur 100 km vers l'ouest jusqu'au horst de Nicola. La succession péricratonique est sous-jacente à des roches actuellement attribuées, à cette latitude, au terrane de Quesnellia.

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INTRODUCTION

Fieldwork for the Vernon project in 1998 focussed on three aspects of the geology which previous work showed as important to understanding the regional evolution. A study by Unterschutz et al. (1999) addressed the transition from Neoproterozoic to Triassic stratigraphy to the northeast of Vernon; a study by Glombick et al. (1999) addressed the nature and timing of ductile shear zones to the southeast of Vernon that affect rocks as young Middle Cretaceous; and the study presented here focussed on five exposures of enigmatic pericratonic rocks in a northwest-striking belt across central Vernon map area.

Although penetratively deformed, Triassic (Nicola Group and Slocan Formation) and Permian (Harper Ranch Group) strata in the south-central Cordillera between latitudes 50°N and 51°N unconformably overlie more ductilely deformed and more metamorphosed pericratonic volcanic and siliciclastic rocks of inferred Paleozoic age. The pericratonic rocks in turn overlie Neoproterozoic–Eocambrian miogeoclinal facies strata of the ancient North American continental margin (Silver Creek Formation). This tripartite regional stratigraphy characterizes the autochthonous part of the Omineca Belt in the western part of Vernon map area (NTS 82 L; Fig. 1). Recent mapping for the Vernon project showed that this stratigraphy can be traced without significant offset across the Okanagan Valley into the Intermontane Belt to near the western limit of Vernon map area (Thompson and Daughtry, 1998).

Our specific objectives were to investigate the strain and metamorphic characteristics of the rocks, test links between isolated exposures, and verify the consistency of their relation to younger and older sequences. Results confirm previous evidence obtained in work for the Vernon project, that this succession forms a distinctive regional marker. On the basis of physical continuity, and similar lithology, ductile strain, metamorphic characteristics, and stratigraphic position, rocks in the five studied exposures are correlated. We propose that the tripartite regional stratigraphy and its subjacent North American Proterozoic or older basement may persist for at least 100 km to the west of the Okanagan Valley, as far as the Nicola horst. The recognition of this stratigraphy so far west is of importance to Cordilleran tectonics, because the rocks described underlie strata presently assigned to the Quesnellia Terrane at this latitude.

PREVIOUS WORK AND LOCATION

The pre-Triassic nature of the pericratonic succession in the Vernon area has been known since the rocks were first studied (*see* Jones, 1959, and Okulitch, 1979). Mapping for the Vernon project (*see* Thompson and Daughtry, 1994, 1996, 1997, 1998) showed that an "...amphibolitic schist-marble-quartzite map unit..." (Thompson and Daughtry, 1998) with local metaconglomerate, and estimated thickness of 100–400 m, could be traced discontinuously for more than 30 km from east of Armstrong to west of Yankee Flats (Fig. 2). Thompson and Daughtry (1998) correlated the succession with the Tsalkom, Sicamous, and Eagle Bay formations, and with the Chapperon Group, and offered a tentative correlation with the Kobau Group. They noted that although internal stratigraphic relationships are variable and likely laterally complex, the succession consistently overlies quartz-rich schists of the Neoproterozoic–Eocambrian Silver Creek Formation. Locally preserved Permian volcaniclastic strata (Harper Ranch Group) have a gradational upper contact with widespread Triassic argillite and slate in the same area. On that basis, we infer that the deposition, deformation, and first metamorphism of the amphibolitic schist-marble-quartzite unit are older than Permian.

Four localities described in this report in western Vernon map area (Kendry Creek, Glenemma, Yankee Flats, and Fowler Creek areas) form a group that straddles the Okanagan Valley near Armstrong (Fig. 2). The fifth locality is 80 km along structural trend to the west-northwest and is in Ashcroft map area, approximately 50 km south of Kamloops (NTS 92 I). This locality lies within the Nicola horst, a northerly-striking crustal block entirely separated from surrounding Nicola Group rocks by post-Eocene normal faults.

KENDRY CREEK AREA

The Neoproterozoic to Triassic stratigraphy is well exposed in logged areas and along forest roads near 1500 m elevation approximately 7 km due east of Armstrong, near the headwaters of Kendry Creek (Fig. 3). From north to south, quartz- and feldspar-rich schist, biotite-sericite schist, semipelite, and quartzite correlated with the Silver Creek Formation

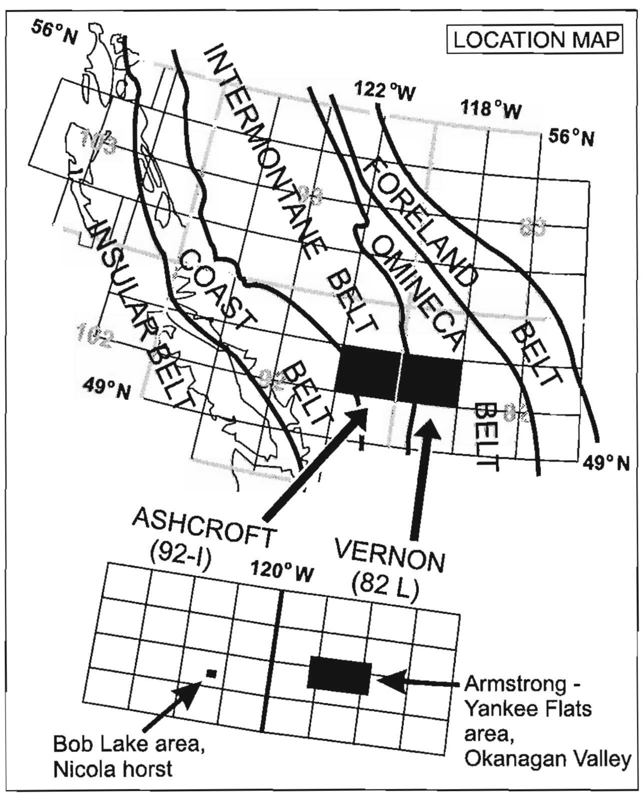


Figure 1. *Location of the Vernon and Ashcroft 1:250 000 scale NTS map areas, and of the study areas covered by this report.*

mapped to the northwest by Jones (1959) are in contact with a succession which includes banded white and grey diopside marble, tuffaceous mica amphibolite and meta-andesite, chlorite-amphibole greenstone, garnet-biotite- and garnet-amphibole-feldspar schist, garnet-muscovite phyllite and schist, and pebble and cobble metaconglomerate of inferred Paleozoic age (*see* report by Unterschutz et al., 1999). The succession is several hundred metres thick, and is compositionally more laterally variable than the Silver Creek Formation. It is truncated to the south by graphitic phyllite, staurolite schist, graphitic metasiltstone, and other fine-grained, dark metaclastic rocks which continue southward into a carbonaceous succession exposed on Silver Star Mountain that is inferred to be of Triassic age (Okulitch, 1979).

The exposure of metaconglomerate near Kendry Creek is noteworthy. Clasts in the largely clast-supported metaconglomerate are nearly exclusively white or grey quartzite ranging from less than one centimetre to more than 25 cm long (Fig. 4); rare other clasts are intermediate metatuff and fine-grained feldspar-bearing rocks of uncertain affinity. The clast shapes are those of triaxial ellipsoids with overall axial ratios of 1:2:10, i.e. both flattened and stretched compared to a sphere. The clasts have strong preferred orientation, defining both a shape foliation and a stretching lineation in the rock. The sparse matrix is micaceous and locally semipelitic. The metaconglomerate is at least 40 m thick, from which a greater depositional thickness can be inferred given the evident flattening component of the strain. Clasts in tuffaceous layers in metavolcanic rocks are up to 3 cm long and 0.5 cm across, and similarly show strong preferred planar and linear orientation, also inferred to be of tectonic origin.

All rocks of the succession are characterized by strong amphibole, mica, or chlorite schistosity that drapes around clasts in metaconglomerate and tuffaceous rocks. Schistosity is overprinted by aggregates of feather amphibole, randomly oriented biotite clots, and static garnet up to several centimetres across. For example, the micaceous matrix of the metaconglomerate hosts coarse almandine porphyroblasts that rival small clasts in size but overprint the biotite schistosity. Thus, at least two metamorphic events are recorded, one of which was static.

Metasiltstone in the Triassic succession is folded into mesoscopic and macroscopic folds and displays cleavage overprinting delicate transposed bedding in fine-grained layers. Staurolite, andalusite, and garnet porphyroblasts from less than 1 cm to several centimetres across grew statically

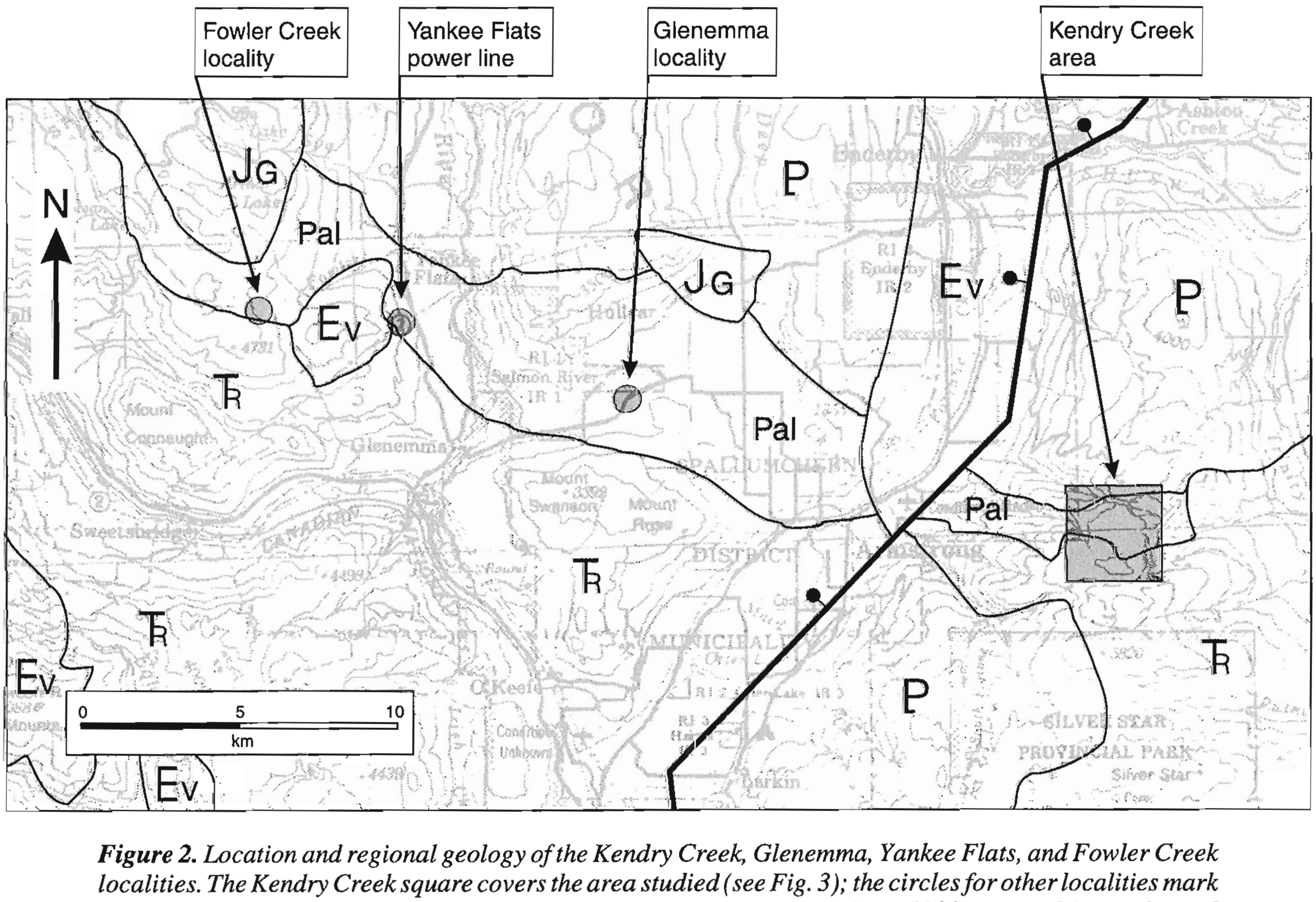
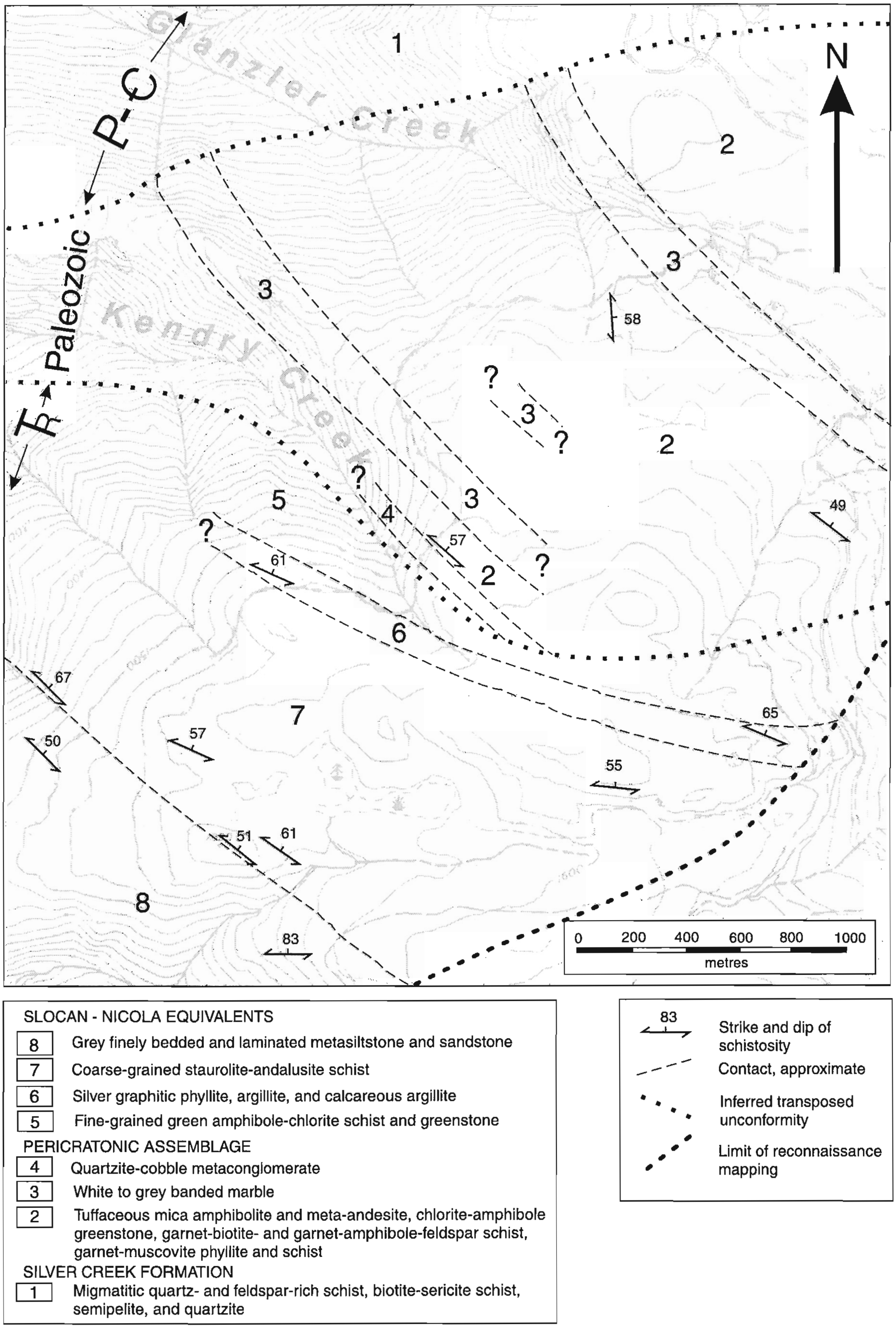


Figure 2. Location and regional geology of the Kendry Creek, Glenemma, Yankee Flats, and Fowler Creek localities. The Kendry Creek square covers the area studied (see Fig. 3); the circles for other localities mark location only. Generalized geology adapted from Thompson and Daughtry (1998). Legend for geological units: P, Proterozoic Silver Creek Formation; Pal, Paleozoic pericratonic belt; Tr, Triassic Nicola Group+Slocan Formation; JG, Jurassic granite; Ev, Eocene volcanic rocks. Heavy line is trace of normal fault, dots in hanging wall. Topographic base is NTS 82 L, Vernon, 1:250 000 scale map.



Glanzler Creek
Kendry Creek
P-C
Paleozoic
T̶R
N
1
2
3
4
5
6
7
8
?
58
49
57
61
67
50
57
65
55
51
61
83
0 200 400 600 800 1000
metres
SLOCAN - NICOLA EQUIVALENTS
8 Grey finely bedded and laminated metasiltstone and sandstone
7 Coarse-grained staurolite-andalusite schist
6 Silver graphitic phyllite, argillite, and calcareous argillite
5 Fine-grained green amphibole-chlorite schist and greenstone
PERICRATONIC ASSEMBLAGE
4 Quartzite-cobble metaconglomerate
3 White to grey banded marble
2 Tuffaceous mica amphibolite and meta-andesite, chlorite-amphibole greenstone, garnet-biotite- and garnet-amphibole-feldspar schist, garnet-muscovite phyllite and schist
SILVER CREEK FORMATION
1 Migmatitic quartz- and feldspar-rich schist, biotite-sericite schist, semipelite, and quartzite
83 Strike and dip of schistosity
Contact, approximate
Inferred transposed unconformity
Limit of reconnaissance mapping

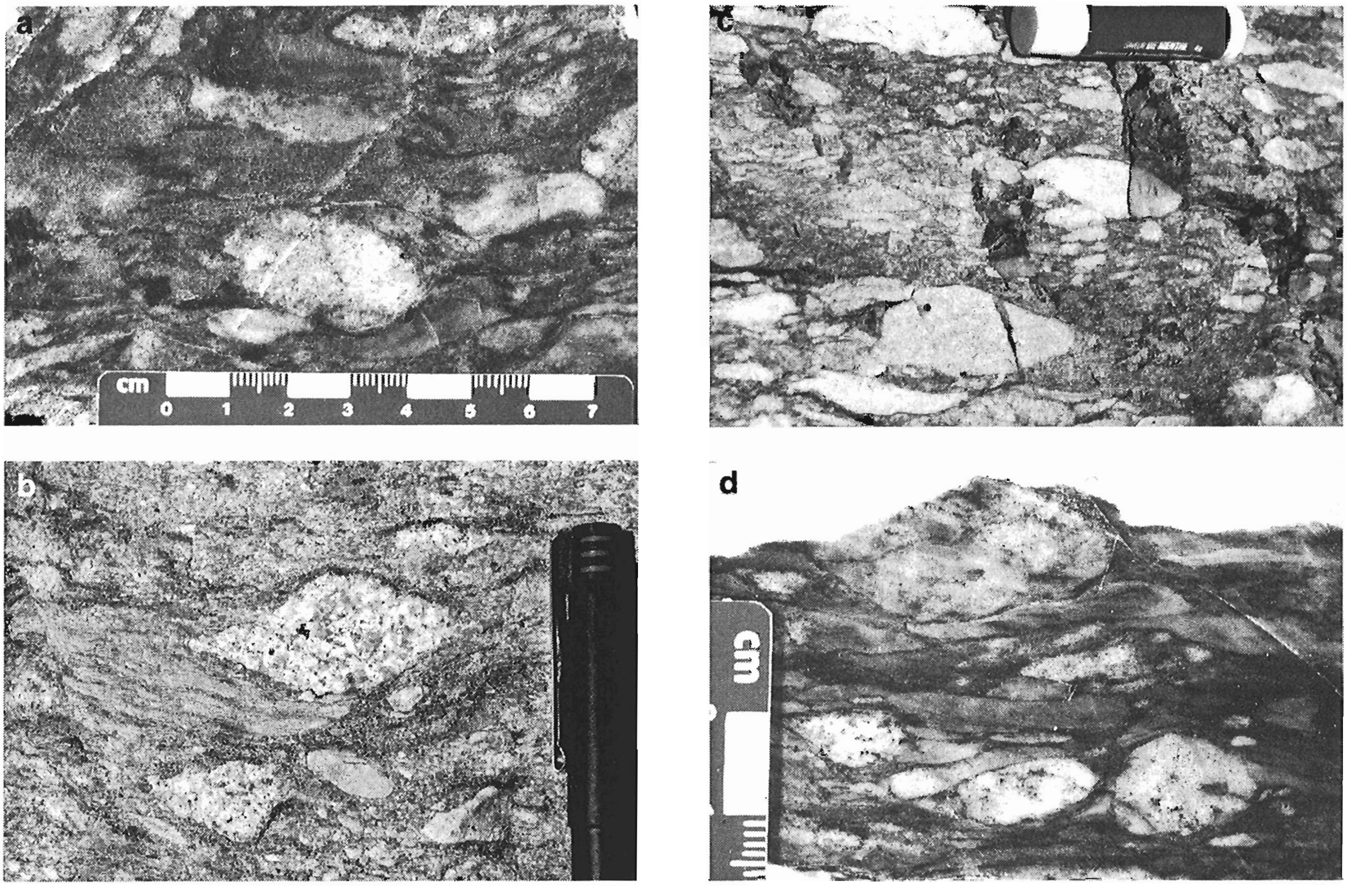


Figure 4. *Photographs of clast types in metaconglomerate.* ***a)*** *quartzite and schist cobbles, Glenemma locality;* ***b)*** *granite and amphibolite cobbles, Fowler Creek area;* ***c)*** *quartzite cobbles, Kendry Creek area;* ***d)*** *schist and quartzite cobbles, Bob Lake area.*

Figure 3. *Geological map of the area of the headwaters of Kendry Creek, approximately 7 km east of Armstrong. North of Glanzier Creek is the quartzofeldspathic schist of the Neoproterozoic to Cambrian Silver Creek Formation; between Glanzier and Kendry creeks is a succession of tuffaceous amphibolite-grade greenstone, biotite schist, marble, quartzite, and metaconglomerate inferred to be of Paleozoic age; south of Kendry Creek are carbonaceous schist units correlated with Triassic strata exposed on Silver Star Mountain, about 3 km farther south (see Fig. 2 for location). Topographic base is British Columbia Ministry of Environment and Parks 82L.045, 1:20 000 scale digital map.*

over schistosity, and are inferred to record the second metamorphic episode. If the static metamorphism is related to the Nelson intrusive suite, it is Middle Jurassic.

GLENEMMA AREA

Along strike to the west-northwest of the Okanagan Valley, and 6 km east-northeast of Glenemma (Fig. 2), a succession of metamorphic rocks includes marble, amphibolite schist, biotite schist, dark phyllite, gritty chloritized metasandstone, and metaconglomerate. Low-grade Triassic argillite and other carbonaceous rocks occur within 1 km to the south (Fig. 2). Feather amphibole patches up to several centimetres long, porphyroblastic garnet, and coarse biotite clots that grew across schistosity are common in schist and phyllite. The marble unit is at least 30 m thick. The schistose units together are at least 100 m thick. The metaconglomerate is at least 30 m thick. Clasts in the metaconglomerate (Fig. 4) are dominated by fine- to medium-grained sugary white to pink quartzite up to 25 cm across in their smallest dimension; other smaller clasts, a few per cent of the total, include amphibolite, chlorite schist, mica schist, and grey phyllite. The nearly prolate ellipsoidal shape and strong preferred orientation of the clasts are like those in the Kendry Creek locality; they are similarly inferred to result from flattening and stretching of the rock under ductile conditions. This strain episode led to development of a mica and amphibole schistosity in the semipelite matrix. Static garnet grains up to 0.5 cm across also occur in the metaconglomerate matrix. This evidence of two metamorphic overprints — one synkinematic with 'deep' ductile fabric development and of pre-Triassic age, the other static and post-Triassic — matches that in the Kendry Creek area.

Between the Glenemma and Kendry Creek areas are isolated exposures of marble, amphibolitic schist, and pelite that represent along-strike continuity of this distinctive belt of rocks. The only interruption occurs at the Okanagan Valley, where offset across a west-side-down, steeply dipping normal fault is apparent (Fig. 2).

YANKEE FLATS AREA

To the northwest of Glenemma, a succession of mafic schists, marble, muscovite-biotite phyllite, grit, and pebble and cobble metaconglomerate is exposed beneath nearly flat-lying unmetamorphosed Eocene dacite porphyry that caps local ridge tops (Fig. 2). Approximately 2 km south of Yankee Flats, a cleared area 50 m wide that follows high-tension cables provides exposure on the west slope of the valley.

A layer of cobble metaconglomerate, at least 20 m thick, occurs within a unit of amphibolite schist and greenstone (hornblende-plagioclase, fine- to medium-grained rock) several hundred metres thick. A number of layers of pebble grit a few metres thick are locally interlayered with mafic schist. Within muscovite-biotite phyllite is at least one layer of quartz-rich medium-grained grit more than 5 m thick that contains local granitoid clasts 2 cm or more in their smallest dimension. The metaconglomerate is matrix supported, with well developed matrix-muscovite schistosity. Clasts, which are mainly prolate ellipsoids with average 1:2:5 aspect ratio and 0.5–2 cm across in their shortest dimension, are translucent to locally glassy, medium-grained quartzite (>95%) and fine-grained, quartzofeldspathic schist, greenstone, and phyllite. Their preferred orientation defines a shape foliation and a stretching lineation. Coarsely crystalline, white and light grey, dusty-banded marble forms a resistant layer at least 50 m thick within the amphibolitic schist and greenstone. Unit contacts are parallel to schistosity and inferred to be transposed.

Schistosity is in the mafic schist unit is overprinted by variably oriented amphibole porphyroblasts up to 0.5 cm long, evidence of a separate static metamorphism.

FOWLER CREEK AREA

Approximately 5 km west of the Yankee Flats power line locality and south of a granitic pluton of inferred Mesozoic age several tens of kilometres across, is another exposure of amphibolitic and other mafic schist, marble, and metaconglomerate. The succession is underlain to the northeast by mica schist, quartz-rich schist, and quartzite of the Silver Creek Formation. It is overlain to the southeast by lower-grade carbonaceous dark grey phyllite, metasiltstone, and argillite that are part of the regional Triassic black clastic succession (Slocan Formation and/or Nicola Group). The exposure is in a logged area (clear cut) at elevation 1350 m near the end of the Spa Creek forest service road, 12.5 km from the Salmon Arm highway. A lithologically similar exposure is located 2 km along strike to the northwest. A third exposure is 2 km to the northeast, across an inferred steep north-striking fault interpreted to have juxtaposed Triassic rocks against the Silver Creek Formation by east-side-down normal slip.

The mafic schist unit is several hundred metres thick. Contacts are parallel to schistosity. The unit includes fine- to medium-grained, hornblende-albite schist; fine-grained amphibolite; hornblende-biotite schist; and minor biotite-muscovite phyllite. Schistosity is overgrown statically by variably oriented porphyroblasts and clots of amphibole or biotite. The marble is at least 10 m thick; contacts with amphibolite schist are not exposed but are inferred to be parallel to schistosity.

The metaconglomerate is at least 40 m thick. Its upper contact is not exposed; it grades downward into tuffaceous amphibolitic schist. It is a clast-supported, polymictic rock with a schistose biotite and muscovite matrix locally reduced to wispy folia less than 0.5 mm thick separating clasts. Clasts range in size from more than 20 cm to less than 1 cm in their shortest dimension, averaging 2–5 cm, with generally flattened prolate ellipsoid shape. Their shape and orientation define a foliation and lineation inferred to result from flattening and stretching under ductile conditions, as in the other localities described.

The clast composition is distinctive. In the top several tens of metres of metaconglomerate, clasts are entirely medium-grained, pink biotite granite; locally, where the matrix constitutes only a few per cent of the rock by volume, the single clast type in the flattened and stretched metaconglomerate imparts the appearance of sheared granite. Preliminary U-Pb dates of 560 Ma have been obtained for two zircon samples from a part of the metaconglomerate consisting almost entirely of granite (L. Heaman, pers. comm., 1998). Toward the gradational lower contact with amphibolitic schist, clasts include an increasing proportion of other rock types; amphibole schist, chlorite schist, biotite schist, grey to sugary white quartzite, quartz-feldspar dacite porphyry, and granodiorite are recognizable in outcrop (Fig. 4).

The metaconglomerate is polymetamorphic. Garnet porphyroblasts averaging 0.5 cm across are present in the matrix, where they overgrow schistosity and record static growth. The Triassic metasiltstone and pelite host small garnet porphyroblasts growing across cleavage. This evidence of two periods of metamorphism matches that in the other localities described above.

BOB LAKE AREA (NICOLA HORST)

A succession lithologically similar to the four localities in Vernon map area occurs more than 80 km west of Fowler Creek, within the Nicola horst near its western boundary. The exposure described here is located between 2 and 4 km east of Highway 5 (the Coquihalla) near the Helmer Lake interchange (Fig. 5). Monger and McMillan (1989) correlated the rocks with the Mount Lytton complex in western Ashcroft map area, in which they also included metamorphic rocks and mylonite of inferred Triassic and/or Jurassic age. Subsequently the area was mapped at 1:100 000 scale by Moore and Pettipas (1990), who reported strongly foliated and lineated quartzite-cobble metaconglomerate and graphitic mica schist with porphyroblasts of staurolite, garnet, and andalusite after kyanite. Moore and Pettipas (1990) considered these rocks distinct from all parts of the Triassic and interpreted them to be structurally overlying, although they noted that the succession is separated from the Nicola Group by plutonic units. The area is shown as 'Metamorphic rocks undivided' on the terrane map of the Cordillera (Wheeler et al., 1991). After examining a number of exposures of metamorphosed Nicola Group rocks within the Nicola horst, which are typically homogeneous amphibolite, meta-augite porphyry, and hornblende greenstone or visibly volcaniclastic rock lacking strong ductile noncoaxial strain, in contrast to the metaconglomerate-bearing succession, we decided to test whether the ductilely strained rocks are basement rocks predating Nicola Group.

The Bob Lake area (Fig. 5) exposes clast-supported metaconglomerate, dark carbonaceous schist hosting one or more of garnet, andalusite, biotite, or muscovite as porphyroblasts or porphyroblastic clots, and fine-grained, felsic biotite schist with a salt-and-pepper appearance interpreted to be metagranite; a sample of the felsic schist has yielded abundant zircons and is being processed for U-Pb dating. The schistose rocks collectively are at least 200 m thick.

The metaconglomerate is at least 30 m thick. Clasts are strongly ductilely flattened and stretched (Fig. 4), and the rock displays phyllonitic texture locally; the ellipsoidal clasts range from a few millimetres to more than 5 cm in their shortest dimension, and have a dominant aspect ratio near 1:2:10. They consist of grey to white quartzite and muscovite quartzite (>90%), graphitic schist (>5%), and other unidentified fine-grained rock types. The matrix is dominantly fine-grained quartz, with minor biotite, muscovite, and rare chlorite forming dark streaky aggregates between clasts. Strong clast-shape defined foliation and lineation characterize the metaconglomerate; the fabrics are inferred to result from penetrative flattening and stretching well below the brittle-ductile transition, i.e. at middle crustal levels.

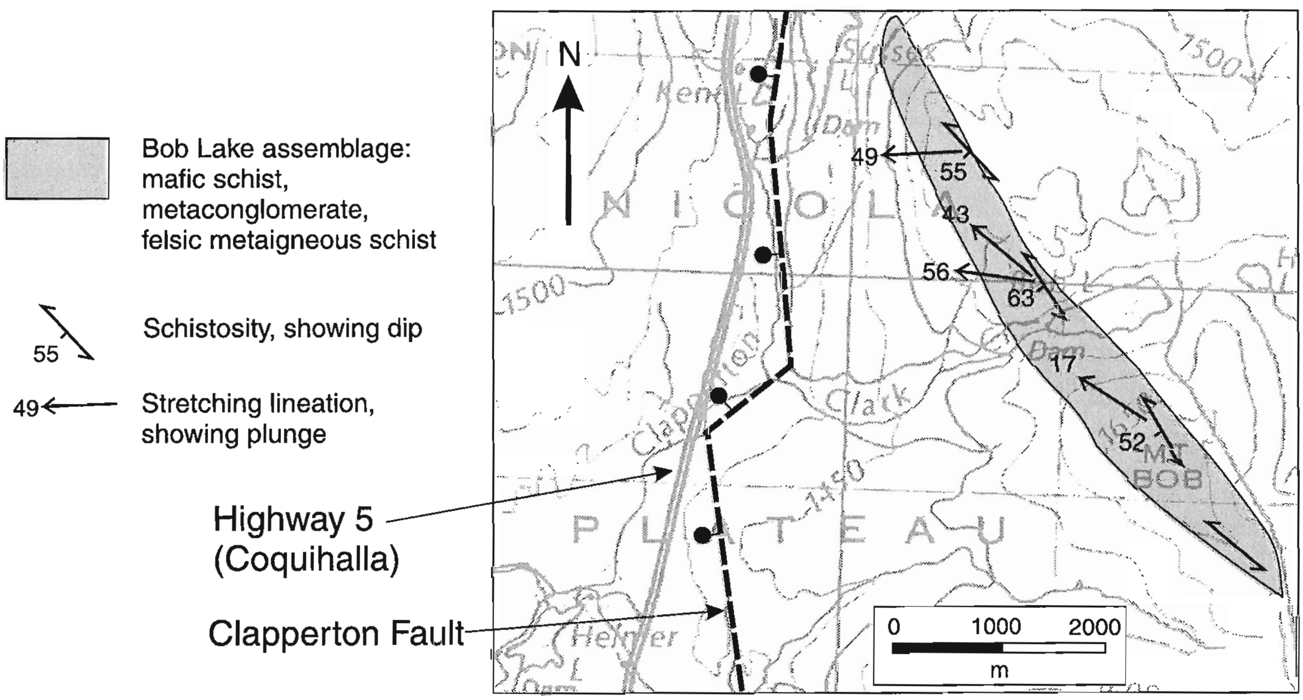


Figure 5. Location of the Bob Lake area in the western part of the Nicola horst. The shaded area is underlain by deformed schist, phyllite, metaconglomerate, and amphibolite. Geology modified from Moore and Pettipas (1990). Heavy dash line is trace of normal fault, dots indicate hanging wall. Topographic base is British Columbia Ministry of Environment 1:100 000 scale map NTS 92 I/SE, Merritt.

The carbonaceous pelitic schist is characteristically fine grained with 0.5–1 cm porphyroblasts. Andalusite porphyroblasts have cores of an unidentified altered mineral in which graphite is concentrated relative to the rim and where sigmoidal inclusion traces record the overgrowth of an early schistosity; andalusite rims either overgrow schistosity or deflect it only moderately, recording late, nearly entirely static growth. This texture is compatible with overprinting of early synkinematic metamorphic porphyroblasts by a later metamorphism. Garnet is similarly either static or only weakly draped by the tectonic fabric in carbonaceous schist; it is also present as a nearly statically grown mineral in the felsic meta-igneous biotite schist. Strong stretching lineation is expressed as mica mineral lineation in carbonaceous schist and as strung out aggregates of feldspar and rodding of quartz in felsic meta-igneous schist; its orientation matches the stretching in the metaconglomerate. Fabrics in carbonaceous schist are overprinted by porphyroblasts and are locally less obvious.

In at least one locality, metaconglomerate and carbonaceous and felsic schist are subjacent to pink to tan, felsic welded tuff to quartz-feldspar microporphyry, which we infer to be part of the Nicola Group on the basis of lower strain and lower metamorphic grade; however, because Nicola Group volcanic rocks are characterized by fine-grained matrix chlorite and epidote (Moore and Pettipas, 1990) and the ignimbrite lacks chlorite, epidote, and amphibole, this correlation needs further testing. Delicate volcanic structure in the felsic ignimbrite is preserved, and the rock does not display a penetrative stretching lineation, i.e. has not undergone the ductile noncoaxial strain of the schist and metaconglomerate succession. The contact is not exposed and the areal extent of the ignimbrite was not determined.

Moore and Pettipas (1990) mapped a unit of lineated and foliated leucotonalite and tonalite porphyry in contact with the metasedimentary-metavolcanic succession both to the northeast and southwest. They interpreted the tonalite as part of the Nicola Group, although they noted that the rocks host ductile strain fabrics similar to the metasedimentary-metavolcanic succession described above, and unlike other parts of the Nicola Group. Study of the leucotonalite unit to test the hypothesis that it is a ductilely strained Paleozoic intrusion is planned as part of the Vernon project.

DISCUSSION AND CONCLUSIONS

The metamorphosed and strained mafic schist, marble, and metaconglomerate in the studied localities belong to a highly distinctive stratigraphic succession of pericratonic affinity, that consistently separates Late Proterozoic quartz-rich metaclastic schist of miogeoclinal affinity (Silver Creek Formation) from Permian and Triassic strata (Harper Ranch and Nicola groups) that overlap them regionally. The rocks were deformed at depths well below the brittle-ductile transition, and are polymetamorphic. Their early metamorphism was synkinematic with peak ductile deformation and did not affect Permian–Triassic strata.

The strike of lithological layering in the Kendry Creek, Glenemma, Yankee Flats, and Fowler Creek areas is west to west-northwest, as is the geographic alignment of known exposures (Fig. 2), suggesting structural continuity across the Okanagan Valley and precluding both significant strike-slip offset and significant extension across the valley.

From exposures near Armstrong (*see* Fig. 2), the pericratonic succession was correlated by Jones (1959) and Okulitch (1979) with the Tsalkom Formation, which includes greenstone, chloritic phyllite, and phyllite of Lower to Middle Paleozoic age. Thompson and Daughtry (1998) extended that correlation to include the Sicamous and Eagle Bay formations, which consist of carbonaceous marble, and a phyllite-breccia-tuff-quartzite-marble assemblage, respectively. The contact of the pericratonic succession with underlying rocks of the Silver Creek Formation is locally sharp or mixed gradational and expressed as interlayering of rocks typical of either sequence, and is transposed. There is structural disharmony across the contact, which is in part the result of deformation that involved Triassic strata, and in part the result of earlier deformation and metamorphism of the pericratonic rocks. The hypothesis that the contact was originally stratigraphic is being tested in a separate study (*see* report by Unterschutz et al., 1999).

The contact of the pericratonic succession with overlying Triassic rocks is an erosional unconformity. In the western part of Vernon map area, Triassic strata rest unconformably on older rocks of the Chapperon Group (Jones, 1959; Read and Okulitch, 1977), which display attributes of amphibolite metamorphic grade and penetrative ductile strain similar to the rocks described here. The Chapperon Group has been correlated with the Tsalkom–Sicamous–Eagle Bay assemblage (Thompson and Daughtry, 1998); even if the correlation is incorrect and the Chapperon is a distinct succession, for example, of Carboniferous age as proposed by Okulitch (1973), the basal contact of the Triassic succession is a regional unconformity truncating higher grade Paleozoic rocks. Where the pericratonic succession is absent in Vernon map area, the Triassic succession directly overlies Silver Creek Formation schists. Thus, Quesnellia stratigraphy (i.e. Nicola and Harper Ranch groups) rests unconformably on older, higher grade strata and therefore cannot be interpreted to be part of a far-travelled nappe or accreted terrane.

We infer that North American continental basement subjacent to the Silver Creek Formation may extend west of the Okanagan Valley as far as the Nicola horst. The basement may even persist as far as the Fraser Fault if exposures of highly metamorphosed rocks mapped there by Brown (1981) and Monger and McMillan (1989) are also part of the pericratonic succession described here.

ACKNOWLEDGMENTS

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Late Cretaceous and Paleocene strata along the Intermontane–Methow terrane boundary, southern Chilcotin Plateau, south-central British Columbia

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Abstract: Late Cretaceous and Late Cretaceous(?) to Paleocene strata exposed in the Dash–Churn drainage at the southern end of the Chilcotin Plateau may provide stratigraphic ties between the Methow terrane and the Intermontane superterrane. The Albian–Cenomanian Dash–Churn succession is a coarse-grained volcanogenic conglomerate and breccia unit that represents proximal volcanism in a tectonically active basin. Plutonic clasts become more prevalent in the succession toward the north, indicating uplift of Upper Jurassic plutonic rocks along syndepositional faults. The Dash–Churn succession is similar in age, lithology, stratigraphy, and geochemical characteristics to the Powell Creek formation, exposed on the Methow terrane to the southwest, across the Yalakom Fault. The Late Cretaceous(?) to Paleocene Flapjack Peak unit is a polymict conglomerate characterized by abundant intrabasinal (volcanic, sandstone and siltstone) and extrabasinal (plutonic, chert, dark mudstone, feldspathic sandstone) clasts. Extrabasinal clasts were probably derived from uplifted thrust sheets of Methow–Tyaughton basin strata to the southwest.

Résumé : Des strates du Crétacé tardif et du Crétacé(?) tardif–Paléocène qui affleurent dans le bassin versant de Dash–Churn à l'extrémité méridionale du plateau de Chilcotin pourraient fournir des indications sur les liens stratigraphiques susceptibles d'exister entre le terrane de Methow et le superterrane intermontagneux. La succession de Dash–Churn de l'Albien–Cénomanien comporte une unité de brèche et de conglomérat volcanogéniques à grain grossier qui représente un volcanisme proximal dans un bassin tectoniquement actif. Les clastes plutoniques deviennent plus nombreux dans la succession vers le nord, ce qui indique un soulèvement des roches plutoniques du Jurassique supérieur le long de failles synsédimentaires. L'âge, la lithologie, la stratigraphie et les caractéristiques géochimiques de la succession de Dash–Churn ressemblent à celles du Groupe de Powell Creek qui affleure dans le terrane de Methow au sud-ouest, de part et d'autre de la faille de Yalakom. L'unité de Flapjack Peak du Crétacé(?) tardif–Paléocène est un conglomérat polygénique caractérisé par d'abondants clastes provenant du bassin (roches volcaniques, grès et siltstone) et de l'extérieur (roches plutoniques, chert, mudstone de couleur foncée et grès feldspathique). Les clastes en provenance de l'extérieur du bassin sont vraisemblablement dérivés de nappes de charriage soulevés de strates du bassin de Methow–Tyaughton au sud-ouest.

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INTRODUCTION

The southern Chilcotin Plateau, adjacent to the northern Camelsfoot and Chilcotin ranges, contains key geological relationships that bear on the timing and magnitude of terrane displacement in the southern Canadian Cordillera. Portions of the Methow, Bridge River, and Quesnellia terranes are juxtaposed along both high-angle strike-slip faults and moderately dipping northeast-vergent thrust faults (Fig. 1). The boundary between the Intermontane and Insular superterranes is traditionally placed along the northeastern edge of the Methow terrane, and the majority of the southern Chilcotin plateau is underlain by rocks assigned to the Intermontane superterrane (Fig. 1). The nature of this superterrane boundary and the timing of terrane amalgamation have become critical in light of the fundamental discrepancy between geological and paleomagnetic interpretations of terrane translation. Paleomagnetic data sets (Irving et al., 1996 and references therein) require large-scale dextral translation of both the Insular (>3000 km) and Intermontane (>1000 km) superterranes. These data sets indicate approximately 2000 km of relative translation between the two superterranes between ca. 90–55 Ma, along a structure that corresponds with the eastern edge of the Methow terrane. Geological data, including documented displacements of geological markers across major translational structures, suggest total margin-parallel displacement of both superterranes was less than 1000 km during the same time interval. Resolution of this controversy requires constraining the geological evolution of the boundary zone immediately prior to and during the proposed translation interval (ca. 90–55 Ma; Cowan et al., 1997).

The boundary between the superterranes bisects the southern Chilcotin Plateau, with Methow terrane strata exposed on the northern flanks of the Camelsfoot and Chilcotin ranges, and rocks of the Intermontane superterrane exposed in the physiographically low region at the southern edge of the plateau (Fig. 1). Geological relations in the area are obscured by overlying thick successions of Eocene volcanic rocks, extensive basalt flows of the Miocene–Pliocene Chilcotin Group, and abundant Quaternary glacial debris (Fig. 1, 2). However, thick sequences of Late Cretaceous and Late Cretaceous(?) to Paleocene clastic sedimentary rocks exposed in Dash and Churn creeks may provide important linkages between terranes on either side of the Methow–Intermontane boundary. In particular, a previously unrecognized section of Late Cretaceous(?) to Paleocene clastic sedimentary rocks exposed near the confluence of Dash and Churn creeks (Fig. 2), on the northern flank of the Camelsfoot Range, may provide new constraints on terrane juxtaposition.

This paper describes Late Cretaceous volcanogenic conglomerate of the Dash–Churn succession and overlying Late Cretaceous(?) to Paleocene clastic sedimentary rocks informally referred to herein as the Flapjack Peak unit. The evolution of this stratigraphic succession is critical, as the Dash–Churn succession predates proposed translation in part, and deposition of the Flapjack Peak unit spans the proposed timing of translation. The Flapjack Peak unit is of particular interest, as Late Cretaceous(?) to Paleocene strata are essentially absent in this region. These strata record the transition from Late Cretaceous volcanism and sedimentation in tectonically active basins (Mahoney et al., 1992; Riesterer et al., 1998) to widespread Eocene volcanism (Hickson et al., 1991; Hickson, 1990, 1992) in the region.

PREVIOUS WORK

Tipper (1978) mapped sedimentary strata in the Dash–Churn drainages as part of the Kingsvale Group, and recognized that these strata were structurally imbricated with rocks of the Jackass Mountain Group of the Methow terrane along the southwest-dipping Hungry Valley fault (Fig. 1). Glover et al. (1988) mapped rocks along Dash and Churn creeks as Cenomanian and younger volcanic strata in fault contact with Methow terrane strata. The Dash–Churn area is at the southern end of the Taseko Lakes (92-O) map area (mapped by Hickson (1990, 1992) and Hickson et al., (1991)). Hickson et al. (1991) described strata in the Dash–Churn area and correlated these rocks with the Albian–Cenomanian Silverquick formation and Powell Creek formation exposed to the southwest across the Yalakom Fault. The study area is also at the northern edge of Taseko–Bridge River area mapped by Schiarizza et al. (1997), who named the rocks in the Dash–Churn drainage the Dash–Churn succession, and recognized that these rocks were, in part, lithologically similar to the Upper Cretaceous Powell Creek formation, a thick succession of andesitic volcanic rocks and associated coarse-grained sedimentary rocks that unconformably overlies rocks of the Tyaughton basin to the southwest. However, Schiarizza et al. (1997) noted that the Dash–Churn succession was associated with Intermontane rocks and that it is separated structurally from rocks of the Methow terrane, and therefore mapped the Dash–Churn succession as a separate unit.

STRATIGRAPHY

Dash–Churn succession

The Dash–Churn succession comprises a thick (minimum 800–1000 m) interval of volcanic conglomerate, lapilli tuff, and breccia intercalated with volcanic lithic sandstone. The succession is well exposed in steep canyon walls near the confluence of Dash and Churn creeks, and discontinuously exposed for 15–20 km downstream. The unit is folded into a series of east-west- to northwest-trending, low-amplitude open folds, and is cut by northwest-trending high-angle, normal to strike-slip faults (Fig. 2). Numerous Eocene aphyric rhyolite dykes cut the section.

Schiarizza et al. (1997) subdivided the Dash–Churn succession into three units: a basal granule to pebble conglomerate, a middle volcanic breccia unit, and an upper volcanic breccia and conglomerate unit. However, they acknowledge that the regional persistence and stratigraphic significance of the subdivisions is unclear. Examination of the unit along Churn Creek and its tributaries indicates that the Dash–Churn succession contains complexly interfingering and laterally discontinuous facies, which, coupled with discontinuous exposure, precludes a regionally consistent subdivision.

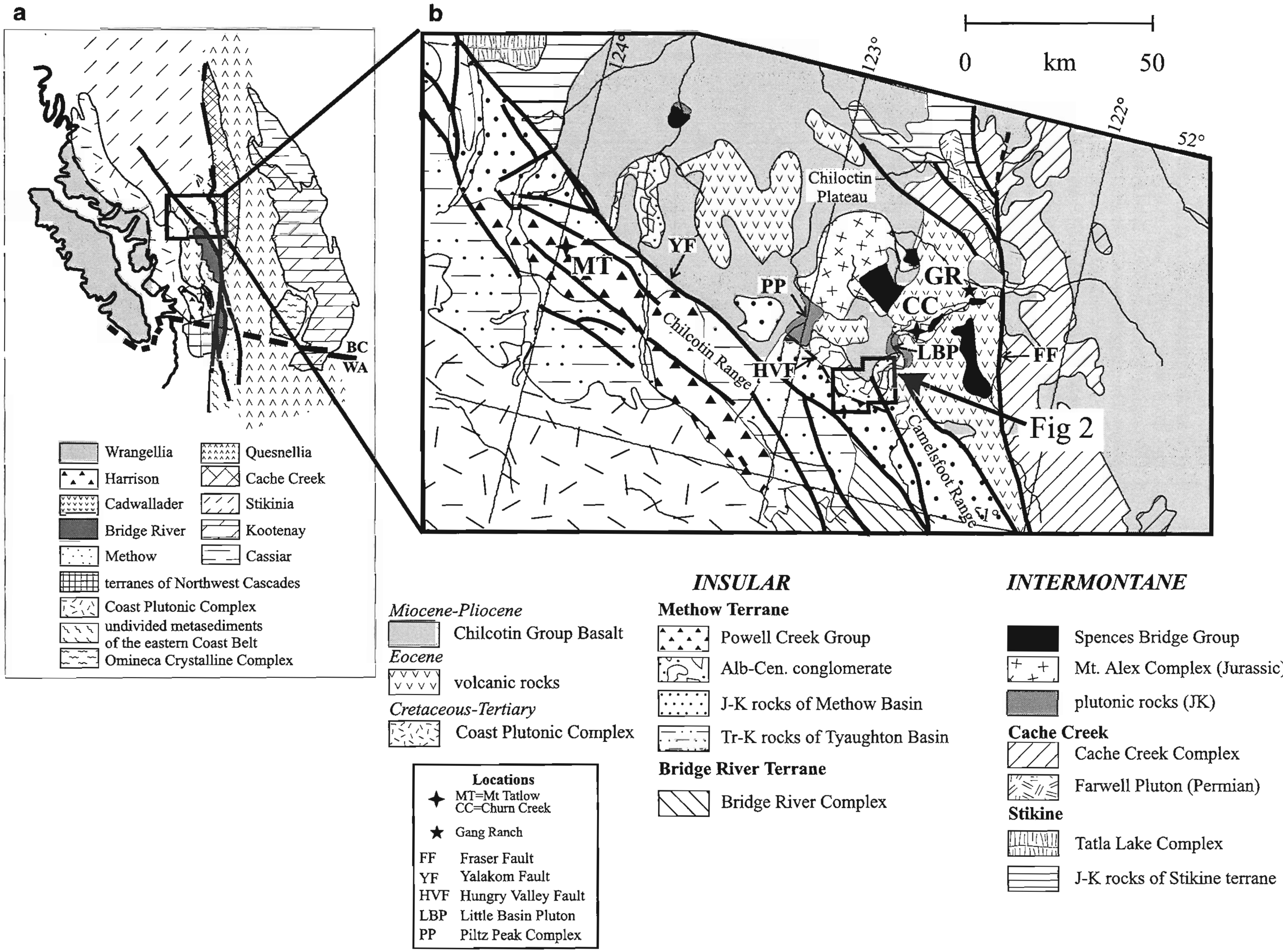

Figure 1. *a) Generalized terrane map of the Canadian Cordillera, showing location of study area.* ***b****) Generalized geologic map of the southern Chilcotin Plateau, showing location of study area. Note study area lies between Fraser and Yalakom fault systems.*

The Dash–Churn succession consists of several distinct lithofacies, including 1) volcanic pebble to boulder conglomerate and interbedded volcanic lithic sandstone; 2) volcanic breccia and associated volcanogenic sediments; 3) lapilli tuff and tuff breccia; 4) mixed volcanic and plutonic cobble to boulder conglomerate. The base of the Dash–Churn succession is not exposed, but correlative strata in the lower reaches of Churn Creek unconformably overlie Albian volcanic rocks which are tentatively correlated with the Spences Bridge Group of the Intermontane superterrane (Riesterer et al., 1998; Haskin et al., 1999). The succession is conformably(?) overlain by Upper Cretaceous(?) to Paleocene conglomerate and sandstone of the Flapjack Peak unit.

The volcanic pebble- to boulder-conglomerate lithofacies consists of thick bedded to massive pebble to boulder conglomerate containing subangular to subrounded clasts of reddish-purple to green plagioclase- and hornblende-plagioclase-phyric andesite to dacite. These clasts average 10–30 cm in diameter, with a maximum size of more than 1.5 m. The conglomerate is dominantly clast supported, matrix supported in part, and varies from moderately organized to disorganized. Crude stratification is locally evident, and basal scour surfaces and reverse grading are common. Coarsening-upward cyclicity (tens of metres) is locally evident. The conglomerate is intercalated with medium- to thick-bedded green to light grey, medium- to coarse-grained, moderately sorted, volcanic lithic sandstone, coarse siltstone, and minor pebbly sandstone. Sandstone interbeds display crude parallel laminae, basal scour surfaces, and both normal and reverse grading, and generally constitute less than 20% of the lithofacies. The lithofacies forms resistant cliff faces which have aggregated to greater than 200 m of total thickness.

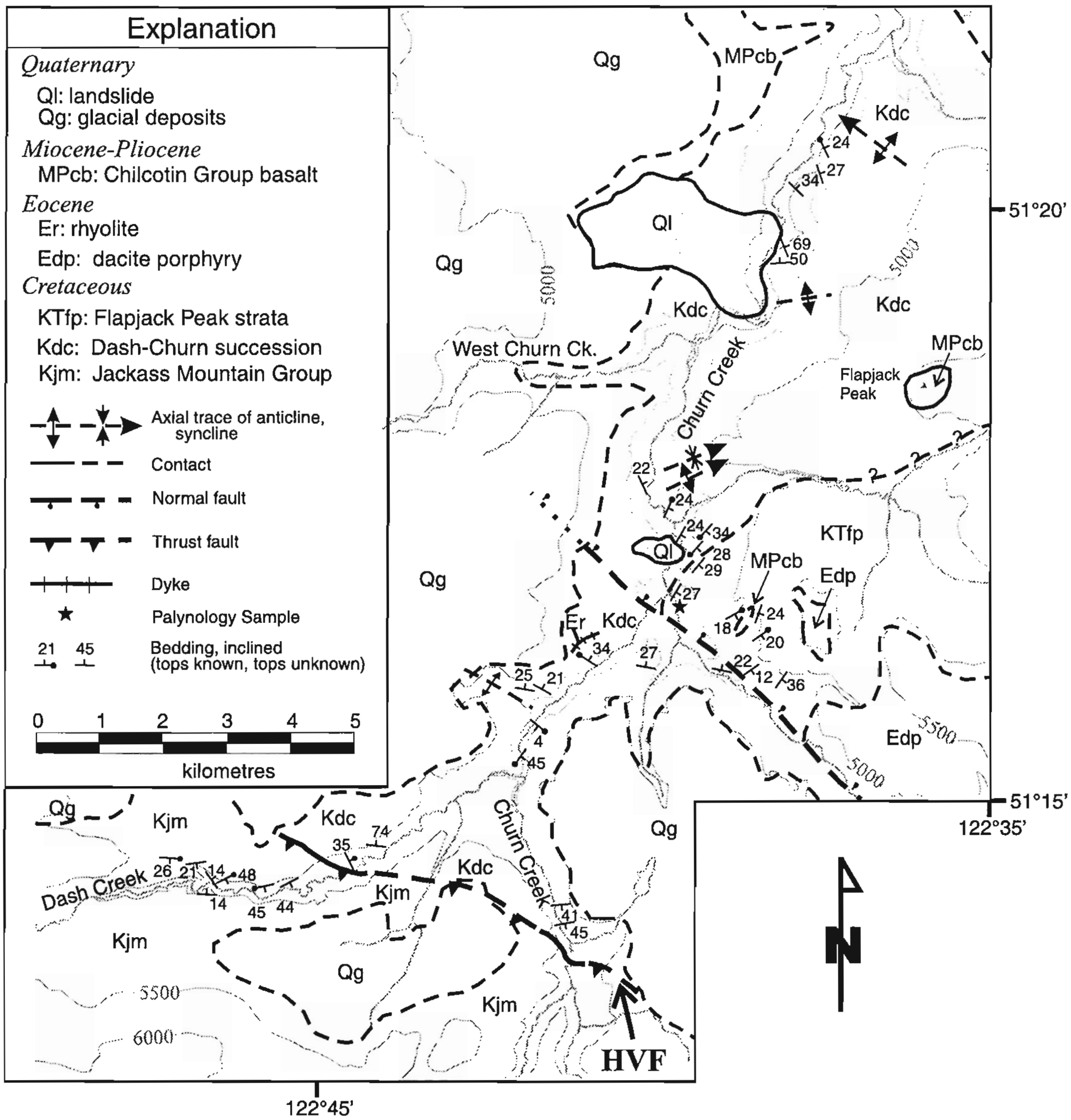

Figure 2. Geological map of the study area. Note Upper Cretaceous to Paleocene strata is generally restricted to incised drainages. HVF=Hungry Valley Fault.

The volcanic-breccia lithofacies is volumetrically subordinate and complexly interstratified with the volcanic pebble- to boulder-conglomerate lithofacies. The breccia lithofacies consists of angular to subangular, subrounded in part, cobble- to boulder-sized clasts of purple to green aphyric to plagioclase-phyric volcanic clasts set in a medium- to coarse-grained volcanic lithic wacke matrix. The lithofacies is commonly chaotically disorganized, but crude reverse grading and rafting of out-sized clasts (>1 m) is locally evident. Thick-bedded to massive intervals of volcanic breccia are intercalated with thick beds of pebble to cobble volcanic conglomerate and thin to medium beds of pebbly sandstone, volcanic lithic sandstone, and coarse siltstone.

Lapilli tuff and tuff breccia comprise a minor yet important portion of the Dash–Churn succession. This lithofacies consists of reddish-brown to greenish-grey, thick-bedded to massive andesitic to rhyolitic lapilli tuff and tuff breccia consisting of angular to subangular, aphyric to plagioclase-phyric clasts set in a hornblende-plagioclase-phyric or plagioclase-phyric matrix. Quartz phenocrysts are locally evident. The tuffs vary from massive, unsorted, and unstratified beds to crudely stratified in part. Lapilli tuff and tuff breccia have been locally aggregated to 20–40 m thick sections interstratified with pebble to boulder conglomerate and associated lithic sandstone.

A very distinctive component of the Dash–Churn succession is a mixed volcanic and plutonic cobble- to boulder-conglomerate lithofacies. This lithofacies consists of thickly bedded to massive, matrix-supported, cobble to boulder conglomerate containing subangular to subrounded clasts of red and green plagioclase porphyry, green aphyric volcanic rocks, and very distinctive mottled red and green biotite-hornblende diorite. Clast composition is distinctly bimodal in part, characterized by large (up to 2 m), subrounded to rounded prominent clasts of diorite mixed with smaller (<0.5 m; average 10–30 cm) subangular to subrounded volcanic clasts. Plutonic clast percentage varies from ~10–60%. Zircon and titanite analyzed from a biotite-hornblende diorite clast collected from the mixed volcanic and plutonic lithofacies yielded a U-Pb age of 148.9 ± 0.7 Ma (Fig. 3; Table 1). This crystallization age is based on four concordant zircon fractions, with the titanite cooling age interpreted to be about 2 Ma younger than the zircon age.

The mixed volcanic and plutonic lithofacies varies from chaotically disorganized matrix-supported conglomerate to crudely stratified matrix- to clast-supported conglomerate with sandstone and coarse siltstone interbeds. The matrix locally consists of a distinctive very coarse-grained grus containing coarse sand to granule plutonic lithic fragments, quartz, feldspar, and biotite. Thin- to medium-bedded, locally thick-bedded, medium- to very coarse-grained lithic feldspathic sandstone and very coarse-grained siltstone separate thick (10–20 m) conglomeratic intervals, and medium to thick beds of disorganized pebble conglomerate consisting of 1–5 cm angular volcanic clasts set in a feldspathic, 'grussy' matrix occur locally. Sandstone and siltstone interbeds constitute less than 20% of the lithofacies.

There is a distinct south-to-north variation in conglomerate composition within the Dash–Churn succession. Essentially monomictic volcanic conglomerate and associated pyroclastic and volcaniclastic interbeds are common in Dash Creek and the upper reaches of Churn Creek, whereas the mixed volcanic and plutonic cobble to boulder conglomerate lithofacies is much more prevalent to the north. This transition is presumed to represent a lateral interfingering of different lithofacies, but a stratigraphic succession cannot be ruled out.

Depositional interpretation

The very coarse grain size, thick-bedded to massive appearance, disorganized to crudely stratified character, and the sedimentological immaturity of the Dash–Churn succession indicate deposition in a first-order basin with a steep gradient and short transport path. The abundance of volcanic debris and intercalated pyroclastic flows require coeval active volcanism, and the coarseness and immaturity of plutonic debris suggest active tectonism uplifting a plutonic source area. The apparent south-to-north gradation from volcanic-dominated

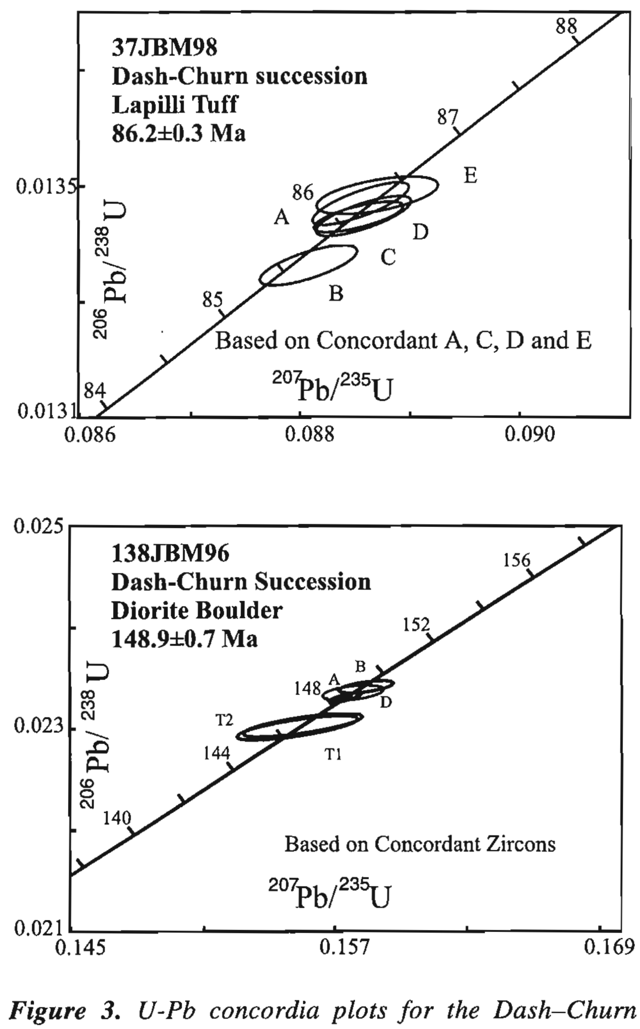

Figure 3. U-Pb concordia plots for the Dash–Churn succession.

detritus to mixed plutonic and volcanic debris argues for a volcanic source to the south that mixed with plutonic debris derived from an uplifted pluton to the north. The abundance of matrix-supported conglomerate, local reverse grading, and rafting of large clasts indicate a debris-flow origin for many of the boulder conglomerates. Crudely stratified conglomerate and sandstone, which locally display a crude clast imbrication, may have been deposited in a sediment-choked braided fluvial system.

Age and correlation

A lapilli tuff collected from the upper portion of the Dash–Churn succession, approximately 100 m below the contact with the overlying Flapjack Peak unit, yields a U-Pb age of 86.2 ± 0.3 Ma (Fig. 3, Table 1). The interpreted age of 86.2 ± 0.3 Ma is based on four concordant and overlapping fractions (Fig. 3). Slightly younger fraction B is likely to have undergone minor Pb loss.

The Dash–Churn succession is strikingly similar to a portion of the conglomerate of Churn Creek exposed in the lower reaches of Churn Creek (Mahoney et al., 1992; Riesterer et al., 1998). The conglomerate of Churn Creek is exposed on the north side of a small pluton (<10 km^2; the Little Basin pluton) that abuts the northern edge of the Dash–Churn succession. Both units contain identical volcanic and plutonic clast assemblages, contain volcanic clasts with overlapping geochemical signatures, display similar depositional architecture, and are cut by northeast-vergent thrust faults (Danielson et al., 1998). The lithological, stratigraphic, geochemical, and structural similarities between the Dash–Churn succession and the conglomerate of Churn Creek strongly suggest the units are directly correlative. The conglomerate of Churn Creek is well constrained palynologically as Albian–Cenomanian in age, which is within the permissible constraints on the age of the Dash–Churn succession.

Previous workers have noted the similarity in clast composition, geochemistry, age, structure, and depositional style between the conglomerate of Churn Creek, the Dash–Churn succession, and the Powell Creek formation of the Methow terrane (Hickson, 1990; Mahoney et al., 1992; Schiarizza et al., 1997; Riesterer et al., 1998). Detailed correlation between these units is beyond the scope of this paper, but multiple lines of evidence document a genetic link between these units.

The Dash–Churn succession was deposited rapidly in a tectonically active volcanogenic basin, and the age of the lapilli tuff in the upper portion of the section is interpreted as the minimum age of volcanism in the basin. Volcanism may have begun as early as Albian–Cenomanian time, the age of the correlative conglomerate of Churn Creek. The minimum age of the Dash–Churn succession is constrained by the Paleocene stratigraphic age of the overlying Flapjack Peak unit. We interpret the Dash–Churn succession as late Albian to at least Coniacian in age.

Table 1. U-Pb analytical data for Dash–Churn succession.

Fraction[1]	Wt mg	U[2] ppm	Pb*[3] ppm	$^{206}Pb/^{204}Pb$[4]	Pb[5] pg	^{208}Pb[6] %	Isotopic ratios (1σ,%)[7]			Apparent ages (2σ,Ma)[7]	
							$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Lapilli Tuff: 37JBM98											
A cc,p,t,2	0.140	76	1.0	2819	3.2	6.0	0.01347 (0.14)	0.0886 (0.25)	0.04768 (0.16)	86.2 (0.2)	83.6 (7.8)
B c,f,p,3	0.149	91	1.2	2491	4.6	6.0	0.01336 (0.13)	0.0881 (0.25)	0.04781 (0.18)	85.6 (0.2)	89.7 (8.7)
C m,p,e,8	0.115	85	1.1	3710	2.3	7.1	0.01345 (0.13)	0.0886 (0.24)	0.04777 (0.17)	86.1 (0.2)	88.1 (8.1)
D f,p,e,13	0.124	86	1.1	2813	3.2	7.8	0.01345 (0.10)	0.0885 (0.23)	0.04775 (0.17)	86.1 (0.2)	87.1 (8.3)
E f,p,e,25	0.084	45	0.60	1509	2.1	8.0	0.01348 (0.12)	0.0887 (0.31)	0.04771 (0.26)	86.3 (0.2)	85 (13)
Diorite Clast: 138JBM96											
A p,13	0.118	162	3.8	2083	14	9.4	0.02331 (0.09)	0.1575 (0.22)	0.04901 (0.16)	148.5 (0.3)	148.2 (7.5)
B p,e,15	0.072	121	2.8	1162	11	10.3	0.02341 (0.13)	0.1584 (0.39)	0.04908 (0.33)	149.2 (0.4)	152 (15)
C p,eq,20	0.126	185	4.3	3183	11	8.9	0.02330 (0.10)	0.1575 (0.20)	0.04902 (0.14)	148.5 (0.3)	148.8 (6.3)
D p,t,7	0.009	893	21	990	12	9.6	0.02335 (0.16)	0.1578 (0.43)	0.04902 (0.39)	148.8 (0.5)	149 (18)
T1	0.660	183	7.4	235	815	48.8	0.02301 (0.26)	0.1553 (0.89)	0.04895 (0.72)	146.6 (0.8)	146 (33/34)
T2	0.510	204	8.1	235	704	47.7	0.02303 (0.25)	0.1555 (0.87)	0.04897 (0.71)	146.8 (0.7)	147 (33/34)

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

1 Upper case letter = zircon fraction identifier; T1, T2: titanite fractions; All zircon fractions air abraded 10-30 volume%; Grain size, approximate: 37JBM98: cc~500x200x100μm; c~400x100x100μm; m~300x75x75μm; f~250x50x50μm; 138JBM96: All fractions >134μm, intermediate axis. All zircon fractions nonmagnetic on Franz separator at sideslope of 2° and field strength of 1.8A. Titanite: nonmagnetic at 20°/0.6A and Magnetic at 20°/1.8A; Front slope for all fractions is 20°; Grain character codes: e=elongate, eq=equant; p=prismatic; t=tabular; Numeral=number of grains analysed.

2 U blank correction of 1pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.004/amu).

3 Radiogenic Pb.

4 Measured ratio corrected for spike and Pb fractionation of 0.0035/amu ± 20% (Daly collector) and laboratory blank Pb of 2-3 pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks.

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.

Flapjack Peak unit

The Dash–Churn succession is stratigraphically overlain by a thick (ca. 800 m) succession of polymict conglomerate and sandstone herein informally named the Flapjack Peak unit. The name is derived from Flapjack Peak, the only named topographic feature in the area, which is located about 3 km northeast of the outcrop area (Fig. 2). Flapjack Peak itself is a volcanic neck of the Miocene–Pliocene Chilcotin Group emplaced within the Dash–Churn succession.

The Flapjack Peak unit is exposed in southeast-dipping beds northeast of the confluence of Dash and Churn creeks (Fig. 2). The section is poorly exposed, and consists of resistant cliffs of conglomerate separated by zones of little or no exposure. The unit attains a thickness of as much as 800 m, albeit estimated from discontinuous outcrops and assuming no repetition by faults in the area. The type section of the Flapjack Peak unit is intruded by hornblende-plagioclase porphyry of the middle Eocene (~45 Ma) Red Mountain complex (Schiarizza et al., 1997; Fig. 2).

The Flapjack Peak unit stratigraphically overlies the Dash–Churn succession with no angular discordance. The contact is believed to be conformable, based on the occurrence of coarse-grained primary volcanogenic conglomerate and the presence of distinctive biotite-hornblende diorite clasts in both units. However, existing age constraints (*see* below) suggest a substantial stratigraphic break (Coniacian to Paleocene) may exist between the two units. Resolution of this discrepancy requires additional age constraints.

The Flapjack Peak unit may be subdivided into three members, including a lower mudstone and sandstone member (<100 m), a middle member consisting of volcaniclastic conglomerate (<280 m), and an upper member containing interbedded volcanic sandstone and conglomerate (>400 m; Fig. 4). Thicknesses reported herein are necessarily broad estimates due to discontinuous exposure.

The lower member of the Flapjack Peak unit is exposed immediately northeast of the bridge over Churn Creek (5680850N, 523000E). The lower portion of the member (~21 m) is exposed just above creek level, and the entire member is estimated at ~100 m thick, although the upper portion of the member is poorly exposed. The member consists of intercalated thin- to medium-bedded mudstone and volcanic lithic sandstone. Thin-bedded (3–7 cm) mudstone beds are tan to dark grey and display a crumbly or spheroidal weathering pattern. Root cavities, leaf fossils, and dark-coloured organic-rich concentrations are locally evident. The mudstone is intercalated with thin- to medium-bedded (5–15 cm average), tan to grey, medium-grained, moderately to poorly sorted, volcanic lithic feldspathic wacke. The sandstone is primarily structureless, but locally displays undulose bases, load features, and graded bedding. Tan to grey, medium- to coarse-grained, locally pebbly sandstone beds locally fill channel scours (0.3 to 1.2 m thick) cut into the intercalated mudstone and sandstone facies. The lower member coarsens upward, becoming interbedded with thin to medium beds of coarse-grained sandstone and pebble conglomerate. A pebble count reveals the conglomerate contains 66% chert, 17% volcanic, 10% green and tan lithified (extrabasinal) mudstone and 7% quartz monzonite (Fig. 2).

The middle member is a thick-bedded volcanic pebble to boulder conglomerate that gradationally overlies the lower member. The middle member may be as much as 275 m thick, though only the lower and upper portions are exposed. The volcanic pebble to boulder conglomerate consists of subrounded to angular, maroon to green hornblende- and plagioclase-phyric volcanic clasts (5 to 40 cm; average 10 cm) set in a maroon to green coarse-grained feldspathic wacke. The unit appears massive, with crude stratification locally evident. One 4 m thick bed contains boulders up to 1 m in diameter. The middle member is polymictic and finer grained near its contact with the upper member.

The upper member of the Flapjack Peak unit consists of a thick succession (>400 m) of interbedded pebble to cobble conglomerate and volcanic sandstone that gradationally overlies the middle member. The unit is dominated by medium- to thick-bedded, locally massive, polymict pebble to cobble conglomerate consisting of volcanic (dominantly plagioclase-phyric intermediate clasts, with lesser white tuff, welded ignimbrite, and rhyolite), plutonic (quartz monzonite and diorite), and both extrabasinal (chert, dark mudstone, pink sandstone, quartzite) and intrabasinal (volcanic lithic sandstone, siltstone) clasts. The conglomerate is poorly sorted and primarily matrix supported. The matrix consists of moderately to poorly sorted, coarse-grained volcanic lithic sandstone with abundant floating volcanic lithic granules. Crude stratification, graded bedding, and cross-stratified channel fills (2–3 m thick) are locally evident.

The conglomerate is intercalated with medium- to thick-bedded granule conglomerate, medium-to coarse-grained volcanic lithic sandstone, and purple pebbly siltstone. The sandstone is moderately to poorly sorted, subangular to subrounded, medium- to coarse-grained, volcanic lithic feldspathic wacke to arenite, with minor pebble lenses and channel fills.

The polymictic character of the upper member is distinctive (Fig. 4). There is an upward increase in intrabasinal clasts (primarily volcanic lithic sandstone, increasing from 1% to 30%), and a concomitant decrease in volcanic clasts (decreasing from 66% to 27%). The member contains 20–32% plutonic clasts, which consistently display a slightly higher percentage of quartz monzonite with respect to diorite.

Provenance and depositional environment

The Flapjack Peak unit is interpreted to represent a fluvial system periodically inundated by volcanic debris. The presence of fine-grained, laterally continuous mudstone and sandstone containing root casts and other organic debris suggests the lower member represents fluvial overbank deposits interbedded with a coarser grained channel facies. The massive appearance, monomictic composition, and matrix-supported character of the middle member suggests deposition as a proximal volcanic fanglomerate or lahar, with a nearby volcanic source region. The presence of channel fills, graded bedding, crude stratification, and conglomerate lenses in finer grained interbeds suggests the upper member represents a braided fluvial system.

The polymictic clast assemblage in the Flapjack Peak unit differs significantly from assemblages within underlying Albian–Cenomanian conglomerates, and may represent a previously unrecognized source region during the Late Cretaceous and Paleocene. Sparse paleocurrents (n=12; Fig. 4) from the lower portion of the upper member suggests a west-southwest–east-northeast transport direction. The presence of chert throughout the section requires a chert-rich source region to the east or west. The most likely source of chert pebbles within the Flapjack Peak unit is from Late Cretaceous thrust sheets within the Methow–Tyaughton section to the west-southwest (Dash formation, Silverquick formation, perhaps slivers of the Bridge River Group; Schiarizza et al., 1997). The only source of chert to the east-northeast is the Cache Creek terrane, and there is no evidence of chert detritus in the upper portion of the conglomerate of Churn Creek, exposed between the study area and the nearest exposure of Cache Creek strata. Extrabasinal sandstone and mudstone clasts

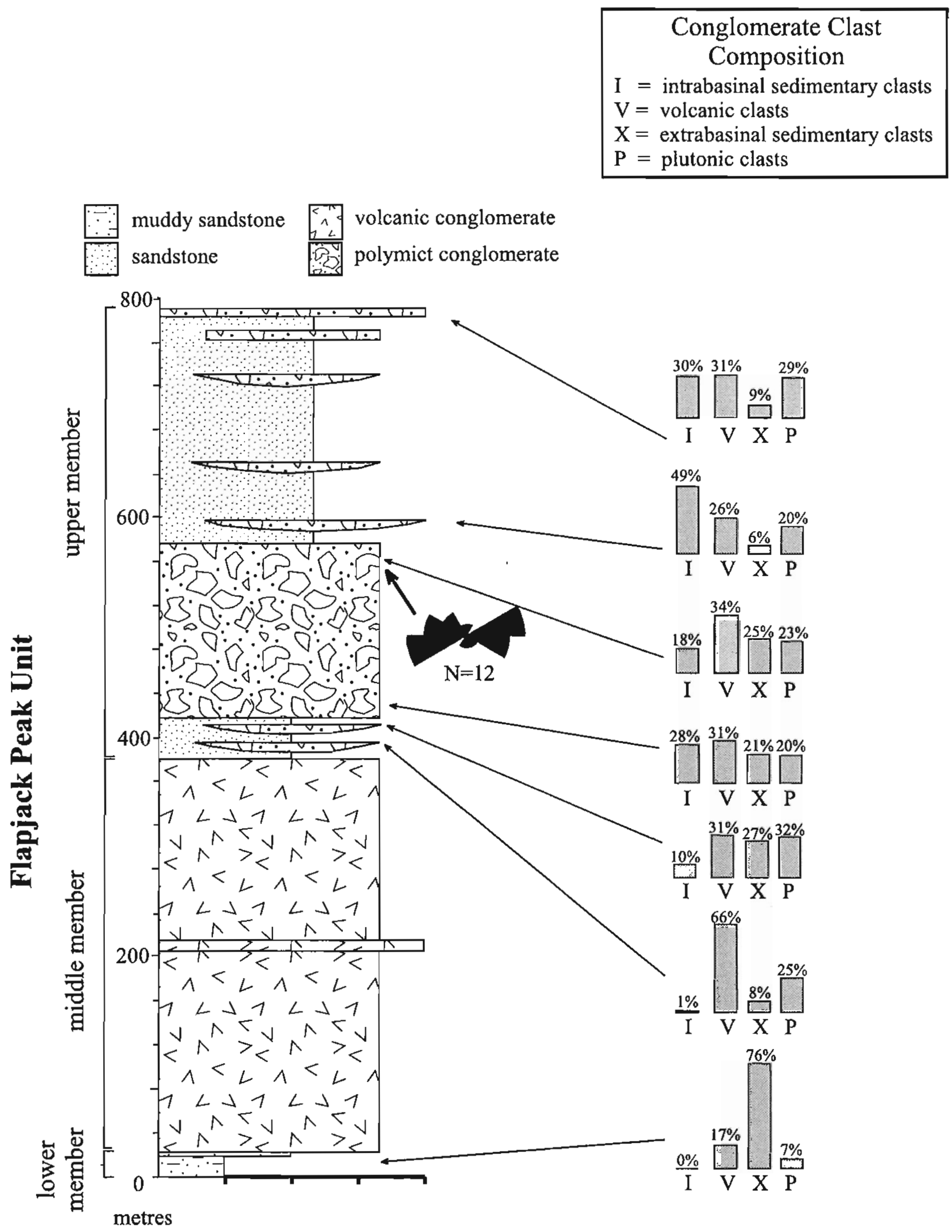

Figure 4.

Schematic stratigraphic column of the Flapjack Peak unit, showing location of pebble counts.

within the succession have no potential source to the east-northeast, and are probably derived at least in part from the uplifted Methow–Tyaughton sequence to the west-southwest. Plutonic clasts within the sequence are very similar to clasts within both the Dash–Churn succession and the conglomerate of Churn Creek, and may indicate reworking, or, more likely, derivation from the Little Basin pluton to the northeast, or the Piltz Peak Complex to the northwest (Hickson, 1990; Mahoney et al., 1992; van der Heyden and Metcalfe, 1992; Riesterer et al., 1998). The large proportion of intrabasinal clasts suggests syndepositional tectonism and cannibalization of the underlying Dash–Churn succession. The source of the volcanic detritus is unknown, and may represent reworking of Powell Creek formation detritus or derivation from the Paleocene Mt. Sheba Complex to the west and southwest (Schiarizza et al., 1997).

Age

The age of the lower member of the Flapjack Peak beds is constrained by palynology as early Tertiary, probably Paleocene: "Tertiary based on the common presence of *Betulaceous* pollen, *Paraalnipollenites alterniporus* and *Tsuga* and the lack of taxa characteristic of the Cretaceous. The low diversity of the assemblage, the presence of *Paraalnipollenites alterniporus*, and the lack of *Alnus* pollen is strongly suggestive of a Paleocene age." (Art Sweet, GSC, written comm., 1998).

CONCLUSIONS

The Albian–Cenomanian Dash–Churn succession is a thick sequence of primarily volcanic cobble to boulder conglomerate deposited proximal to an active volcanic source. The succession contains an increasing number of plutonic clasts to the north, suggesting derivation of plutonic debris from an uplifted plutonic source to the north (Little Basin pluton) or west (Piltz Peak Complex). The Dash–Churn succession is directly correlative with the conglomerate of Churn Creek to the north, which in turn is correlated with the Powell Creek formation of the Methow terrane (Riesterer et al., 1998). The Dash–Churn succession therefore links the conglomerate of Churn Creek with the Powell Creek formation of the Methow terrane. The significance of this correlation is that these volcanogenic Albian–Cenomanian rocks form an overlap assemblage between the Methow terrane and the Intermontane superterrane. This overlap assemblage therefore limits the magnitude of permissible post-Cenomanian translational offset between the terranes to less than 110–200 km, the aggregate offset along known faults separating the terranes.

The Flapjack Peak unit is dominantly a polymict pebble to cobble conglomerate that stratigraphically overlies the Dash–Churn succession, and contains volcanic, plutonic, and sedimentary clasts. Palynology strongly suggests the unit is Paleocene, and represents a transition from Late Cretaceous volcanism and basin tectonism (Mahoney et al., 1992; Riesterer et al., 1998) to Paleocene braided fluvial deposition. The polymict clast assemblage may indicate derivation of extrabasinal clasts from uplifted thrust sheets of the Methow–Tyaughton succession (Schiarizza et al., 1997). Late Cretaceous stratigraphy in the Dash–Churn Creek area provides an additional stratigraphic tie between rocks of the Intermontane superterrane and those of the Methow terrane.

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Geological Survey of Canada Project 890039

Stratigraphic affinity of Upper Cretaceous volcanic rocks in the Churn Creek–Gang Ranch area, south-central British Columbia

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Abstract: Albian volcanic rocks in south-central British Columbia may link the Intermontane and Insular superterranes. These rocks have been correlated with the Spences Bridge Group of the Intermontane Superterrane, but stratigraphically underlie Albian–Cenomanian Silverquick conglomerate and Powell Creek Group of the Insular Superterrane. Paleomagnetic, geochemical, lithological, stratigraphic, and geochronological studies will test the Spences Bridge Group correlation. The 300–400 m thick Albian volcanic package unconformably overlies Jurassic (?) argillite and siltstone and is unconformably overlain by Albian–Cenomanian conglomerate. Tertiary volcanic rocks and intrusions overlie or intrude the older successions. The Albian volcanic rocks are divisible into two units: a lower unit of plagioclase-phyric andesite flows, intercalated volcaniclastic rocks and massive tuffaceous/pyroclastic flows/breccias and an upper unit of vesicular andesite, pyroclastic flows and volcanic breccias. If this package is Spences Bridge Group, its paleomagnetic inclination will place strong constraints on the Baja–British Columbia model.

Résumé : Dans le centre sud de la Colombie-Britannique, des roches volcaniques de l'Albien pourraient vraisemblablement relier les superterranes intermontagneux et insulaire. Ces roches ont été mises en corrélation avec le Groupe de Spences Bridge du superterrane intermontagneux, mais, d'un point de vue stratigraphique, elles sont sous-jacentes au conglomérat albien-cénomanien de Silverquick et au Groupe de Powell Creek du superterrane insulaire. Les études paléomagnétiques, géochimiques, lithologiques, stratigraphiques et géochronologiques permettront de vérifier la corrélation avec le Groupe de Spences Bridge. L'assemblage volcanique albien de 300 à 400 m d'épaisseur repose en discordance sur des argilites et siltstones jurassiques(?) et est recouvert en discordance par du conglomérat albien-cénomanien. Des roches volcaniques et intrusives du Tertiaire reposent sur les successions plus anciennes ou les recoupent. Les roches volcaniques de l'Albien se répartissent en deux unités : une unité inférieure comportant des coulées d'andésite à phénocristaux de plagioclase, des roches volcanoclastiques et des coulées et brèches pyroclastiques et tufacées massives intercalées, et une unité supérieure composée d'andésites vacuolaires, de coulées pyroclastiques et de brèches volcaniques. Dans l'éventualité où cet assemblage ferait partie du Groupe de Spences Bridge, son inclinaison paléomagnétique nous obligerait sans doute à revoir le modèle Baja–Colombie-Britannique.

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INTRODUCTION

A key controversy in the tectonic evolution of the Canadian Cordillera centres on the timing and magnitude of dextral translation of two tectonic entities which, in general, correspond to the Insular and the western part of the Intermontane superterranes. Paleomagnetic data from several locales suggest large-scale northward translation of both the Insular (3000 to 4000 km) and western Intermontane (1000 to 2000 km) superterranes with respect to cratonic North America between about 90 to 55 Ma (Irving et al., 1996). Conversely, geological data suggest the total margin-parallel displacement of both superterranes was less than 1000 km during the same time interval. These differing data sets have generated conflicting tectonic models, each proposing specific paleogeographic predictions; both hypotheses cannot be correct.

Implicit in the large-scale translation hypothesis is approximately 2000 km of relative displacement between the Insular and Intermontane superterranes. Key paleomagnetic studies on either side of the Fraser and Pasayten faults (Wynne et al., 1995; Irving et al., 1995) constrain the locus of this displacement to within this fault system. In addition, the approximately 2000 km of relative displacement between the superterranes prohibits pretranslation strata on either side of the superterrane boundary from being part of the same stratigraphic unit.

The southern Chilcotin Plateau, near Gang Ranch in south-central British Columbia, contains key geological relationships that may constrain the magnitude of displacement between the Intermontane and Insular superterranes (Fig. 1). The boundary between the superterranes in this region has traditionally been placed at the northeastern edge of the Methow terrane, with the majority of the southern Chilcotin Plateau underlain by rocks of the Intermontane superterrane (Fig. 1). However, recent geochemical, geochronological, stratigraphic, lithological and paleomagnetic data demonstrate that Albian–Cenomanian conglomerate along Churn Creek (Fig. 1) is stratigraphically linked to the Silverquick conglomerate and Powell Creek Group (Danielson et al., 1997; Riesterer et al., 1998). This correlation indicates that Albian–Cenomanian strata tied to the Insular superterrane extend much further to the northeast than previously assumed (Fig. 1). More importantly, this Albian–Cenomanian conglomerate unconformably overlies Albian volcanic rocks that have previously been assigned to the Spences Bridge Group of the Intermontane superterrane (Mathews and Rouse, 1984; Thorkelson and Rouse, 1989; Green, 1990; Mahoney et al., 1992; Riesterer et al., 1998). The correlation between Albian volcanic rocks of the southern Chilcotin Plateau and the Spences Bridge Group of the Intermontane superterrane is critical, as it requires that rocks paleomagnetically constrained to have been translated approximately 1100 km are unconformably overlain by rocks translated 3000 km. The occurrence of definitive Spences Bridge Group strata at the southern end of the Chilcotin Plateau would thus prohibit post-Albian large-scale relative translation between the Insular and Intermontane superterranes. The goal of this investigation is to verify or refute the correlation between Albian volcanic rocks in the Gang Ranch area and the Spences Bridge Group.

GEOLOGICAL SETTING

The southern Chilcotin Plateau is an area of low physiographic relief east of the main Coast Ranges and north of the Chilcotin Range (Fig. 1). The region is dominated by Miocene–Pliocene Chilcotin basalt, with older rocks generally restricted to high-standing edifices or erosional exposures in Pleistocene drainages. The study area is bounded on the west and north by Churn Creek, on the east by Fraser River, and on the south by the northern flank of the Chilcotin Range (Fig. 1). Geologically, the area is bounded on the east by the Fraser fault system, and on the south by the presumed trace of the Hungry Valley Fault (Tipper, 1978). Albian volcanic rocks are exposed in the Churn Creek drainage and on a high plateau region bounded by Lone Cabin, Churn, and Grinder creeks (Fig. 1). For this study, the outcrop distribution serves to divide the region into two sampling areas. The northern area is in the drainage of Churn Creek, approximately 5–10 km southwest of Gang Ranch. Here, Albian volcanic rocks are exposed in a core of a northeast-trending anticline and are unconformably overlain by Albian–Cenomanian conglomerate (Hickson et al., 1991; Mahoney et al., 1992; Riesterer et al., 1998). The other sampling area lies between Grinder Creek and Lone Cabin Creek, approximately 25 km south of Gang Ranch, where Albian volcanic rocks are exposed in an elongate, roughly north-south-trending panel flanked on the west by Eocene volcanic rocks and on the east by the Fraser fault system (Hickson et al., 1991).

Albian volcanic rocks are unconformably underlain by dark grey argillite and siltstone of uncertain stratigraphic affinity, although they resemble Jurassic Ladner Group present across the Fraser Fault to the southeast (Fig. 2). These rocks are exposed in the core of a north-trending anticline bisected by the lower reaches of Churn Creek, about 5 km southwest of Gang Ranch (Fig. 1). The fine-grained strata are overlain by a 300–400 m thick succession of Albian intermediate volcanic rocks, breccia, lapilli tuff, and volcanic lithic sandstone (Green, 1990; Hickson et al., 1991; Hickson, 1992). A similar succession of volcanogenic sedimentary rocks is exposed in Lone Cabin Creek to the south. These volcanogenic sedimentary rocks are conformably overlain by a thick succession of basaltic andesite, which is exposed in Churn Creek, on the plateau north of Lone Cabin Creek, and on the northern flank of the Chilcotin Range south of Lone Cabin Creek (Fig. 2). Within the Churn Creek drainage, this basaltic andesite is unconformably overlain by Albian–Cenomanian chert pebble/volcanic/plutonic conglomerate and sandstone (Riesterer et al., 1998). Both the Albian volcanic rocks and the Albian–Cenomanian conglomerate are overlain by extensive sequences of Eocene rhyolite, dacite, and andesite, and Miocene gravels and tuffs which are, in turn, capped by Miocene and Pliocene Chilcotin Plateau basalt (Mathews and Rouse, 1984; Hickson, 1990; Hickson et al., 1991). Quaternary lacustrine and glaciofluvial

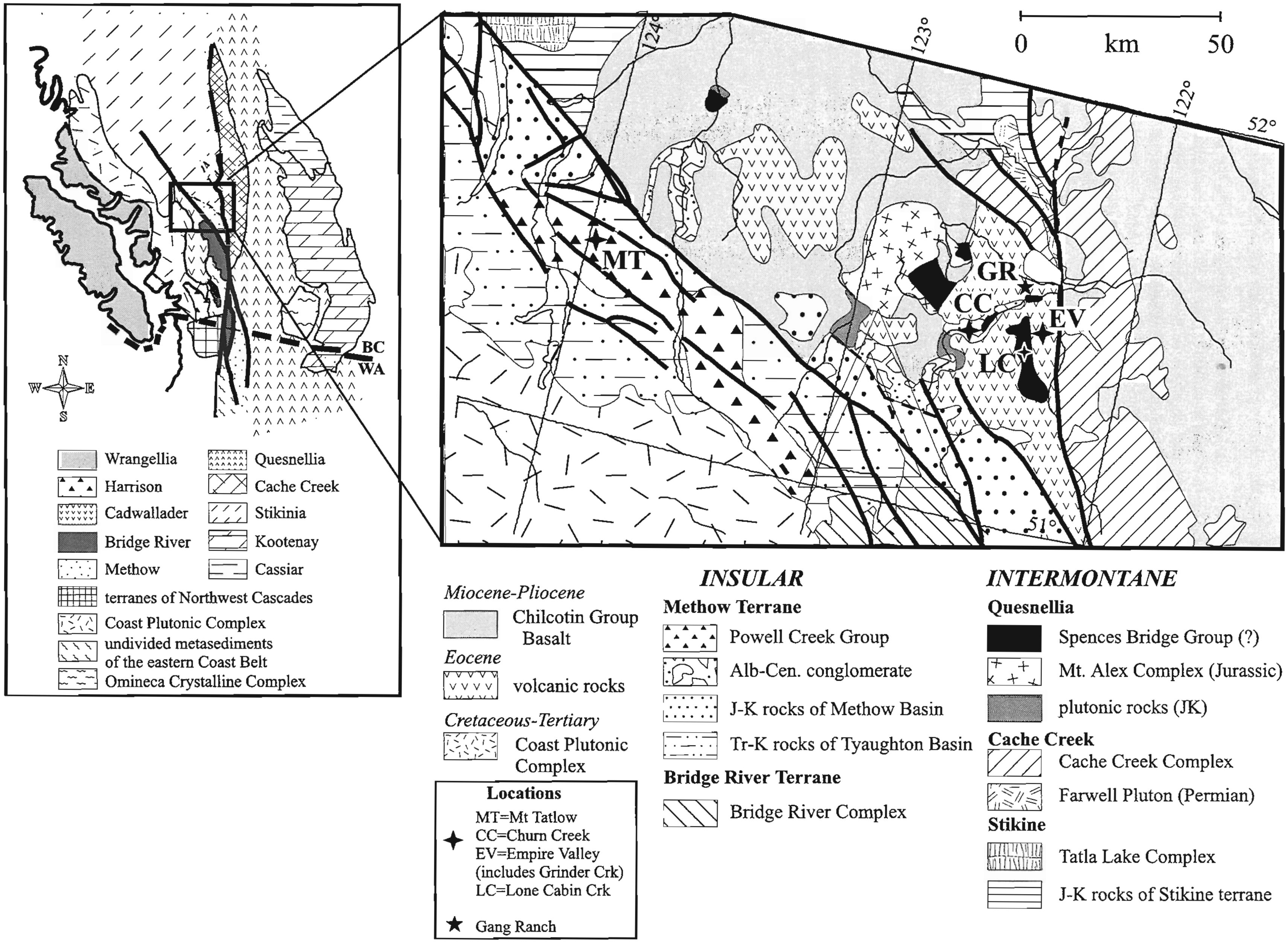

Figure 1. *Major tectonic elements of southwest British Columbia and northwest Washington State (at left) with southern Chilcotin Plateau area outlined and shown separately at right. Main locations discussed in text are shown with symbols. Detailed geology based on mapping of Tipper (1978), Hickson et al. (1991), Mahoney et al. (1992), Riesterer et al. (1998) and Schiarizza et al. (1997).*

sediments are widespread in the region, and constitute a thick (>100 m) succession of valley fill along Churn and Lone Cabin creeks, and the Fraser River (Fig. 2). Multiple felsic hornblende-phyric and pyroxene- and plagioclase-phyric mafic dykes and sills crosscut the study area and intrude the Albian volcanic rocks.

ALBIAN VOLCANIC ROCKS

Unit descriptions

Albian volcanic rocks in the Gang Ranch area can be split into two divisions. These are similar to the Pimainus and Spius formations of the Spences Bridge Group as defined by Thorkelson and Rouse (1989). The lowermost unit consists of more than 100 m of plagioclase-phyric flows, probably andesitic, and intercalated volcaniclastic sediments, plus tuffaceous and massive pyroclastic flows and breccias. This unit is exposed in the limbs of an anticline 5 km southwest of Gang Ranch and also near the intersection of Lone Cabin Creek and the Fraser River (Fig. 1). The upper unit consists more than 200 m of 1–3 m thick, vesicular, basaltic andesite flows, plus minor pyroclastic flows and volcanic breccia. Exposure of this unit is generally restricted to the Empire Valley area.

Individual volcanic flows in both the upper and lower units are commonly poorly formed, with extensive weathering and poorly developed flow-top breccias. Flow contacts consist of a 5–10 cm aphanitic white layer and have an undulose character, but where recognized, are traceable and laterally continuous. The flow interiors tend to be more coherent, and in places they are solid and massive, but are commonly host to a penetrative and prominent fracture cleavage which makes appropriate paleomagnetic site selection difficult.

The lower unit ranges in composition from flows and pyroclastic flows and breccias to interbedded volcaniclastic sandstone. Mafic flows are usually dark grey to black, aphyric to plagioclase-phyric with phenocrysts up to 0.5 mm. Light grey tuffs appear andesitic, and contain subangular to subrounded, lapilli-sized, green to black, plagioclase-phyric volcanic clasts. Reddish-brown, matrix-supported pyroclastic flows containing angular to subrounded, lapilli-sized, plagioclase-phyric clasts are common. Intercalated tuffaceous lithic arenite with medium-grained chert and volcanic

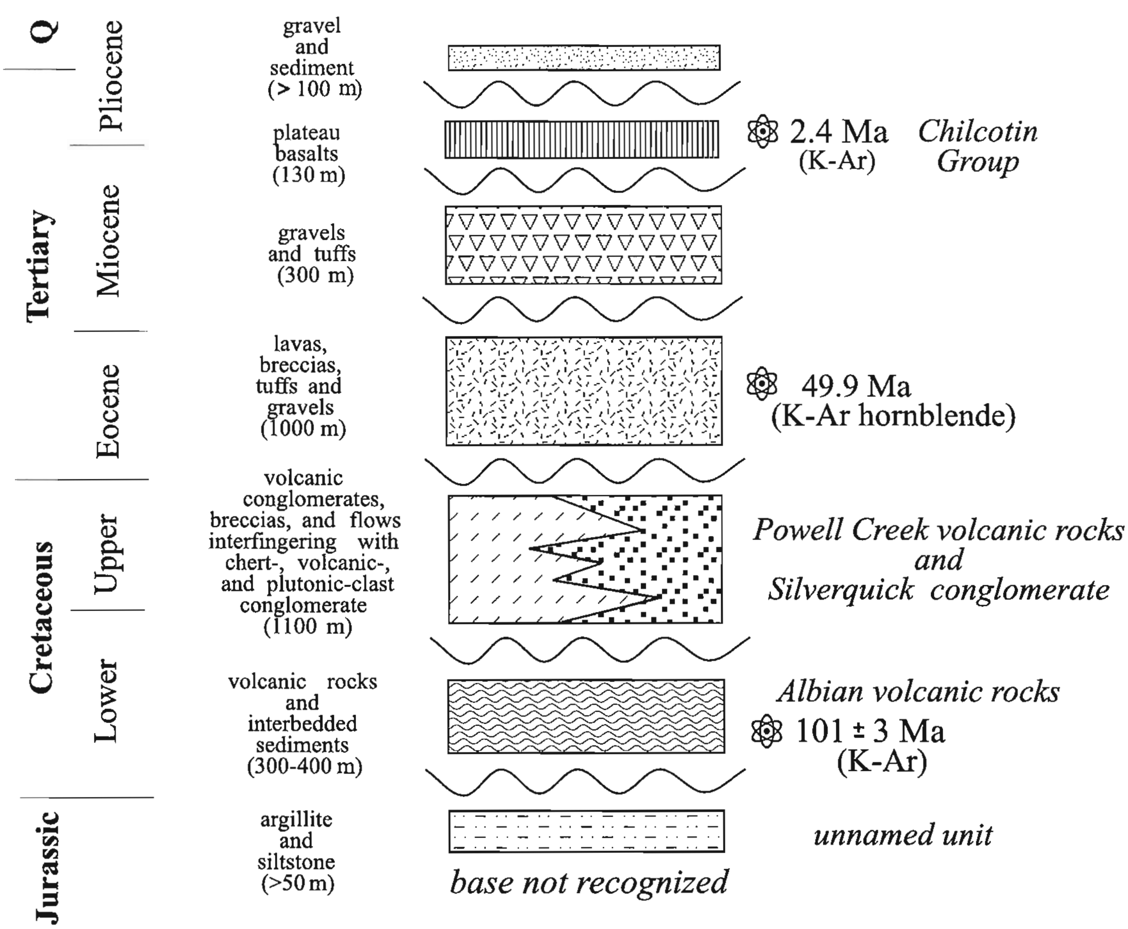

***Figure 2.** Schematic representation of the main stratigraphic units of the southern Chilcotin Plateau in the Churn Creek–Empire Valley areas. Geochronological ages are shown at right.*

fragments make up the final constituents of this package. In addition, a single occurrence of columnar jointed andesite and welded ignimbrite with fiamme up to 5 cm is present 5 km west of Gang Ranch.

Basaltic andesite flows of the upper unit are vesicular with 5% rounded millimetre-sized vesicles dispersed throughout the flow body. Vesicle flattening occurs proximal to basal contacts. These flows are purplish brown to dark brown and aphanitic. In hand sample, phenocrysts consist of 5–10% subhedral, 1 mm diameter, pyroxene crystals and finely interspersed plagioclase microphenocrysts up to 0.5 mm long, the latter resulting in a glittery sucrosic texture. The pyroclastic flows of this unit consist of brown-purplish matrix-supported flows containing 5–8 cm diameter, angular to subrounded, plagioclase-phyric mafic clasts.

Exposure

Exposure of Albian volcanic rocks ranges from isolated 5–10 m high outcrops to 100 m high cliffs of near-continuous exposure. Localities near the Empire Valley Ranch and south of Lone Cabin Creek provide moderate exposure, but are crosscut by multiple felsic hornblende-phyric (Eocene?) and pyroxene- and plagioclase-phyric mafic (Cretaceous?) dykes and sills. The banks of Churn Creek and the prominent northwest-trending knob north of the Fraser River–Lone Cabin Creek intersection in Empire Valley provide near-continuous exposure and contain substantially fewer intrusive bodies.

Alteration/weathering

The Albian volcanic rocks exhibit a dull brown weathering surface with numerous micropits due to the weathering of plagioclase crystals. Outcrops appear angular and rubbly and are frequently covered with orange and white lichen. Penetrative weathering and extensive hydrothermal alteration are characteristic, leaving iron-stained calcite and chalcedony amygdules and veins. Weathering products commonly include 1 mm blebs of chlorite, epidote, and various pink and white zeolites. Celadonite, and to a lesser extent limonite, coats interior weathering and fracture surfaces. The majority of the rock in the study area is unfit for paleomagnetic sampling. However, all efforts were made to sample massive flow interiors which provide the freshest and least altered specimens. Sites where samples were collected on the banks of Churn Creek were notably unaltered, with minimal weathering.

Age

Whole-rock K-Ar studies conducted in the Gang Ranch area yielded dates ranging from 101 ± 3 Ma on banded rhyodacite to 91 to 97 Ma on volcanic rocks (Mathews and Rouse, 1984). The overlying conglomerate of Churn Creek/Silverquick conglomerate is late Albian to Cenomanian age, and provides an uppermost age constraint for the Albian volcanic rocks (Hickson et al., 1991; Mahoney et al., 1992; Riesterer et al., 1998). Establishing further age constraints for this unit will be the focus of the 1999 field season.

Paleohorizontal estimates

Paleogeographic interpretation of paleomagnetic remanence depends critically on proper determination of the paleohorizontal at the time the sampled rocks were deposited. Paleoslope and bedding orientations were measured on flow contacts and sandstone beds. At one site in Churn Creek, paleohorizontal estimates were calculated from measurements taken on columnar jointed andesites. The orientations are regionally consistent, except for station 55 in Empire Valley, which was unfit for paleomagnetic sampling. It is important to note that measurements regarded as 'paleohorizontal' for this study are estimates. Factors such as lava viscosity, proximity to volcanic centres, and sediment deposition on slopes all affect accurate determinations of true paleohorizontal (Irving and Thorkelson, 1990; Irving et al., 1995). This is a potential source of error which, at best, may be a source of noise and, at worst, may produce a systematic error in the results. Fluid, low-viscosity flows, similar to flows in the upper unit of these Albian volcanic rocks, are believed to provide good estimates of paleohorizontal (Irving and Thorkelson, 1990; Irving et al., 1995). The surfaces on which paleohorizontal was measured were noted at each of the drill sites, as was the degree of confidence to which it reflects true paleohorizontal. These factors will be taken into account during analysis.

PROCEDURE, FURTHER INVESTIGATIONS

Paleomagnetic sample cores, each 2.5 cm in diameter, were collected from a total of 58 sites, using standard drilling procedures. An average of six cores was extracted from each site. Each core was magnetically oriented while 66% of the sites were also oriented in situ by solar or topo compass. Magnetic deflections of more than 10° were often noted, implying strongly magnetized rocks. Seven samples were taken from the contact zone of intrusive bodies for stability tests. Each site was a separate cooling unit or bed and stratigraphically independent of other sites. Preliminary magnetic susceptibility was measured using a Exploranium KT-9 Kappameter. Paleomagnetic analysis will be conducted at the Geological Survey of Canada, Pacific Division in the fall of 1998.

Eighteen samples were also collected for geochemical investigations, including one felsic and two mafic dyke samples. X-ray florescence spectrometry will be conducted at the University of Wisconsin – Eau Claire during the winter of 1998. These results will be compared to geochemical data from the type area of the Spences Bridge Group. Two geochronological samples were taken to attempt to determine the age relation of the mafic and felsic intrusive bodies to the Albian volcanic rocks. These samples will be analyzed at the University of British Columbia. Further fieldwork is scheduled for the summer of 1999.

CONCLUSIONS

Determining the paleomagnetic and geochemical signature, as well as defining lithological, stratigraphic, and geochronological constraints on Albian volcanic rocks in the Churn Creek–Gang Ranch is critical in evaluating the validity of the Baja–British Columbia translation hypothesis. This package consists of plagioclase-phyric andesite flows to vesicular andesite flows, intercalated volcaniclastic sediments, tuffaceous, pyroclastic flows, and volcanic breccia. All of these rocks stratigraphically underlie Albian–Cenomanian conglomerates. These conglomerates and associated volcaniclastic rocks have been correlated to the Silverquick conglomerate and Powell Creek Group of the Insular superterrane, from which paleomagnetic data indicates 3000–4000 km displacement. If the Albian volcanic rocks of this study area can be definitively correlated with the Spences Bridge Group of the Intermontane superterrane (of 1000–2000 km displacement), then a greater than 1900 km paleomagnetic displacement discrepancy exists between the two stratigraphic units. This would make post-Albian large-scale relative translation between the Insular and Intermontane superterrane unlikely.

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Multidisciplinary studies of the Upper Cretaceous Nanaimo Group, Hornby and Denman islands, British Columbia

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Abstract: Hornby and Denman islands provide a nearly undeformed, continuous, more than 2 km thick succession through the upper two-thirds of the upper Cretaceous Nanaimo Group. The succession comprises six formations with thick-bedded conglomerate- and sandstone-dominated formations separated by mudstone and thin-bedded sandstone formations. Formation contacts are in general gradational and intertongue laterally. Sedimentological studies demonstrate these rocks were derived from eastern sources and deposited in submarine fan complexes. Earlier mapping interpreted several high-angle faults. However, this more detailed work documents that there are no major faults on these islands. A paleomagnetic study of the formations on these islands will test paleogeographic models of the western Cordillera, following preliminary work supporting large-scale (>3000 km) northward displacement. Isotopic studies may also provide evidence for the basin latitude during deposition. Palynology from the upper formations should provide biostratigraphic evidence for these poorly age-constrained units.

Résumé : Les îles Hornby et Denman renferment une succession continue, à peine déformée, de plus de 2 km d'épaisseur, des deux-tiers supérieurs du Groupe de Nanaimo du Crétacé supérieur. Cette succession comprend six formations, les formations où dominent des lits épais de conglomérat et de grès étant séparées par des formations de mudstone et de minces lits de grès. Les contacts entre les formations sont généralement progressifs et imbriqués latéralement. Les études sédimentologiques ont montré que ces roches sont dérivées de sources à l'est et qu'elles ont été déposées dans des complexes de cônes sous-marins. Bien que des travaux de cartographie antérieurs aient conclu à la présence de plusieurs failles fortement inclinées, la présente étude, plus détaillée, confirme l'absence de failles majeures dans ces îles. L'étude paléomagnétique des formations observées dans ces îles permettra de vérifier les modèles paléogéographiques de la Cordillère de l'Ouest, à la suite de travaux préliminaires soutenant l'existence de déplacement à grande échelle (> 3 000 km) vers le nord. Des études isotopiques fourniront vraisemblablement des indications sur la latitude du bassin au cours de la sédimentation. L'étude palynologique des formations supérieures devrait apporter des informations biostratigraphiques sur ces unités dont l'âge est incertain.

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INTRODUCTION

The upper Cretaceous Nanaimo Group is preserved on eastern Vancouver Island, the islands of the Strait of Georgia, and on the western mainland of British Columbia (Fig. 1). Studies of the Nanaimo Group in the last ten years have generally concentrated on the southern, better exposed parts of the basin (e.g. England and Hiscott, 1992; Mustard, 1994; Mustard et al., 1995). A comprehensive review of Nanaimo Group research and detailed analysis of the stratigraphy, sedimentology, and basin evolution is contained within Mustard (1994).

A series of multidisciplinary projects were initiated in the summer of 1998 to study aspects of geology and evolution of the Nanaimo Group, and to provide data significant to the late Cretaceous evolution of the western Cordillera. These studies concentrate on Hornby and Denman islands, an area of the northern Nanaimo Group which has been relatively neglected, though it is both well exposed and preserves approximately the upper two-thirds of known Nanaimo Group stratigraphy. Detailed geological mapping (1:20 000 scale) plus stratigraphic and sedimentological studies of these rocks has been initiated by D. Katnick and P. Mustard (Simon Fraser University). This new information provides a base for new paleomagnetic studies of Nanaimo Group strata (J. Baker and R.J. Enkin, GSC Pacific), biostratigraphy (A. Sweet, GSC Calgary), and isotopic provenance studies (B. Mahoney, University of Wisconsin, Eau Claire).

GEOLOGICAL SETTING

The Nanaimo Group is exposed in four major and several minor separate areas (Fig. 1). Most early workers interpreted the larger geographic regions as separate sedimentary basins (e.g. Clapp and Cooke, 1917). Most recent regional studies suggest these slightly separate regions are erosional remnants of once continuous strata and consider the Nanaimo Group to have been deposited in a single basin (Muller and Jeletzky, 1970; Ward, 1978a; Mustard, 1994; *see* England, 1989 for an alternate view), and use a single formation nomenclature, as is done here (Fig. 2, based on Muller and Jeletzky, 1970 as modified by Ward, 1978a and Haggart, 1991). The basin in which Nanaimo Group sediments were deposited was termed part of the Georgia Basin by the senior author (Mustard, 1994), following the terminology suggested by Monger (1990) for the Cretaceous to recent sedimentary successions preserved in the Strait of Georgia region. However, it is now apparent that the term Georgia Basin had been previously applied and continues to be used for the modern biogeographic region of the Strait of Georgia and Puget Sound (e.g. McCloskey, 1987; British Columbia Round Table on the Environment and the Economy, unpub. report, 1993). Thus here we follow Muller and Jeletzky (1970) and Ward et al. (1997) in considering the term Nanaimo Basin to refer to the entire basin into which the Nanaimo Group was deposited. This differs from earlier workers who used 'Nanaimo Basin' to mean only the succession of the Nanaimo area and southern islands of the Strait of Georgia.

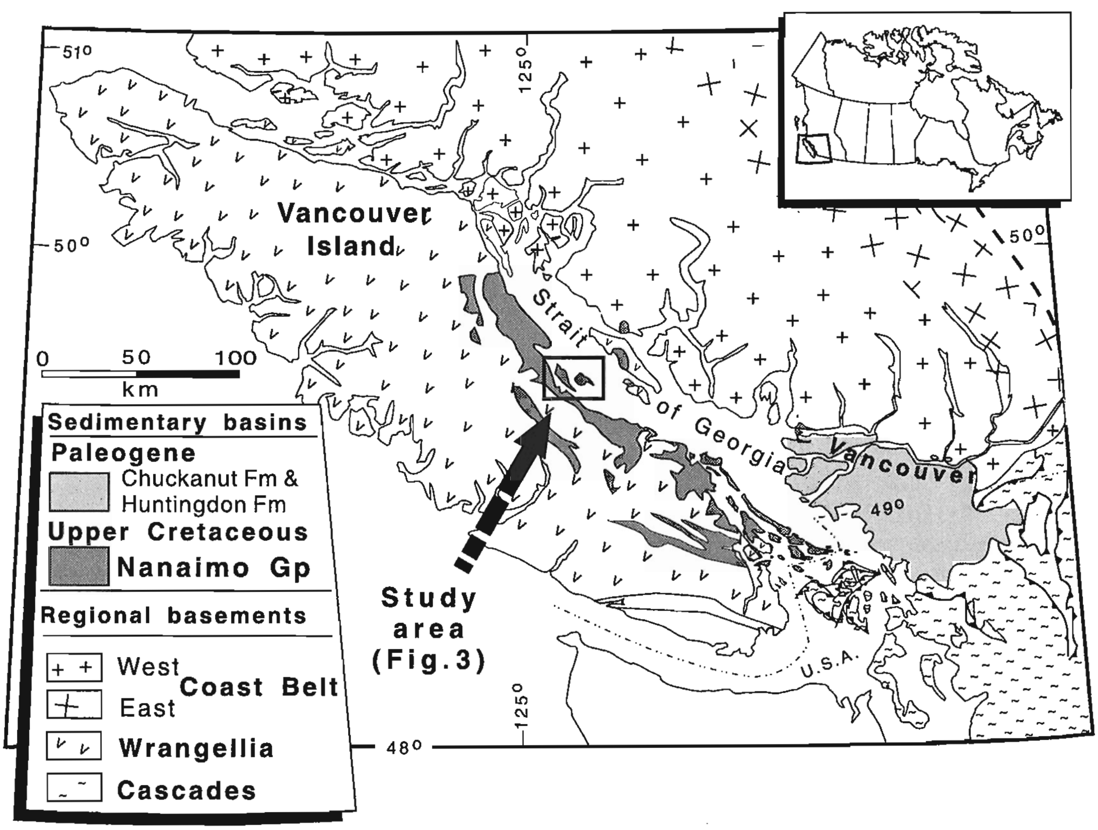

Figure 1. Regional geological setting with the upper Cretaceous Nanaimo Group shown in dark grey.

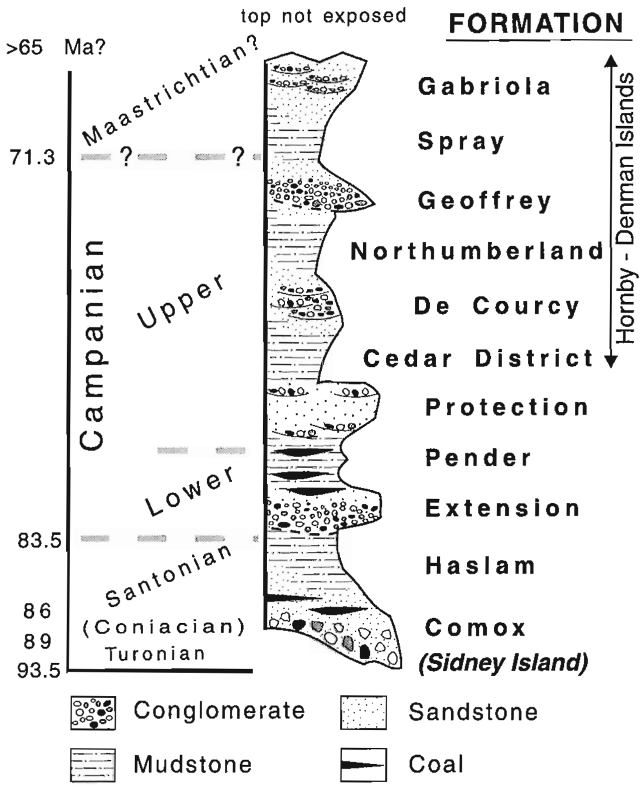

Figure 2. *Stratigraphy and formation nomenclature of the Nanaimo Group.*

The basin unconformably overlies Wrangellia terrane on its west side, the Coast Belt on its east side, and is in inferred fault contact with the San Juan thrust system (part of the northwest Cascade terranes) to the southeast (Fig. 1). The Nanaimo Basin was an elongate northwest-trending depocenter during Turonian to Maastrichtian time, although there is no constraint on its original extent to the west or north (Mustard, 1994). Deposition was probably continuous at least from about 86 million years ago to some time in the Maastrichtian. The basin accumulated a succession more than 4 km thick, consisting of subaerial and marine siliciclastics, with the upper two-thirds of the succession represented mostly by a stacked repetition of submarine fan complexes. Deposition occurred within a foreland basin, in front of, and mostly derived from, a west-directed thrust belt which formed in the west Coast Belt and San Juan terranes about 100–85 million years ago (Mustard, 1994; Mustard et al., 1995, and references therein).

NANAIMO GROUP OF HORNBY AND DENMAN ISLANDS

Hornby and Denman islands comprise the only preserved example of the upper two-thirds of the Nanaimo Group in the northern part of the Nanaimo Basin. Outcrop is abundant on the coasts of these islands, with nearly continuous exposure of the upper Cedar District to Gabriola formations, a stratigraphic thickness of greater than 2 km (Fig. 3). The only formally published geological maps of these islands are those of Muller and Jeletzky (1970) at 1:250 000 scale (inset map of Fig. 3), although preliminary geological maps which include Denman Island have recently been released (Cathyl-Bickford and Hoffman, 1998, *see also* Cathyl-Bickford, 1992). Unpublished geological studies were conducted on Hornby Island by Fiske (1977) and on Denman Island by Allmaras (1979). The type areas of both the Geoffrey and Spray formations occur on Hornby Island, yet no formal type sections or other detailed documentation of the stratigraphy of these formations on Hornby Island have been published. In addition, the age of the top three formations of the Nanaimo Group, the Geoffrey, Spray, and Gabriola formations is based on fossil evidence from more than 100 km to the southeast. There is no biostratigraphic or other age control on these formations within their northern occurrence (we present evidence here that foraminifera described by McGugan, 1982, from what he considered to be Spray Formation, actually occur in the stratigraphically lower Northumberland Formation).

Our new geological, stratigraphic, and sedimentological studies have several objectives. A detailed geological map will provide a modern base for these and future studies (simplified as Fig. 3). Detailed stratigraphic sections will provide a stratigraphic base not previously available and document the type sections for the Geoffrey and Spray formations for the first time. Sedimentological studies provide a modern analysis of the depositional environment, provenance, and evolution of the Nanaimo Basin in its northern facies. All of the above evidence will allow a comparison of the northern facies of the Nanaimo Group to the much more extensively studied Nanaimo Group to the south.

New geological mapping

A simplified and preliminary version of the new geological map for this area is shown in Figure 3. There are several changes from the published maps of Muller and Jeletzky (1970, included for comparison as an inset in Fig. 3). We can find no evidence for any major faults on these islands and believe the overall structure to consist of a homocline dipping gently (4–18°) to the northeast. The major northwest- and north-trending normal faults Muller and Jeletzky (1970) show on Hornby Island, downdropping their Spray Formation about 300 m on the west side, do not exist. The mudstone-rich formation on the western coast can be traced continuously around the coastline to the northeast and east in this area and shown to be below and in gradational contact with the overlying Geoffrey Formation. This mudstone unit is thus all part of the upper Northumberland Formation, and is in fact very similar to the Northumberland Formation exposed on the southeast side of Hornby Island. However, synsedimentary slump breccias and chaotic slump layers are common in some parts of the upper Northumberland and the basal Geoffrey formations, including spectacular blocks of sandstone several tens of metres in extent which display sharp lateral contacts with the Northumberland Formation mudstone into which they have slumped. We speculate that these sedimentary breccias were interpreted as fault breccias by Muller and Jeletzky (1970).

A regional fracture system and several minor faults are present on these islands. Subvertical fractures are common in these formations and a strong northeast trend and a slightly weaker northwest trend are apparent. Some fractures are extensional joints, displaying plumose structures, but most are probably shear fractures as there is a gradation from fractures which have no obvious offset to parallel shear fractures or minor faults with millimetres to a few centimetres offset, to rare faults with offsets of up to 3 m. Rare, well exposed minor fault planes which preserve striations, grooves, or crystal fibre growth consistently indicate dip-slip normal faulting.

Although all faults are minor on these islands, the strong fracture trends have been accentuated by glaciation and post-glacial erosion and on regional airphotos some are obvious linear features, several of which are shown as faults on the Muller and Jeletzky (1970) map. Detailed examination of these features where they cross continuously exposed outcrop demonstrate that they are not major structural breaks.

Stratigraphic and sedimentological studies

Detailed mapping shows that the contacts between formations are generally both conformable and gradational. In some places the conglomerate- or sandstone-dominant formations erode directly into the underlying mudstone-dominate formations, but in others the same contact is gradational over metres to tens of metres vertically. On the scale of the entire map area it is clear that these contacts laterally intertongue (Fig. 3), suggesting formation contacts are regionally conformable and represent lateral and vertical migration of depositional systems, not major unconformable boundaries. This relationship is identical to that extensively documented for the correlative formations in the southern Nanaimo Basin (England and Hiscott, 1992; Mustard, 1994).

The formations consist of alternating units of mudstone and thin-bedded sandstone (Cedar District, Northumberland, and Spray formations) and units of thick-bedded sandstone,

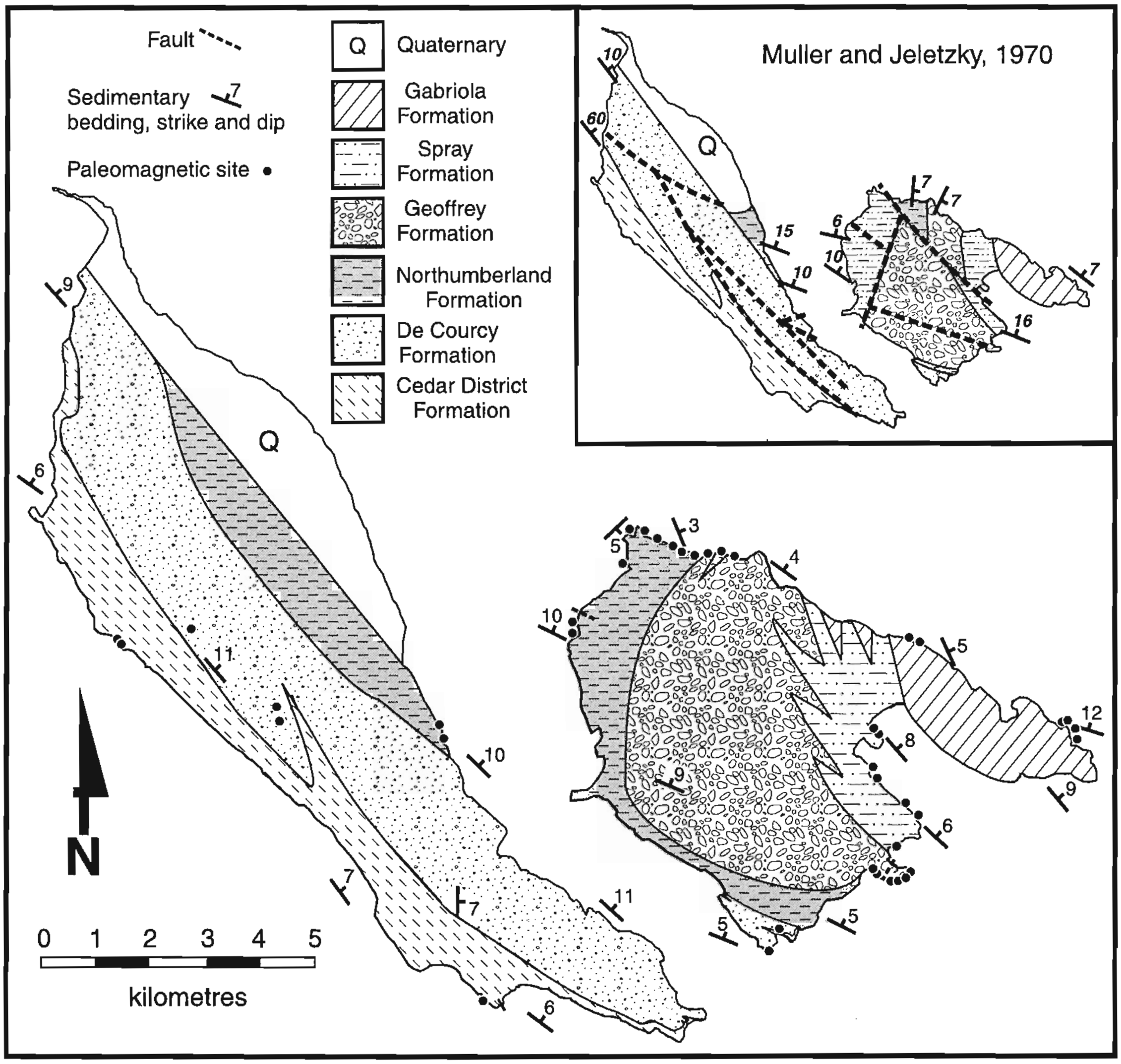

Figure 3. *Simplified geological map of the Nanaimo Group on Hornby and Denman islands. Inset map shows geology of these islands as interpreted by Muller and Jeletzky (1970).*

conglomerate, and very minor mudstone (De Courcy, Geoffrey, and Gabriola formations), as shown in Figure 4. Formation thicknesses vary from about 280–400 m with common lateral variation in all formations. Lateral thickness variation is most apparent for the Geoffrey Formation, which changes from a calculated thickness of 380 m in the central part of the island, to a measured thickness of 130 m on the southeast Hornby Island coast.

The finer grained formations are almost entirely composed of alternating mudstone and thin-bedded sandstone. The mudstone is silt-rich and generally massive to faintly laminated. The sandstone interbeds are generally very fine- to medium-grained, lithic arenite which occur as laterally persistent sheets commonly 1–5 cm thick, rarely thicker. The sandstone units have massive to normal graded bases which change upward to some combination of planar, rippled, or convolutely deformed lamina. These features are typical of the Bouma turbidite sequence and we interpret these finer grained formations as turbidite and intraturbidite deposits of an outer fan to rarely off-fan depositional environment (cf. Walker, 1992).

The coarser formations consist mostly of medium- to thick-bedded sandstone and cobble-pebble conglomerate. The sandstone is typically medium-grained lithic arenite ranging from 10–150 cm thick. Most sandstone beds are laterally persistent for hundreds of metres and display nonerosive to only slightly erosive bases, but commonly are loaded or have deformed underlying beds. The sandstone beds are generally massive to rarely normal graded and in some places the upper 10% of the bed is rippled or planar laminated and grade upwards to an overlying mudstone. These are interpreted to be thick turbidite deposits typical of mid- to upper fan regions of submarine fan complexes (Walker, 1992). Conglomerate lithofacies within these formations are typically 20–175 cm thick beds of clast-supported cobble and pebble conglomerates, rarely including boulder-sized clasts. The conglomerate are moderately to poorly sorted and generally nonstratified. They display a range of grading types including nongraded, normal-graded, reverse-graded, and reverse- to normal-graded. Imbrication of tabular clasts is relatively common in the lower part of some beds, especially where normal or reverse grading also occurs. The beds are laterally persistent in most places, but some occur as lenses that have eroded into underlying beds for tens to hundreds of centimetres and laterally pinch out over a few tens of metres. Where conglomerate beds directly overlie sandstone or mudstone, loading of the conglomerate into the underlying unit is common and the underlying unit is disrupted and incorporated into the conglomerate, either as large flames or as rip-ups up to several metres in diameter. The features of the conglomerates suggest deposition as sediment gravity flows, ranging from debris flows to gravel turbidity flows (cf. Nemec and Steel, 1984).

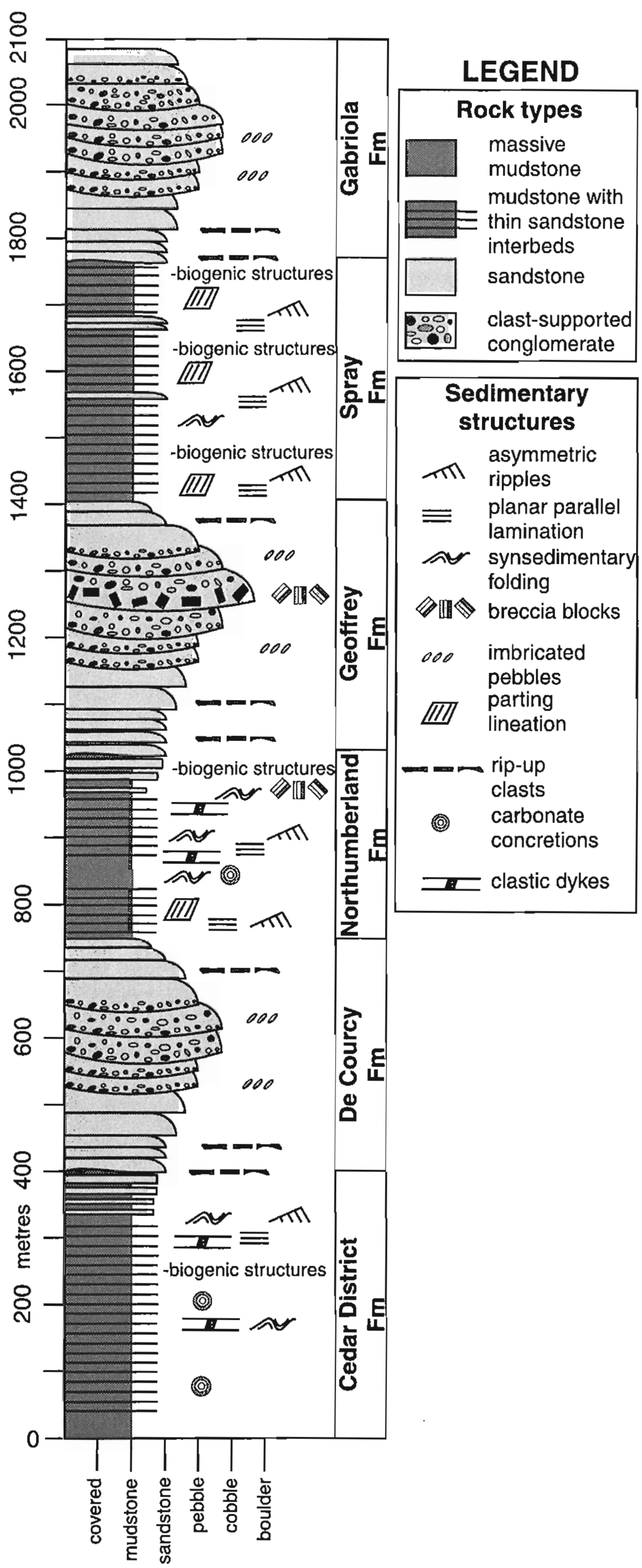

Figure 4. Generalized stratigraphy of Hornby and Denman islands.

Paleocurrents were measured from all formations, using clast imbrication, cross-lamination, and parting lineation. A total of 31 statistically significant paleocurrent trend sites were established, representing 1280 individual measurements. A radial trend of paleoflow varying from southwest to northwest is apparent, confirming that here as elsewhere in the Nanaimo Basin the source areas for all but the basal Nanaimo Group is to the east of the basin (Mustard, 1994).

At 20 sites within the study area, identifications of 100 clasts/site were conducted. Clast types in the conglomerates include common mafic volcanic, felsic volcanic, and plutonic compositions, with lesser chert, vein quartz, and sedimentary clasts. These clast types are consistent with the paleocurrent trends; all are of rock types typical of the Coast Belt to the east and/or the Cascades to the southeast. The only clast type which does not have a known local source is a white, very fine-grained quartzite-quartz arenite which occurs as well rounded and highly spherical pebbles to rarely small cobbles and comprises less than 3% of the total clast compositions. The source for these clasts is unknown, although detrital zircon analyses from the southern Nanaimo Basin suggest a possible contribution of detritus from the Proterozoic Belt Supergroup in eastern Washington State (Mahoney et al., in press), a unit which contains abundant white quartzite-quartz arenite.

A somewhat unusual feature is the abundance and extent of clastic dykes and chaotic facies within the formations. The mudstone-dominant units include common sandstone dykes. Most seem to be randomly oriented with respect to nearby dykes, but in some places several tens of dykes occur with similar trends and somewhat regular spacing over several hundred metres laterally, suggesting a common control on their origin and mode of injection. Synsedimentary slump folds, some several tens of metres in amplitude, are also common in the mudstone-rich units. Some slump-folded layers preserve a common trend of fold vergence and fold axial planes, and in these places the slumping can be shown to be in a generally westerly direction, supporting the westerly dipping paleoslope suggested by paleocurrent trends. In addition to synsedimentary folds, chaotic facies includes randomly rotated blocks of sandstone within a disrupted mudstone matrix which occur in layers up to several metres thick. The sandstone blocks within these layers commonly display irregular 'feathered' edges and injections of the mudstone matrix within the sandstone margins, demonstrating their synsedimentary origin. Chaotic facies also occur within the sandstone- and conglomerate-dominate units. The best example occurs in the lower Geoffrey Formation both on the northwest and southeast sides of Hornby Island. On the southeast side of the island, a layer about 35 m thick consists of interbedded sandstone-mudstone blocks randomly distributed within a sandstone-mudstone matrix. Blocks up to 20 m preserve the internal bedding of the original deposit, but at the margins intense folding and irregular boundaries with the matrix demonstrate that these blocks were only partially lithified. The blocks probably moved as part of a large debris flow, perhaps representing a collapse of material on a slope.

Paleomagnetic studies

The paleomagnetic record of Cretaceous formations across the Canadian Cordillera suggests that the Insular and Coast belts have displaced from the south by about 3000 km (Irving et al., 1996). By Eocene time, the entire Cordilleran belt was welded together in close to its present configuration (Irving and Brandon, 1990). The data are considered controversial, however, as faults and other structures have not been found that could accommodate such movement (Cowan et al., 1997). The Nanaimo Group is a clear target for paleomagnetic study as it was a relatively stable depocentre during the period of presumed motion, and it sits far from the presumed locus of motion between the Coast and Intermontane belts. If the so-called 'Baja-BC' hypothesis is correct, one would expect to see relatively steeper inclinations in younger rocks of the Nanaimo Group, reflecting northward displacement during deposition.

Ward et al. (1997) presented results from Nanaimo Group rocks collected on Texada and Hornby islands. They argue that the presence of unaltered aragonitic fossil shells indicates that thermal and chemical remagnetization is minimal as aragonite is unstable above 100°C. The paleomagnetic poles they report are significantly far-sided with respect to North American cratonic poles, supporting large displacements from the south. Their study however, must be considered preliminary because it was small (only 131 samples studied), incomplete (only two formations studied), and measurements revealed less than ideal behaviour (weak and soft magnetizations). On Hornby Island, they sampled the Nanaimo Group at the northwest end of the island, within the succession that Muller and Jeletzky (1970) considered Spray Formation, but that our new data suggests is Northumberland Formation.

During 1998 we collected paleomagnetic samples from all formations of Hornby and Denman islands (Fig. 2). A total of 218 oriented cores from 37 sites were collected. Competent fine-grained sandstone and concretions were prime targets, but we also collected sand dykes and mudstone. The large sedimentary breccia clasts in the Geoffrey Formation were also sampled to attempt a modified fold test. Peter Ward (University of Washington) and colleagues also collected sites, targeting the finest grained lithologies.

At writing, 75% of our collection have been processed. The specimens have a soft remanence requiring detailed thermal demagnetization up to 400°C at 25°C steps. About 10% of the collection have been processed with alternating field demagnetization, also revealing soft remanence. Koenigsberger ratios are often below 0.1, indicating that the dominant magnetic carriers are multidomain magnetites. This supports the observation that the clastic source was the Coast plutonic complex, which has similar magnetic carriers. Despite the difficult nature of the remanence, we have sites which are coherent, show both magnetic polarities, and have inclinations that are shallower than expected for cratonic North America.

Isotopic studies

One method of establishing the paleolatitude position of the Nanaimo Basin is to study the provenance of the sediments and especially to look for evidence of derivation from the Precambrian crust of North America east of this basin. Cowan et al. (1997) point out a striking contrast in the ages of Precambrian crust of the north and south regions of western North America. South of about 40° latitude the crust is dominated by 1.8–1.6 and 1.3–1.0 Ga material. Regions north of 40° are dominated by crust more than 2.05 Ga with large areas of Archean crust, although crustal regions of 1.8–1.6 Ga are also present in northern latitudes. Thus a clear test of the 'Baja B.C.' hypothesis is to examine late Cretaceous sedimentary basins of the 'Baja B.C.' entity for any indication that Archean or early Proterozoic crust was in part a source area. This has been done for the southern Nanaimo Basin using detrital zircons as a provenance indicator and both Archean and early Proterozoic provenance has been established (Mustard et al., 1995; Mahoney et al., in press).

The provenance of the Nanaimo Basin is also being examined utilizing the isotopic signature of fine-grained sediments. Recent studies show that variations in the isotopic signature of fine-grained clastic rocks are sensitive indicators of basin evolution and provenance shifts (McLennan and Hemming, 1992; Mahoney, 1994; Gleason et al., 1995; Mahoney et al., 1998), and that Nd-Sr isotopic analysis can detect sediment influx from source areas overlooked by conventional stratigraphic techniques (Mahoney, 1994). Fine-grained clastic rocks generally represent sediment with longer transport histories and more accurately represent the average crustal composition of the entire source region. Isotopic analyses of these rocks provide a weighted average of sediment derived from different source rocks throughout the entire drainage basin. The major differences between the average crustal composition of source rocks along the continental margin should result in a distinct latitudinal control on the isotopic signature of the fine-grained clastic rocks of the Nanaimo Basin. Thus, variation of ε_{Nd} values in Nanaimo Basin strata should both provide constraints on the nature of the sediment supply to the basin through time and a clear paleolatitudinal provenance signature.

Preliminary sampling was conducted in 1998, with samples collected from mudstone intervals on Hornby and Denman islands. Results will be used to guide a more detailed sampling program in 1999.

Paleontological studies

In general the biostratigraphy of the Nanaimo Group has been extensively studied using macrofossils (e.g. Ward, 1978a, b; Haggart, 1989, 1991, 1994; Haggart and Ward, 1989) and microfossils (e.g. Rouse et al., 1975; McGugan, 1982). Several problems remain, especially concerning the ages of the youngest formations of the Nanaimo Group. In the southern Nanaimo Basin, a few macrofossils have been recovered from the Spray Formation, indicating a Maastrichtian age for this unit (Haggart, 1989). However, the age of the overlying Gabriola Formation is not well constrained and there has suggestion that, at least in some areas and including Hornby Island, the Gabriola Formation may be Paleocene (G. Rouse, unpub. data and pers. comm., 1998).

In the northern Nanaimo Basin, no age diagnostic macrofossils or microfossils have been formally described from the Geoffrey, Spray, or Gabriola formations of Hornby Island as these formations are defined by our new mapping. McGugan (1982) describes foraminifera from the northwest part of Hornby Island in mudstone he considered Spray Formation. However, our mapping suggests this unit is actually the upper part of the Northumberland Formation. The foraminifera McGugan (1982) identified from his "Spray Formation" on Hornby Island are also present in undisputed upper Northumberland Formation of the southern Nanaimo Basin (McGugan, 1982). He suggested the presence of these foraminifera in the Spray Formation on Hornby Island and from Northumberland Formation in the southern part of the basin indicated a diachronous depositional history for the upper units of the Nanaimo Group. Our new evidence that both areas are actually Northumberland Formation calls into question this conclusion.

The Northumberland Formation on Hornby Island also contains abundant macrofossils, including ammonites and baculitids, which indicate a late Campanian age for this unit (Ward, 1978a, b; P.D. Ward, pers. comm., 1998). The present lack of age-diagnostic macrofossils from formations above the Northumberland Formation has prompted renewed sampling of these units for microfossil analysis. Fifteen samples were collected on Hornby Island, mostly from the Spray and Gabriola formations, but also from the Geoffrey and upper Northumberland formations. Initial processing and examination indicates that fair to good recovery of palynomorphs has occurred from most samples; that distinctively different assemblages of palynomorphs exist in the Northumberland, Spray, and Gabriola formations; and that the assemblages should provide the probable age of these upper formations (A. Sweet, GSC Calgary, pers. comm., 1998).

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Field investigation of Cenozoic structures in the northern Cascadia forearc, southwestern British Columbia

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Abstract: Structural studies of fault systems in the northern Cascadia forearc document a transition from margin-normal shortening to dextral strike-slip faulting and associated margin-parallel extension some time in the Late Oligocene–Early Miocene. The transition from compression to extension in the northern forearc region is coeval with subduction and northeastward underplating along the Cascadia subduction zone, and with northward migration of forearc slivers and associated margin-parallel shortening in the southern Cascadia forearc of Washington State and Oregon. We present a working hypothesis for strain partitioning along the plate margin that involves both decoupling of the northern Cascadia forearc from the subduction-accretion complex to the west and the corresponding arc to the east, and internal deformation along linked systems of dextral strike-slip and normal dip-slip faults. The transition from compression to dextral transtension along the northern Cascadia forearc likely reflects changing boundary conditions associated with oblique subduction beneath an arcuate bend in the plate margin.

Résumé : Les études structurales effectuées sur les systèmes de failles dans la partie septentrionale de l'avant-arc de Cascadia confirment l'existence d'une transition allant du raccourcissement perpendiculaire à la marge au décrochement dextre et à la distension associée parallèle à la marge, au cours de l'Oligocène tardif–Miocène précoce. Dans la région septentrionale de l'avant-arc, la transition allant de la compression à la distension est contemporaine de la subduction et de la remontée du magma vers le nord-est le long de la zone de subduction de Cascadia, et de la migration vers le nord de fragments de l'avant-arc et du raccourcissement associé, parallèle à la marge, dans la partie méridionale de l'avant-arc de Cascadia de Washington et de l'Oregon. Pour expliquer la répartition des contraintes le long de la marge de plaque, nous présentons une hypothèse de travail faisant intervenir un découplage entre la partie septentrionale de l'avant-arc de Cascadia et le complexe de subduction et d'accrétion à l'ouest et l'arc correspondant à l'est, ainsi qu'une déformation interne le long de systèmes reliés de failles de décrochement dextre et de failles d'effondrement normal. La transition allant de la compression à la transtension dextre le long de la partie septentrionale de l'avant-arc de Cascadia traduit vraisemblablement de nouvelles conditions de frontières de plaque associées à une subduction oblique sous une courbure arquée sur la marge de plaque.

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INTRODUCTION

This study is part of a multiyear GSC bedrock mapping initiative to explore the Cenozoic crustal response to oblique underthrusting and dextral transcurrent faulting in northern Cascadia. Overall objectives are to document the history and mechanisms of crustal deformation in the upper plate of the Cascadia subduction-accretion complex and, more specifically, to address the question of whether strain within this zone of oblique convergence is homogeneously distributed across broad networks of linked fault systems, or partitioned along discrete zones of margin normal-and margin-parallel slip. The study supports ongoing crustal dynamic and seismic hazard research of Neogene and active tectonic processes along the northern Cascadia subduction zone boundary (Wang et al., 1995) and provides a regional framework for more detailed studies of site-specific seismic hazards associated with shallow crustal deformation in the forearc and backarc regions of the plate margin, parts of which are densely populated.

In this paper we summarize the results of reconnaissance geological mapping and structural studies in the frontal arc and forearc regions of southwestern British Columbia, and advance the development of a working hypothesis for strain partitioning in the upper plate of the northern Cascadia subduction-accretion complex throughout the Cenozoic.

REGIONAL SETTING

Northern Cascadia is constructed on the remnants of an older Mesozoic accretionary complex that includes both exotic fragments of island arc and oceanic terranes, and disrupted belts of Jura-Cretaceous plutons that represent part of a once continuous continental margin magmatic arc. Assemblages of the southwestern Coast Mountains and Vancouver Island predating the Middle Jurassic are part of an amalgamated crustal block of Devonian–Jurassic arc volcanic rocks and associated plutonic rocks (Wrangellia) that is believed to have been displaced southward along the ancient continental margin in the Early Cretaceous (120–100 Ma), thereby trapping a fragment of the Pacific Plate along its inboard margin (Monger et al., 1994). Fault-bounded slivers of oceanic crust and subduction-accretion complexes, well exposed in the southeastern Coast Belt (Bridge River complex), represent slivers of the Pacific–North American plate margin that were trapped behind this composite arc terrane. Since the Early Cretaceous, these crustal fragments and associated plutonic suites have been structurally imbricated and shuffled along the continental margin in response to subduction-accretion processes and large-scale transcurrent displacements between North America and oceanic crust of the Pacific, Kula, and Juan de Fuca plates.

Paleogene structures in the forearc of this subduction-accretion complex record a history of margin-normal shortening that appears to be linked, in part, to the accretion and northeastward underplating of Pacific Rim and Crescent terranes along the outboard margin of Wrangellia. Coeval structures formed along the axis of the early Cenozoic arc, in the southeastern Coast Mountain and northern Cascade regions, record both margin-parallel extension and decoupling along systems of northwest- and north-trending dextral transcurrent faults. In the early Oligocene, the axis of arc magmatism shifted 60–70 km southwestward toward the plate margin to a position along the boundary between southwestern and southeastern Coast belts, where brittle fault structures record an abrupt transition from margin-normal to margin-parallel shortening (Journeay and van Ulden, 1998).

NORTHERN CASCADIA FOREARC

The Cascadia forearc of southwestern British Columbia extends northeastward from the Juan de Fuca trench to the Neogene volcanic front (Fig. 1). It includes imbricated Cenozoic slope, rise, and underplated continental margin assemblages of the forearc accretionary complex, and exhumed pre-Tertiary crystalline rocks of Vancouver Island and the southwestern Coast Mountains, the latter of which record a complex history of early Cenozoic thrust imbrication and high-angle brittle faulting (Muller, 1977; England and Calon, 1991). The record of Neogene deformation is best preserved in the continental margin forearc succession, where seismic reflection profiles document thin-skinned imbrication and northeastward underplating of upper Tertiary sedimentary rocks along a system of shallow, northeast-dipping thrust faults. Detailed shallow marine seismic studies inboard of the accretionary complex, in the Juan de Fuca Strait and Puget lowland, have recently documented evidence for brittle faulting, that locally involves Pleistocene glacial deposits, and overlying sedimentary successions of presumed Holocene age (Mosher et al., 1997).

In an effort to constrain the geometry and kinematics of regional Cenozoic fault systems in this part of the Cascadia margin, we have carried out both an assessment of previously mapped faults, and 1:50 000 scale bedrock geological mapping and associated structural analyses of outcrop-scale faults along a transect that encompasses more than 1000 km of shoreline in the Howe Sound–eastern Georgia Strait (frontal arc) and southern Gulf Island–San Juan Island (eastern forearc) regions of southwestern British Columbia and adjacent Washington State (Fig. 1). The studies have identified several hundred new zones of brittle and brittle-ductile faulting, nearly a third of which have yielded useful information on timing and/or kinematics of shallow crustal deformation in the northern Cascadia forearc.

FRONTAL ARC

The frontal arc region of the 1998 study area straddles the boundary with Plio-Pleistocene eruptive centres of the Garibaldi volcanic belt at the north end of Howe Sound, and encompasses both rugged terrain of the southwest Coast Mountains, parts of which record uplift of 1–2 km in the last 10 Ma, and relatively stable low-lying coastal regions of the Fraser Valley.

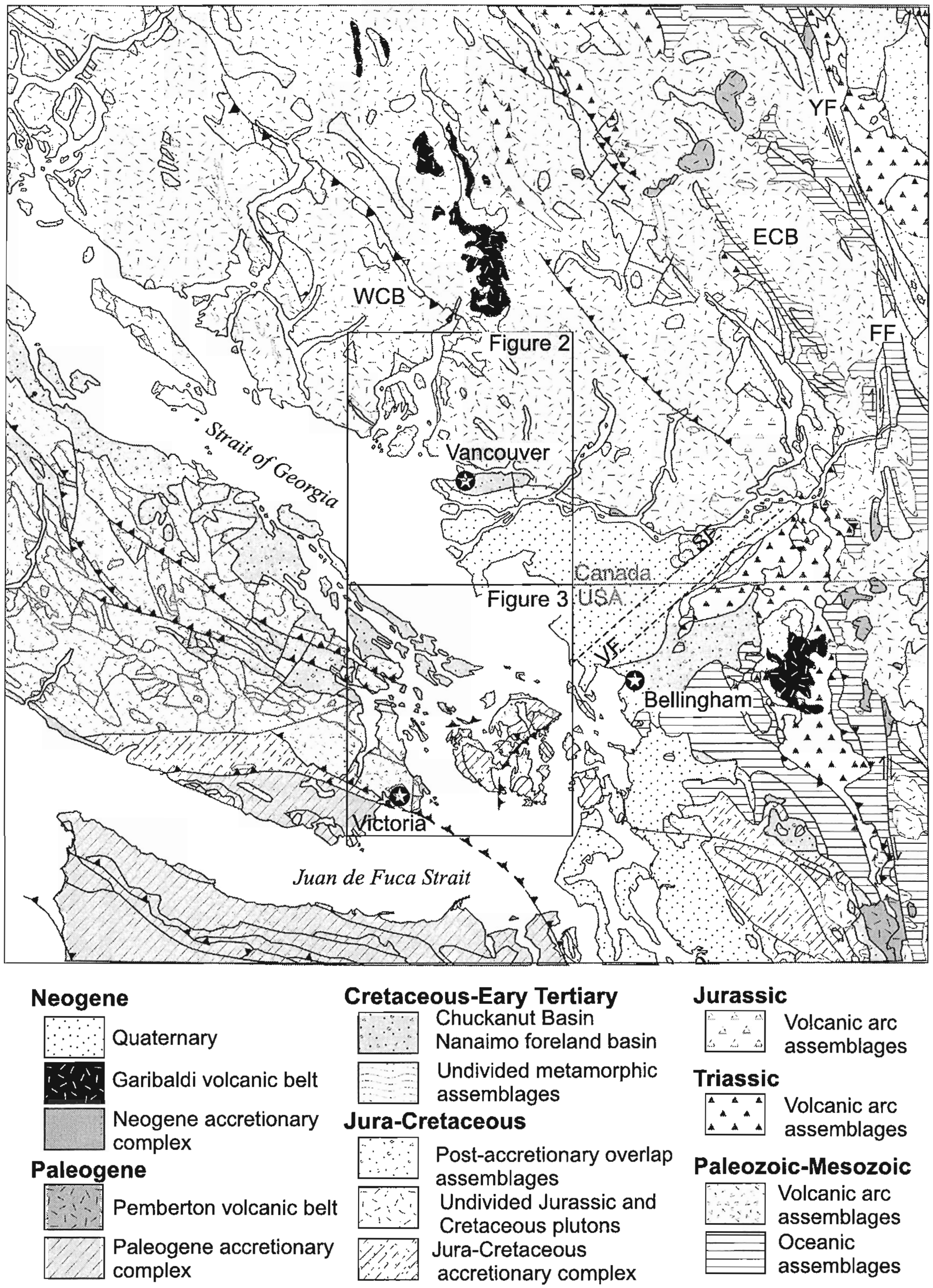


Figure 1. Regional bedrock geology of northern Cascadia. Shaded regions highlight Cascadia frontal arc and forearc regions examined in this study. Abbreviations: WCB=western Coast Belt, ECB=eastern Coast Belt, YF=Yalakom Fault, FF=Fraser Fault, SF=Sumas Fault, VF= Vedder Fault.

Britannia-Ashlu Creek fault system

The Britannia and Ashlu Creek fault zones (Fig. 2) form the boundary between late Middle Jurassic plutons to the northeast and a belt of early to middle Cretaceous plutons and overlying volcanic arc assemblages of the Gambier Group to the southwest (Monger and Journeay, 1994). Both structures dip steeply to the southwest, and are marked by networks (about 500 m wide) of interlocking ductile shear zones (locally mylonitic) and superposed brittle fault splays that record episodic top-to-the-northeast, high-angle reverse displacement. Early-stage thrust imbrication occurred under greenschist grade conditions of regional metamorphism, and postdates the emplacement of mid-Cretaceous (94 Ma) plutons in the upper plate of the Britannia fault zone. Late-stage thrust imbrication is undated, but presumed to be coeval, in part, with Paleogene margin-normal shortening documented in adjacent parts of the Coast Mountains (Journeay and van Ulden, 1998).

Both Ashlu Creek and Britannia zones are reactivated along coincident northwest-trending brittle faults with subhorizontal slickenside striae and inclined shear fabrics that record a superposed history of dextral strike-slip displacement. These structures, marked by 2–5 m zones of fracturing and brecciation, are well documented both along strike of the Ashlu Creek Fault in the Stuwamus and Indian river valleys (Monger and Journeay, 1994; Journeay and van Ulden, 1998), and along the Britannia Fault in the Britannia mining district, where offset ductile shear zones and associated mineralized horizons record oblique dextral-slip displacement of up to 75 m (Payne et al., 1980). Comparable northwest-trending dextral strike-slip faults occur in the Garibaldi volcanic complex 20 km to the northeast, where offset dykes of presumed Plio-Pleistocene age record incremental Neogene displacements of 1–5 m (Journeay and van Ulden, 1998).

Several new occurrences of margin-parallel strike-slip faults were documented this summer in the central Howe Sound region, along a structural corridor that extends northwest from Horseshoe Bay, across Gambier Island, to the Sunshine Coast (Fig. 2; this study). The most prominent of these structures dip steeply both to the northeast and southwest, and are marked by 2–5 m zones of brecciation and associated clay gouge, along which gentle northwest-plunging slickenside striae (10° pitch) and asymmetric shear record oblique dextral-slip displacement.

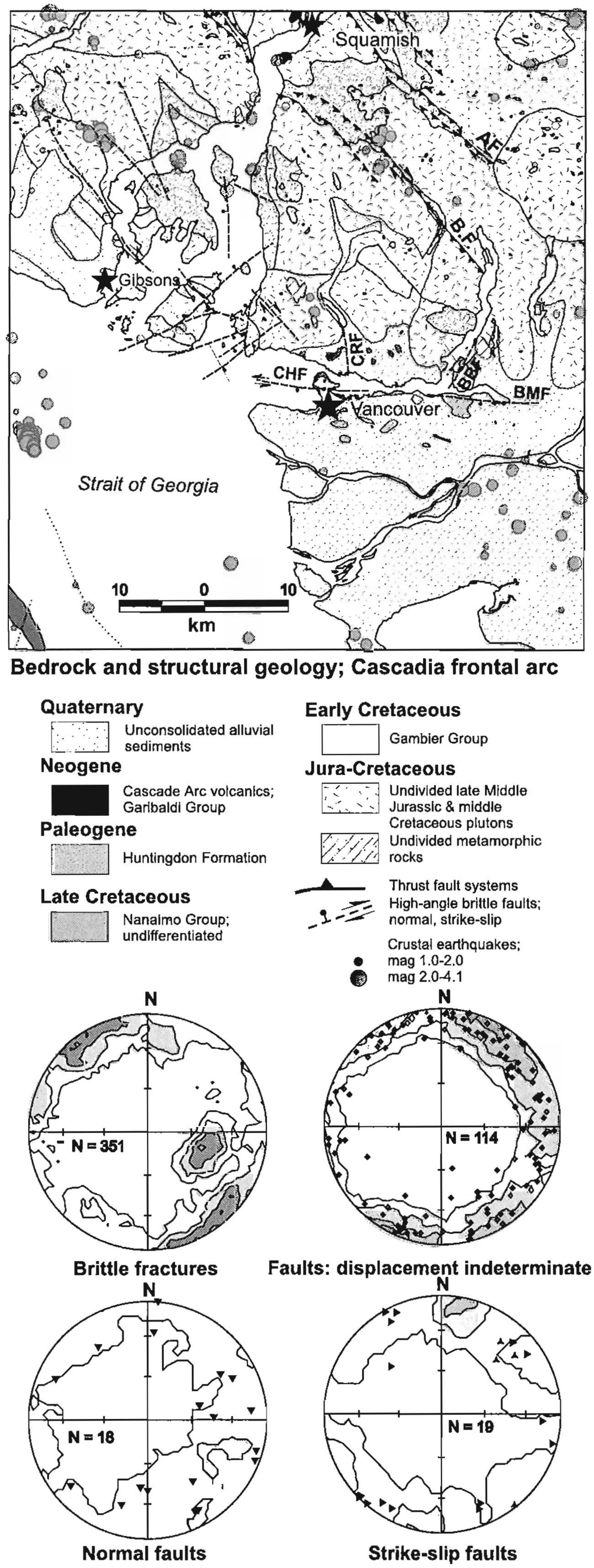


Figure 2.

Bedrock geology and synoptic lower hemisphere stereonet analysis of Cenozoic frontal arc structures in the southwestern Coast Mountain region of northern Cascadia. Abbreviations: AF=Ashlu Creek Fault, BF=Britannia fault zone, BMF=Burnaby Mountain Fault, CHF=Coal Harbour fault zone, BBF=Bedwell Bay Fault, CRF=Capilano River Fault.

Northeast-trending faults

Northeast-trending, high-angle brittle faults are well developed in the southern Coast Mountains and adjacent Fraser lowland. The most prominent of these structures include the Vedder and Sumas faults of the eastern Fraser Valley (Fig. 1; Armstrong, 1981), the Blanshard Peak Fault, and the Bedwell Bay Fault (Roddick, 1965) along the southeastern shore of Indian Arm. The Vedder and Sumas faults cut crystalline basement and overlying Paleogene sedimentary successions of the Chuckanut Formation, and record normal dip-slip offsets in excess of several kilometres. They are interpreted to be coeval, in part, with the emplacement of Neogene (25–14 Ma) plutons and associated volcanic assemblages that occur within and along the flanks of the Fraser Valley (Monger and Journeay, 1994; Journeay and van Ulden, 1998).

Smaller magnitude faults of similar orientation were identified this season along the southeastern entrance of Howe Sound, where they cut homogeneous, late Middle Jurassic quartz diorite of the Horseshoe Bay pluton and lower Cretaceous volcaniclastic rocks of the overlying Gambier Group (Fig. 2). The faults dip steeply to the northwest and southeast, and are well defined by 1–2 m zones of brecciation, hydrothermal alteration, and associated clay gouge, in which inclined extension veins and shear fractures record normal dip-slip displacement. They are coincident with prominent topographic lineaments in the region, and appear to be concentrated along a broad 10–12 km wide zone of brittle deformation that extends northeast-southwest across Queen Charlotte Channel into the adjacent North Shore Mountains.

West-northwest-trending faults

The Burnaby Mountain Fault, initially described by Johnston (1923) in his memoir on the geology of the Fraser River Delta, is a west-northwest-trending, high-angle fault that cuts Paleocene and younger sedimentary rocks of the Huntington Formation. The fault extends nearly 4 km along the steep, north-facing flank of Burnaby Mountain, and is interpreted to have accommodated several hundred metres of normal dip-slip displacement some time prior to the onset of Quaternary sedimentation (Armstrong, 1981).

Along strike to the west is the Coal Harbor fault zone (Blunden, 1971), a network of four discrete west-northwest-trending, high-angle faults that extend along the waterfront and Coal Harbor regions of downtown Vancouver and adjacent Stanley Park. Three of these structures cut well dated Paleocene and younger sediments of the Huntington Formation (Mustard and Rouse, 1994), and are inferred to involve submarine postglacial (10 000–13 000 a) sediments along the south shore of Burrard Inlet. Cross-sectional profiles constructed from engineering boreholes, drilled as part of the proposed Burrard Inlet crossing, suggest normal dip-slip displacements of 10–150 m. High-resolution marine seismic surveys of Burrard Inlet, carried out in support of a regional earthquake hazard study by the Greater Vancouver Regional District, are consistent with this interpretation, and suggest that faulting likely predates deposition of Holocene marine sediments in this part of the basin. Comparable west-northwest-trending faults in the Howe Sound–Squamish regions record both normal dip-slip and sinistral strike-slip displacement.

North-trending faults

The Capilano River Fault (Roddick, 1965) is one of only a few well documented, north-trending faults in the frontal arc region of the southwest Coast Mountains. It underlies the west abutment of the Capilano River concrete dam, and has been intersected both in trenches and in drill holes along the upper Capilano River valley. The kinematics and regional extent of the fault are uncertain. However, similar structures documented along the Howe Sound–Garibaldi corridor, in the vicinity of Horseshoe Bay and Anvil Island (this study; Fig. 2), record evidence of both normal and strike-slip displacement. North-trending brittle faults are well developed in proximity to the Garibaldi volcanic arc, where they localize both the emplacement of hypabyssal dykes, and the effusion of overlying Pliocene–Pleistocene volcanic rocks, the youngest of which are dated at ca. 220 000 a.

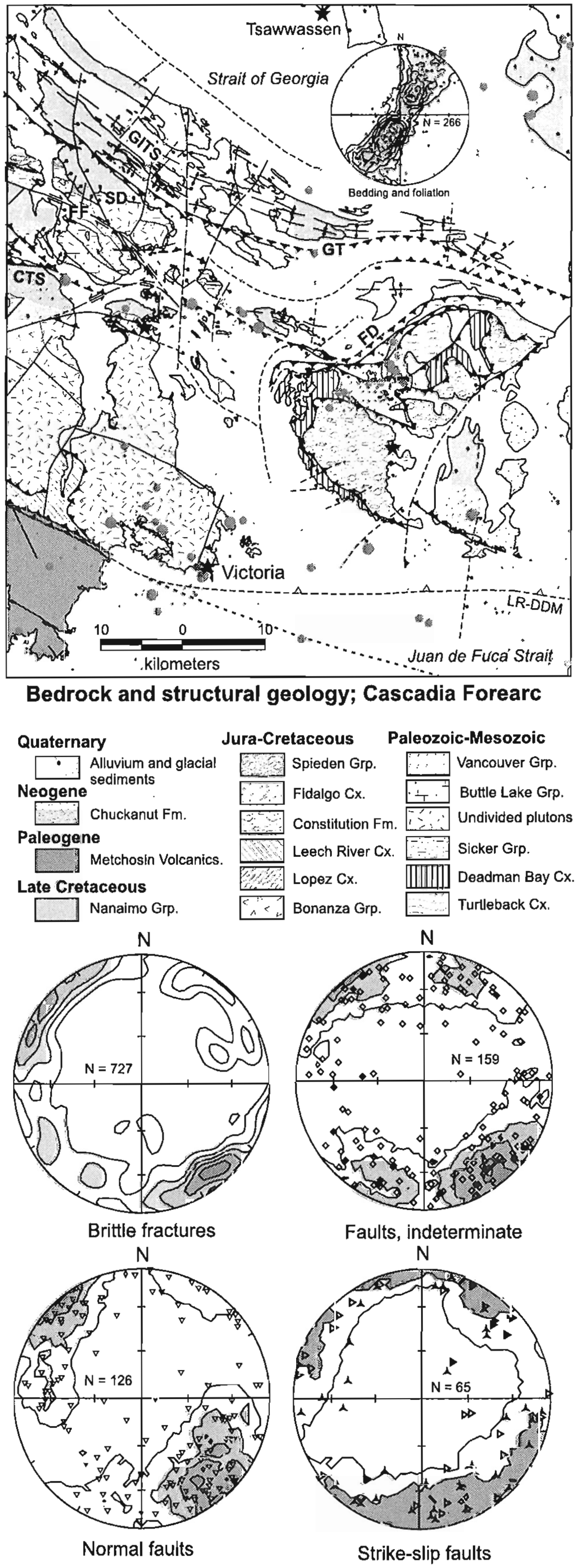
EASTERN FOREARC

The portion of the eastern forearc examined in the course of this study includes the southern Gulf Islands of the Georgia depression in southwestern British Columbia, and the San Juan Islands of the northern Puget lowland in northwestern Washington State (Fig. 3). This part of the forearc is situated northeast of the Paleogene accretionary complex, in the upper plate of the Leech River and Darrington–Devils Mountain fault systems, and encompasses both imbricated Late Cretaceous–Early Tertiary clastic successions of the Georgia Basin and underlying crystalline 'basement' rocks of Wrangellia and the San Juan terranes.

Cowichan thrust system

As defined by England and Calon (1991), the Cowichan thrust system is a southwest-vergent, Late Cretaceous–Early Tertiary fold and thrust belt formed by thick-skinned imbrication of Wrangellia and unconformably overlying Late Cretaceous clastic rocks of the Nanaimo Group. In its type section (Cowichan Lake region), the thrust system is defined by an imbricate array of northeast-dipping thrust faults and related folds that record top-to-the-southwest displacement. These structures extend along strike to the southeast into the Saanich Peninsula and Saltspring Island regions, where they are interpreted by England and Calon (1991) to be part of a hinterland-dipping duplex. Asymmetric folds and thrust faults of the Nanaimo Group in the outer Gulf Island region of the eastern forearc were interpreted to have formed by thin-skinned imbrication in the upper plate of this duplex structure (England and Calon, 1991).

In light of critical new information collected as part of this study, we propose an alternate view for the geometry and kinematic evolution of the southern Gulf Island region. Our interpretations are based on the recognition that folds of



Nanaimo Group stratigraphy in the outer Gulf Islands are overturned to the north and northeast, and are kinematically linked to a system of southwest-dipping, northeast-directed thrust faults (here called the Gulf Island thrust system), that involve late Paleogene clastic successions of the Chuckanut Formation. These structures cut southwest-vergent, recumbent nappes and associated thrust faults of the Cowichan thrust system on southern Saltspring Island, and apparently root into a low-angle decollement that can be traced southeastward beneath imbricate thrust nappes of the San Juan Islands. Structures in the lower plate of this decollement on Portland, Moresby, and Stuart islands involve both foliated metamorphic rocks of the Sicker Group and unconformably overlying shallow marine clastic rocks of the Nanaimo Group. Folds are overturned to the southwest, and are locally cut by an undated angular unconformity that is itself folded. These southwest-vergent structures involve late Cretaceous clastic rocks of the lower Nanaimo Group on Stuart Island and northern Orcas Island, and are interpreted to represent shallow crustal levels of the Cowichan thrust belt that were exhumed, then overridden and buried beneath northeast-vergent thrust nappes of the Gulf Island thrust system some time in the late Paleogene or early Neogene.

Saltspring detachment

In the course of examining basement-cover relationships on northern Saltspring Island, we discovered several isolated exposures of a low-angle detachment fault (*see* Fig. 4) that we believe may record an important and, as yet, unrecognized history of margin-parallel extension in this part of the Cascadia forearc. The fault zone separates well foliated, low-grade metamorphic rocks of the Sicker Group in the footwall from unmetamorphosed sedimentary rocks of the lower Nanaimo Group in the hanging wall. It is marked by concordant, lower plate, mylonitic shear zones that extend more than 50 m into the footwall, and a detached upper plate carapace of chaotic fault breccia and cataclasite that is hydrothermally altered and locally mineralized.

Down-dip stretching lineations and asymmetric shear zone fabrics in the mylonitic footwall, together with listric shear bands and deformed extensional veins in the brecciated hanging wall, record a consistent history of normal, top-down-to-the southeast displacement. The upward transition from mylonite to microbreccia-cataclasite and the structural relationship of younger, weakly deformed sedimentary rocks

Figure 3.

Bedrock geology and synoptic lower hemisphere stereonet analysis of Cenozoic forearc structures in the Gulf Island region of northern Cascadia. Abbreviations: GITS=Gulf Island thrust system, GT=Ganges thrust, SD=Saltspring detachment, FF= Fulford Fault, FD= Fulford decollement, CTS=Cowichan thrust system, LR-DDM=Leech River–Darrington–Devils Mountain fault zone.

Figure 4. View of Saltspring detachment along south shore of Ganges Harbour on Saltspring Island. Hammer head marks the transition from well foliated and lineated mylonitic footwall rocks of the Sicker Group to brecciated, low-grade hanging wall rocks of the overlying Nanaimo Group. The detachment is itself offset along a steep, north-northeast-trending brittle normal fault.

on older, penetratively deformed metamorphic rocks indicate that the fault likely roots to the southeast as a low-angle extensional fault. The regional extent and timing of this structure are uncertain.

Regional geological relationships in the Gulf Islands region indicate that extensional faulting and exhumation of the underlying Wrangellian basement likely occurred sometime in the early Tertiary, either during or after development of the southwest-vergent Cowichan thrust system, and before development of the northeast-vergent Gulf Island thrust system. Comparable low-angle detachment faults, involving early Tertiary volcanic rocks and shallow-level plutons of the late Eocene–early Oligocene Catface suite, are documented by Muller (1989) in the Mount Washington region of east-central Vancouver Island, more than 150 km to the northwest, and in isolated exposures throughout the Beaufort Range and Nanaimo Lakes area of southeastern Vancouver Island. Our findings in the Gulf Islands support Muller's (1989) hypothesis that low-angle detachment faults may be "...widespread and important features of the island's structure,..." that record an important episode of late Paleogene extension along the axis of the northern Cascadia forearc.

Gulf Island thrust system

The Gulf Island thrust system is defined by a sinuous belt of northwest-trending buckle folds and associated northeast-vergent thrust faults, the most prominent of which is the Ganges fault zone of northern Saltspring and Pender islands (Fig. 3). The thrust belt swings eastward across Boundary Pass into the northernmost San Juan Islands, and is likely part of a regional system of northeast-vergent folds and imbricate thrust faults that are known to cut Paleogene clastic rocks of the Chuckanut Basin in the Bellingham Bay region of the northern Puget lowland (Haugerud, 1998).

Folds in the outermost Gulf Island region of the thrust system, along Trincomali Channel and Plumper Sound (Galiano, Mayne, and Saturna islands) are broad, open structures with wavelengths of about 1 km and amplitudes of several hundred metres or less. They are superimposed on a gentle, east-northeast-dipping monoclinal succession of late Cretaceous and early Tertiary clastic rocks that extends more than 70 km northwestward along the western Strait of Georgia. Structures in the central part of the thrust belt, along northern Saltspring, Prevost, and Pender islands, include both low-angle, northeast-vergent thrust faults, and superposed upright to overturned, asymmetric buckle folds with steep southwest-dipping axial surfaces and hingelines that plunge gently to the northwest (*see* Fig. 5). With proximity to the Ganges fault zone, folds become tight to nearly isoclinal with steep, southwest-dipping overturned limbs that are several kilometres in length. Hingelines of these folds trend northwest in the Gulf Island region, and west-northwest to nearly west in the Boundary Pass area between Saturna and the northern San Juan islands (Fig. 3).

The Ganges Fault, initially mapped by England and Calon (1991) as part of the southwest-vergent Cowichan thrust system, is marked along the western shore of Pender Island by an imbricate array of brittle-ductile shear zones that dip steeply to the southwest, and that record both top-to-the-northeast and oblique dextral-slip displacement. The fault is poorly exposed along strike to the northwest in Swanson Channel and northern Saltspring Island, but is well defined by the repetition of steep, southwest-dipping clastic successions of

Figure 5. Northeast-vergent thrust and related fault propagation fold on Pender Island; interpreted to be part of the Gulf Island thrust system, here cutting thinly laminated siltstone of the Nanaimo Group.

the Lower Nanaimo Group in both Ganges Harbor and Booth Bay. Although not well constrained along strike to the southeast of Pender Island, the Ganges Fault is here correlated with a comparable southwest-dipping thrust fault on Suchia Island, which juxtaposes upper plate siltstone units of the Late Cretaceous Nanaimo Group and lower plate sandstone and conglomerate units of the Paleogene Chuckanut Formation. Folding of Padden Member conglomerates (ca. 40 Ma) in the lower plate of this fault indicates that margin-normal shortening was active in this part of the Cascadia forearc some time in the Late Paleogene and/or early Neogene.

Fulford fault zone

The boundary between older southwest-vergent structures of the Cowichan system and younger northeast-vergent structures of the Gulf Island system is marked on Saltspring Island and adjacent parts of Vancouver Island by a high-angle fault zone that extends southeastward through Maple Bay to Fulford Harbor (Fig. 3). Although mapped as part of the southwest-vergent Cowichan thrust system (England and Calon, 1991), the Fulford fault zone is defined by a network of southwest-dipping, ductile and brittle shear zones with subhorizontal lineations, and asymmetric fault zone fabrics that record an episodic history of oblique top-to-the northeast, dextral strike-slip displacement. Truncation and offset of north-trending, high-angle normal faults along Sansum Narrows and northern Saltspring Island record late-stage, dextral strike-slip displacement of about 6 km. However, juxtaposition of regional northeast- and southwest-vergent thrust systems across this same fault zone suggests that cumulative displacements along the Fulford Fault may be significantly greater.

Figure 6. Asymmetric fault zone fabrics along southwest-dipping Fulford Fault on south shore of Fulford Harbour. Asymmetric folds and shear band structures record oblique dextral, top-to-the-northeast shear.

The ductile portion of the fault zone dips moderately to the southwest along the south shore of Fulford Harbor, where it juxtaposes polydeformed upper plate metamorphic rocks of the Sicker Group and chaotically deformed lower plate siltstone units of the Nanaimo Group. Asymmetric fault zone fabrics along this segment of the fault record right-lateral, top-to-the northwest displacement (*see* Fig. 6). The fault projects southeastward along Prevost Passage into northern Haro Strait, and is interpreted to be part of the Fulford decollement, a low-angle detachment zone that we believe roots southeastward beneath imbricate thrust nappes of the San Juan Islands.

Fulford decollement

The Fulford decollement dips moderately to the southeast along President Channel on the north coast of Orcas Island, where it separates imbricate upper plate, accretionary complex assemblages of the Turtleback terrane from lower plate, weakly deformed clastic rocks of the southern Georgia Basin. We interpret the decollement to be part of a shallow-dipping crustal ramp within a linked system of en echelon dextral transcurrent faults in the Cascadia forearc, along which Paleogene and younger transcurrent displacements on the Fulford Fault have been transferred inboard onto deeper level strike-slip faults of the northern Puget lowland.

High-angle brittle faults

Paleogene and younger structures of the eastern Cascadia forearc are cut by widely distributed networks of northwest-, north- and northeast-trending, high-angle brittle faults, the majority of which record evidence of either strike-slip or normal dip-slip displacement. In addition to previously mapped structures, nearly 350 new occurrences of high-angle brittle faults have been documented in shoreline exposures of the southern Gulf and San Juan islands (Fig. 3).

The majority of these structures are marked by 1–5 m wide zones of fracturing, brecciation, localized fault gouge development, and associated hydrothermal alteration. Where measurable, displacements are typically small, on the order of 10 m or less, and appear to be partitioned along either northwest-trending, dextral strike-slip or north- and northeast-trending, dip-slip normal faults (*see* Fig. 7). The larger of these faults record offsets of about 500 m or more, and can be traced along strike for several kilometres.

The most prominent of these structures include north- and northeast-trending normal faults on Saltspring, Prevost, Galiano, Mayne, and North Pender islands; reactivated portions of the northwest-trending Fulford Fault along Maple Bay and central Saltspring Island; and northeast-trending normal faults along the outer coast of San Juan Island, the last of which are on strike with, and presumed to be part of, the Sumas–Vedder Mountain system of the southern Fraser

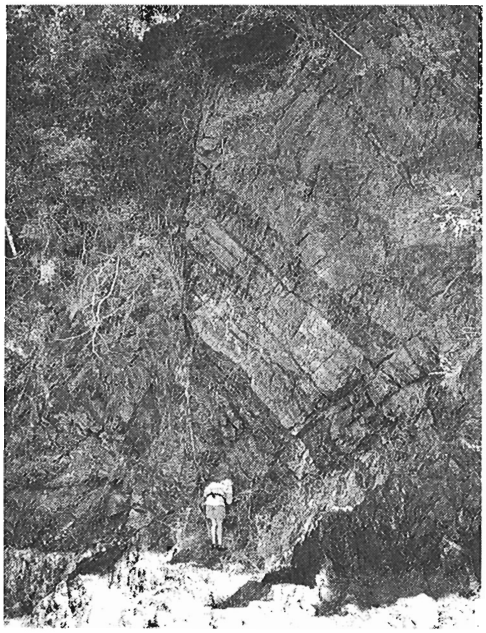


Figure 7. View northeast, along strike of high-angle, brittle normal faults cutting metasedimentary rocks of the Constitution Formation on Orcas Island.

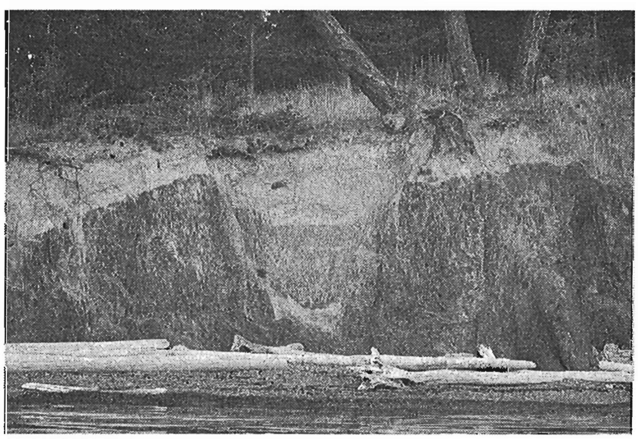


Figure 8. View northwest, along strike of high-angle fault on Pender Island. The fault clearly offsets brecciated clastic rocks of the Nanaimo Group, and locally involves weakly consolidated glacial-fluvial sediments of the unconformably overlying cover succession.

lowland. The timing of these high-angle, brittle fault structures is not well constrained in this part of the forearc. They offset fold axes of the Gulf Island thrust system, which are believed to be Late Paleogene or younger, and are presumed to have been active throughout the Neogene (*see* Fig. 8).

WORKING HYPOTHESIS

Regional variations in the geometry and kinematics of late Cenozoic fault structures in the arc and forearc regions of northern Cascadia are summarized in Figure 9. These observations form the basis of a preliminary working hypothesis for strain partitioning along the northern Cascadia margin (*see* Fig. 10) that reconciles paleomagnetic and geological evidence of forearc migration and associated margin-parallel shortening in Washington State and northern Oregon (Wells et al., 1998), and geological evidence presented herein for decoupling and margin-parallel elongation of the forearc in the southern Gulf Islands and northern Puget lowland.

Our working hypothesis involves the following two-stage history of crustal evolution: 1) an early Paleogene history of margin-normal shortening involving thrust imbrication along both the southwest-vergent Cowichan thrust system and the northeast-vergent Britannia-Ashlu Creek fault zone, and 2) a superposed Neogene history of decoupling and dextral transtension in the forearc, involving early-stage detachment and imbrication of the Georgia Basin along the Gulf Island thrust system, and late-stage dextral shear and margin-parallel extension along the Fulford Fault and associated networks of north- and northeast-trending, high-angle normal faults. The transition from margin-normal shortening to dextral translation and associated margin-parallel extension along the forearc margin in the Late Paleogene–Early Neogene coincides with the northward migration of forearc slivers in southern Cascadia (Walcott, 1993; Wells et al., 1998), and required decoupling of the northern Cascadia forearc from the subduction-accretion complex to the west, and from the corresponding volcanic arc to the east.

Our kinematic model is similar in many respects to that proposed by Tsukuda (1993) for the southern Kyushu and northern Okinawa regions of the Nankai Trough, where the transition from margin-parallel compression to margin-parallel extension in the forearc region is controlled, in part, by changing boundary conditions associated with oblique subduction along a concave bend in the plate boundary. The model has important implications for seismic hazard research of shallow crustal deformation in the southern Vancouver Island, northern Puget lowland, and Greater Vancouver Regional districts of northern Cascadia, all of which lie in the transition zone from forearc compression to forearc extension.

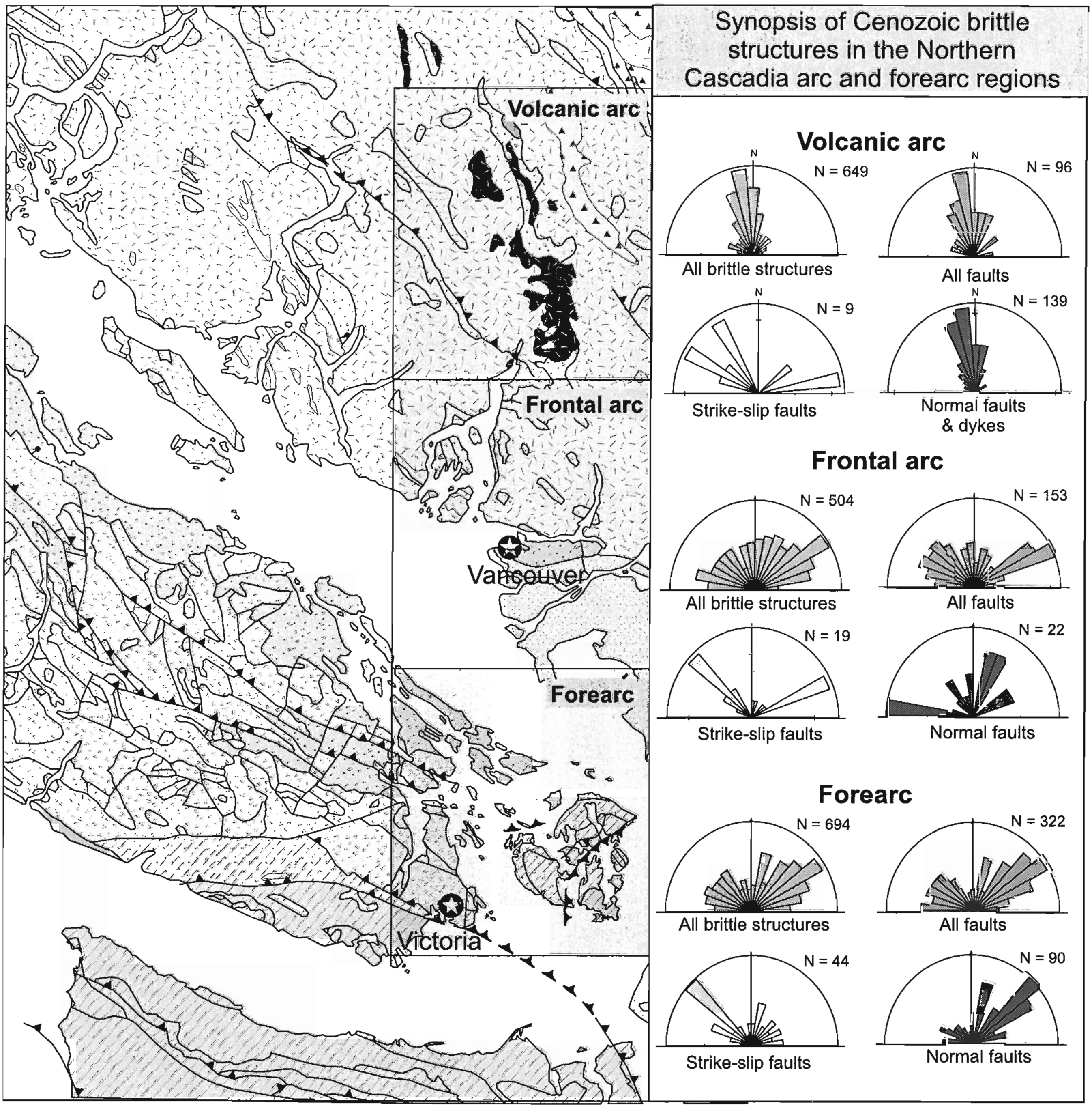


Figure 9. *Synoptic rose diagrams illustrating variations in the orientation of Cenozoic structures across the arc and forearc regions of northern Cascadia.*

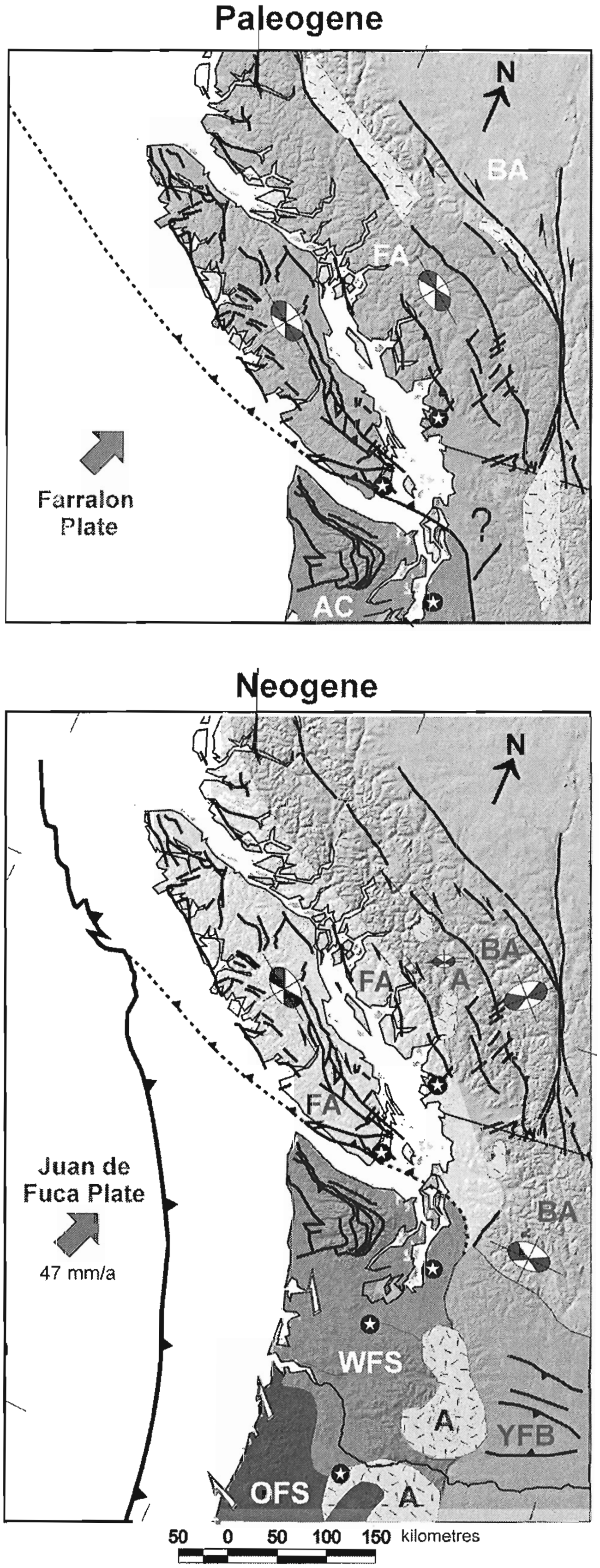


Figure 10.

Working hypothesis for strain partitioning across the northern Cascadia forearc. Kinematic model for Neogene deformation in the southern Cascadia margin is taken directly from Wells et al. (1998). Short axes of strain ellipsoids indicate the inferred direction of maximum shortening. Abbreviations: FA=forearc, WFS=Washington forearc sliver, OFS=Oregon forearc sliver, A=arc, BA=backarc, YFB=Yakima fold belt, AC= accretionary complex; circled stars represent major population centers in the Pacific northwest; '?' denotes uncertainty in the state of stress in the forearc region of northwestern Washington State in the Paleogene; teeth along thrust fault symbols point in the direction of the upper plate; half arrows in Neogene figure indicate relative movement of plate.

ACKNOWLEDGMENTS

Many of the ideas expressed in this paper evolved through discussions with Jim Monger, Kelin Wang, and Dave Mosher of the GSC Pacific Division; Ray Wells and Ralph Haugerud of the USGS; Peter Mustard of Simon Fraser University; and Eikichi Tsukuda of the Geological Survey of Japan. We thank Daniela Joost for her assistance in the field, Jim and Jacki Monger for the use of their cabin on Wise Island, and Bert Struik for a thoughtful and constructive review of the manuscript.

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Interior Plains and Arctic Canada

Plaines intérieures et région arctique du Canada

Ordovician stratigraphy of Dobbin Bay, Radmore Harbour, and John Richardson Bay, east-central Ellesmere Island

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Turner, E.C. and Mayr, U., 1999: Ordovician stratigraphy of Dobbin Bay, Radmore Harbour, and John Richardson Bay, east-central Ellesmere Island; in *Current Research 1999-B; Geological Survey of Canada, p. 253–262.*

Abstract: Stratigraphic sections were measured and described at three localities on east-central Ellesmere Island, providing two, nearly continuous composite sections through more than 2 km of Ordovician strata. These successions conform to previously established formations from the Arctic Archipelago and northwest Greenland.

All units are platformal in character: restricted-marine carbonates deposited above storm wave-base are the rocks of the Christian Elv Formation and of part of the Baumann Fiord, Eleanor River, and Bay Fiord formations; normal-marine, lagoonal carbonates are represented by the Cape Clay, Eleanor River, Thumb Mountain, Irene Bay, and Allen Bay formations, as well as parts of the Bay Fiord Formation. Peritidal deposits are present in parts of the Eleanor River and Bay Fiord formations. Lagoonal evaporites are present in the Baumann Fiord and Bay Fiord formations.

Résumé : On a mesuré et décrit des coupes stratigraphiques à trois endroits dans le centre est de l'île d'Ellesmere, ce qui permis d'établir deux coupes composées, presque continus, qui traversent plus de 2 km de strates ordoviciennes. Ces successions concordent avec des formations définies antérieurement dans l'archipel Arctique et le nord-ouest du Groenland.

Toutes les unités ont été déposées sur des plates-formes. Des roches carbonatées de milieu marin à circulation restreinte, accumulées au-dessus de la base des vagues de tempêtes, constituent la Formation de Christian Elv et une partie des formations de Baumann Fiord, d'Eleanor River et de Bay Fiord. Des roches carbonatées lagunaires de milieu marin normal se rencontrent dans les formations de Cape Clay, d'Eleanor River, de Thumb Mountain, d'Irene Bay et d'Allen Bay et dans certaines parties de la Formation de Bay Fiord. Des dépôts de milieu péritidal se rencontrent dans certaines parties des formations d'Eleanor River et de Bay Fiord. Des évaporites lagunaires sont présentes dans les formations de Baumann Fiord et de Bay Fiord.

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INTRODUCTION

Fieldwork on east-central Ellesmere Island during the summer of 1998 included investigation of Ordovician strata, which, together with Cambrian units, compose the bulk of rocks exposed in the map area. The fieldwork was the first season of a major, three-year mapping project conducted by the Geological Survey of Canada in conjunction with the Bundesanstalt fur Geowissenschaften und Rohstoffe in Hannover, Germany. The aim of the project is to map (1:250 000 scale) and to describe the part of Ellesmere Island adjacent to Kane Basin and Kennedy Channel, an area where the geology is only partly known (Fig. 1). (In this paper, numbers in parentheses indicate formation thickness.) The Cambrian stratigraphy of the area has been addressed by de Freitas (1998a, b, c).

CAPE CLAY FORMATION

Dobbin Bay (217.5 m)

The base of this formation is placed at the top of a 1.2 m thick unit of quartz arenite that bears tabular and herringbone cross-stratification, ripple crosslamination, flute marks, shrinkage cracks, and carbonate lithoclasts (Fig. 2). This is the last quartzose unit in this part of the section. It conformably separates the upper Cass Fjord Formation, consisting of cyclic restricted-marine and peritidal carbonates (thin-bedded, rippled and mudcracked lime mudstone — ex-calcarenite/lutite — with flat pebble rudstone caps), from largely normal-marine, resistant and grey-weathering dolomitic limestones of the Cape Clay Formation. In the lowermost 6 m of the Cape Clay Formation are cycles like those in the upper Cass Fjord, with horizontal burrows toward the top; the remainder of the formation consists of massive, resistant, homogeneous, burrow-mottled, dolomitic, skeletal mudstone to wackestone (Fig. 3A), sparsely bearing flat-pebble rudstones only in the lowermost 40 m. A 20 m thick unit of columnar microbialites 2 cm in diameter, with intercolumn burrow-mottled limestone (Fig. 3, 4) is present from 122.4–143.9 m; this is similar to Facies A of inner shelf-margin buildups of de Freitas and Mayr (1995).

Radmore Harbour (176.1 m)

The uppermost Cass Fjord Formation contains 38 m of cross-bedded quartz arenites with carbonate lithoclasts, about 31 m of parallel- and crosslaminated, locally intraclastic calcarenite, and 10 m of interbedded quartzose limestone and calcareous quartz arenite. The contact with the Cape Clay Formation is drawn where the latter unit is overlain by 130 m of lower Cape Clay Formation with burrow-mottled lime mud-wackestone, sparsely interlayered in the lower 18 m with planar and ripple crosslaminated calcarenite, and flat-pebble rudstones. A unit of of columnar microbialites 2.6 m thick is present at 38 m; this resembles Facies C of de Freitas and Mayr (1995). The upper part of the section consists of 24 m of parallel-laminated, lightly burrowed, wavy-bedded dolomitic calcarenite, 15 m of massive, burrow-mottled dolomitic calcarenite, and 7 m of rippled, laminated, and burrow-mottled calcarenite with flat-pebble rudstones.

With the possible exception of parts of the lowest few metres, the Cape Clay Formation records normal-marine, lagoonal deposition, with rare intraclast rudstones indicating episodes of reworking above storm wave-base. The contact with the Cass Fjord Formation appears to be conformable, with restricted-marine, thin-bedded carbonates and intraclast rudstones enclosing the sandstone. Transgression is clearly indicated by the sandstone-restricted-carbonate normal-marine-carbonate succession below and above the base of the formation, respectively.

CHRISTIAN ELV FORMATION

Dobbin Bay (>258.8 m)

The lower contact of this lithologically heterogeneous formation is placed at the top of a 9.8 m covered interval, separating heavily burrowed limestones of the Cape Clay Formation from mainly unburrowed, grey-weathering, recessive carbonates of the lower Christian Elv Formation (Fig. 2). Wavy bedded, crosslaminated, guttered calcarenites and flat-pebble rudstones of the lowest 20.5 m enclose a mud-rich, lenticular bioherm about 4.5 m thick and more than 50 m in diameter (Fig. 5); both are overlain by a 1.7 m thick unit of planar microbial laminite containing evaporite crystal moulds. Above this are 138.7 m of crosslaminated, thin- to medium-bedded calcarenite with rare, flat-pebble rudstone and centimetre-scale layers of digitate microbialite (Member 1; Fig. 6); mudcracks and quartz sand appear upward.

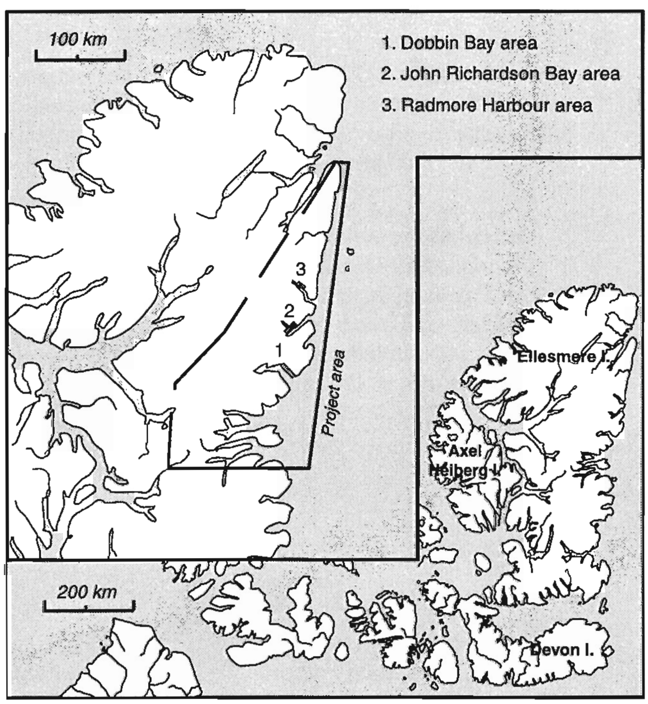

Figure 1. Index map of project area and section locations.

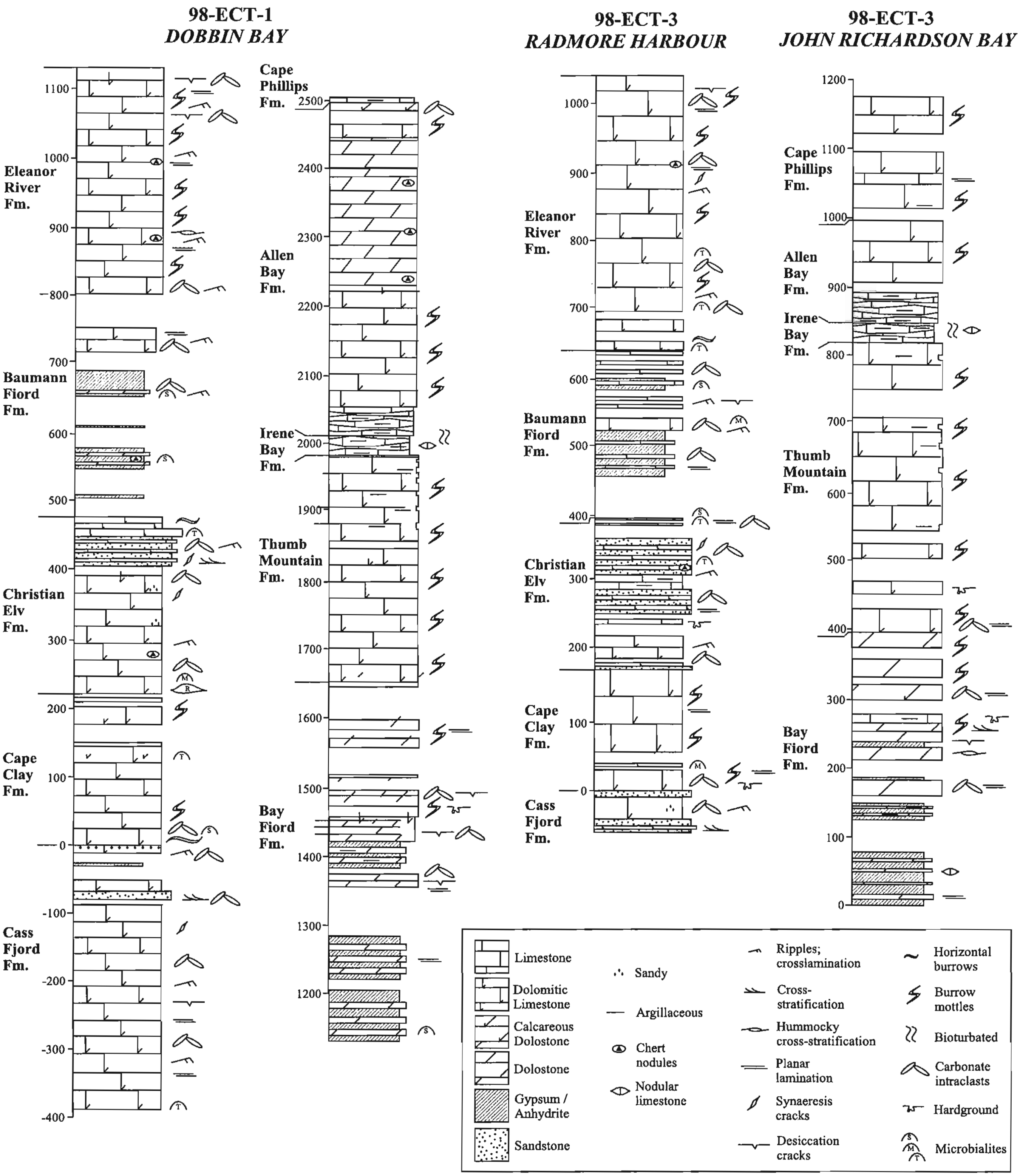

Figure 2. *Simplified stratigraphic sections of Ordovician formations on eastern Ellesmere Island. Member boundaries for Christian Elv, Baumann Fiord and Bay Fiord formations are not indicated because of scale limitation. See Figure 1 for locations.*

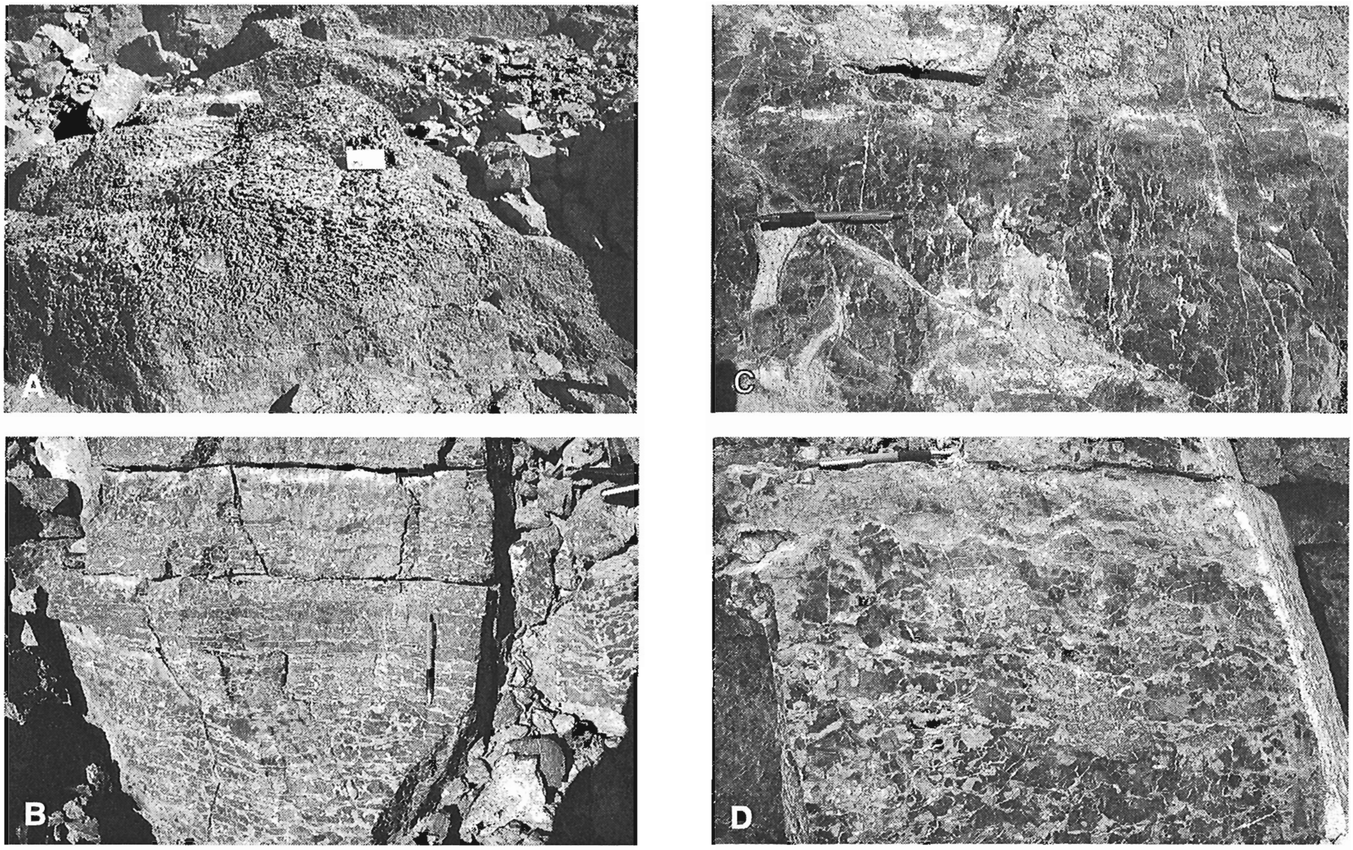

Figure 3. Burrow-mottling varies subtly between formations. A) Cape Clay burrow mottles are typically densely labyrinthine, rarely display only weak relict bedding-parallel fabric, and are defined by grey-buff, resistant, dolomitic areas of equal volume to the inter-mottle limestone. B) Eleanor River burrow mottles show varying degrees of disruption to original, mechanically generated sedimentary structures and bedding, and are picked out by slightly recessively weathering, buff-coloured, dolomitic seams generally subordinate in volume to the limestone component. Here, a range of burrow disruption is shown, from pervasive (lower) to virtually insignificant (one thin bed under centre of pen). Note that even in highly disrupted areas, relict bedding-parallel fabric is still apparent. C) Thumb Mountain burrow mottles are typically relatively uniform in size and extent, and are picked out by more or less equant, ragged areas of brownish dolomite in subequal volumes relative to inter-mottle limestone. No bedding-parallel fabric is present. D) Where Allen Bay rocks are not completely dolomitized, burrow mottles are roughly equant, equal in volume to inter-mottle limestone areas, defined by buff–brown dolomite, and show no bedding-parallel fabric. Pen = 14 cm.

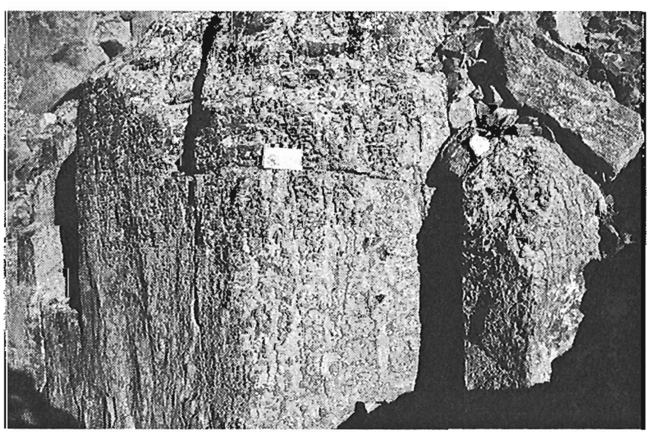

Figure 4. Columnar microbialites with intercolumn burrowed limestone, Cape Clay Formation, Dobbin Bay. Scale = 8 cm.

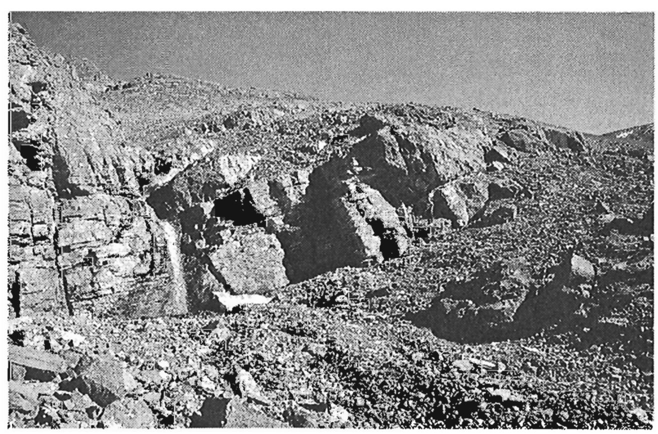

Figure 5. Muddy reef mound enclosed by wavy bedded, crosslaminated calcarenites and intraclast rudstones, lowest Christian Elv Formation, Dobbin Bay. Mound is about 5 m thick.

Above the calcarenite are 67 m of interbedded, thin-bedded lime mudstone, crosslaminated calcisiltite, thin- to medium-bedded, orange-weathering, fine- to medium-grained quartz arenite, and flat-pebble rudstones in quartzose matrix (Member 2).

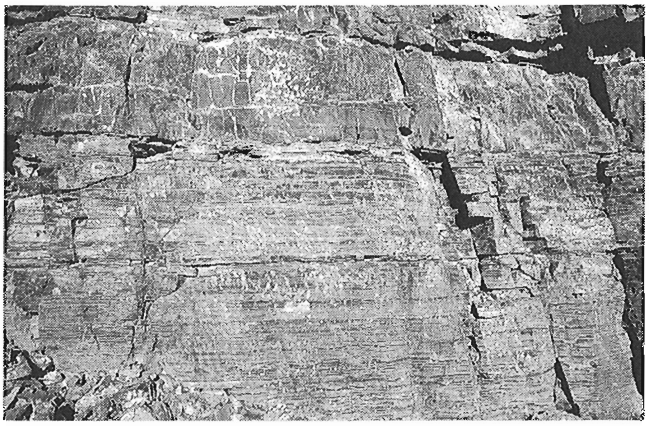

Figure 6. *Planar- and crosslaminated, thin-bedded dolomitic calcarenite and flat-pebble rudstone, middle Christian Elv Formation, Dobbin Bay. Pen = 14 cm (in upper part of photo).*

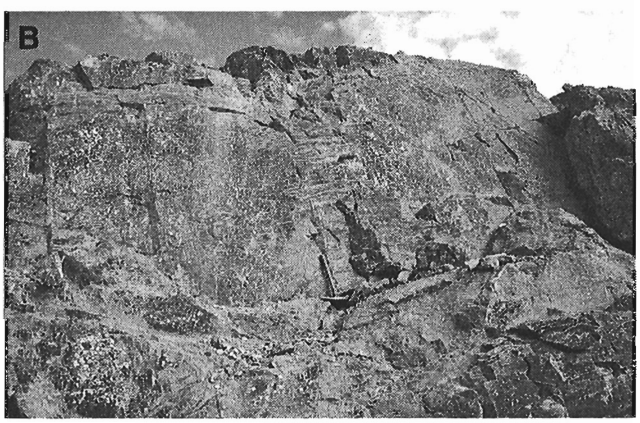

Figure 7. A) *Cliff-forming thrombolite complex in upper Christian Elv Formation overlying interbedded quartz arenite/calcarenite interval, Dobbin Bay. P. Hesje for scale.* ***B)*** *Two thrombolite heads with intervening dolomitic lime mudstone and intraclast rud-floatstone. Hammer = 34 cm.*

Overlying Member 2 is a 9.3 m thick, cliff-forming thrombolite complex in which digitate and pendent thromboids form heads up to 2 m high, with equant intraclast rud-floatstone and dolomitic lime mudstone between heads and individual clots (Fig. 7). Above this, 21.6 m of strata contain metre-scale cycles: lower portions consist of thin-bedded, burrowed, ripple crosslaminated and syneresis-cracked calcarenite; upper portions are flat-pebble rudstones with planar- and crosslaminated calcarenite (Member 3). The uppermost part of this formation is talus covered.

Radmore Harbour (>226.5 m)

The base of the formation is drawn below a 4.5 m interval of parallel-laminated quartz arenite resting conformably on calcarenites of the Cape Clay Formation. The lower 100 m or so (Member 1) consist of parallel-laminated, centimetre-scale-bedded calcarenites with flat-pebble rudstones and local iron-oxide-stained hardgrounds.

Approximately 98 m from the base, parallel- and cross-laminated quartz arenite with syneresis cracks is interbedded with calcarenite, slightly argillaceous and quartz-silty lime mudstone and flat-pebble rudstones in quartz arenite matrix, and rare, decimetre-scale thrombolite heads (Member 2; approximately 94 m thick). Carbonate and siliciclastic units are interbedded on a metre scale (Fig. 8), with a distinct packaging, unlike the intimate centimetre–decimetre-scale intermixing present at Dobbin Bay.

Member 3 (>33.5 m) is poorly exposed, consisting of sparse, metre-scale outcrops of microbialite and parallel-laminated calcarenite with flat-pebble rudstone interbeds 13.5 m above the last-exposed beds of the quartz arenite interval.

The contact with the Cape Clay Formation conformably separates burrowed, normal-marine carbonates from those characterized by mechanically generated structures, representing more restricted conditions. These restricted-marine carbonates were deposited above storm wave-base: calcarenites/lutites were laminated, rippled, and crossbedded by currents, and episodically reworked into flat-pebble rudstones. Evidence for normal-marine conditions is sparse. Fossil fragments or burrows are rare.

BAUMANN FIORD FORMATION

Dobbin Bay (326.3 m)

Exposures of Member A evaporites begin 25.8 m above the last outcrop of Christian Elv limestone (Fig. 2). About 164 m of intermittently exposed, recessive, locally cherty, thinly interbedded dolostone and gypsum are interrupted by a 2.3 m interval of stromatolites about 153 m above the first evaporites exposed. Five metres of rippled evaporite are present at the top of this interval.

Above a 28 m covered interval are cliffs of Member B, which consists of 34 m of cyclically interbedded (0.5–5 m-scale), pale-grey-weathering, thin-bedded lime mudstone, rippled calcarenite, and flat-pebble rudstone. Fossiliferous limestone is sparsely interbedded. A further 5 m of planar and ripple crosslaminated calcarenite is followed by a 48.5 m covered interval that represents Member C.

Radmore Harbour (>237.2 m)

The true thickness of the formation is uncertain owing to structural deformation, but is in the range of 250 to 300 m. The basal contact is not exposed. Member A consists of at least 60 m (and possibly up to 200 m) of interbedded gypsum/anhydrite and fissile lime mudstone, blocky-weathering, laminated lime mudstone, and flat-pebble rudstones (Fig. 8).

Member B consists of 33 to 48 m (varies laterally) of parallel, hummocky, and ripple crosslaminated calcarenite, shaly, fissile lime mudstone, flat-pebble rudstones, and minor stromatolites.

Above this, Member C (about 67–103 m thick) comprises gypsum interbedded with centimetre-scale bands of blocky- and buff-weathering skeletal lime mud-wackestone and flat-pebble rudstones.

Lagoonal evaporites make up a large part of this formation. Flat-pebble rudstones indicate episodic effects of storms; stromatolites may suggest that the substrate was at least episodically in the photic zone. The carbonate member is generally of a restricted, shallow-marine nature, similar to Member 1 of the Christian Elv Formation, with conditions favourable for diverse marine organisms rarely prevailing.

ELEANOR RIVER FORMATION

Dobbin Bay (about 325 m)

The lower contact of this cliff-forming unit with the Baumann Fiord Formation is not exposed (Fig. 2). The lowest 10 m exposed consist of interbedded, crosslaminated calcarenite and flat-pebble rudstone. The overlying 219 m are characterized by subtidal packages in which brownish grey-weathering, massive, burrow-mottled, skeletal mudstone–wackestone is overlain by thin-bedded, parallel- and crosslaminated, locally horizontally burrowed calcarenite, and then decimetre-scale beds of flat-pebble rudstone. Packages may be complete, or may lack the capping flat-pebble rudstone. Package thicknesses range from 5 to 40 m, and are greatest in the middle of this interval. The burrow-mottled part is typically thickest (tens of metres), whereas the other two units together are much thinner (on the order of 2–3 m). Burrowing generally obliterates original textures, but locally, parallel- and crosslamination may be discerned between the dolomitic burrow mottles, and relict horizontal fabric is apparent at outcrop scale (Fig. 3B).

The remaining 82 m of the section consist of intertidal packages, 1 to 10 m thick. These contain the same burrowed, parallel- and crosslaminated calcarenite and intraclastic units as do the subtidal packages, with the addition, at package tops, of pale, buff-grey-weathering, sub-millimetre-scale laminae of desiccation-cracked limestone or dolostone with millimetre–centimetre sized intraclasts (Fig. 9). Packages commonly consist of the parallel- and crosslaminated calcarenite and the sub-millimetre-scale-laminated, mudcracked lithofacies, with the burrowed unit only rarely present. An estimated 15 m of section are missing below the contact with the Bay Fiord Formation at this location.

The uppermost Eleanor River was also measured at a second location about 6 km away. There, the uppermost 80 m of the Eleanor River Formation consists mainly of massive, burrow-mottled wackestone, with sub-millimetre-scale-laminated, shrinkage-cracked lithofacies appearing only in the upper 22 m.

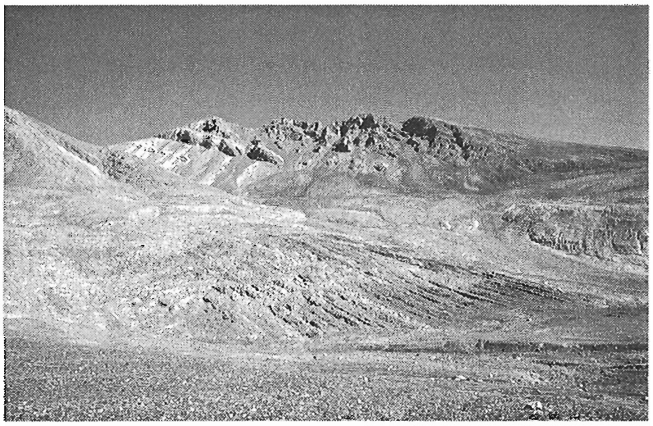

Figure 8. Part of the Ordovician section at Radmore Harbour. Foreground shows interval of well-bedded interbedded quartz arenite and limestone of upper Christian Elv Formation. Recessive-weathering Baumann Fiord evaporites form middle part of the succession. Thin, resistant Member B carbonate is visible in upper left, below skyline. Resistant limestone of the Eleanor River Formation forms cliffs along the skyline in upper centre.

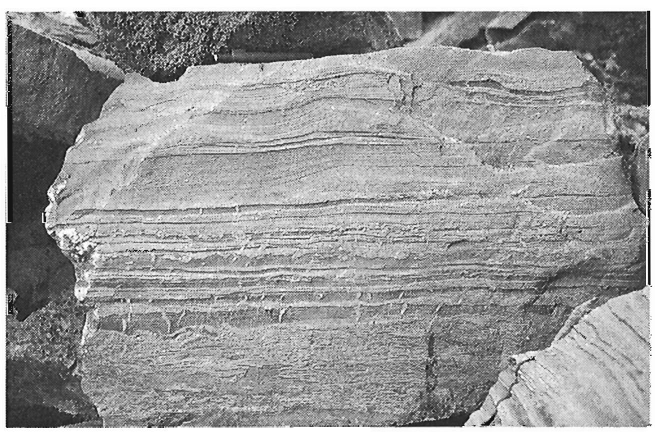

Figure 9. Millimetre-scale laminated, rippled, and desiccation-cracked intraclastic, dolomitic limestone of Eleanor River Formation, in upper peritidal-cyclic interval, Dobbin Bay. Pen = 14 cm (on top of rockslab).

Radmore Harbour (about 399 m)

The base of the cliff-forming Eleanor River Formation (Fig. 8) is drawn below a distinctive, 1.5 m thick thrombolite–stromatolite unit outcropping at the bottom of the Eleanor River cliffs (Fig. 10), above a 3.7 m covered interval. The 8 m that overlie this are pale grey from a distance and similar lithologically to the carbonates of the Baumann Fiord Formation, containing parallel-lamination and flat-pebble rudstones, but no significant burrowing. This is overlain by similar beds containing horizontal traces; above 27 m from the contact are variably burrow-mottled dolomitic lime mud-wackestone with rare, iron-oxide-stained hardgrounds, flat pebble rudstones, and local relict parallel- and crosslaminae discernable between burrow mottles. At about 65 m, spheroidal thrombolites 50 cm high are embedded in flat-pebble rudstone. Burrowing varies from minor, where original stratification features are visible, to pervasive, where little evidence of the former presence of mechanically generated sedimentary structures is present. From 103 to 129 m from the base is a succession of centimetre-scale beds of parallel- and crosslaminated calcarenite, laminated lime mudstones with desiccation cracks, and decimetre-scale flat-pebble rudstones. This is overlain (129–260 m) by homogeneously burrow-mottled, dolomitic, locally fossiliferous lime mudstones, with a 3 m unit of columnar microbialites at 139 m. Above 260 m, such burrowed limestones are interlayered with 2 to 7 m thick units of parallel and ripple crosslaminated, syneresis-cracked calcarenite, laminated, desiccation-cracked dolomitic lime mudstones, and flat-pebble rudstones. Above 327 m, these packages become thinner, alternating on a metre scale. Sub-metre thick beds of dark grey gastropod–intraclast floatstone with skeletal wackestone–grainstone matrix are present. A further 10 to 20 m of outcrop are present in cliffs above the end of the measured section (at 379 m), corresponding approximately to the upper boundary of the formation.

The Eleanor River Formation cannot be divided into laterally traceable members, although peritidal facies are more common in the uppermost parts of the sections. Three lithofacies assemblages are present: 1) normal-marine, burrow-mottled limestones, grading into 2) restricted-marine, physically structured limestones, and 3) peritidal lithofacies, including desiccation-cracked microbial laminites and intraclast–gastropod facies, possibly representing tidal channels. Particularly in the upper part of the formation, these facies replace one another both laterally and vertically, depicting a paleoenvironment of shifting peritidal islands separated by tranquil, subtidal areas.

BAY FIORD FORMATION

Dobbin Bay (531.2 m)

The lower contact with the Eleanor River Formation is erosional, cutting across finely laminated dolostone with surface relief of at least one decimetre. This surface is overlain by a one-decimetre bed of reworked carbonate lithoclasts. This is followed by 155 m of centimetre–decimetre interbedded gypsum and dolostone (Member 1; Fig. 11). Gypsum (avg. 60%) is granular, thin to medium bedded, commonly laminated with dolomite, and weathers out in decimetre-scale oblate nodules. Dolostone (roughly 40%) is either: granular, crumbly, and grey; laminated, fissile and dark brown; or blocky, weakly laminated, and pale brown. One stromatolite horizon is present 16 to 19 m above the base. From 155 to 291 m, dolostone is more volumetrically important (90%) than gypsum (10%); carbonate rocks are locally argillaceous.

Member 2 of the Bay Fiord Formation begins 291 m from the base. There, cycles of shaly dolostone to mudcracked, tepeed, massive dolostone are interbedded with evaporites (291–307 m). Evaporites disappear upward, where further cycles of shaly, fissile dolostone to massive-weathering buff dolostone are present (the latter containing lower

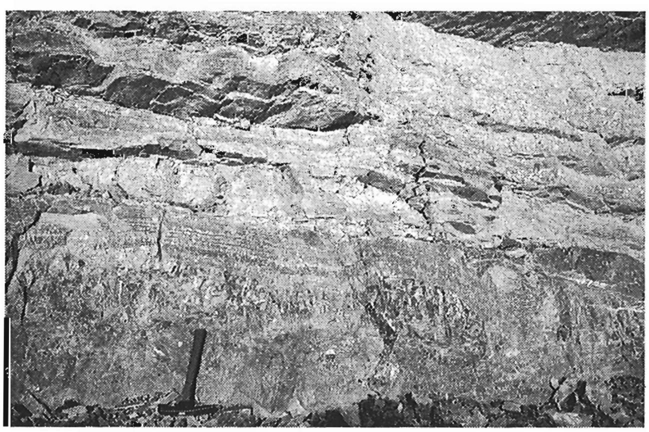

Figure 10. Thrombolite–stromatolite unit marking base of Eleanor River Formation at Radmore Harbour. Dark grey thrombolite digits are arranged in metre-scale heads, and are overlain by pale grey, evenly laminated stromatolitic layer. Hammer = 34 cm.

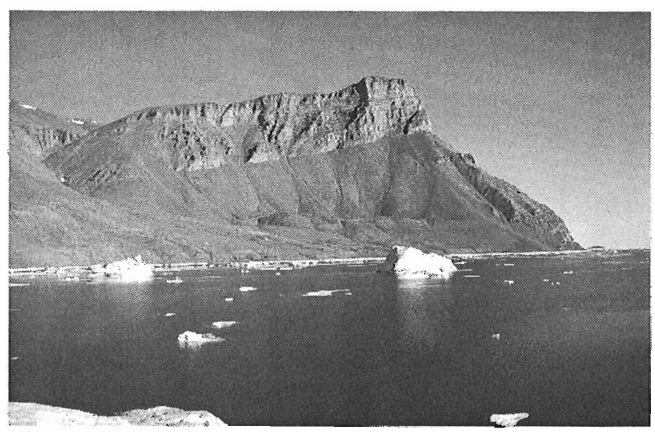

Figure 11. Recessive-weathering Bay Fiord Formation and resistant Thumb Mountain Formation at east side of Dobbin Bay.

homogeneous dolomudstone, and upper planar-laminated, mudcracked, intraclastic dolostone). Shaly parts of cycles diminish upward leaving 1 to 2 m thick dolomudstone cycles. These pass upward into grey-weathering, burrowed, fossiliferous lime mud-wacke-packstones with iron-oxide-stained hardgrounds (334–359 m). A final 5 m of shaly dolostone–mudcracked, intraclastic dolostone cycles are present before the section passes into a covered interval of 23 m.

Above this, burrow-mottled, pale brown dolostones are intermittently exposed over 140 m (Member 3).

John Richardson Bay (>393.4 m)

The lower contact with the Eleanor River is not exposed. The lowest 160 m of the measured section consist of interlayered, vaguely laminated, white, locally limonite-stained gypsum (avg. 60%) and blocky, brown-weathering dolostone (avg. 40%; Fig. 12). This grades into 26 m of laminated, blocky, brown-weathering dolostone with minor gypsum interbeds. A 27 m covered interval is followed by about 48 m of laminated, blocky-weathering, locally slightly argillaceous dolostone, with desiccation cracks, flat-pebble rudstones, and minor gypsum interbeds. Quartz-crystal-lined, centimetre-scale cavities are present in the upper few metres of this interval (Member 1).

This passes upward into an incompletely exposed 32 m interval of parallel- and crosslaminated, locally fossiliferous, dolomitic limestones with iron-oxide-stained hardgrounds and local horizontal burrows and burrow-mottled units (Member 2).

Overlying this is an intermittently exposed 100 m succession of burrow-mottled, locally parallel-laminated dolostones with sparse, flat-pebble rudstones. A pod (<10 m diameter) of rubbly, dolomite-cemented subsurface solution breccia is present at 315 m. The upper contact with the Thumb Mountain Formation is drawn where burrow-mottled carbonates become limestone and first contain significant skeletal material, some 40 m stratigraphically below the base of massive cliffs of homogeneous Thumb Mountain strata (Member 3).

The contact of the Bay Fiord Formation with Eleanor River carbonates is sharp and possibly erosional. Member 1 records sub-storm-wave-base lagoonal evaporite deposition. Member 2 records freshening-up to normal-marine conditions complete with a diverse shelly fauna. Member 3 burrow-mottled dolostones are also of normal-marine aspect, but do not contain a significant shelly fauna.

THUMB MOUNTAIN FORMATION

Dobbin Bay (>320 m)

The lower contact is within a 4.5 m covered interval across which brown, burrowed dolostones of the upper Bay Fiord pass into orange- and grey-weathering, burrow-mottled, dolomitic, skeletal lime mud-wacke-packstones, which persist monotonously for about 163 m (lower half of the formation; Fig. 3C). Large fossils belonging to the Arctic Ordovician fauna appear at about 195 m. The upper half of the formation consists of the same burrow-mottled limestone, bearing intermittent intervals of rubbly to nodular weathering, lime mud-wackestone, with slightly argillaceous partings and red-stained, possible hardgrounds (Fig. 13). These recessive intervals, typically less than 1 m thick and separated by 0.5 to 15 m of resistant limestone, become thicker (up to about 5 m) and closer together (separated by about 5 m) toward the top of the formation, where the two portions are interbedded in roughly equal amounts, finally thinning to metre-scale alternations in the last 20 m.

John Richardson Bay (>386.6 m)

The section begins within the lowermost Thumb Mountain Formation. Consisting of burrow-mottled, dolomitic, skeletal lime mudstone–wackestones and, locally, packstones with millimetre- to centimetre-scale fossil fragments of bivalves, trilobites, gastropods, crinoids, and brachiopods, the only

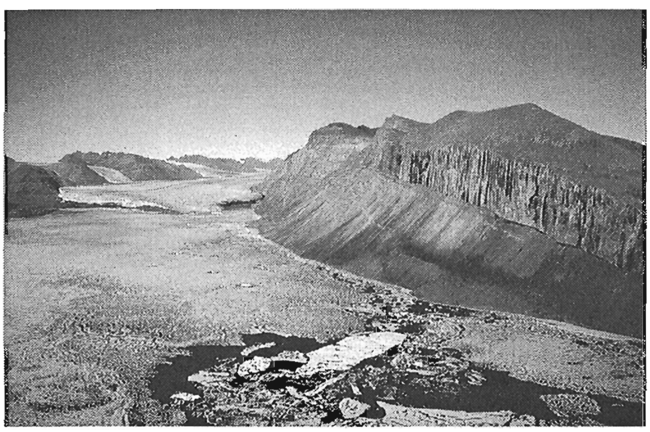

Figure 12. *Bay Fiord and Thumb Mountain sections at John Richardson Bay.*

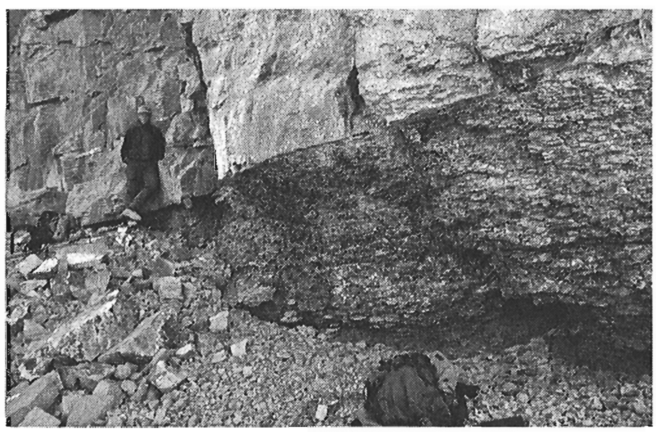

Figure 13. *Recessive and resistant units in upper Thumb Mountain Formation, Dobbin Bay.*

lithological variability is the local appearance of slightly more argillaceous, nodular, recessive intervals about 0.5 to 3 m thick, most common in the upper half of the section. Large specimens of fossils belonging to the Arctic Ordovician fauna (predominantly receptaculitids, solitary rugosans, gastropods, and nautiloids) appear 135 m above the base of the formation. Rare, iron-oxide-stained hardgrounds are present about 72 m from the base of the section.

The burrowed lime mudstone–wackestones of the Thumb Mountain Formation record a lengthy interval of normal-marine carbonate deposition, probably below storm wave-base but, at least in the upper part of the formation, above the photic zone. Resistant/recessive cycles in the upper part of the formation are the result of an influx of argillaceous material, presumably presaging the shaly interval of the Irene Bay–lowermost Allen Bay formations.

IRENE BAY FORMATION

Dobbin Bay (31.5 m)

The contact with the Thumb Mountain Formation is abrupt (Fig. 14): the last 30 cm of the uppermost bed of resistant, burrowed lime mudstone–wackestone of the Thumb Mountain is dark blue–grey, and is overlain by 0.5 m of very dark grey, argillaceous nodular lime mudstone, 1 m of burrowed massive lime mudstone, and 0.2 m of silty, laminated lime mudstone. Above this are 29.8 m of recessive, green–buff weathering, thinly parted, nodular skeletal wackestones–packstones with argillaceous partings 1 mm to 1 cm thick. This is subtly packaged into sub-metre-scale cycles of more recessive, argillaceous units, and more resistant, less argillaceous units of roughly equal thickness (Fig. 14). Large (decimetres in diameter) receptaculitids and colonial corals are common.

Figure 14. Well-bedded Irene Bay Formation at Dobbin Bay. Units dipping to right. Extensive bedding plane on left is upper surface of Thumb Mountain Formation. Irene Bay Formation consists of sub-metre-scale recessive–resistant pairs. Lowermost Allen Bay Formation (AB) begins where ridged exposure forms a cliff at right slope and recessive–resistant couplets thicken to greater than 1 m scale.

John Richardson Bay (32 m)

Nodular, fossiliferous limestones of the Irene Bay Formation are represented by a few outcrops 1 to 6 m thick. As at Dobbin Bay, metre-scale recessive–resistant pairs are apparent. The thickness of the formation is readily measured between resistant units of the uppermost Thumb Mountain and lowest Allen Bay formations.

Irregularly bedded to nodular, argillaceous and fossiliferous limestones are the result of carbonate deposition under normal-marine conditions. The substrate was within the photic zone, and either below storm wave-base, or was so thoroughly bioturbated as to erase any evidence of storm effects.

ALLEN BAY FORMATION

Dobbin Bay (481.3 m)

The contact of the Allen Bay Formation with Irene Bay limestones is gradational. Metre-scale, recessive–resistant cycles of Irene Bay wackestone–packstone pass upward into 2 to 3 metre-scale limestone cycles of similar aspect in the lower Allen Bay (57 m thick; Fig. 14). The lower contact is drawn at the base of the lowest, thick (m-sized) unit of nodular limestone lacking significant argillaceous partings that occurs at the base of the very resistant, elsewhere ridge-forming, 57 metre-thick lower Allen Bay cliff. Above the very resistant unit are about 160 m of orange- and grey-weathering, massive, burrow-mottled, dolomitic lime mudstone–wackestone (Fig. 3D), commonly crazed with randomly oriented, millimetre-scale dolomite veins. Dolomitic burrow mottles compose roughly half of the rock volume. Dolomitization is complete in the uppermost 15 m.

The overlying 203 m are pale-brown-weathering, finely crystalline dolostone with variable proportions of centimetre- to decimetre-scale cavities and patches of coarsely crystalline dolomite, brown to grey, oblate chert nodules 1 to 5 cm thick, aligned roughly parallel to stratification, and local, white, millimetre-scale ghosts of unknown original allochems. Original burrow mottling is only locally discernable. The ensuing 13 m of possibly mottled and skeletal, finely crystalline dolostone may be an expanded wedge of reef rock extending from a reefal body to the east of the section. The overlying 40 m are variably dolomitic, burrowed lime mud-wackestone. The final 6.5 m consist of intraclastic, fossiliferous rudstone and floatstone, and skeletal grainstone. Allochems are millimetre- to decimetre-scale, angular, tabular intraclasts and millimetre–centimetre-sized fossil fragments in an orange, dolomitic matrix.

John Richardson Bay (145.4 m)

The transition from the Irene Bay Formation is identical to that at Dobbin Bay. The lowermost Allen Bay interval of 2 metre-scale recessive–resistant pairs is 41 m thick. Overlying this are 83 m of burrow-mottled, dolomitic lime mud-wackestone. A covered interval 21.4 m thick separates the last outcrop if this lithofacies from the lowermost, thin-bedded, *Pseudogygites*-bearing beds of the Cape Phillips Formation.

The lower member of the Allen Bay resembles the Irene Bay Formation in composition and bedding style, except for the thicker packaging of recessive–resistant pairs. The remainder of the formation at Dobbin Bay is difficult to characterize, owing to pervasive dolomitization and proximity to a fault, which have obliterated textural features in most of the succession. Where visible, textural and compositional features suggest normal-marine conditions like those of the Thumb Mountain Formation. The thin succession at John Richardson Bay also indicates such a depositional environment. Variable thickness of the Allen Bay indicates that fluctuations in subsidence and configuration of the platform, together with varying position with respect to depositional strike, resulted in differential timing of the transition to deeper water Cape Phillips facies.

CAPE PHILLIPS FORMATION

Dobbin Bay

Thin- to very thin-bedded grey lime mudstones interlayered with black shale immediately overlie intraclast–skeletal rud-floatstone of the top of the thick Allen Bay section.

John Richardson Bay

Transition from the Allen Bay to the Cape Phillips Formation occurs within a covered gully (21 m). The lowest 3 m are grey-weathering, wavy and thinly parted lime mudstone with cm-sized *Pseudogygites* fragments. This is overlain by about 30 m of lumpy, thinly parted lime mudstone with dolomitic partings, mottles, discrete, partly spar-filled burrows, and abundant millimetre-scale trilobite fragments; 21 m of thin- to medium-parted, planar-laminated lime mudstone lacking argillaceous partings; and 29 m of burrow-mottled, dolomitic skeletal lime mud-wackestone interbedded with slightly recessive units on a metre scale, in which crosscutting, coarsely crystalline dolomite veins and pods to 10 cm wide are abundant. A 27 m covered interval is littered with platy-weathering *Pseudogygites* floatstone, followed by 41 m of massive, burrow-mottled dolomitic limestone, and 17 m of thin-bedded lime mudstone with dolomitic, argillaceous partings.

CONCLUSIONS

Lithofacies and thicknesses of Ordovician formations addressed are comparatively uniform in the two sections studied. The section localities are roughly on strike with one another (Richardson / Radmore being one thrust sheet west of Dobbin), and confirm the remarkable consistency of the Ordovician succession in the Arctic. Deposition through the Ordovician occurred without any obvious interruption: only one possible discontinuity was identified sedimentologically, at the Eleanor River–Bay Fiord contact. Future work in this map area is expected to address facies changes across strike, where these platformal facies pass into more basinward equivalents, providing information about the configuration of the platform margin, its evolution through the lengthy interval of time represented, and its influence on platformal sedimentation. More regionally complete knowledge of the platformal succession on east-central Ellesmere Island will be assessed together with published data from the undeformed succession in northwest Greenland to give a better picture of the paleogeography and evolution of this hitherto poorly known part of the lower Paleozoic platform.

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AUTHOR INDEX

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Nous encourageons tant le personnel de la Commission géologique que le grand public à nous faire parvenir des articles destinés à la section discussion de la publication Recherches en cours. Le texte doit comprendre au plus six pages dactylographiées à double interligne (environ 1500 mots), texte qui peut faire l'objet d'un réexamen par la rédactrice en chef administrative. Les discussions doivent se limiter au contenu scientifique des rapports de la Commission géologique. Les discussions générales sur le Secteur ou les politiques gouvernementales ne seront pas acceptées. Le texte doit être soumis à un traitement de texte informatisé par un système IBM compatible et enregistré sur disquette WordPerfect. Les illustrations ne seront acceptées que dans la mesure où, selon l'opinion du rédacteur, elles seront considérées comme essentielles. Aucune retouche ne sera faite aux illustrations et dans tous les cas, une copie qui puisse être reproduite doit accompagner le texte original. Les discussions en français ou en anglais doivent se limiter aux rapports récents (au plus de deux ans). On s'efforcera de faire coïncider les articles destinés aux rubriques discussions et réponses dans le même numéro. La publication Recherches en cours paraît en janvier et en juillet. Les articles doivent être envoyés à la rédactrice en chef administrative, Commission géologique du Canada, 601, rue Booth, Ottawa K1A 0E8.

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Partie B: Plaines intérieures et région arctique du Canada

Part C: Canadian Shield
Partie C: Bouclier canadien

Part D: Eastern Canada and national and general programs
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